Broadband Outdoor Radiometer Calibration

BORCAL
2006-02

Calibration Facility:
Southern Great Plains

Latitude: 36.605°N
Longitude: 97.488°W
Elevation: 317.0 meters AMSL
Time Zone: -6.0

Calibration date
07/23/2006 to 08/12/2006

Report Date
September 7, 2006

NOTICE

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

This report compiles the calibration results from a Broadband Outdoor Radiometer Calibration (BORCAL). The work was accomplished at the Radiometer Calibration Facility shown on the front of this report. The calibration results reported here are traceable to the World Radiometric Reference and to the National Institute of Standards and Technology.

This report includes these sections:

- Calibration Environment - meteorological conditions and irradiance reference data encountered during the event.
- Control Instruments - a group of instruments included in each BORCAL event that provides a measure of process consistency.
- Results Summary - a table of all instruments included in this report summarizing their calibration results and uncertainty.
- Instrument Details - the calibration certificates and suggested methods of applying results for each instrument.

The BORCAL process is described in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002.

Reference Irradiance

0.0° / 0.0° Tilt / Azm

Figure 1. Reference Irradiance

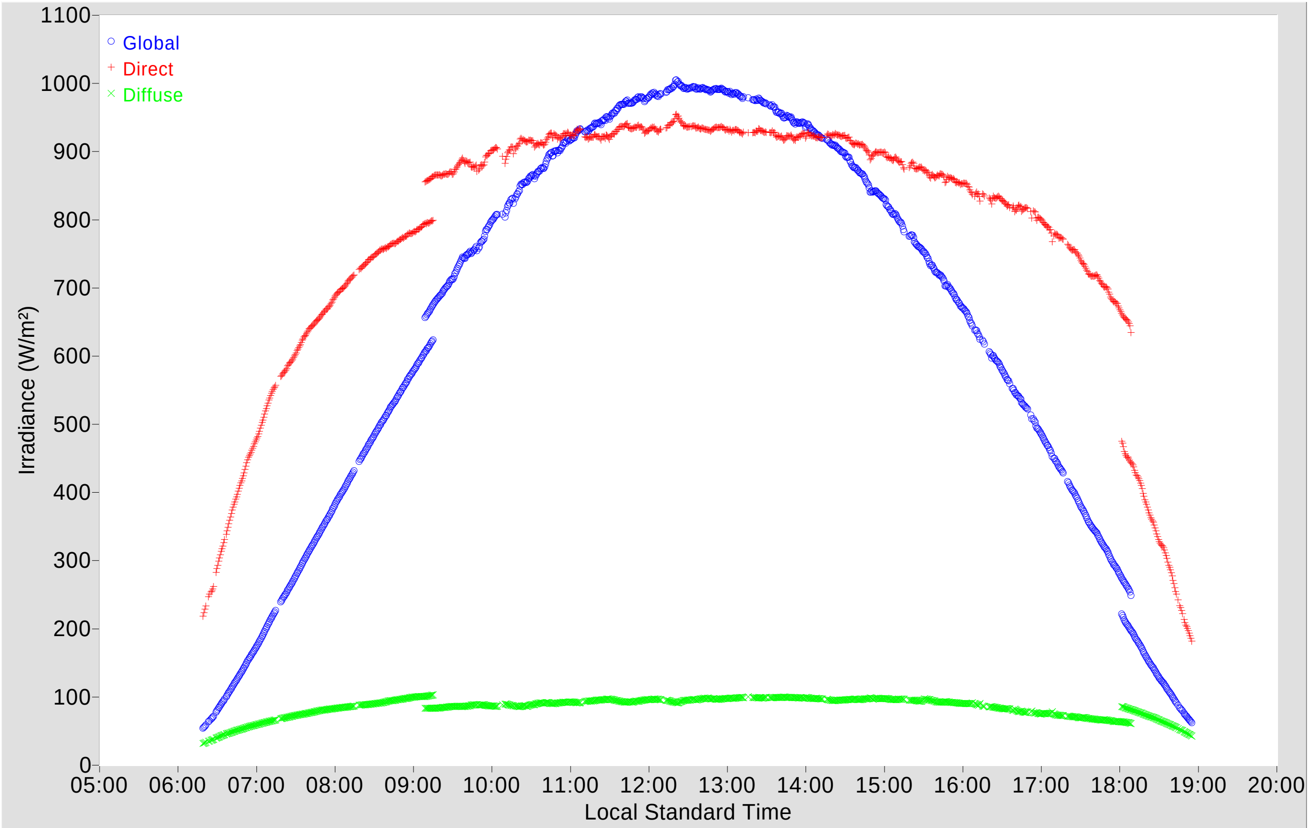
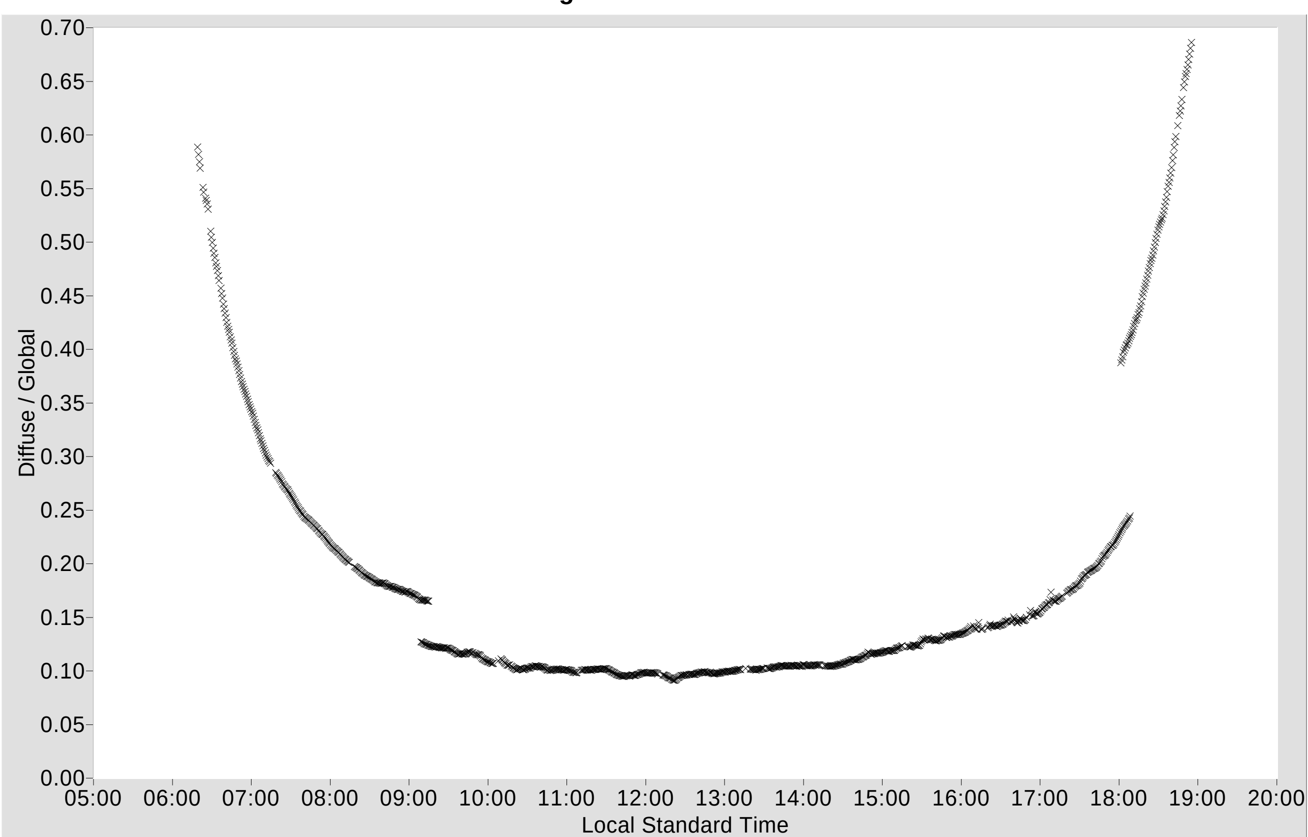


Figure 2. Diffuse / Global



Meteorological Observations

Figure 3. Effective Net Infrared

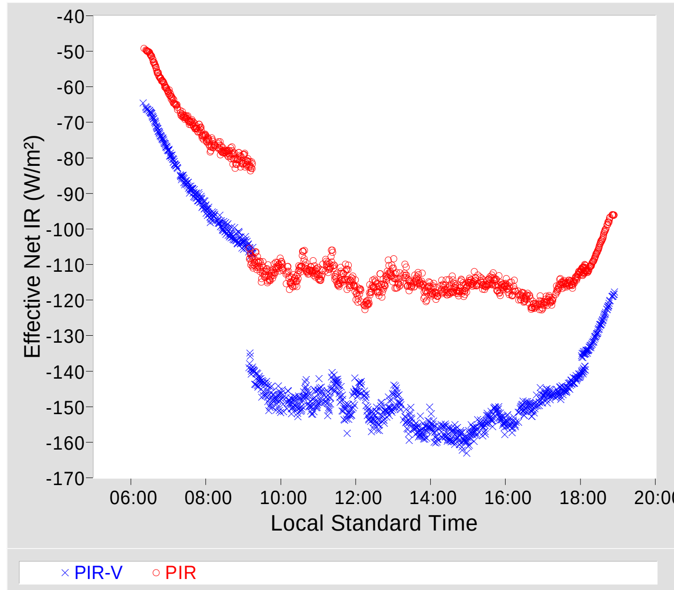


Table 1. Meteorological Observations

Observations	Mean
Temperature (°C)	31.47
Humidity (%)	45.13
Pressure (mBar)	N/A
Est. Aerosol Optical Depth (BB)	0.1012

Figure 4. Temperature

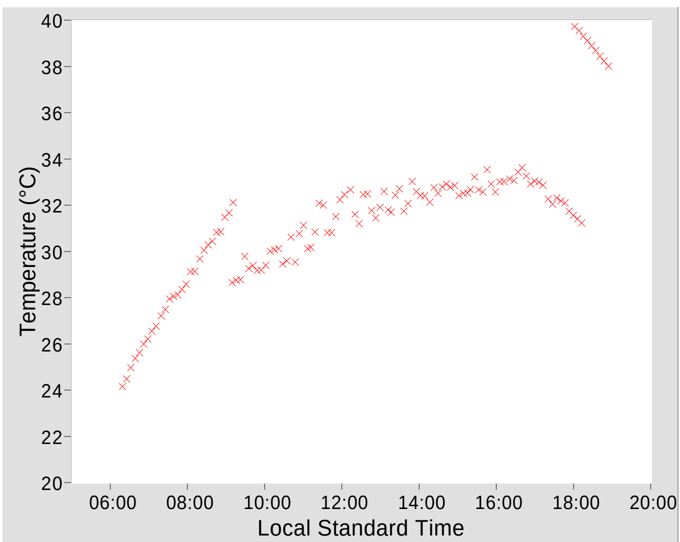


Figure 5. Humidity

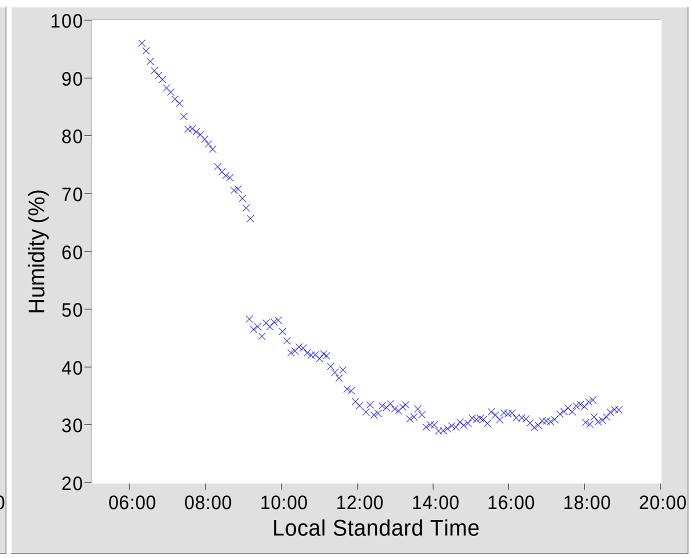


Figure 6. Pressure

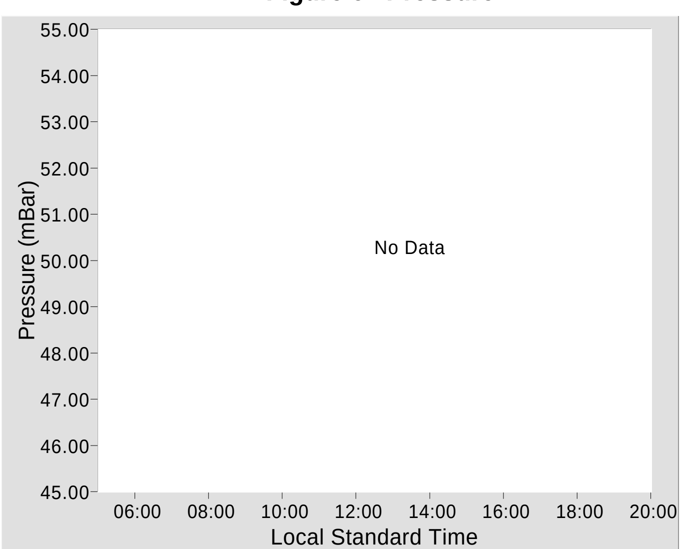
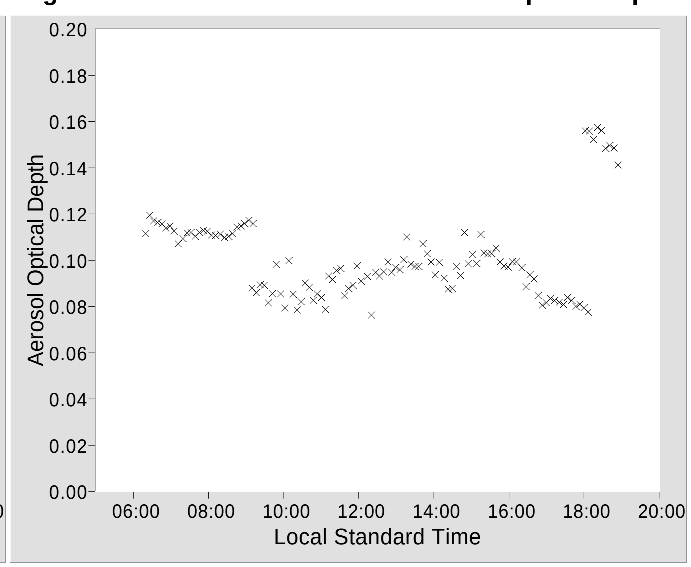


Figure 7. Estimated Broadband Aerosol Optical Depth



Control Instrument History

Figure 8. Eppley NIP Control Instrument History

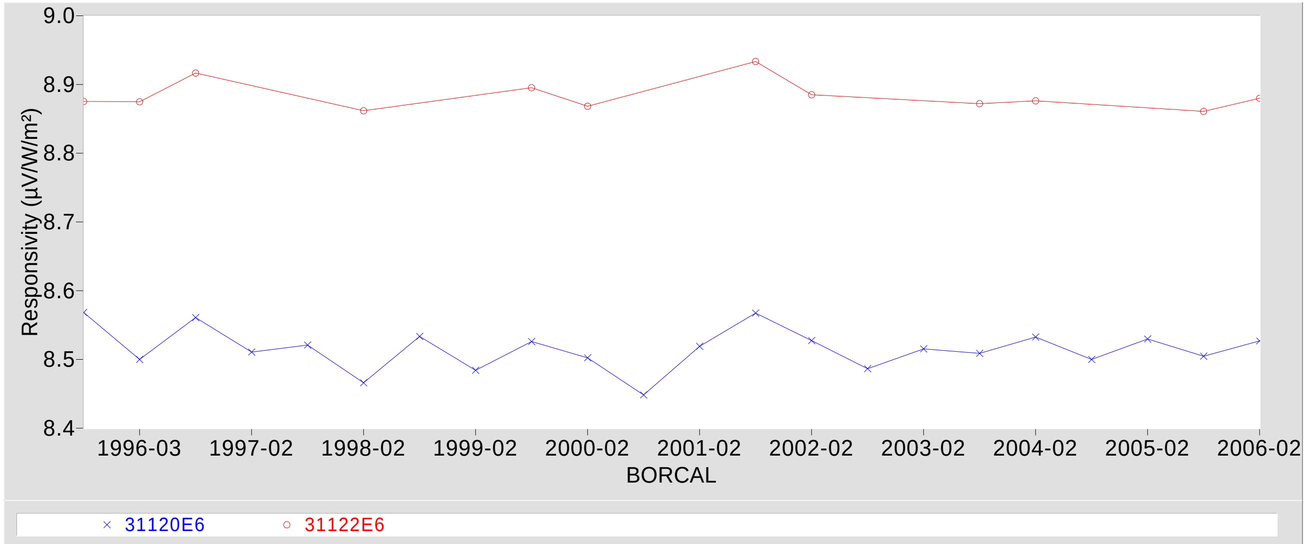


Figure 9. Eppley PSP Control Instrument History

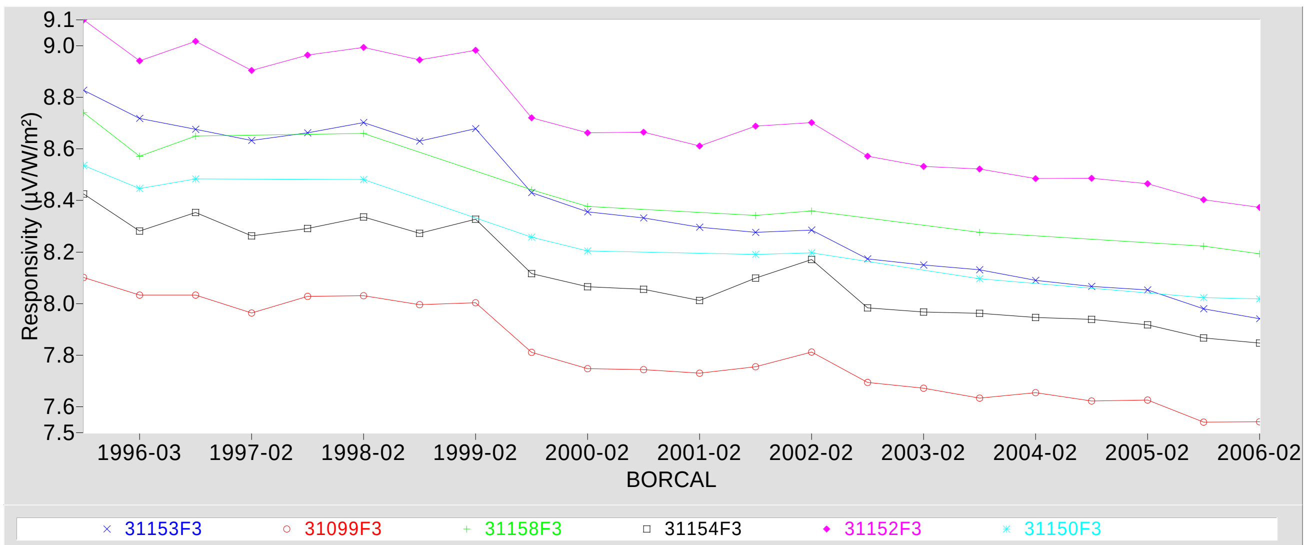
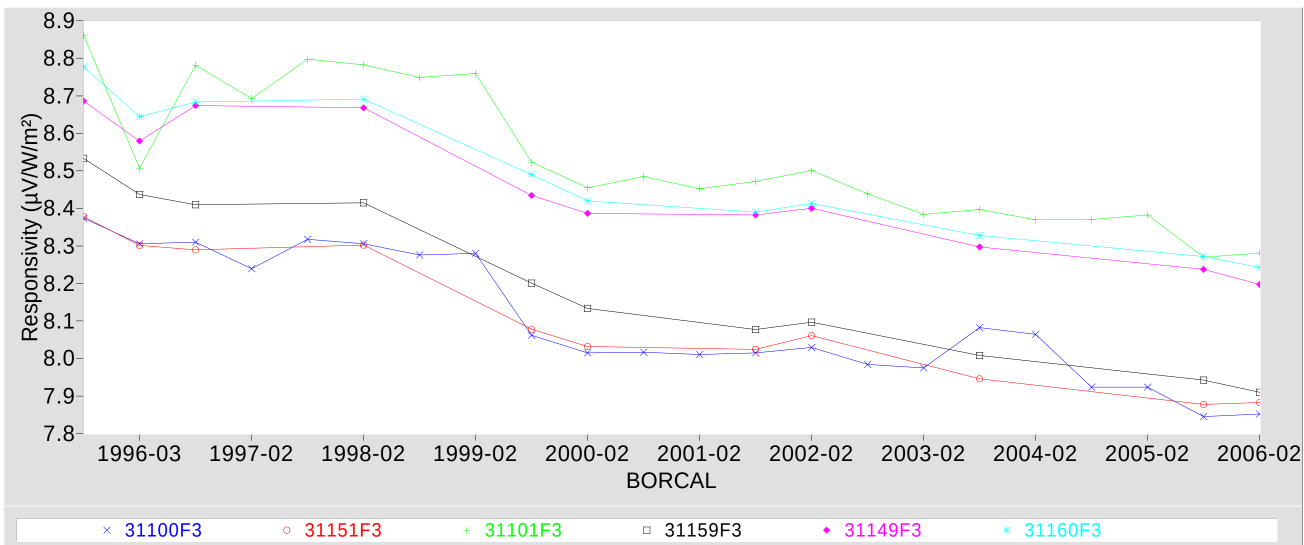


Figure 10. Eppley PSP Control Instrument History



Control Instrument History

Figure 11. Eppley PSP Control Instrument History (Effective Net IR Corrected)

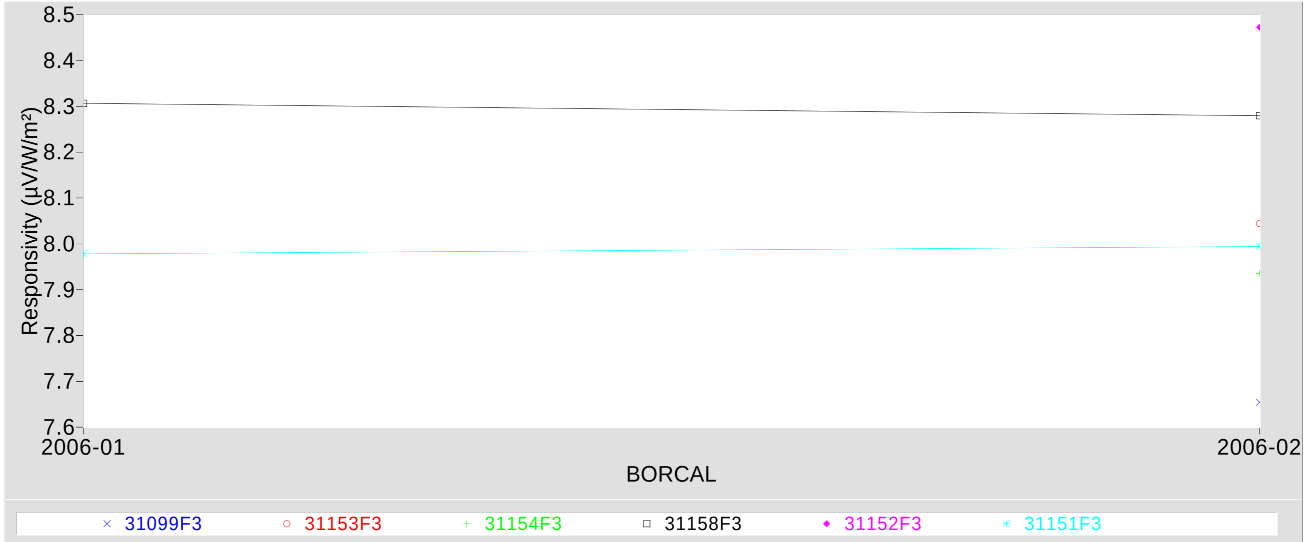
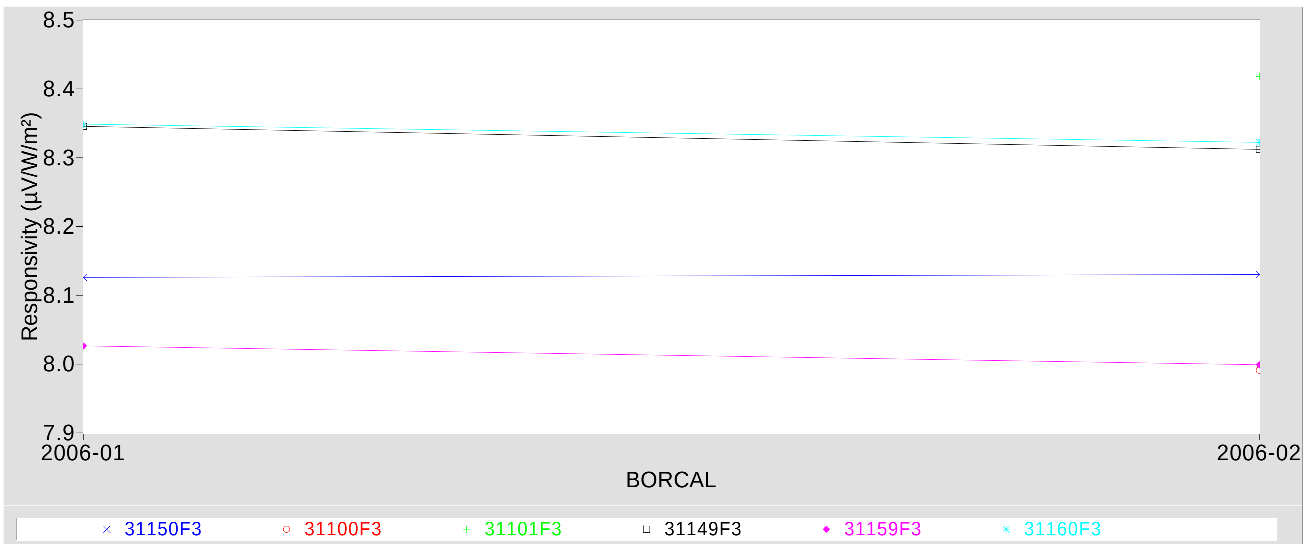


Figure 12. Eppley PSP Control Instrument History (Effective Net IR Corrected)



Results Summary

Table 2. Results Summary

Instrument	Customer	RS@45 [1] (µV/W/m²)	U95 (%)	RSc@45 [1 2] (µV/W/m²)	U95 corr. [2] (%)	RS net [3] (µV/W/m²)	Page
14862F3	SGP	8.0880	+3.49 / -5.41	8.2449	+3.20 / -5.37	0.74536	A1-2
29001E6	SGP	8.5299	+0.91 / -1.23	n/a	n/a	n/a	A1-7
29009E6	SGP	9.0130	+0.78 / -1.34	n/a	n/a	n/a	A1-10
29010E6	SGP	8.6913	+0.84 / -1.07	n/a	n/a	n/a	A1-13
29279F3	SGP	7.4622	+2.77 / -4.83	7.5943	+2.54 / -4.81	0.62721	A1-16
29554E6	SGP	8.1045	+1.08 / -1.45	n/a	n/a	n/a	A1-21
29556E6	SGP	8.2261	+1.02 / -1.46	n/a	n/a	n/a	A1-24
29578E6	SGP	8.4637	+1.13 / -1.93	n/a	n/a	n/a	A1-27
29610F3	SGP	7.9273	+2.98 / -4.78	8.0682	+2.74 / -4.78	0.66876	A1-30
29615F3	SGP	7.6590	+2.84 / -3.56	7.7946	+2.50 / -3.21	0.64378	A1-35
29742E6	SGP	7.4075	+1.31 / -1.59	n/a	n/a	n/a	A1-40
29743E6	SGP	8.1951	+1.03 / -1.27	n/a	n/a	n/a	A1-43
29848E6	SGP	8.1096	+1.00 / -1.24	n/a	n/a	n/a	A1-46
29850E6	SGP	8.1702	+0.95 / -1.63	n/a	n/a	n/a	A1-49
29852E6	SGP	7.8097	+1.07 / -1.54	n/a	n/a	n/a	A1-52
29853E6	SGP	8.2750	+1.07 / -1.19	n/a	n/a	n/a	A1-55
29912F3	SGP	7.7033	+2.38 / -4.57	7.8309	+2.17 / -4.54	0.60562	A1-58
29915F3	TWP	7.7338	+2.60 / -6.01	7.8670	+2.40 / -5.98	0.63274	A1-63
29934E6	TWP	8.5455	+0.94 / -1.14	n/a	n/a	n/a	A1-68
29935E6	SGP	8.5551	+1.33 / -1.95	n/a	n/a	n/a	A1-71
30585E6	SGP	8.5391	+1.11 / -1.42	n/a	n/a	n/a	A1-74
30614F3	SGP	8.6507	+2.16 / -2.74	8.7524	+1.94 / -2.23	0.63119	A1-77
30620F3	SGP	8.8756	+2.84 / -3.43	8.9833	+2.60 / -3.40	0.66913	A1-82
30652F3	SGP	8.9119	+2.52 / -3.20	9.0183	+2.32 / -3.18	0.66095	A1-87
30664F3	SGP	8.6391	+2.36 / -3.04	8.7396	+2.16 / -2.38	0.62455	A1-92
30665F3	SGP	8.1635	+2.75 / -4.14	8.3083	+2.52 / -4.15	0.68788	A1-97
30666F3	SGP	8.2008	+2.87 / -4.31	8.3465	+2.54 / -3.50	0.69195	A1-102
30709F3	SGP	8.0550	+2.40 / -4.17	8.1845	+2.18 / -4.16	0.61495	A1-107
30775F3	SGP	8.5441	+2.30 / -2.67	8.6418	+2.11 / -2.66	0.60686	A1-112
30778F3	SGP	8.5504	+2.32 / -2.74	8.6539	+2.13 / -2.66	0.64306	A1-117
30812F3	SGP	7.9282	+2.38 / -4.64	8.0685	+2.15 / -4.60	0.66610	A1-122
30823F3	SGP	8.0407	+1.86 / -2.61	8.1746	+1.64 / -2.65	0.63457	A1-127
30888F3	SGP	8.8063	+2.05 / -2.28	8.9088	+1.85 / -2.25	0.63655	A1-132
30890F3	SGP	7.7616	+2.02 / -3.00	7.8870	+1.77 / -2.69	0.59445	A1-137
30891F3	SGP	7.5117	+2.29 / -3.53	7.6332	+2.09 / -3.53	0.57550	A1-142
30894F3	SGP	8.0786	+2.15 / -3.39	8.2150	+1.94 / -3.37	0.64666	A1-147
30902F3	SGP	8.3654	+2.06 / -2.68	8.4540	+1.88 / -2.39	0.55035	A1-152
30929F3	SGP	8.0279	+2.57 / -4.66	8.1609	+2.36 / -4.63	0.63036	A1-157
30933F3	SGP	7.6559	+2.46 / -3.87	7.7798	+2.16 / -3.16	0.58687	A1-162
30940F3	SGP	7.3899	+2.50 / -3.97	7.5204	+2.28 / -3.94	0.61870	A1-167
30945F3	SGP	7.7528	+2.49 / -3.85	7.8388	+2.31 / -3.84	0.53402	A1-172
30949F3	SGP	8.1206	+2.30 / -2.63	8.2154	+2.10 / -2.61	0.58852	A1-177
30951F3	SGP	8.5838	+2.08 / -2.77	8.6871	+1.96 / -2.73	0.64270	A1-182
30954F3	SGP	8.6412	+2.47 / -3.77	8.7429	+2.28 / -3.72	0.63330	A1-187
30955F3	SGP	8.8375	+2.23 / -2.75	8.9363	+2.07 / -2.71	0.61498	A1-192
30958F3	SGP	9.0553	+2.45 / -2.75	9.1542	+2.28 / -2.73	0.61540	A1-197
30961F3	SGP	8.8662	+2.01 / -2.35	8.9594	+1.85 / -1.91	0.58065	A1-202
31099F3	Calibration System	7.5423	+2.63 / -4.12	7.6543	+2.47 / -4.03	0.57866	A1-207
31100F3	Calibration System	7.8519	+2.22 / -3.22	7.9911	+2.01 / -3.16	0.64729	A1-212

[1] CF = 1000 / Rs [2] Effective Net IR Corrected
[3] Instrument's Effective Net IR Response

Results Summary

Table 2. Results Summary

Instrument	Customer	RS@45 [1] (µV/W/m²)	U95 (%)	RSc@45 [1 2] (µV/W/m²)	U95 corr. [2] (%)	RS net [3] (µV/W/m²)	Page
31101F3	Calibration System	8.2812	+2.67 / -4.39	8.4181	+2.47 / -4.40	0.64834	A1-217
31120E6	Calibration System	8.5268	+0.96 / -1.24	n/a	n/a	n/a	A1-222
31122E6	Calibration System	8.8798	+0.95 / -1.25	n/a	n/a	n/a	A1-225
31149F3	Calibration System	8.1974	+2.52 / -2.88	8.3121	+2.33 / -2.69	0.54900	A1-228
31150F3	Calibration System	8.0183	+2.18 / -3.55	8.1302	+2.01 / -3.45	0.55100	A1-233
31151F3	Calibration System	7.8830	+2.24 / -3.99	7.9944	+2.06 / -3.98	0.53300	A1-238
31152F3	Calibration System	8.3730	+2.40 / -2.71	8.4729	+2.20 / -2.73	0.63390	A1-243
31153F3	Calibration System	7.9410	+3.39 / -4.08	8.0445	+3.18 / -4.08	0.64286	A1-248
31154F3	Calibration System	7.8472	+2.50 / -2.96	7.9359	+2.33 / -2.93	0.56158	A1-253
31158F3	Calibration System	8.1939	+2.21 / -2.25	8.2797	+2.05 / -2.26	0.52400	A1-258
31159F3	Calibration System	7.9104	+2.63 / -2.57	7.9989	+2.45 / -2.56	0.53200	A1-263
31160F3	Calibration System	8.2423	+2.41 / -2.79	8.3224	+2.26 / -2.79	0.49000	A1-268
31274F3	TWP	7.4152	+2.89 / -4.04	7.5486	+2.68 / -4.03	0.63228	A1-273
31276F3	TWP	7.9913	+2.27 / -3.93	8.1115	+2.09 / -3.92	0.56944	A1-278
31279F3	TWP	7.1673	+1.89 / -2.78	7.2693	+1.76 / -2.80	0.48347	A1-283
31285F3	TWP	7.9801	+2.51 / -2.71	8.0734	+2.33 / -2.66	0.58129	A1-288
31289F3	TWP	8.2596	+2.54 / -2.93	8.3575	+2.35 / -2.89	0.60965	A1-293
31290F3	TWP	8.2934	+2.65 / -3.69	8.3895	+2.46 / -3.65	0.59895	A1-298
31295F3	TWP	8.5845	+2.38 / -3.56	8.6722	+2.27 / -3.53	0.54645	A1-303
31344E6	NSA	8.2152	+1.01 / -1.29	n/a	n/a	n/a	A1-308
31345E6	TWP	8.1671	+1.15 / -1.35	n/a	n/a	n/a	A1-311
31361E6	TWP	8.4443	+1.34 / -1.39	n/a	n/a	n/a	A1-314
31386E6	SGP	8.7211	+1.03 / -1.34	n/a	n/a	n/a	A1-317
31387E6	SGP	8.4237	+1.16 / -1.58	n/a	n/a	n/a	A1-320
31388E6	SGP	8.9996	+1.16 / -1.59	n/a	n/a	n/a	A1-323
31633F3	SGP	8.8281	+2.43 / -3.12	8.9662	+2.12 / -3.11	0.65459	A1-326
31762E6	NSA	8.5865	+1.16 / -1.18	n/a	n/a	n/a	A1-331
32012F3	NSA	8.9987	+1.43 / -1.35	9.1379	+1.23 / -1.28	0.65965	A1-334
32016F3	NSA	8.6222	+2.17 / -4.27	8.7574	+2.02 / -4.24	0.64054	A1-339
32018F3	NSA	8.5935	+2.61 / -3.89	8.7213	+2.43 / -3.87	0.60555	A1-344
32026F3	NSA	8.6798	+1.81 / -3.26	8.8111	+1.65 / -3.25	0.62415	A1-349
32039F3	NSA	9.0765	+1.80 / -2.18	9.2148	+1.61 / -2.19	0.65771	A1-354
32330	SGP	8.6337	+2.44 / -1.82	n/a	n/a	n/a	A1-359
32972	SGP	8.7030	+2.60 / -1.78	n/a	n/a	n/a	A1-364
33236	SGP	9.1653	+3.41 / -1.82	n/a	n/a	n/a	A1-369
33239	SGP	9.6305	+2.44 / -2.15	n/a	n/a	n/a	A1-374
33247	SGP	9.1469	+4.30 / -2.50	n/a	n/a	n/a	A1-379
33252	SGP	9.2965	+3.58 / -2.13	n/a	n/a	n/a	A1-384
33256	SGP	8.6277	+2.04 / -1.67	n/a	n/a	n/a	A1-389
33261	SGP	8.7064	+2.88 / -1.60	n/a	n/a	n/a	A1-394
33262	SGP	7.9971	+2.30 / -2.10	n/a	n/a	n/a	A1-399
33267	SGP	8.8380	+2.82 / -1.75	n/a	n/a	n/a	A1-404
33270	SGP	7.8905	+4.25 / -1.81	n/a	n/a	n/a	A1-409
33274	SGP	8.8020	+1.38 / -2.13	n/a	n/a	n/a	A1-414
33275	SGP	8.3371	+4.78 / -1.84	n/a	n/a	n/a	A1-419
33278	SGP	8.6958	+4.00 / -2.11	n/a	n/a	n/a	A1-424
33375	NSA	8.5862	+4.19 / -2.29	n/a	n/a	n/a	A1-429
33378	AMF	9.1708	+4.58 / -1.90	n/a	n/a	n/a	A1-434
33379	TWP	8.6267	+4.85 / -1.64	n/a	n/a	n/a	A1-439

[1] CF = 1000 / Rs [2] Effective Net IR Corrected
[3] Instrument's Effective Net IR Response

Results Summary

Table 2. Results Summary

Instrument	Customer	RS@45 [1] (µV/W/m²)	U95 (%)	RSc@45 [1 2] (µV/W/m²)	U95 corr. [2] (%)	RS net [3] (µV/W/m²)	Page
33785	SGP	9.3097	+1.88 / -1.54	n/a	n/a	n/a	A1-444
33787	SGP	8.3300	+1.79 / -1.69	n/a	n/a	n/a	A1-449
33788	SGP	8.5827	+4.67 / -1.38	n/a	n/a	n/a	A1-454
34507E6	SGP	8.0058	+1.18 / -1.70	n/a	n/a	n/a	A1-459
34546E6	AMF	8.1238	+1.15 / -1.20	n/a	n/a	n/a	A1-462

Note: Ancillary Data for BORCAL starts on page A1-465.

[1] CF = 1000 / Rs [2] Effective Net IR Corrected
[3] Instrument's Effective Net IR Response

Appendix 1
Instrument Details

Calibration Certificates: 2 Pages for each Pyrheliometer/Shaded Pyranometer and 3 Pages for each Unshaded Pyranometer.
Suggested Methods: 1 Page for each Pyrheliometer/Shaded Pyranometer and 2 Pages for each Unshaded Pyranometer.
Ancillary Data for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 14862F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

14862F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

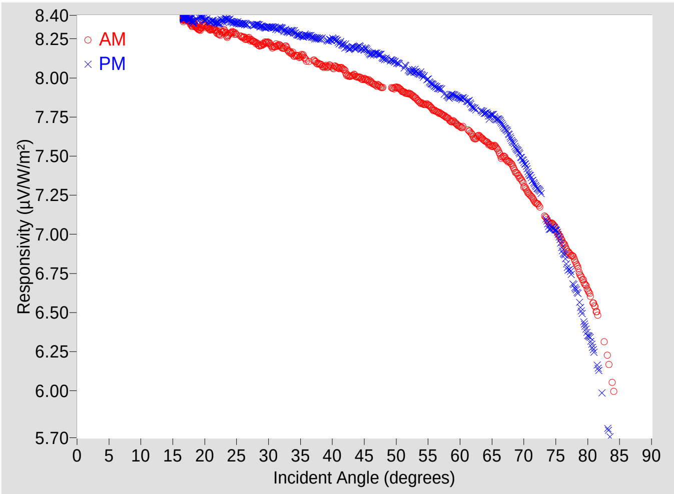


Figure 2. Responsivity vs Local Standard Time

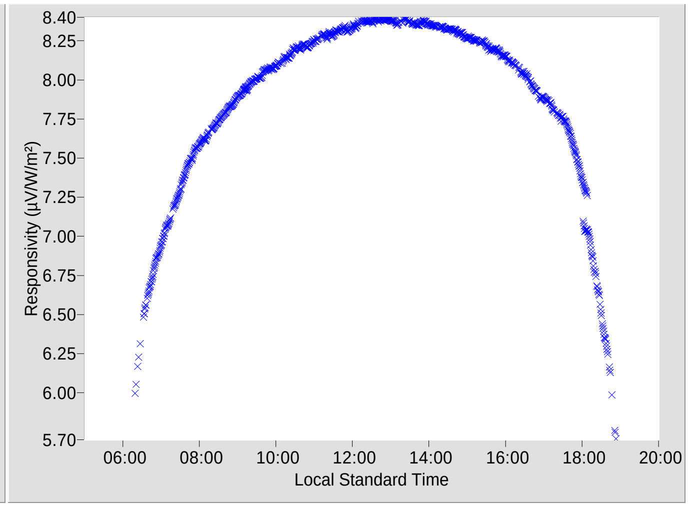


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0880	+3.49 / -5.41	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9768	0.63	97.18	8.1529	0.61	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9373	N/A	95.64	8.1235	0.60	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9392	0.63	101.80	8.0982	0.60	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8996	0.67	100.06	8.0421	0.65	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8381	0.70	98.26	8.0197	0.68	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7917	0.75	96.58	7.9466	0.74	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7442	0.76	94.94	7.8794	0.73	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6895	0.76	93.40	7.8680	0.69	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6296	0.84	91.83	7.8086	0.79	274.97
18	8.3455	0.62	155.25	8.3648	0.52	204.58	64	7.5954	0.90	90.31	7.7741	0.80	276.39
20	8.3331	0.53	142.58	8.3737	0.53	217.20	66	7.5354	1.01	88.85	7.7325	0.96	277.75
22	8.2895	0.55	134.49	8.3510	0.50	225.32	68	7.4526	1.15	87.37	7.6067	1.23	279.13
24	8.2827	0.56	128.48	8.3655	0.53	231.49	70	7.3149	1.30	85.91	7.4609	1.37	280.49
26	8.2614	0.49	123.46	8.3454	0.50	236.46	72	7.1977	1.20	84.47	7.2976	1.25	281.90
28	8.2257	0.54	119.32	8.3397	0.49	240.56	74	7.0743	1.30	83.02	7.0430	1.46	278.95
30	8.2248	0.53	115.72	8.3247	0.49	244.17	76	6.9611	1.70	81.64	6.9005	2.42	280.41
32	8.1992	0.53	112.58	8.3169	0.52	247.32	78	6.8297	1.96	80.16	6.6587	2.70	281.83
34	8.1488	0.55	109.88	8.2924	0.55	250.09	80	6.6487	2.38	78.72	6.3625	2.92	283.26
36	8.1112	0.57	107.27	8.2715	0.52	252.60	82	N/A	N/A	N/A	6.0586	3.21	284.73
38	8.0889	0.58	104.92	8.2496	0.52	254.93	84	6.0251	4.21	75.78	N/A	N/A	N/A
40	8.0659	0.53	102.80	8.2454	0.55	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0407	0.62	100.85	8.2019	0.61	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0057	0.57	98.90	8.1975	0.56	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

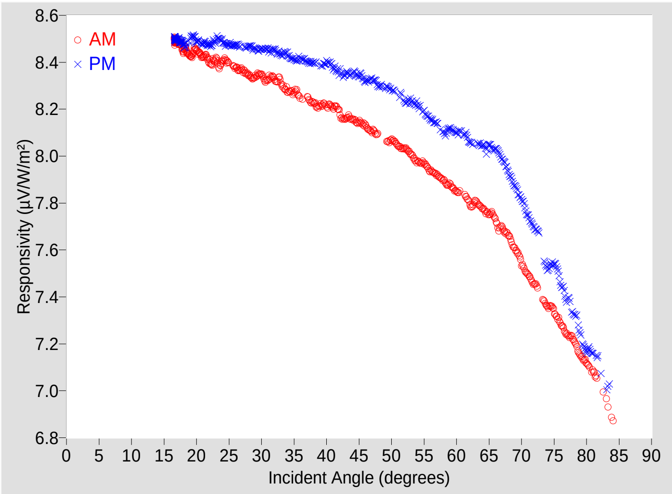

Figure 4. Responsivity vs Local Standard Time

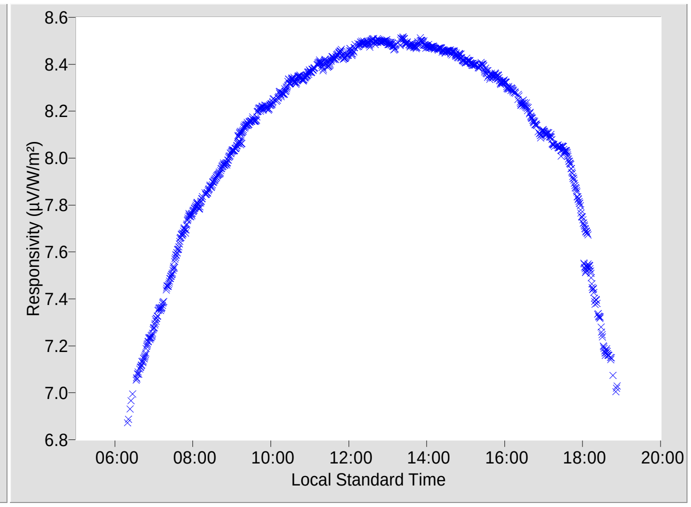

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2449	+3.20 / -5.37	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.74536 µV/W/m², determination date: 06/08/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1315	0.67	97.18	8.3199	0.66	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0931	N/A	95.64	8.2978	0.65	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0686	0.67	101.80	8.2825	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0331	0.70	100.06	8.2299	0.72	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9770	0.73	98.26	8.2163	0.74	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9369	0.78	96.58	8.1554	0.78	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8970	0.79	94.94	8.0974	0.79	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8498	0.80	93.40	8.0985	0.78	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8003	0.87	91.83	8.0583	0.86	274.97
18	8.4555	0.64	155.25	8.4770	0.56	204.58	64	7.7782	0.93	90.31	8.0455	0.90	276.39
20	8.4496	0.56	142.58	8.4915	0.56	217.20	66	7.7300	1.06	88.85	8.0288	0.99	277.75
22	8.4016	0.57	134.49	8.4738	0.54	225.32	68	7.6641	1.14	87.37	7.9268	1.22	279.13
24	8.4010	0.59	128.48	8.4888	0.58	231.49	70	7.5464	1.26	85.91	7.8158	1.33	280.49
26	8.3794	0.52	123.46	8.4724	0.53	236.46	72	7.4553	1.24	84.47	7.6916	1.30	281.90
28	8.3471	0.56	119.32	8.4680	0.53	240.56	74	7.3594	1.34	83.02	7.5221	1.64	278.95
30	8.3472	0.57	115.72	8.4571	0.53	244.17	76	7.2906	1.64	81.64	7.4568	2.15	280.41
32	8.3280	0.56	112.58	8.4520	0.55	247.32	78	7.2165	1.89	80.16	7.3276	2.42	281.83
34	8.2802	0.58	109.88	8.4330	0.58	250.09	80	7.1201	2.27	78.72	7.1713	2.71	283.26
36	8.2485	0.60	107.27	8.4160	0.57	252.60	82	N/A	N/A	N/A	7.1117	3.54	284.73
38	8.2284	0.62	104.92	8.3972	0.57	254.93	84	6.8802	4.17	75.78	N/A	N/A	N/A
40	8.2112	0.58	102.80	8.3975	0.60	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1868	0.67	100.85	8.3566	0.65	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1568	0.62	98.90	8.3543	0.61	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

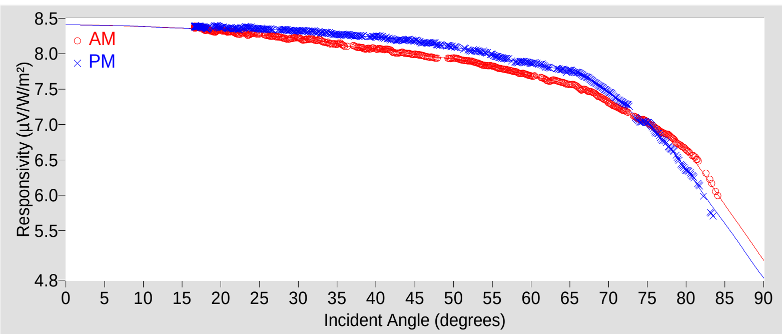
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

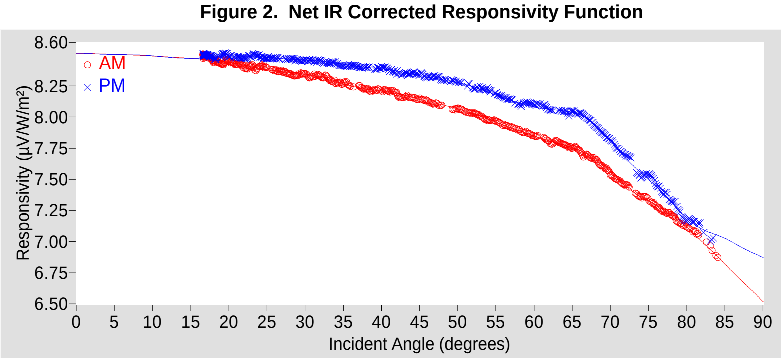


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.79	±1.79
R^2	0.9999994	0.9999985
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.75	±1.75
Net IR corrected R^2	0.9999996	0.9999987
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.4015	*	8.4015	*	8.4015	*	8.5048	*	8.5048	*	8.5048	*
9-18	8.3696	*	8.3712	*	8.3704	*	8.4781	*	8.4798	*	8.4790	*
18-27	8.2981	±1.88	8.3596	±1.79	8.3289	±2.07	8.4134	±1.83	8.4809	±1.75	8.4471	±2.03
27-36	8.1961	±1.94	8.3156	±1.83	8.2559	±2.64	8.3227	±1.86	8.4503	±1.77	8.3865	±2.53
36-45	8.0595	±1.93	8.2304	±1.87	8.1449	±2.99	8.2039	±1.85	8.3821	±1.81	8.2930	±2.86
45-54	7.9321	±1.96	8.1017	±2.02	8.0169	±3.27	8.0749	±1.97	8.2807	±1.89	8.1778	±3.42
54-63	7.7339	±2.28	7.8957	±2.18	7.8148	±3.85	7.8882	±2.10	8.1175	±1.95	8.0029	±3.96
63-72	7.4581	±3.17	7.6222	±3.60	7.5402	±5.68	7.6659	±2.71	7.9370	±2.82	7.8014	±5.61
72-81	6.9253	±4.84	6.8277	±7.38	6.8765	±10.39	7.2768	±3.02	7.4201	±3.85	7.3485	±5.91
81-90	5.7905	*	5.5216	*	5.6561	*	6.7899	*	7.0049	*	6.8974	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

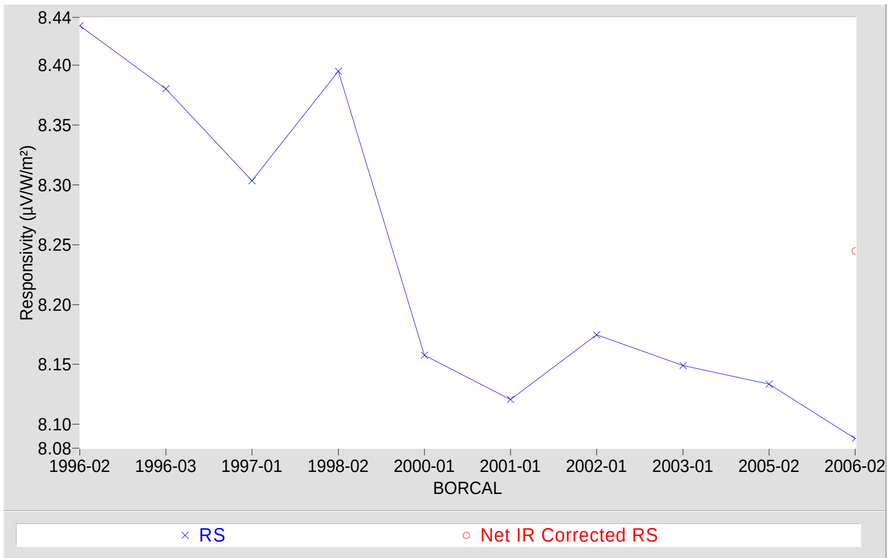
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.0880	+3.49 / -5.41
45° - 55°	8.0019	±2.83
Composite	8.1113	+3.60 / -29.18
45° (Net IR Corr.)	8.2449	+3.20 / -5.37
45° - 55° (Net IR Corr.)	8.1639	±2.88
Composite (Net IR Corr.)	8.2739	+3.09 / -16.92

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



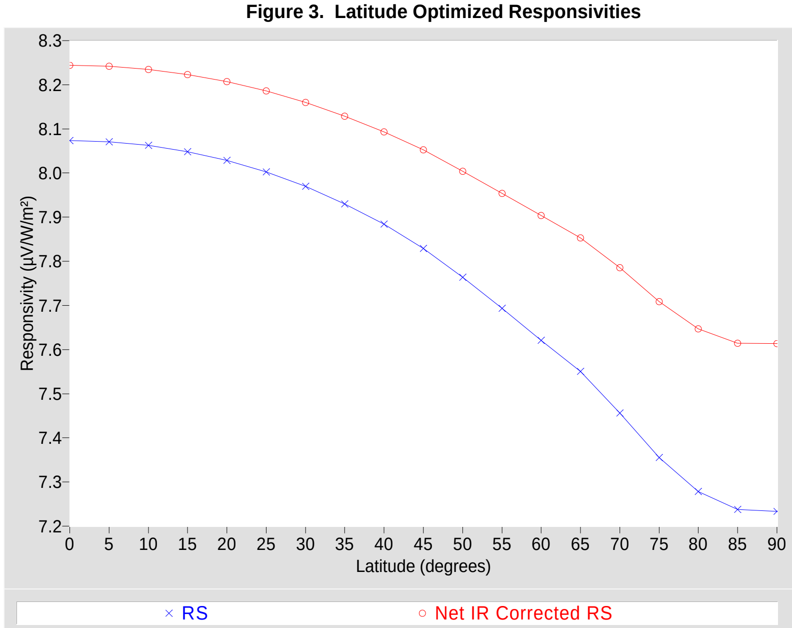
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.0735	+4.54 / -38.36	8.2438	+3.70 / -20.24
5	8.0710	+4.56 / -38.34	8.2418	+3.72 / -20.22
10	8.0625	+4.67 / -38.28	8.2348	+3.80 / -20.16
15	8.0482	+4.84 / -38.17	8.2232	+3.93 / -20.04
20	8.0284	+5.08 / -38.01	8.2072	+4.11 / -19.89
25	8.0022	+5.39 / -37.81	8.1860	+4.34 / -19.68
30	7.9697	+5.67 / -37.56	8.1598	+4.54 / -19.42
35	7.9298	+5.96 / -37.24	8.1284	+4.75 / -19.11
40	7.8840	+6.36 / -36.88	8.0935	+5.14 / -18.77
45	7.8293	+7.07 / -36.44	8.0523	+5.65 / -18.35
50	7.7641	+7.74 / -35.91	8.0038	+6.14 / -17.86
55	7.6936	+8.35 / -35.32	7.9536	+6.54 / -17.34
60	7.6207	+8.73 / -34.70	7.9038	+6.71 / -16.82
65	7.5505	+9.14 / -34.09	7.8533	+6.93 / -16.29
70	7.4562	+9.54 / -33.26	7.7855	+7.09 / -15.57
75	7.3555	+9.96 / -32.35	7.7090	+7.39 / -14.73
80	7.2780	+9.37 / -31.63	7.6468	+6.87 / -14.04
85	7.2380	+8.41 / -31.25	7.6146	+6.24 / -13.68
90	7.2334	+6.97 / -31.21	7.6133	+5.61 / -13.67

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

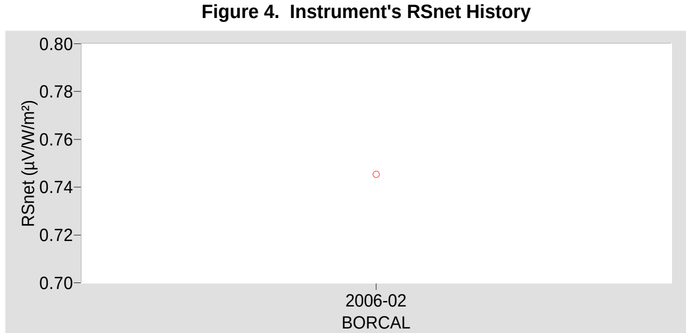
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29001E6
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29001E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

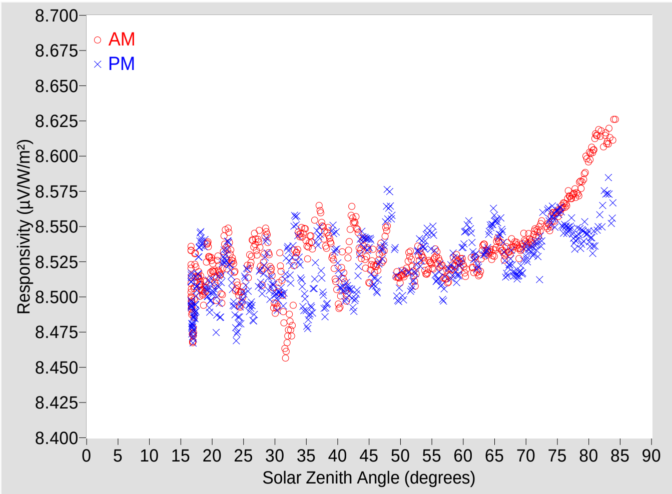


Figure 2. Responsivity vs Local Standard Time

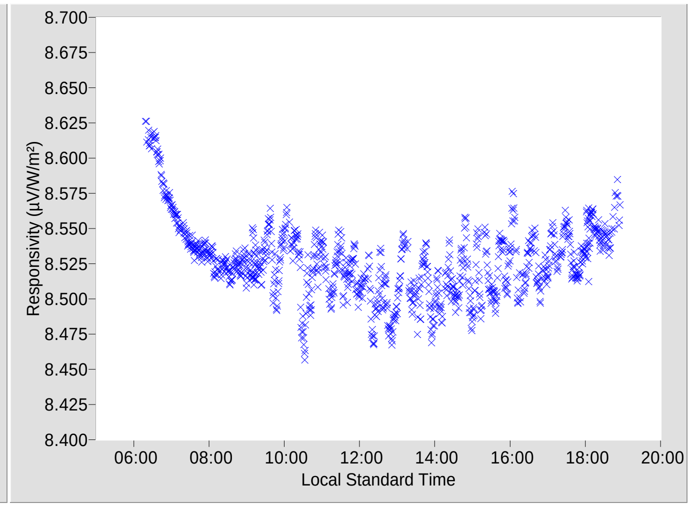


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5299	+0.91 / -1.23	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5213	0.41	97.16	8.5083	0.43	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5470	N/A	95.62	8.5668	0.47	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5136	0.38	101.84	8.5124	0.43	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5186	0.41	100.03	8.5108	0.41	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5187	0.39	98.24	8.5417	0.40	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5276	0.39	96.61	8.5156	0.49	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5195	0.39	94.92	8.5178	0.39	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5228	0.38	93.38	8.5385	0.44	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5244	0.39	91.81	8.5259	0.41	275.00
18	8.5103	0.49	154.91	8.5336	0.55	204.48	64	8.5326	0.38	90.29	8.5420	0.42	276.37
20	8.5214	0.44	142.69	8.5040	0.44	217.31	66	8.5357	0.39	88.83	8.5479	0.45	277.73
22	8.5346	0.48	134.59	8.5283	0.49	225.42	68	8.5359	0.39	87.35	8.5168	0.40	279.20
24	8.5056	0.42	128.42	8.4772	0.46	231.43	70	8.5380	0.39	85.90	8.5307	0.40	280.47
26	8.5232	0.41	123.41	8.4951	0.43	236.41	72	8.5468	0.40	84.49	8.5322	0.47	281.89
28	8.5208	0.44	119.27	8.5112	0.43	240.63	74	8.5521	0.40	83.05	8.5571	0.42	278.98
30	8.4927	0.45	115.68	8.5029	0.39	244.22	76	8.5651	0.42	81.62	8.5494	0.44	280.39
32	8.4731	0.49	112.55	8.5313	0.49	247.37	78	8.5736	0.42	80.16	8.5415	0.46	281.86
34	8.5455	0.40	109.84	8.5202	0.54	250.05	80	8.5987	0.47	78.66	8.5417	0.49	283.28
36	8.5387	0.40	107.49	8.4973	0.55	252.57	82	8.6160	0.48	77.32	8.5578	0.56	284.74
38	8.5396	0.41	104.96	8.4932	0.53	254.90	84	8.6212	0.56	75.73	8.5615	0.66	286.06
40	8.5007	0.44	102.87	8.5272	0.46	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5485	0.54	100.82	8.5032	0.39	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5365	0.43	98.94	8.5407	0.44	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29001E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

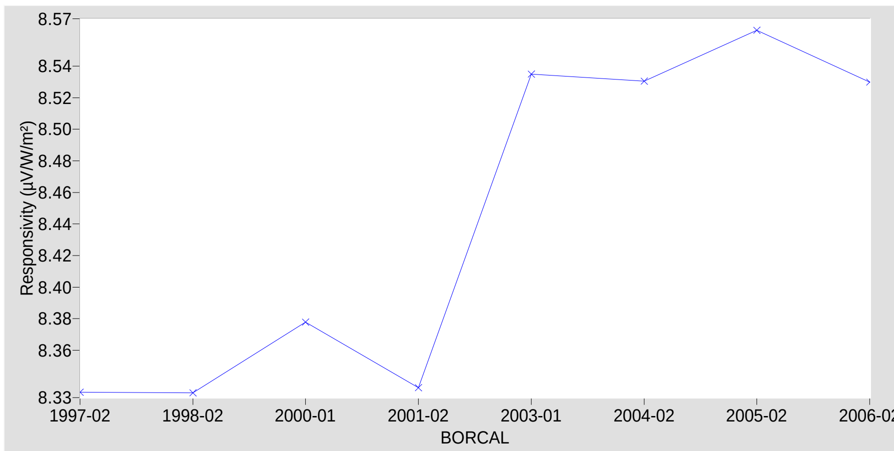
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5299	+0.91 / -1.23 †
Average	8.5309	+1.63 / -1.17 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley

Model: NIP
Serial Number: 29009E6

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: SGP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29009E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

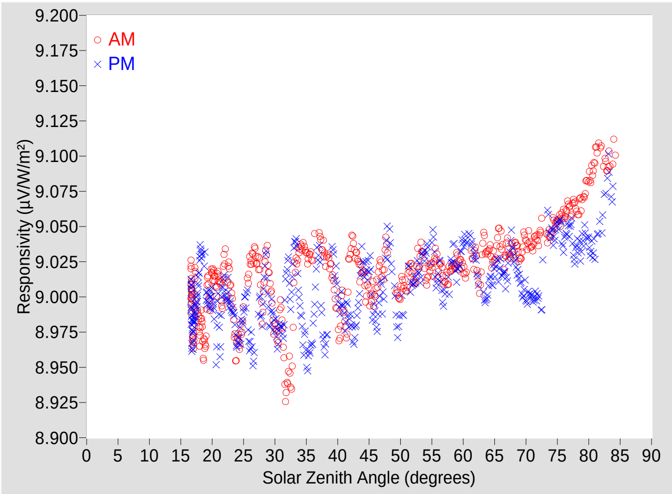


Figure 2. Responsivity vs Local Standard Time

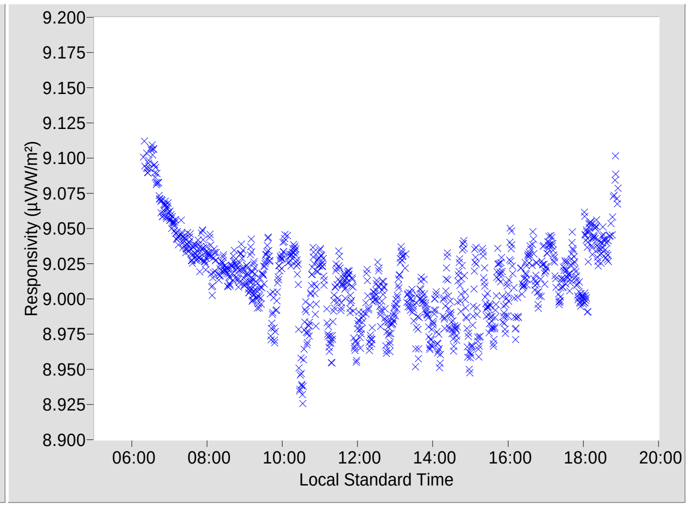


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.0130	+0.78 / -1.34	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0027	0.41	97.16	8.9843	0.47	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0370	N/A	95.62	9.0403	0.50	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0048	0.38	101.84	8.9938	0.42	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0145	0.40	100.03	9.0103	0.39	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0159	0.41	98.24	9.0318	0.40	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0225	0.40	96.61	9.0181	0.48	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0202	0.39	94.92	9.0193	0.42	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0199	0.38	93.38	9.0398	0.40	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0291	0.42	91.81	9.0234	0.42	275.00
18	8.9800	0.52	154.91	9.0229	0.50	204.48	64	9.0333	0.40	90.29	9.0070	0.40	276.37
20	9.0140	0.45	142.69	8.9965	0.48	217.31	66	9.0405	0.41	88.83	9.0195	0.39	277.73
22	9.0194	0.43	134.59	9.0049	0.49	225.42	68	9.0331	0.39	87.35	9.0303	0.43	279.16
24	8.9653	0.45	128.42	8.9681	0.40	231.43	70	9.0393	0.40	85.90	9.0013	0.39	280.47
26	9.0211	0.39	123.41	8.9688	0.47	236.41	72	9.0424	0.41	84.49	9.0007	0.43	281.80
28	8.9982	0.48	119.27	8.9944	0.47	240.63	74	9.0445	0.40	83.05	9.0459	0.42	278.98
30	8.9778	0.46	115.68	8.9786	0.42	244.22	76	9.0582	0.41	81.62	9.0384	0.43	280.39
32	8.9430	0.49	112.55	9.0201	0.51	247.37	78	9.0625	0.42	80.16	9.0335	0.47	281.86
34	9.0349	0.40	109.84	8.9942	0.59	250.05	80	9.0845	0.45	78.66	9.0370	0.48	283.28
36	9.0280	0.39	107.49	8.9737	0.61	252.57	82	9.1066	0.48	77.32	9.0524	0.56	284.74
38	9.0274	0.39	104.96	8.9666	0.57	254.90	84	9.1023	0.55	75.73	9.0731	0.63	286.06
40	8.9825	0.45	102.87	9.0044	0.45	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0325	0.55	100.82	8.9819	0.40	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0176	0.42	98.94	9.0237	0.46	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29009E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

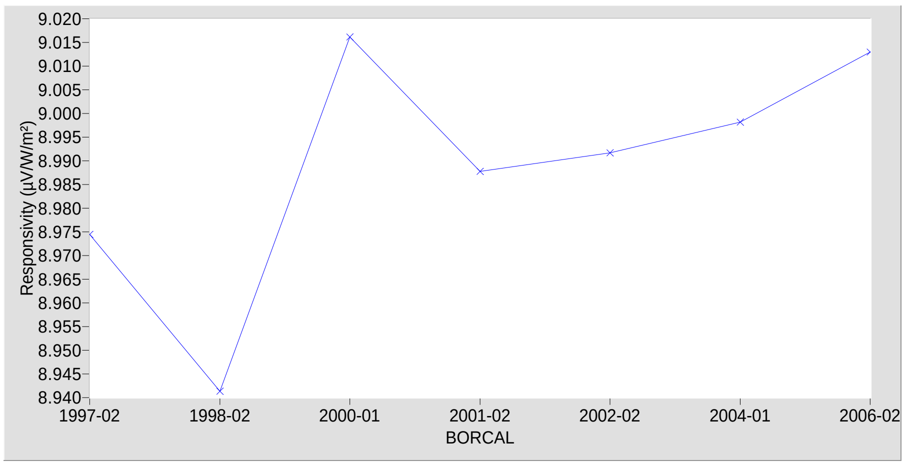
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	9.0130	+0.78 / -1.34 †
Average	9.0184	+1.48 / -1.32 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 29010E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: _________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: _________________

Calibration Results

29010E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

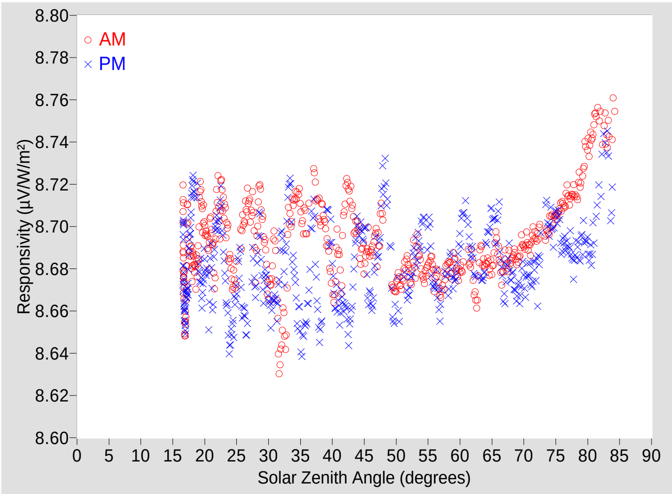


Figure 2. Responsivity vs Local Standard Time

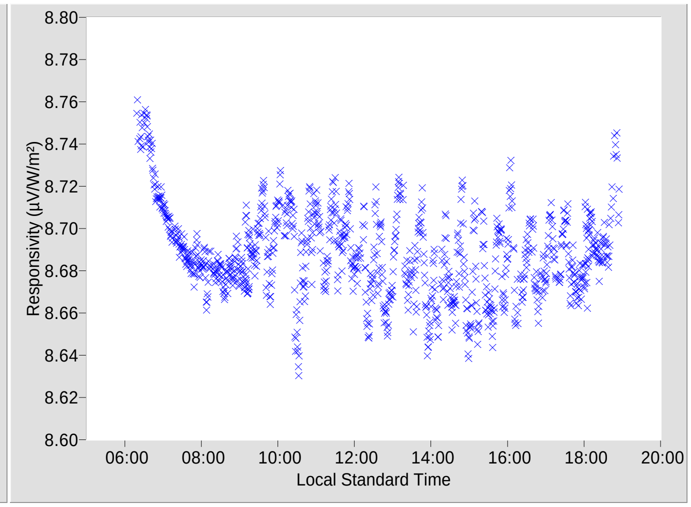


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6913	+0.84 / -1.07	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6883	0.38	97.16	8.6649	0.43	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7062	N/A	95.62	8.7227	0.46	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6719	0.38	101.84	8.6696	0.43	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6796	0.39	100.03	8.6694	0.40	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6785	0.40	98.24	8.6992	0.39	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6772	0.39	96.61	8.6733	0.47	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6814	0.39	94.92	8.6729	0.39	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6787	0.38	93.38	8.6957	0.43	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6790	0.41	91.81	8.6836	0.41	275.00
18	8.6846	0.49	154.91	8.7125	0.54	204.48	64	8.6825	0.39	90.29	8.6877	0.42	276.37
20	8.7007	0.44	142.69	8.6795	0.44	217.31	66	8.6879	0.41	88.83	8.7005	0.46	277.73
22	8.7095	0.48	134.59	8.7017	0.50	225.42	68	8.6843	0.39	87.35	8.6770	0.41	279.16
24	8.6825	0.43	128.42	8.6460	0.45	231.43	70	8.6907	0.39	85.90	8.6756	0.40	280.47
26	8.6996	0.40	123.41	8.6619	0.44	236.41	72	8.6951	0.40	84.49	8.6783	0.43	281.89
28	8.6910	0.45	119.27	8.6760	0.43	240.63	74	8.6994	0.40	83.05	8.7014	0.43	278.98
30	8.6709	0.43	115.68	8.6662	0.40	244.22	76	8.7100	0.41	81.62	8.6908	0.44	280.39
32	8.6466	0.50	112.55	8.6934	0.50	247.37	78	8.7158	0.42	80.16	8.6848	0.46	281.86
34	8.7130	0.39	109.84	8.6799	0.56	250.05	80	8.7371	0.46	78.66	8.6897	0.48	283.28
36	8.7003	0.38	107.49	8.6578	0.54	252.57	82	8.7523	0.48	77.32	8.7227	0.58	284.74
38	8.7050	0.40	104.96	8.6528	0.54	254.90	84	8.7522	0.57	75.73	8.7126	0.67	286.06
40	8.6709	0.42	102.87	8.6847	0.46	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7130	0.48	100.82	8.6606	0.40	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6994	0.41	98.94	8.6988	0.44	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
29010E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

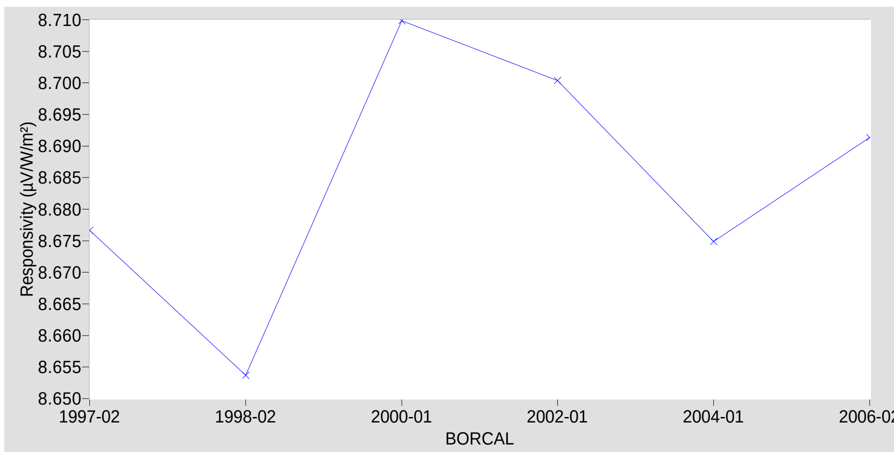
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.6913	+0.84 / -1.07 †
Average	8.6894	+1.29 / -0.99 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 29279F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: SGP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29279F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

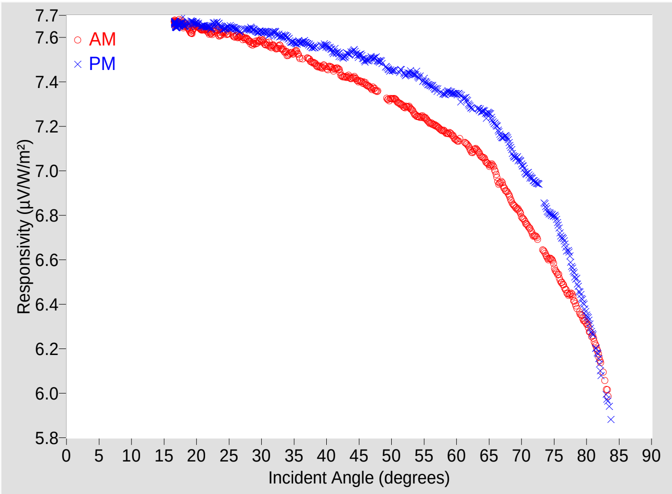


Figure 2. Responsivity vs Local Standard Time

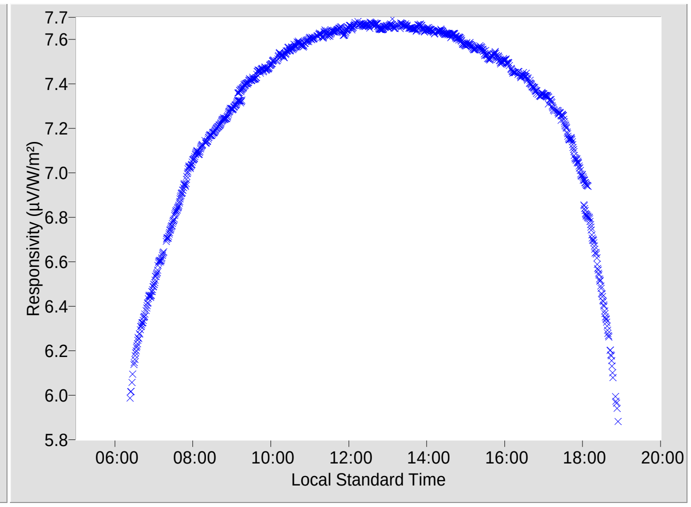


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.4622	+2.77 / -4.83	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.3930	0.60	97.18	7.4969	0.60	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3573	N/A	95.64	7.4936	0.60	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3253	0.63	101.80	7.4510	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2893	0.66	100.06	7.4333	0.62	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2464	0.70	98.26	7.4288	0.68	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2153	0.72	96.58	7.3832	0.73	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1800	0.72	94.94	7.3454	0.66	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1393	0.76	93.40	7.3464	0.74	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1029	0.82	91.83	7.2925	0.78	274.97
18	7.6572	0.56	155.25	7.6626	0.55	204.58	64	7.0623	0.94	90.31	7.2686	0.79	276.39
20	7.6501	0.53	142.58	7.6622	0.50	217.20	66	6.9954	1.08	88.85	7.2079	1.08	277.75
22	7.6223	0.51	134.49	7.6459	0.51	225.32	68	6.8955	1.19	87.37	7.1326	1.07	279.13
24	7.6199	0.53	128.48	7.6416	0.53	231.49	70	6.7987	1.15	85.91	7.0329	1.06	280.49
26	7.6058	0.48	123.46	7.6396	0.52	236.46	72	6.7075	1.18	84.47	6.9508	1.06	281.90
28	7.5886	0.53	119.32	7.6379	0.49	240.56	74	6.6087	1.30	83.02	6.8214	1.45	278.95
30	7.5877	0.51	115.72	7.6265	0.49	244.17	76	6.5117	1.66	81.64	6.7136	1.96	280.41
32	7.5590	0.52	112.58	7.6240	0.52	247.32	78	6.4227	1.81	80.16	6.5438	2.32	281.83
34	7.5274	0.52	109.88	7.5993	0.55	250.09	80	6.3155	2.21	78.72	6.3564	2.60	283.26
36	7.5077	0.55	107.27	7.5787	0.52	252.60	82	6.1559	3.11	77.24	6.1285	3.27	284.73
38	7.4864	0.57	104.92	7.5552	0.53	254.93	84	N/A	N/A	N/A	5.8820	N/A	286.03
40	7.4614	0.54	102.80	7.5616	0.57	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4498	0.59	100.85	7.5216	0.61	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4194	0.57	98.90	7.5385	0.59	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

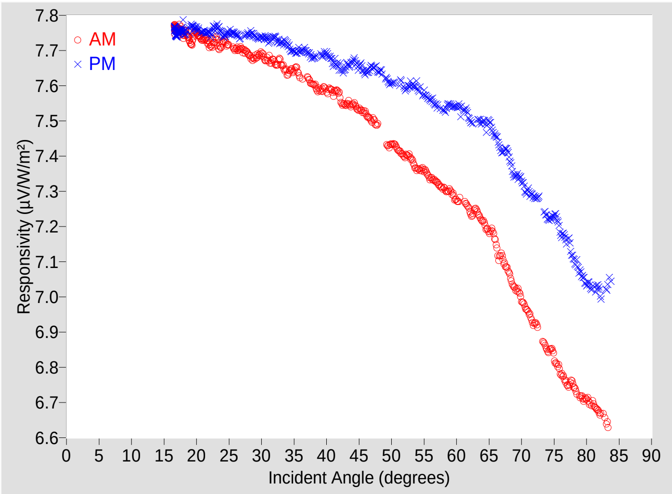

Figure 4. Responsivity vs Local Standard Time

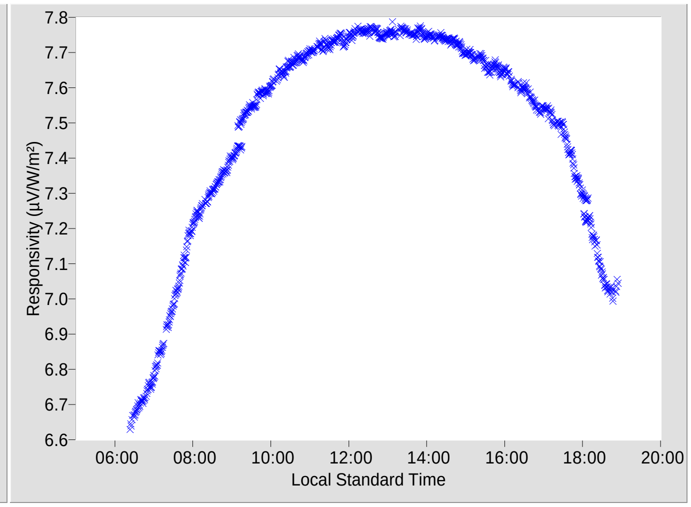

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.5943	+2.54 / -4.81	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.62721 µV/W/m², determination date: 06/08/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5231	0.66	97.18	7.6374	0.66	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4884	N/A	95.64	7.6403	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4342	0.67	101.80	7.6061	0.68	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4017	0.70	100.06	7.5913	0.70	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3632	0.73	98.26	7.5942	0.75	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3375	0.76	96.58	7.5589	0.79	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3086	0.77	94.94	7.5289	0.76	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2742	0.81	93.40	7.5403	0.81	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2466	0.87	91.83	7.5026	0.87	274.97
18	7.7497	0.58	155.25	7.7570	0.58	204.58	64	7.2162	0.97	90.31	7.4970	0.91	276.39
20	7.7482	0.57	142.58	7.7613	0.54	217.20	66	7.1591	1.13	88.85	7.4572	1.11	277.75
22	7.7166	0.55	134.49	7.7493	0.56	225.32	68	7.0735	1.18	87.37	7.4020	1.15	279.13
24	7.7193	0.57	128.48	7.7453	0.57	231.49	70	6.9935	1.18	85.91	7.3316	1.18	280.49
26	7.7051	0.52	123.46	7.7465	0.55	236.46	72	6.9242	1.25	84.47	7.2824	1.24	281.90
28	7.6907	0.56	119.32	7.7459	0.54	240.56	74	6.8486	1.37	83.02	7.2246	1.65	278.95
30	7.6906	0.55	115.72	7.7379	0.54	244.17	76	6.7890	1.64	81.64	7.1817	1.96	280.41
32	7.6674	0.56	112.58	7.7378	0.56	247.32	78	6.7482	1.88	80.16	7.1067	2.33	281.83
34	7.6379	0.57	109.88	7.7177	0.60	250.09	80	6.7122	2.27	78.72	7.0370	2.69	283.26
36	7.6233	0.60	107.27	7.7003	0.58	252.60	82	6.6708	2.99	77.24	7.0156	3.45	284.73
38	7.6038	0.62	104.92	7.6794	0.59	254.93	84	N/A	N/A	N/A	7.0449	N/A	286.03
40	7.5838	0.59	102.80	7.6896	0.63	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5728	0.65	100.85	7.6517	0.66	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5465	0.62	98.90	7.6705	0.65	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

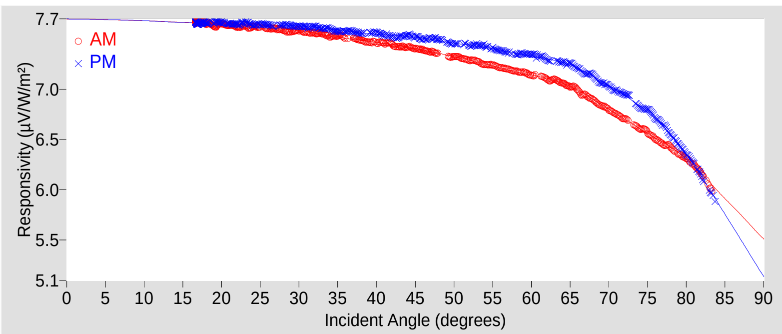
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \quad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

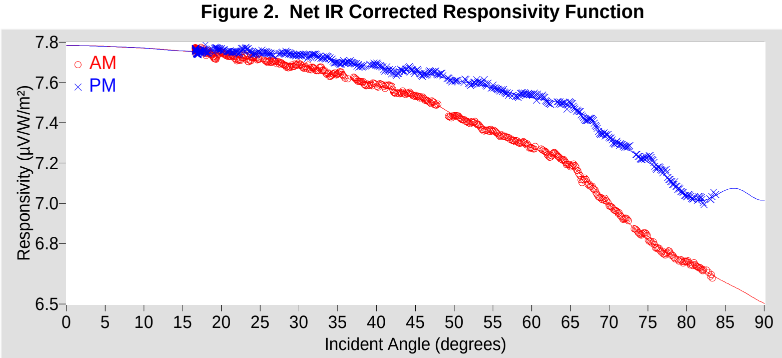


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.55	±1.55
R²	0.9999998	0.9999992
Valid incidence angle range	16.6° to 83.3°	16.6° to 83.7°
Net IR corr. uncert. U95 (%)	±1.59	±1.59
Net IR corrected R²	0.9999998	0.9999993
Corr. valid inc. angle range	16.6° to 83.3°	16.6° to 83.7°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.6929	*	7.6929	*	7.6929	*	7.7798	*	7.7798	*	7.7798	*
9-18	7.6705	*	7.6710	*	7.6707	*	7.7618	*	7.7623	*	7.7620	*
18-27	7.6286	±1.59	7.6492	±1.56	7.6389	±1.66	7.7256	±1.62	7.7513	±1.59	7.7384	±1.67
27-36	7.5632	±1.66	7.6191	±1.59	7.5912	±1.97	7.6698	±1.66	7.7325	±1.61	7.7011	±1.95
36-45	7.4621	±1.67	7.5483	±1.60	7.5052	±2.20	7.5837	±1.67	7.6760	±1.61	7.6298	±2.15
45-54	7.3360	±1.85	7.4687	±1.68	7.4023	±2.91	7.4562	±1.93	7.6195	±1.65	7.5378	±3.10
54-63	7.1732	±1.89	7.3549	±1.76	7.2641	±3.47	7.3031	±1.80	7.5416	±1.66	7.4223	±3.61
63-72	6.9248	±3.02	7.1482	±2.73	7.0365	±5.86	7.0997	±2.62	7.4132	±2.15	7.2565	±5.79
72-81	6.5003	±3.64	6.6622	±5.05	6.5813	±7.34	6.7955	±2.25	7.1600	±2.36	6.9778	±6.04
81-90	5.8748	*	5.6954	*	5.7851	*	6.5979	*	7.0402	*	6.8191	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

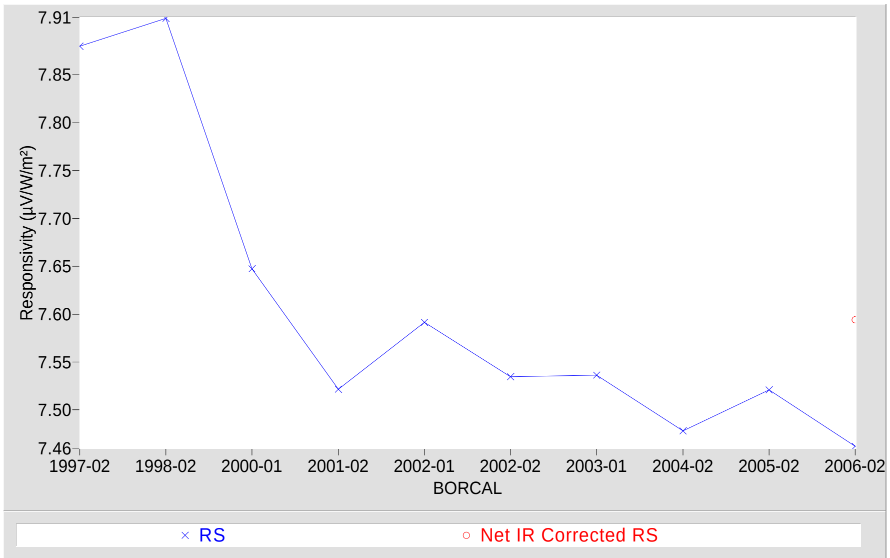
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.4622	+2.77 / -4.83
45° - 55°	7.3915	±2.47
Composite	7.4799	+2.90 / -20.59
45° (Net IR Corr.)	7.5943	+2.54 / -4.81
45° - 55° (Net IR Corr.)	7.5279	±2.55
Composite (Net IR Corr.)	7.6166	+2.44 / -12.93

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.3°, 16.6° to 83.3° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



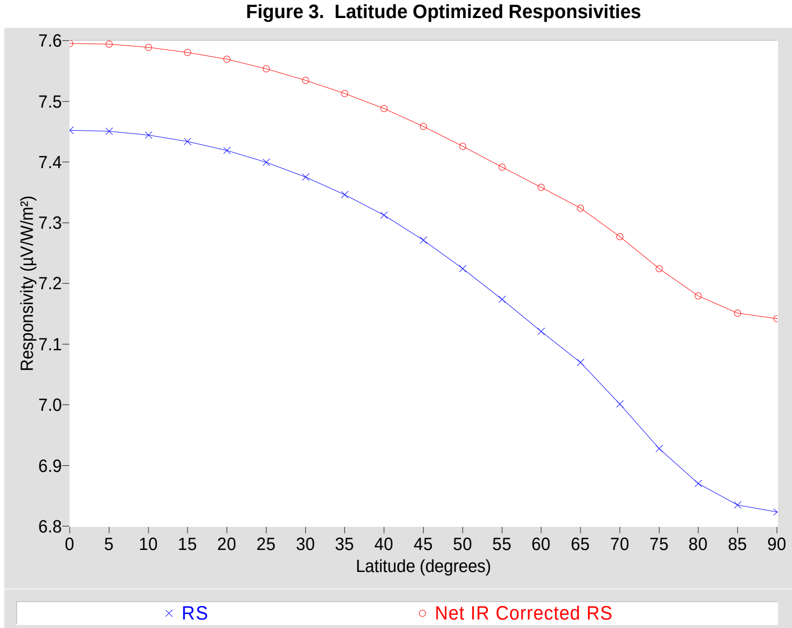
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.4522	+3.65 / -29.44	7.5954	+2.95 / -14.21
5	7.4506	+3.67 / -29.43	7.5941	+2.96 / -14.19
10	7.4443	+3.75 / -29.37	7.5891	+3.02 / -14.14
15	7.4336	+3.89 / -29.27	7.5807	+3.12 / -14.04
20	7.4188	+4.08 / -29.13	7.5691	+3.25 / -13.91
25	7.3993	+4.33 / -28.94	7.5538	+3.43 / -13.74
30	7.3750	+4.55 / -28.71	7.5348	+3.59 / -13.52
35	7.3461	+4.78 / -28.43	7.5130	+3.75 / -13.27
40	7.3123	+5.04 / -28.10	7.4883	+3.93 / -12.99
45	7.2713	+5.49 / -27.69	7.4587	+4.28 / -12.65
50	7.2245	+5.93 / -27.22	7.4259	+4.58 / -12.26
55	7.1734	+6.51 / -26.71	7.3918	+4.96 / -11.86
60	7.1210	+6.62 / -26.17	7.3585	+4.91 / -11.47
65	7.0699	+6.87 / -25.63	7.3240	+5.00 / -11.05
70	7.0009	+7.39 / -24.90	7.2772	+5.32 / -10.49
75	6.9277	+7.67 / -24.11	7.2241	+5.50 / -9.84
80	6.8702	+7.69 / -23.48	7.1796	+5.56 / -9.28
85	6.8348	+7.22 / -23.08	7.1510	+5.37 / -8.93
90	6.8233	+5.85 / -22.95	7.1420	+4.70 / -8.81

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

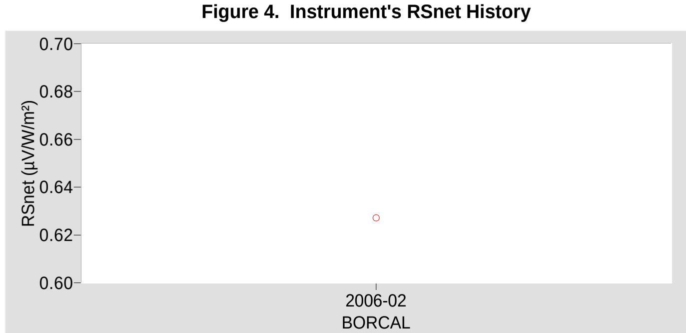
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley

Model: NIP
Serial Number: 29554E6

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: SGP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29554E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

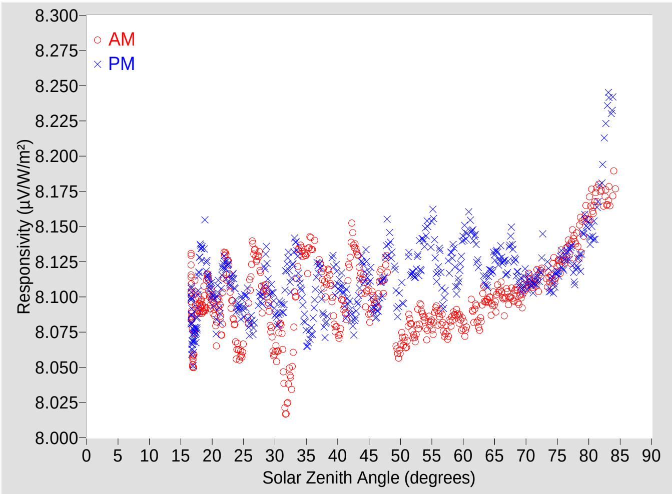


Figure 2. Responsivity vs Local Standard Time

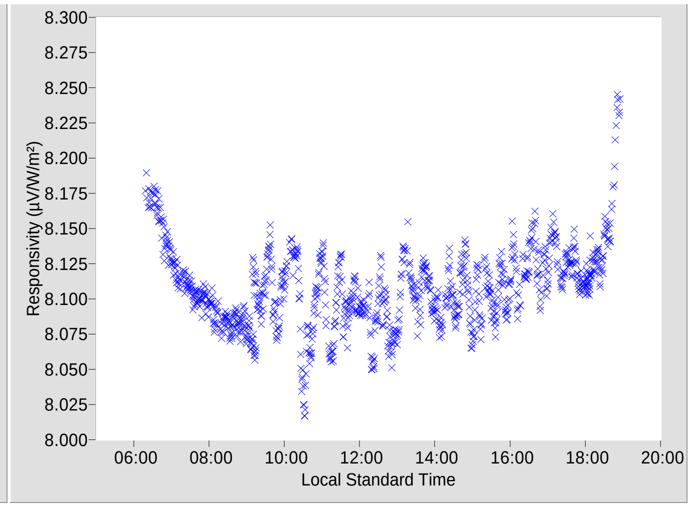


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1045	+1.08 / -1.45	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0957	0.44	97.16	8.0894	0.43	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1293	N/A	95.62	8.1407	0.50	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0657	0.39	101.84	8.1065	0.43	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0744	0.40	100.03	8.1161	0.39	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0784	0.41	98.24	8.1455	0.43	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0876	0.40	96.61	8.1234	0.57	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0829	0.40	94.92	8.1269	0.43	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0787	0.39	93.38	8.1435	0.50	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0905	0.40	91.81	8.1351	0.43	275.00
18	8.0936	0.53	154.91	8.1224	0.65	204.48	64	8.0985	0.40	90.29	8.1136	0.41	276.37
20	8.0972	0.48	142.69	8.1014	0.49	217.31	66	8.1046	0.41	88.83	8.1282	0.40	277.73
22	8.1223	0.52	134.59	8.1220	0.47	225.42	68	8.0995	0.39	87.35	8.1299	0.46	279.16
24	8.0631	0.45	128.42	8.0932	0.42	231.43	70	8.1077	0.42	85.90	8.1118	0.40	280.47
26	8.1052	0.52	123.41	8.0806	0.42	236.41	72	8.1137	0.41	84.49	8.1148	0.46	281.89
28	8.1046	0.46	119.27	8.1038	0.45	240.63	74	8.1115	0.42	83.05	8.1092	0.43	278.98
30	8.0597	0.43	115.68	8.0899	0.41	244.22	76	8.1261	0.43	81.62	8.1232	0.44	280.39
32	8.0309	0.51	112.55	8.1239	0.45	247.37	78	8.1395	0.47	80.16	8.1198	0.51	281.86
34	8.1342	0.51	109.84	8.1101	0.55	250.05	80	8.1603	0.49	78.66	8.1456	0.50	283.28
36	8.1366	0.40	107.49	8.0804	0.52	252.57	82	8.1753	0.50	77.32	8.1848	0.71	284.74
38	8.1066	0.40	104.96	8.0801	0.49	254.90	84	8.1794	0.59	75.73	8.2373	0.65	286.06
40	8.0752	0.41	102.87	8.1137	0.41	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1328	0.56	100.82	8.0893	0.42	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1103	0.46	98.94	8.1226	0.44	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29554E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

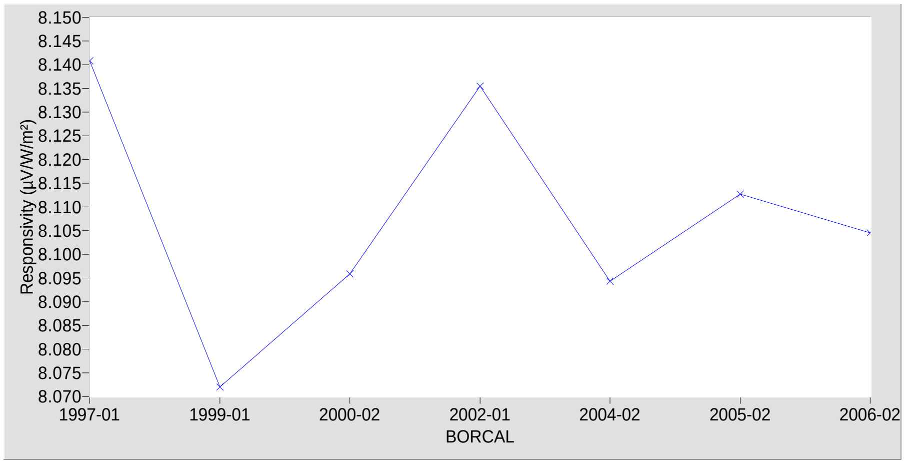
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1045	+1.08 / -1.45 †
Average	8.1125	+2.20 / -1.51 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer **Manufacturer:** Eppley

Model: NIP **Serial Number:** 29556E6

Calibration Date: 8/12/2006 **Due Date:** 8/12/2007

Customer: SGP **Calibration Site Parameters:** see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

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Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29556E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

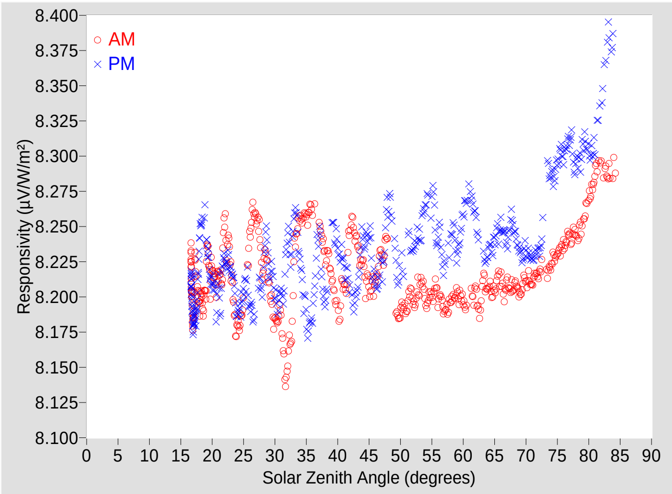


Figure 2. Responsivity vs Local Standard Time

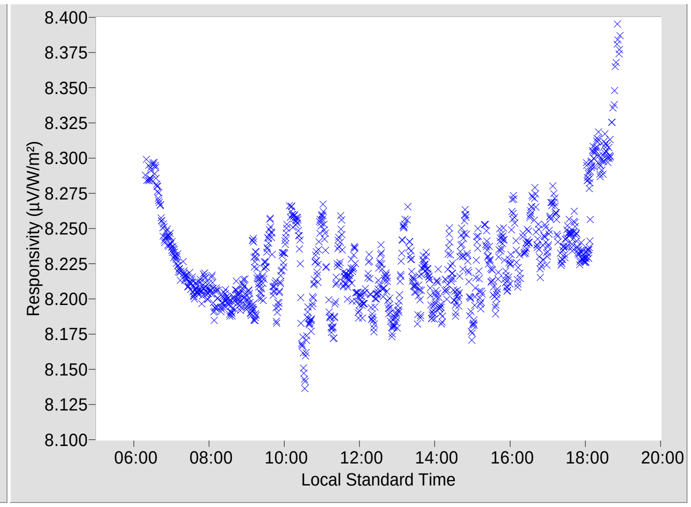


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2261	+1.02 / -1.46	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2099	0.42	97.16	8.2113	0.46	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2416	N/A	95.62	8.2647	0.53	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1897	0.38	101.84	8.2268	0.42	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1977	0.40	100.03	8.2345	0.39	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1972	0.40	98.24	8.2662	0.42	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2010	0.41	96.61	8.2439	0.54	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1976	0.39	94.92	8.2403	0.41	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1967	0.39	93.38	8.2606	0.48	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2032	0.40	91.81	8.2538	0.43	275.00
18	8.1980	0.46	154.91	8.2358	0.64	204.48	64	8.2072	0.40	90.29	8.2330	0.39	276.37
20	8.2185	0.44	142.69	8.2094	0.51	217.31	66	8.2117	0.41	88.83	8.2486	0.40	277.73
22	8.2445	0.48	134.59	8.2260	0.46	225.42	68	8.2060	0.39	87.35	8.2488	0.42	279.16
24	8.1776	0.46	128.42	8.1895	0.42	231.43	70	8.2108	0.40	85.90	8.2327	0.39	280.47
26	8.2413	0.46	123.41	8.1946	0.44	236.41	72	8.2165	0.41	84.49	8.2331	0.43	281.89
28	8.2225	0.46	119.27	8.2124	0.48	240.63	74	8.2218	0.41	83.05	8.2875	0.43	278.98
30	8.1826	0.42	115.68	8.2011	0.43	244.22	76	8.2363	0.42	81.62	8.3006	0.44	280.39
32	8.1551	0.47	112.55	8.2413	0.52	247.37	78	8.2437	0.43	80.16	8.2941	0.49	281.86
34	8.2561	0.42	109.84	8.2258	0.59	250.05	80	8.2712	0.48	78.66	8.3026	0.49	283.28
36	8.2619	0.38	107.49	8.1892	0.58	252.57	82	8.2959	0.49	77.32	8.3406	0.64	284.74
38	8.2284	0.43	104.96	8.1986	0.51	254.90	84	8.2904	0.57	75.73	8.3821	0.65	286.06
40	8.1913	0.41	102.87	8.2368	0.41	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2493	0.50	100.82	8.2043	0.42	259.09	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2242	0.46	98.94	8.2406	0.46	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29556E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

- *IRR* = solar irradiance (Watts per square meter)
- *V* = radiometer output voltage (microvolts)
- *RS* = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

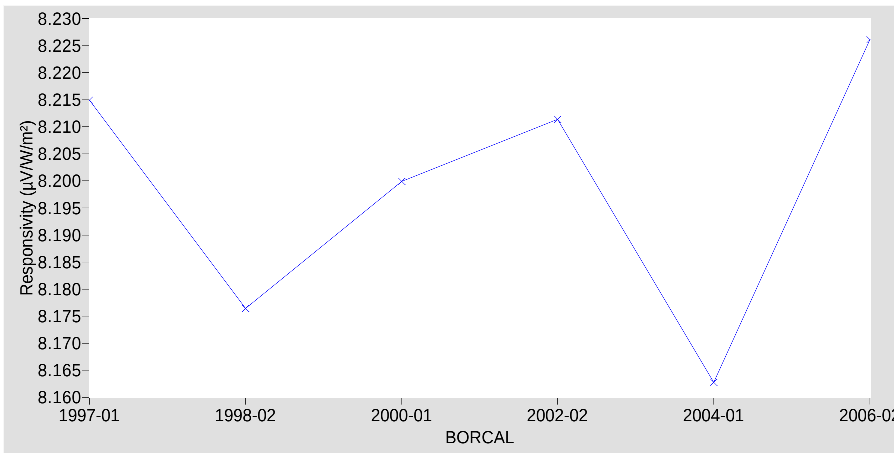
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2261	+1.02 / -1.46 †
Average	8.2325	+2.48 / -1.40 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 29578E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29578E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

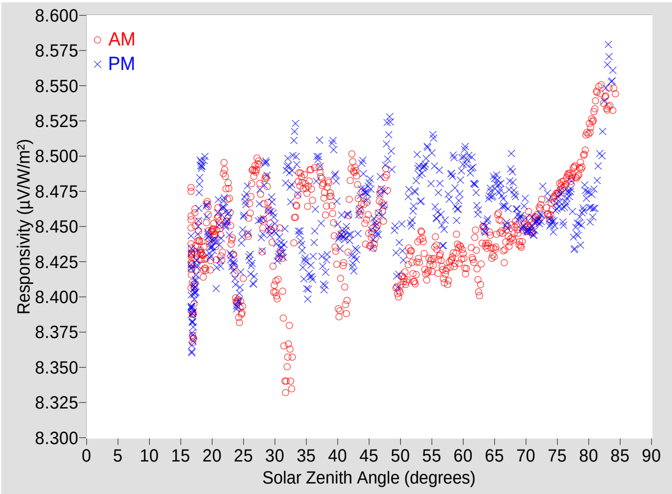


Figure 2. Responsivity vs Local Standard Time

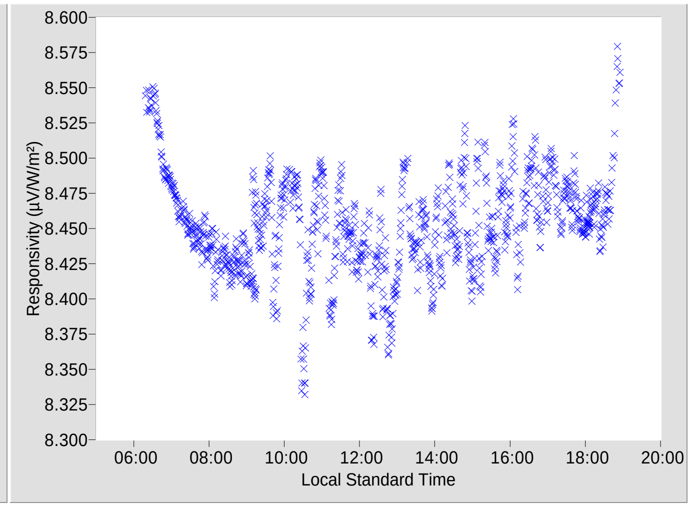


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.4637	+1.13 / -1.93	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4435	0.44	97.16	8.4501	0.48	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4866	N/A	95.62	8.5147	0.56	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4077	0.39	101.84	8.4452	0.46	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4191	0.41	100.03	8.4611	0.48	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4192	0.43	98.24	8.4982	0.44	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4286	0.42	96.61	8.4721	0.60	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4254	0.43	94.92	8.4825	0.46	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4278	0.40	93.38	8.4994	0.46	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4358	0.47	91.81	8.4716	0.44	275.00
18	8.4360	0.66	154.91	8.4753	0.75	204.48	64	8.4399	0.40	90.29	8.4657	0.44	276.37
20	8.4449	0.47	142.69	8.4367	0.53	217.31	66	8.4493	0.44	88.83	8.4735	0.43	277.73
22	8.4787	0.55	134.59	8.4592	0.47	225.42	68	8.4444	0.40	87.35	8.4779	0.49	279.16
24	8.3955	0.51	128.42	8.3968	0.54	231.43	70	8.4497	0.42	85.90	8.4567	0.41	280.47
26	8.4628	0.47	123.41	8.4281	0.55	236.41	72	8.4585	0.42	84.49	8.4546	0.43	281.89
28	8.4550	0.54	119.27	8.4515	0.53	240.63	74	8.4605	0.41	83.05	8.4524	0.43	278.98
30	8.4055	0.53	115.68	8.4477	0.46	244.22	76	8.4799	0.41	81.62	8.4597	0.45	280.39
32	8.3589	0.68	112.55	8.4926	0.61	247.37	78	8.4872	0.43	80.16	8.4449	0.53	281.86
34	8.4845	0.47	109.84	8.4430	0.75	250.05	80	8.5186	0.48	78.66	8.4665	0.50	283.28
36	8.4785	0.40	107.49	8.4234	0.71	252.57	82	8.5476	0.49	77.32	8.5065	0.72	284.74
38	8.4668	0.42	104.96	8.4133	0.73	254.90	84	8.5417	0.56	75.73	8.5571	0.65	286.06
40	8.4083	0.60	102.87	8.4571	0.59	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4805	0.76	100.82	8.4359	0.44	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4693	0.47	98.94	8.4866	0.53	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
29578E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4637	+1.13 / -1.93 †
Average	8.4581	+1.82 / -1.84 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°

Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 29610F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

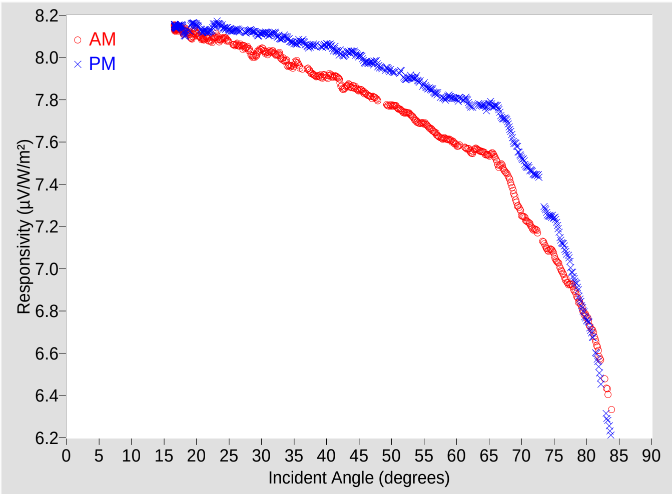

Figure 2. Responsivity vs Local Standard Time

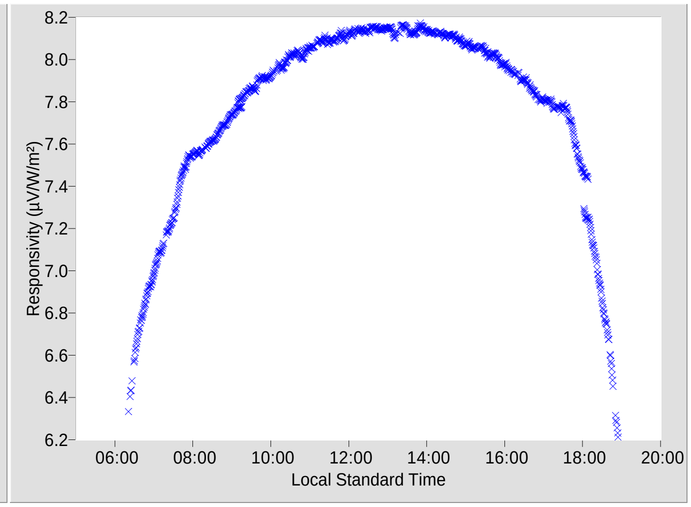

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9273	+2.98 / -4.78	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8315	0.61	97.18	7.9776	0.60	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8037	N/A	95.64	7.9589	0.61	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7735	0.62	101.80	7.9357	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7411	0.65	100.06	7.8994	0.65	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6950	0.69	98.26	7.8957	0.67	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6641	0.77	96.58	7.8503	0.71	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6171	0.70	94.94	7.8057	0.67	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5866	0.74	93.40	7.8028	0.67	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5621	0.78	91.83	7.7753	0.75	274.97
18	8.1258	0.53	155.25	8.1264	0.57	204.58	64	7.5538	0.82	90.31	7.7735	0.75	276.39
20	8.1147	0.56	142.58	8.1536	0.55	217.20	66	7.5247	0.96	88.85	7.7715	0.91	277.75
22	8.0842	0.50	134.49	8.1248	0.55	225.32	68	7.4356	1.34	87.37	7.6778	1.14	279.13
24	8.0885	0.53	128.48	8.1441	0.54	231.49	70	7.2615	1.22	85.91	7.5267	1.17	280.49
26	8.0620	0.48	123.46	8.1303	0.49	236.46	72	7.1864	1.14	84.47	7.4464	1.04	281.90
28	8.0409	0.59	119.32	8.1268	0.49	240.56	74	7.0908	1.26	83.02	7.2595	1.42	278.95
30	8.0409	0.54	115.72	8.1149	0.50	244.17	76	7.0046	1.65	81.64	7.1393	1.97	280.41
32	8.0207	0.53	112.58	8.1137	0.53	247.32	78	6.9059	1.78	80.16	6.9602	2.34	281.83
34	7.9721	0.57	109.88	8.0918	0.56	250.09	80	6.7753	2.22	78.72	6.7605	2.49	283.26
36	7.9523	0.56	107.27	8.0768	0.54	252.60	82	6.5847	3.13	77.24	6.5076	3.52	284.73
38	7.9190	0.56	104.92	8.0569	0.52	254.93	84	6.3336	N/A	75.88	6.2126	N/A	286.03
40	7.9076	0.53	102.80	8.0598	0.54	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8900	0.67	100.85	8.0225	0.61	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8609	0.57	98.90	8.0290	0.57	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

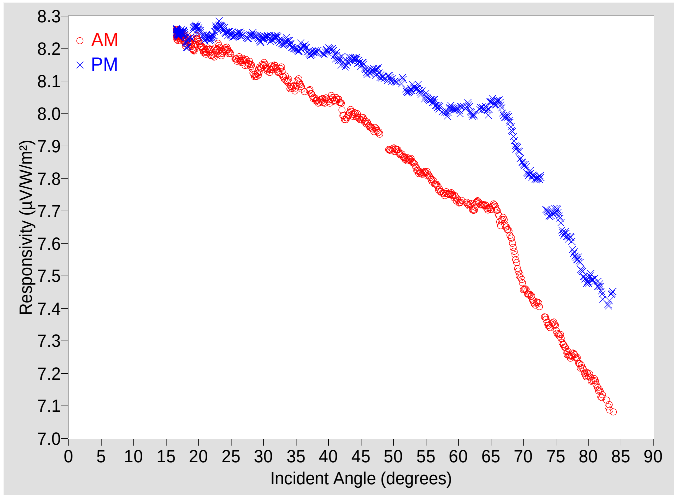

Figure 4. Responsivity vs Local Standard Time

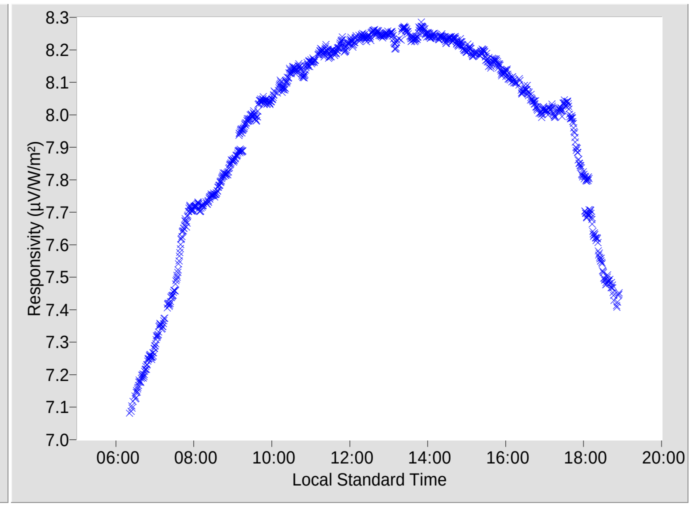

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0682	+2.74 / -4.78	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.66876 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9703	0.66	97.18	8.1275	0.65	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9434	N/A	95.64	8.1153	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8896	0.66	101.80	8.1010	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8609	0.69	100.06	8.0679	0.72	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8196	0.72	98.26	8.0721	0.73	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7944	0.77	96.58	8.0377	0.77	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7541	0.75	94.94	8.0013	0.76	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7305	0.79	93.40	8.0096	0.77	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7153	0.83	91.83	7.9993	0.84	274.97
18	8.2245	0.56	155.25	8.2270	0.60	204.58	64	7.7179	0.87	90.31	8.0170	0.89	276.39
20	8.2193	0.59	142.58	8.2593	0.58	217.20	66	7.6993	1.01	88.85	8.0374	0.97	277.75
22	8.1847	0.53	134.49	8.2351	0.58	225.32	68	7.6254	1.31	87.37	7.9650	1.19	279.13
24	8.1946	0.56	128.48	8.2547	0.59	231.49	70	7.4693	1.20	85.91	7.8452	1.21	280.49
26	8.1679	0.52	123.46	8.2442	0.53	236.46	72	7.4175	1.21	84.47	7.8000	1.20	281.90
28	8.1498	0.61	119.32	8.2419	0.53	240.56	74	7.3466	1.33	83.02	7.6893	1.61	278.95
30	8.1508	0.57	115.72	8.2337	0.54	244.17	76	7.3002	1.61	81.64	7.6384	1.92	280.41
32	8.1363	0.57	112.58	8.2350	0.56	247.32	78	7.2530	1.83	80.16	7.5604	2.27	281.83
34	8.0900	0.60	109.88	8.2180	0.60	250.09	80	7.1983	2.22	78.72	7.4862	2.60	283.26
36	8.0754	0.60	107.27	8.2065	0.59	252.60	82	7.1337	2.92	77.24	7.4535	3.37	284.73
38	8.0442	0.60	104.92	8.1893	0.58	254.93	84	7.0819	N/A	75.88	7.4525	N/A	286.03
40	8.0380	0.59	102.80	8.1963	0.60	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0211	0.71	100.85	8.1613	0.65	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9964	0.62	98.90	8.1697	0.62	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

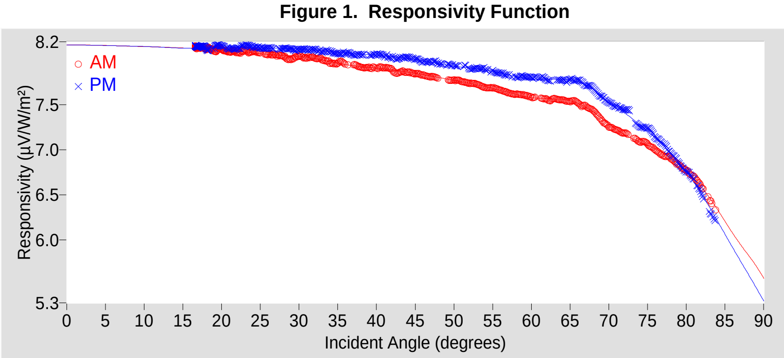
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

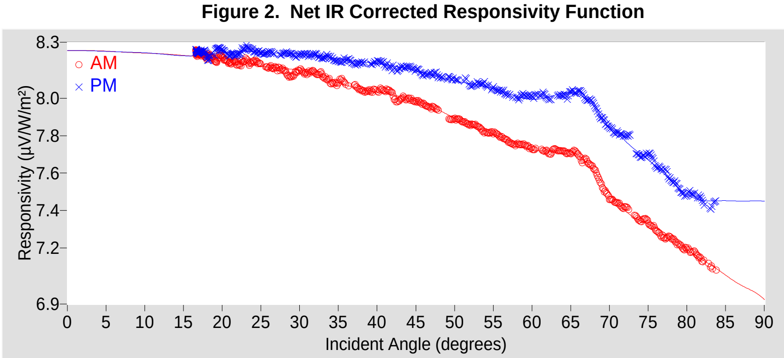


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.59	±1.59
R^2	0.9999992	0.9999985
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.7°
Net IR corr. uncert. U95 (%)	±1.56	±1.56
Net IR corrected R^2	0.9999992	0.9999989
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.7°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.1592	*	8.1591	*	8.1592	*	8.2518	*	8.2517	*	8.2518	*
9-18	8.1368	*	8.1370	*	8.1369	*	8.2342	*	8.2345	*	8.2343	*
18-27	8.0922	±1.64	8.1362	±1.59	8.1142	±1.77	8.1956	±1.60	8.2450	±1.56	8.2203	±1.74
27-36	8.0160	±1.71	8.1097	±1.61	8.0629	±2.23	8.1297	±1.64	8.2305	±1.57	8.1801	±2.14
36-45	7.9025	±1.69	8.0461	±1.64	7.9743	±2.53	8.0322	±1.63	8.1823	±1.59	8.1072	±2.42
45-54	7.7823	±1.81	7.9433	±1.73	7.8628	±3.06	7.9105	±1.84	8.1040	±1.63	8.0072	±3.20
54-63	7.6205	±1.82	7.8203	±1.72	7.7204	±3.34	7.7590	±1.70	8.0193	±1.61	7.8892	±3.46
63-72	7.4294	±2.94	7.6739	±2.70	7.5516	±5.84	7.6159	±2.52	7.9563	±2.15	7.7861	±5.87
72-81	6.9791	±3.55	7.0922	±5.29	7.0356	±7.38	7.2932	±2.18	7.6229	±2.51	7.4580	±5.88
81-90	6.1440	*	5.9893	*	6.0667	*	7.0441	*	7.4526	*	7.2483	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.9273	+2.98 / -4.78
45° - 55°	7.8519	±2.58
Composite	7.9481	+2.90 / -20.91
45° (Net IR Corr.)	8.0682	+2.74 / -4.78
45° - 55° (Net IR Corr.)	7.9973	±2.62
Composite (Net IR Corr.)	8.0944	+2.48 / -12.41

† Valid incident angle ranges:

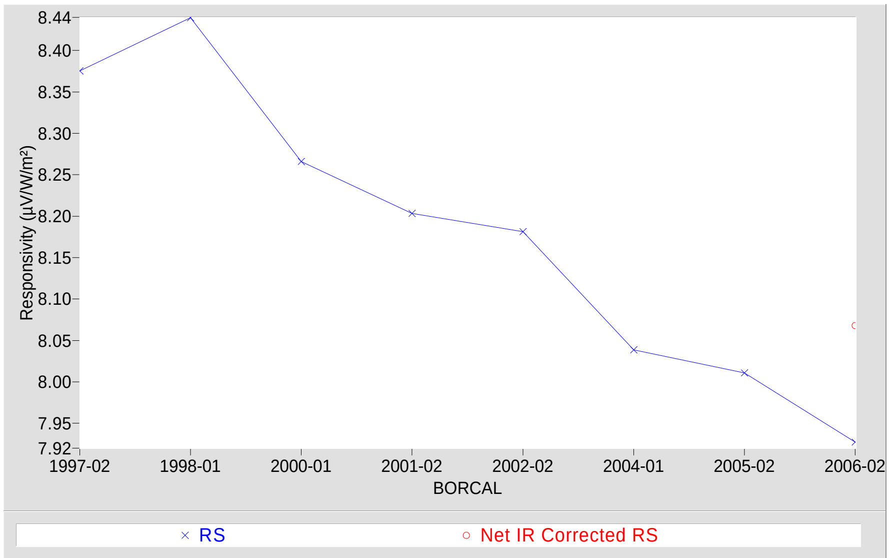
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.7°, 16.6° to 83.7° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



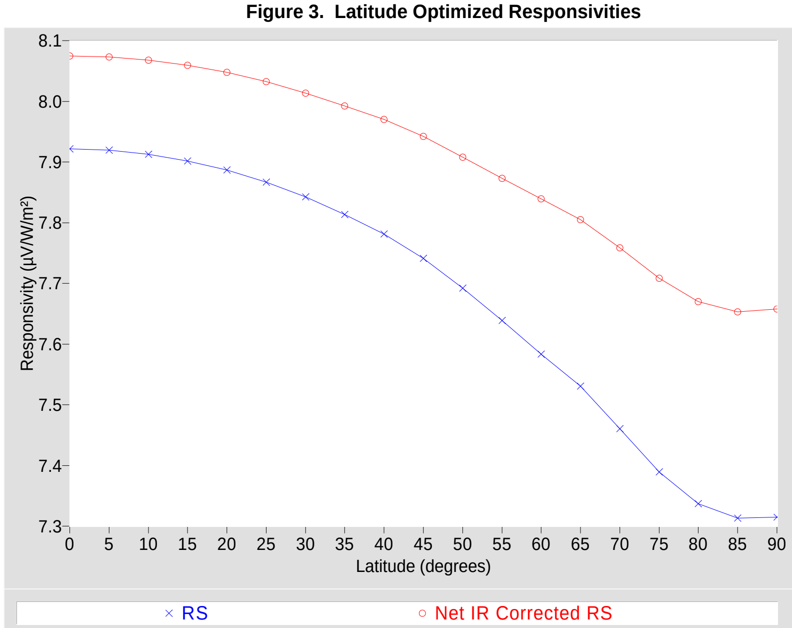
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.9214	+3.45 / -30.94	8.0746	+2.73 / -13.92
5	7.9194	+3.47 / -30.92	8.0730	+2.75 / -13.90
10	7.9128	+3.55 / -30.86	8.0678	+2.80 / -13.85
15	7.9018	+3.68 / -30.77	8.0592	+2.89 / -13.76
20	7.8868	+3.86 / -30.64	8.0477	+3.02 / -13.63
25	7.8669	+4.09 / -30.46	8.0323	+3.19 / -13.47
30	7.8426	+4.31 / -30.24	8.0136	+3.34 / -13.27
35	7.8137	+4.53 / -29.99	7.9925	+3.58 / -13.04
40	7.7814	+4.89 / -29.70	7.9699	+3.85 / -12.80
45	7.7413	+5.40 / -29.33	7.9421	+4.18 / -12.49
50	7.6919	+5.91 / -28.88	7.9078	+4.52 / -12.12
55	7.6385	+6.44 / -28.38	7.8731	+4.86 / -11.73
60	7.5835	+6.69 / -27.86	7.8392	+4.93 / -11.35
65	7.5304	+6.99 / -27.36	7.8048	+5.06 / -10.97
70	7.4602	+7.25 / -26.67	7.7587	+5.11 / -10.44
75	7.3893	+7.34 / -25.97	7.7087	+5.13 / -9.87
80	7.3367	+7.22 / -25.44	7.6697	+5.06 / -9.42
85	7.3132	+6.65 / -25.20	7.6532	+5.18 / -9.22
90	7.3150	+6.22 / -25.22	7.6579	+5.01 / -9.28

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

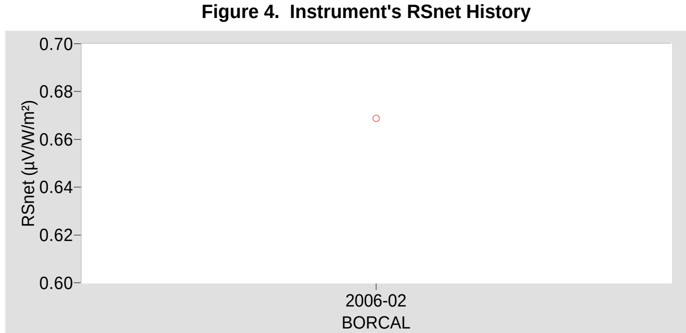
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 29615F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

29615F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

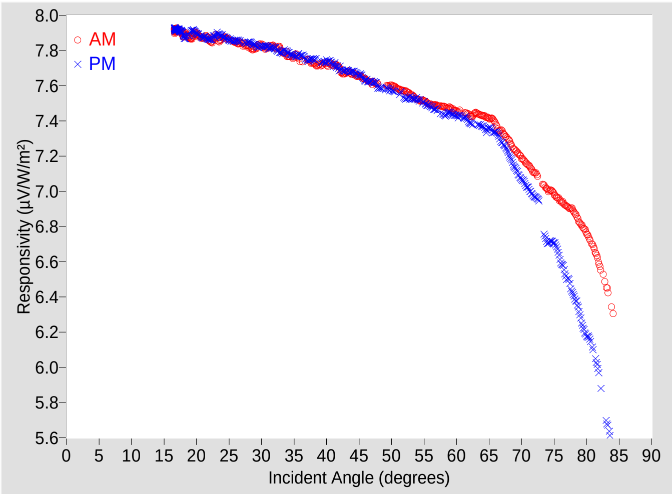


Figure 2. Responsivity vs Local Standard Time

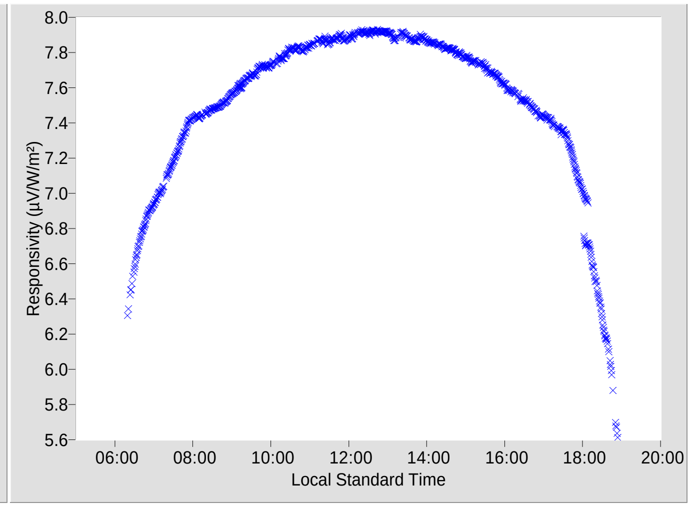


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.6590	+2.84 / -3.56	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6376	0.63	97.18	7.6303	0.62	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6128	N/A	95.64	7.5893	0.62	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6016	0.63	101.80	7.5734	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5704	0.66	100.06	7.5276	0.65	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5235	0.69	98.26	7.5212	0.63	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4945	0.69	96.58	7.4806	0.71	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4814	0.69	94.94	7.4339	0.68	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4550	0.74	93.40	7.4276	0.69	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4338	0.77	91.83	7.3888	0.76	274.97
18	7.8922	0.59	155.25	7.8870	0.58	204.58	64	7.4310	0.82	90.31	7.3678	0.79	276.39
20	7.8929	0.54	142.58	7.8969	0.56	217.20	66	7.3876	0.99	88.85	7.3340	0.97	277.75
22	7.8594	0.54	134.49	7.8639	0.50	225.32	68	7.2939	1.16	87.37	7.2123	1.27	279.13
24	7.8697	0.55	128.48	7.8810	0.55	231.49	70	7.1917	1.12	85.91	7.0688	1.18	280.49
26	7.8496	0.48	123.46	7.8555	0.49	236.46	72	7.1060	1.17	84.47	6.9680	1.14	281.90
28	7.8249	0.53	119.32	7.8453	0.49	240.56	74	7.0097	1.25	83.02	6.7121	1.44	278.95
30	7.8332	0.52	115.72	7.8246	0.50	244.17	76	6.9479	1.47	81.64	6.6016	2.22	280.41
32	7.8190	0.52	112.58	7.8145	0.54	247.32	78	6.8866	1.77	80.16	6.4070	2.45	281.83
34	7.7761	0.55	109.88	7.7916	0.55	250.09	80	6.7652	2.20	78.72	6.1820	2.63	283.26
36	7.7422	0.57	107.27	7.7725	0.56	252.60	82	6.5775	3.05	77.24	5.9474	4.08	284.70
38	7.7275	0.56	104.92	7.7493	0.53	254.93	84	6.3247	3.86	75.78	N/A	N/A	N/A
40	7.7173	0.53	102.80	7.7380	0.55	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6981	0.62	100.85	7.6955	0.63	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6684	0.57	98.90	7.6807	0.58	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

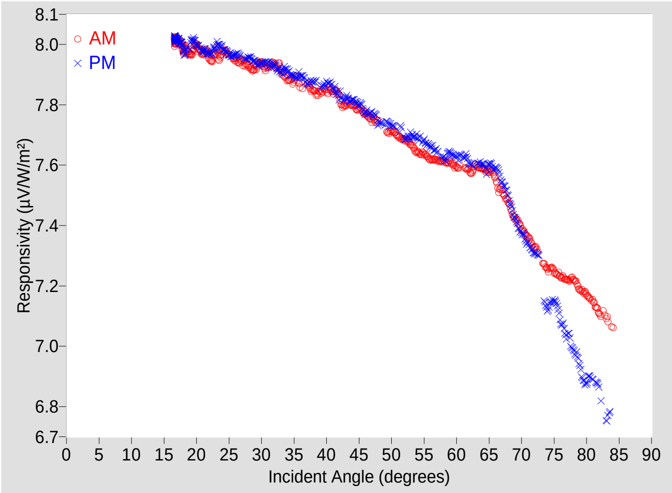

Figure 4. Responsivity vs Local Standard Time

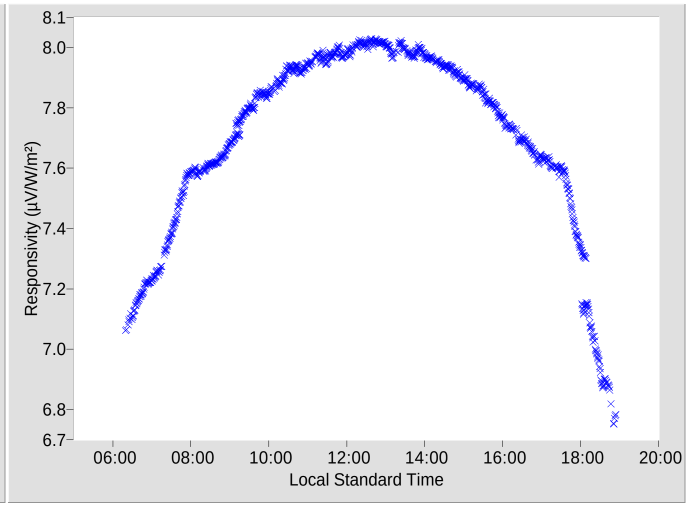

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.7946	+2.50 / -3.21	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64378 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7712	0.68	97.18	7.7746	0.67	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7474	N/A	95.64	7.7398	0.69	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7134	0.67	101.80	7.7326	0.67	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6857	0.69	100.06	7.6898	0.73	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6434	0.72	98.26	7.6910	0.71	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6199	0.73	96.58	7.6610	0.77	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6133	0.74	94.94	7.6222	0.77	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5935	0.79	93.40	7.6266	0.79	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5813	0.84	91.83	7.6045	0.86	274.97
18	7.9872	0.61	155.25	7.9839	0.61	204.58	64	7.5889	0.87	90.31	7.6022	0.91	276.39
20	7.9935	0.57	142.58	7.9987	0.59	217.20	66	7.5557	1.04	88.85	7.5899	1.03	277.75
22	7.9562	0.57	134.49	7.9701	0.55	225.32	68	7.4767	1.16	87.37	7.4888	1.27	279.13
24	7.9719	0.58	128.48	7.9875	0.59	231.49	70	7.3916	1.14	85.91	7.3754	1.24	280.49
26	7.9515	0.52	123.46	7.9652	0.53	236.46	72	7.3284	1.23	84.47	7.3084	1.27	281.90
28	7.9298	0.56	119.32	7.9561	0.54	240.56	74	7.2560	1.33	83.02	7.1259	1.67	278.95
30	7.9389	0.55	115.72	7.9389	0.54	244.17	76	7.2325	1.54	81.64	7.0821	2.09	280.41
32	7.9303	0.56	112.58	7.9312	0.57	247.32	78	7.2207	1.82	80.16	6.9848	2.37	281.83
34	7.8896	0.59	109.88	7.9130	0.59	250.09	80	7.1723	2.22	78.72	6.8806	2.72	283.26
36	7.8608	0.61	107.27	7.8974	0.61	252.60	82	7.1061	2.91	77.24	6.8524	3.61	284.70
38	7.8480	0.60	104.92	7.8768	0.58	254.93	84	7.0633	4.03	75.78	N/A	N/A	N/A
40	7.8429	0.59	102.80	7.8694	0.60	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8243	0.68	100.85	7.8291	0.67	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7989	0.63	98.90	7.8162	0.64	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

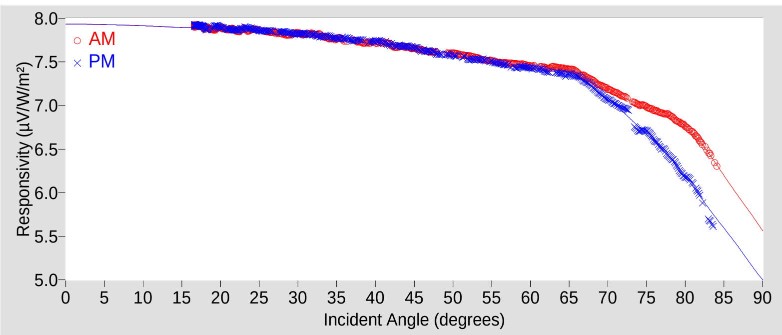
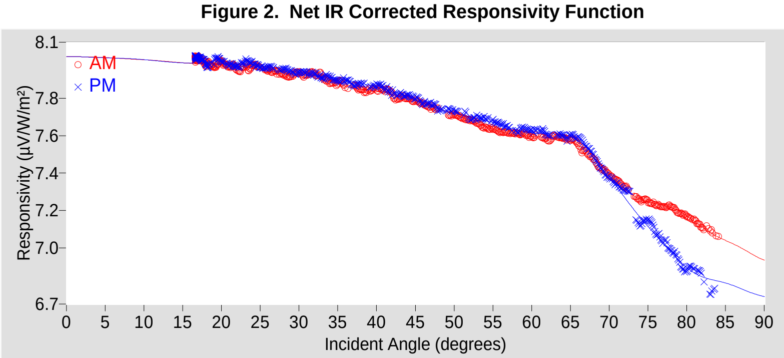


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.85	±1.85
R²	0.9999994	0.9999976
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.81	±1.81
Net IR corrected R²	0.9999994	0.9999981
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	7.9289	*	7.9289	*	7.9289	*	8.0180	*	8.0180	*	8.0180	*
9-18	7.9027	*	7.9024	*	7.9025	*	7.9964	*	7.9962	*	7.9963	*
18-27	7.8700	±1.88	7.8761	±1.87	7.8731	±1.91	7.9696	±1.83	7.9808	±1.81	7.9752	±1.86
27-36	7.8103	±1.93	7.8165	±1.91	7.8134	±2.07	7.9197	±1.87	7.9328	±1.85	7.9262	±1.99
36-45	7.7088	±1.93	7.7241	±1.98	7.7165	±2.12	7.8337	±1.86	7.8552	±1.91	7.8444	±2.03
45-54	7.6009	±1.99	7.5795	±2.05	7.5902	±2.23	7.7243	±1.99	7.7342	±1.93	7.7293	±2.19
54-63	7.4761	±1.95	7.4453	±2.02	7.4607	±2.27	7.6094	±1.85	7.6369	±1.87	7.6231	±2.02
63-72	7.3116	±2.86	7.2296	±3.45	7.2706	±5.12	7.4912	±2.48	7.5014	±2.75	7.4963	±3.54
72-81	6.9326	±3.25	6.5500	±6.34	6.7413	±10.63	7.2347	±2.11	7.0616	±3.31	7.1481	±4.78
81-90	6.1329	*	5.5330	*	5.8329	*	7.0318	*	6.8016	*	6.9167	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

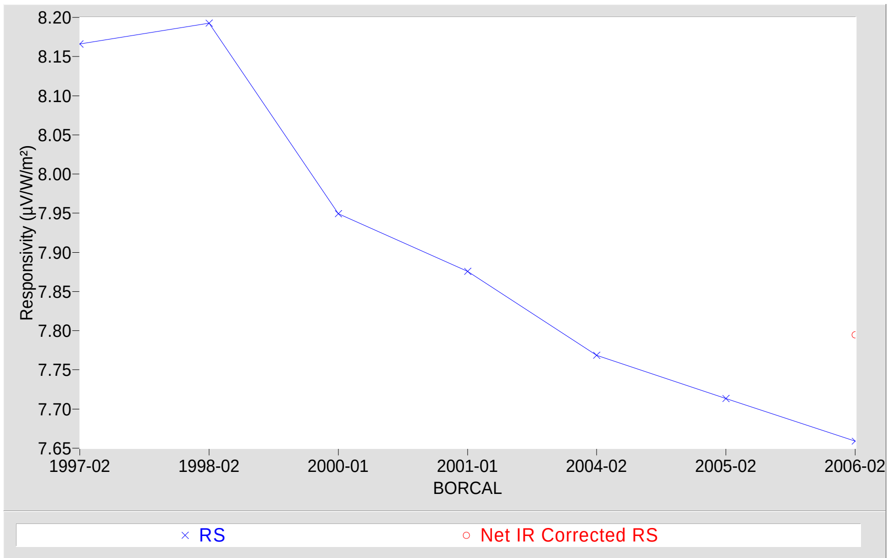
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.6590	+2.84 / -3.56
45° - 55°	7.5793	±2.12
Composite	7.6972	+3.12 / -25.92
45° (Net IR Corr.)	7.7946	+2.50 / -3.21
45° - 55° (Net IR Corr.)	7.7193	±2.08
Composite (Net IR Corr.)	7.8376	+2.63 / -13.07

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



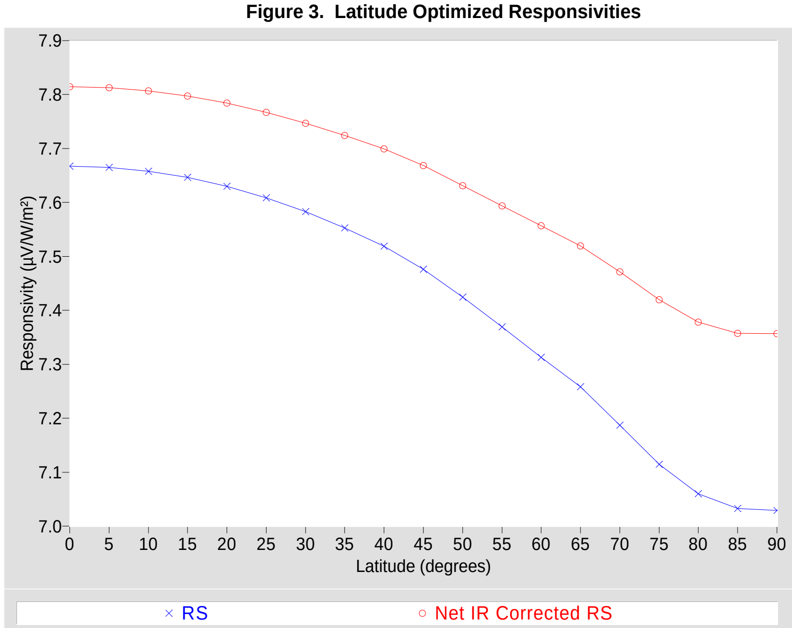
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.6672	+3.96 / -33.37	7.8143	+3.23 / -13.72
5	7.6651	+3.98 / -33.35	7.8125	+3.25 / -13.70
10	7.6580	+4.07 / -33.29	7.8068	+3.31 / -13.64
15	7.6463	+4.21 / -33.19	7.7974	+3.42 / -13.54
20	7.6300	+4.41 / -33.04	7.7843	+3.57 / -13.39
25	7.6085	+4.67 / -32.85	7.7672	+3.76 / -13.20
30	7.5829	+4.89 / -32.63	7.7470	+3.91 / -12.98
35	7.5529	+5.09 / -32.36	7.7243	+4.04 / -12.73
40	7.5186	+5.30 / -32.05	7.6994	+4.16 / -12.45
45	7.4760	+5.75 / -31.66	7.6684	+4.52 / -12.10
50	7.4243	+6.14 / -31.19	7.6312	+4.77 / -11.67
55	7.3692	+6.45 / -30.68	7.5936	+4.85 / -11.24
60	7.3128	+6.56 / -30.14	7.5569	+4.85 / -10.81
65	7.2581	+6.61 / -29.62	7.5196	+4.76 / -10.38
70	7.1869	+6.55 / -28.92	7.4711	+4.46 / -9.80
75	7.1147	+6.84 / -28.20	7.4195	+4.34 / -9.19
80	7.0599	+6.44 / -27.64	7.3780	+4.21 / -8.69
85	7.0325	+6.24 / -27.36	7.3575	+3.90 / -8.44
90	7.0291	+5.31 / -27.33	7.3567	+3.47 / -8.43

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

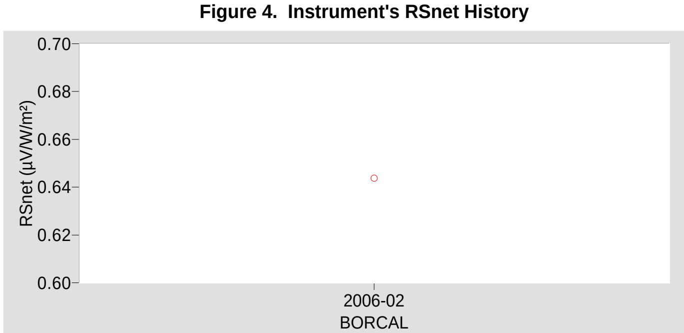
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 29742E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Zenith Angle

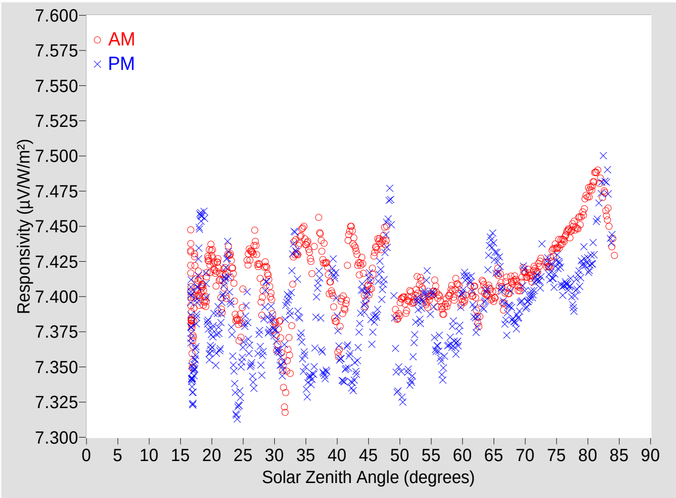


Figure 2. Responsivity vs Local Standard Time

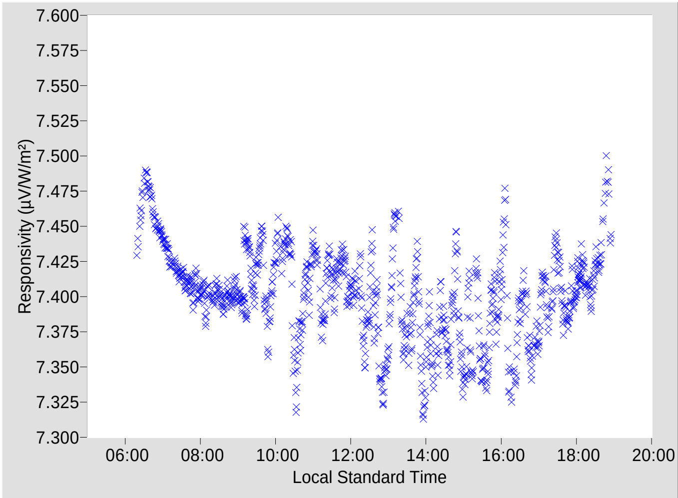


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.4075	+1.31 / -1.59	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4293	0.46	97.16	7.3853	0.55	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4399	N/A	95.62	7.4511	0.65	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3921	0.39	101.84	7.3483	0.64	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3981	0.41	100.03	7.3496	0.57	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3970	0.41	98.24	7.4049	0.45	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4007	0.42	96.61	7.3650	0.57	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4034	0.41	94.92	7.3667	0.41	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3970	0.40	93.38	7.4060	0.52	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4012	0.43	91.81	7.3832	0.47	275.00
18	7.4061	0.58	154.91	7.4379	0.94	204.48	64	7.4036	0.40	90.29	7.4188	0.53	276.37
20	7.4287	0.48	142.69	7.3726	0.58	217.31	66	7.4112	0.44	88.83	7.4152	0.52	277.73
22	7.4129	0.49	134.59	7.4114	0.64	225.42	68	7.4105	0.40	87.35	7.3849	0.44	279.16
24	7.3837	0.54	128.42	7.3202	0.67	231.43	70	7.4160	0.41	85.90	7.4059	0.44	280.47
26	7.4297	0.41	123.41	7.3629	0.60	236.41	72	7.4195	0.42	84.49	7.4124	0.47	281.89
28	7.4016	0.50	119.27	7.3605	0.59	240.63	74	7.4238	0.42	83.05	7.4171	0.45	278.98
30	7.3789	0.51	115.68	7.3741	0.47	244.22	76	7.4398	0.43	81.62	7.4064	0.48	280.39
32	7.3534	0.72	112.55	7.3979	0.74	247.37	78	7.4497	0.45	80.16	7.4024	0.53	281.86
34	7.4381	0.40	109.84	7.3811	0.77	250.05	80	7.4731	0.49	78.66	7.4220	0.52	283.28
36	7.4228	0.40	107.49	7.3424	0.67	252.57	82	7.4824	0.55	77.32	7.4738	0.66	284.74
38	7.4274	0.52	104.96	7.3450	0.64	254.90	84	7.4354	0.65	75.73	7.4411	0.78	286.06
40	7.3706	0.49	102.87	7.3886	0.70	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4462	0.55	100.82	7.3482	0.44	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4226	0.46	98.94	7.4001	0.57	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
29742E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.4075	+1.31 / -1.59 †
Average	7.4037	+1.62 / -1.79 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°

Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 29743E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29743E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

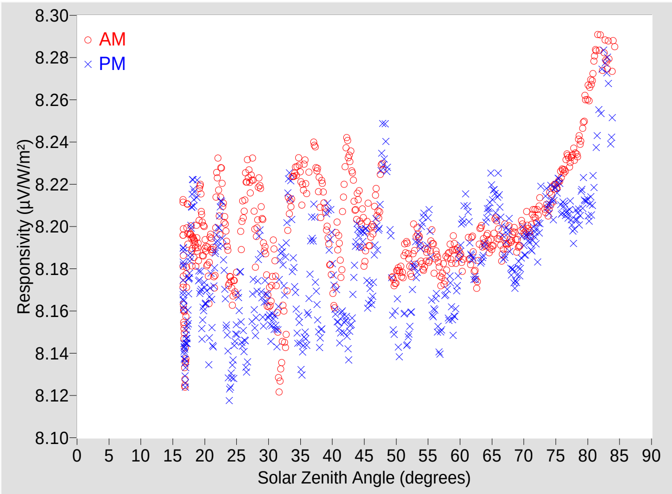


Figure 2. Responsivity vs Local Standard Time

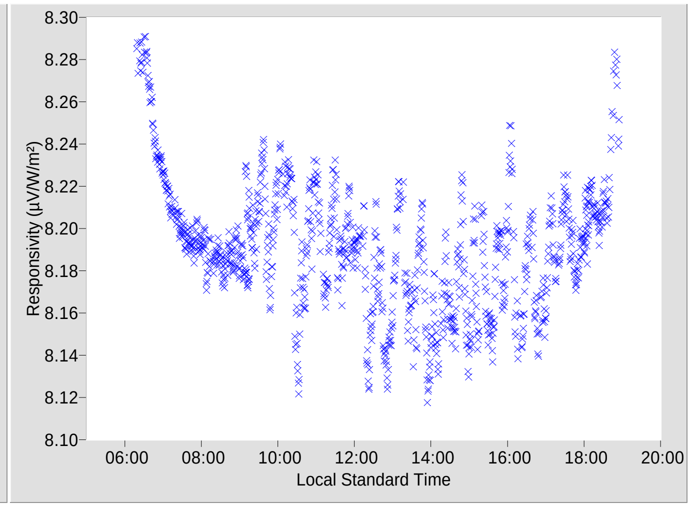


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1951	+1.03 / -1.27	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1955	0.43	97.16	8.1678	0.45	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2299	N/A	95.62	8.2387	0.52	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1762	0.38	101.84	8.1628	0.52	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1845	0.41	100.03	8.1506	0.44	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1833	0.40	98.24	8.1990	0.42	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1870	0.41	96.61	8.1626	0.56	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1851	0.40	94.92	8.1626	0.41	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1859	0.39	93.38	8.1912	0.52	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1893	0.41	91.81	8.1813	0.43	275.00
18	8.1920	0.58	154.91	8.2071	0.66	204.48	64	8.1933	0.39	90.29	8.1995	0.46	276.37
20	8.1927	0.50	142.69	8.1658	0.46	217.31	66	8.1971	0.40	88.83	8.2134	0.45	277.73
22	8.2167	0.53	134.59	8.1952	0.56	225.42	68	8.1939	0.39	87.35	8.1810	0.43	279.16
24	8.1738	0.45	128.42	8.1253	0.53	231.43	70	8.1982	0.40	85.90	8.1918	0.41	280.47
26	8.2046	0.45	123.41	8.1468	0.47	236.41	72	8.2055	0.41	84.49	8.1946	0.44	281.89
28	8.1974	0.48	119.27	8.1602	0.48	240.63	74	8.2098	0.41	83.05	8.2117	0.43	278.98
30	8.1651	0.45	115.68	8.1587	0.41	244.22	76	8.2258	0.42	81.62	8.2087	0.44	280.39
32	8.1407	0.50	112.55	8.1863	0.58	247.37	78	8.2344	0.43	80.16	8.2010	0.47	281.86
34	8.2249	0.42	109.84	8.1769	0.62	250.05	80	8.2622	0.49	78.66	8.2082	0.50	283.28
36	8.2225	0.39	107.49	8.1516	0.59	252.57	82	8.2871	0.50	77.32	8.2611	0.61	284.74
38	8.2133	0.43	104.96	8.1494	0.56	254.90	84	8.2823	0.57	75.73	8.2469	0.69	286.06
40	8.1725	0.45	102.87	8.1874	0.51	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2283	0.55	100.82	8.1531	0.40	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2122	0.46	98.94	8.1957	0.46	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29743E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1951	+1.03 / -1.27 †
Average	8.1950	+1.65 / -1.37 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°

Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29848E6
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29848E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

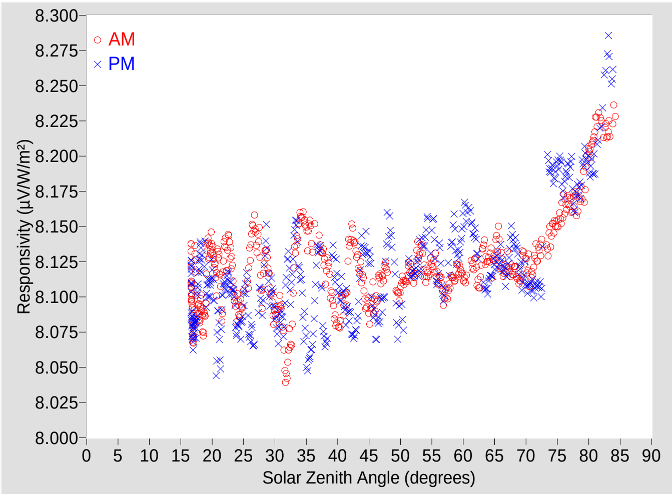


Figure 2. Responsivity vs Local Standard Time

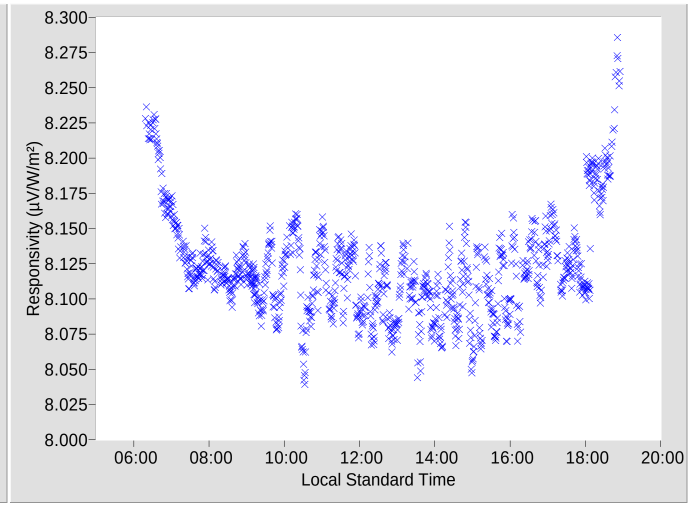


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1096	+1.00 / -1.24	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0948	0.43	97.16	8.0803	0.54	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1197	N/A	95.62	8.1469	0.57	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1044	0.39	101.84	8.0943	0.50	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1150	0.42	100.03	8.1166	0.38	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1158	0.41	98.24	8.1458	0.45	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1132	0.44	96.61	8.1218	0.52	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1117	0.41	94.92	8.1323	0.50	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1140	0.39	93.38	8.1562	0.45	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1210	0.42	91.81	8.1387	0.43	275.00
18	8.0910	0.56	154.91	8.1241	0.56	204.48	64	8.1268	0.42	90.29	8.1097	0.41	276.37
20	8.1342	0.48	142.69	8.1112	0.63	217.31	66	8.1280	0.44	88.83	8.1265	0.42	277.73
22	8.1305	0.53	134.59	8.1082	0.56	225.42	68	8.1188	0.41	87.35	8.1397	0.43	279.16
24	8.0934	0.47	128.42	8.0773	0.45	231.43	70	8.1228	0.42	85.90	8.1119	0.41	280.47
26	8.1282	0.49	123.41	8.0756	0.49	236.41	72	8.1313	0.42	84.49	8.1089	0.45	281.89
28	8.1095	0.51	119.27	8.1013	0.54	240.63	74	8.1452	0.43	83.05	8.1911	0.43	278.98
30	8.0867	0.43	115.68	8.0870	0.47	244.22	76	8.1649	0.43	81.62	8.1787	0.46	280.39
32	8.0563	0.54	112.55	8.1241	0.58	247.37	78	8.1665	0.44	80.16	8.1716	0.51	281.86
34	8.1554	0.44	109.84	8.1167	0.65	250.05	80	8.2046	0.54	78.66	8.1923	0.50	283.28
36	8.1401	0.40	107.49	8.0700	0.67	252.57	82	8.2263	0.50	77.32	8.2252	0.67	284.74
38	8.1193	0.46	104.96	8.0695	0.58	254.90	84	8.2291	0.59	75.73	8.2582	0.68	286.06
40	8.0796	0.40	102.87	8.1113	0.44	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1417	0.51	100.82	8.0816	0.43	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1110	0.45	98.94	8.1353	0.54	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29848E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

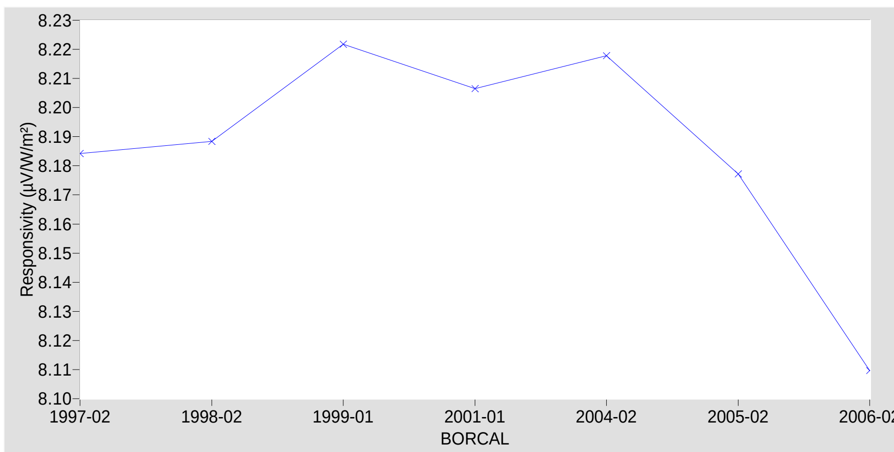
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1096	+1.00 / -1.24 †
Average	8.1278	+2.29 / -1.41 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 29850E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29850E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

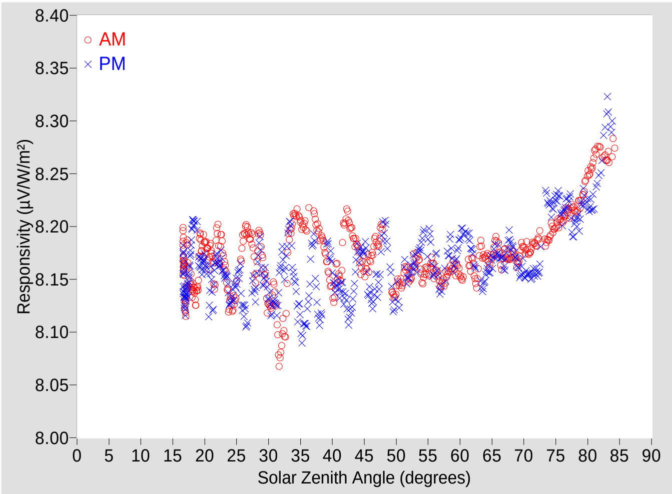


Figure 2. Responsivity vs Local Standard Time

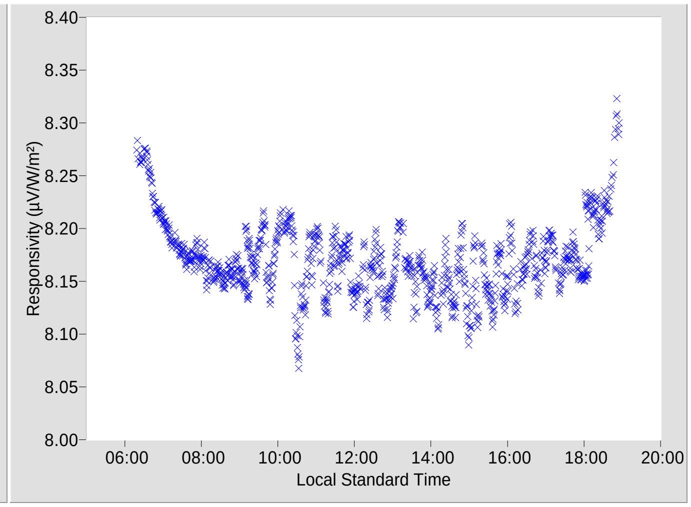


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1702	+0.95 / -1.63	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1678	0.44	97.16	8.1322	0.54	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1973	N/A	95.62	8.1963	0.58	264.45
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1409	0.39	101.84	8.1394	0.45	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1525	0.41	100.03	8.1550	0.41	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1519	0.42	98.24	8.1865	0.45	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1591	0.41	96.61	8.1640	0.53	270.72
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1559	0.41	94.92	8.1674	0.50	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1543	0.39	93.38	8.1905	0.43	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1646	0.42	91.81	8.1714	0.43	275.00
18	8.1427	0.58	154.91	8.1916	0.60	204.48	64	8.1717	0.41	90.29	8.1534	0.43	276.37
20	8.1830	0.46	142.69	8.1646	0.52	217.31	66	8.1791	0.43	88.83	8.1745	0.41	277.73
22	8.1855	0.53	134.59	8.1683	0.51	225.42	68	8.1715	0.40	87.35	8.1826	0.45	279.16
24	8.1269	0.47	128.42	8.1299	0.41	231.43	70	8.1788	0.41	85.90	8.1580	0.40	280.47
26	8.1853	0.42	123.41	8.1249	0.52	236.41	72	8.1849	0.41	84.49	8.1567	0.43	281.89
28	8.1619	0.48	119.27	8.1453	0.53	240.63	74	8.1892	0.42	83.05	8.2222	0.44	278.98
30	8.1248	0.49	115.68	8.1338	0.46	244.22	76	8.2064	0.43	81.62	8.2107	0.47	280.39
32	8.0911	0.61	112.55	8.1698	0.60	247.37	78	8.2156	0.43	80.16	8.2012	0.51	281.86
34	8.2096	0.45	109.84	8.1531	0.69	250.05	80	8.2499	0.49	78.66	8.2201	0.50	283.28
36	8.1994	0.39	107.49	8.1141	0.69	252.57	82	8.2754	0.49	77.32	8.2539	0.69	284.74
38	8.1919	0.45	104.96	8.1133	0.65	254.90	84	8.2745	0.58	75.73	8.2945	0.67	286.06
40	8.1370	0.44	102.87	8.1586	0.47	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2064	0.56	100.82	8.1296	0.45	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1804	0.46	98.94	8.1740	0.52	260.94	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29850E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

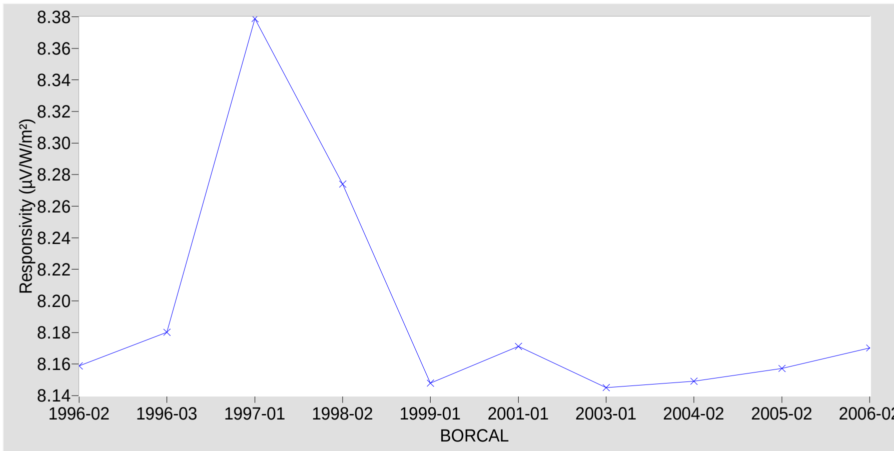
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1702	+0.95 / -1.63 †
Average	8.1745	+2.15 / -1.62 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.8°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29852E6
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29852E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

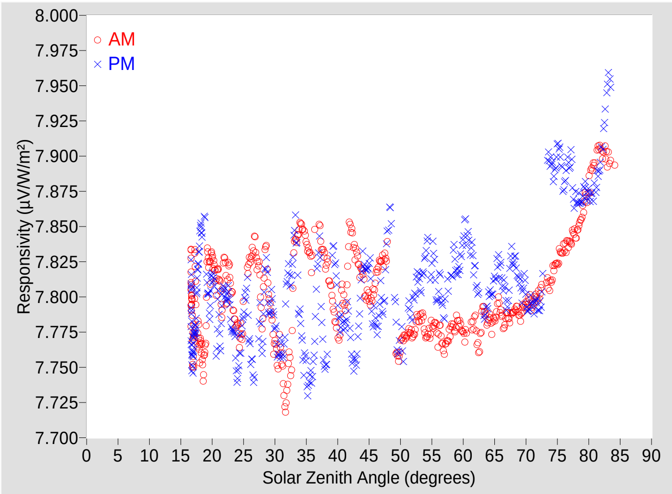


Figure 2. Responsivity vs Local Standard Time

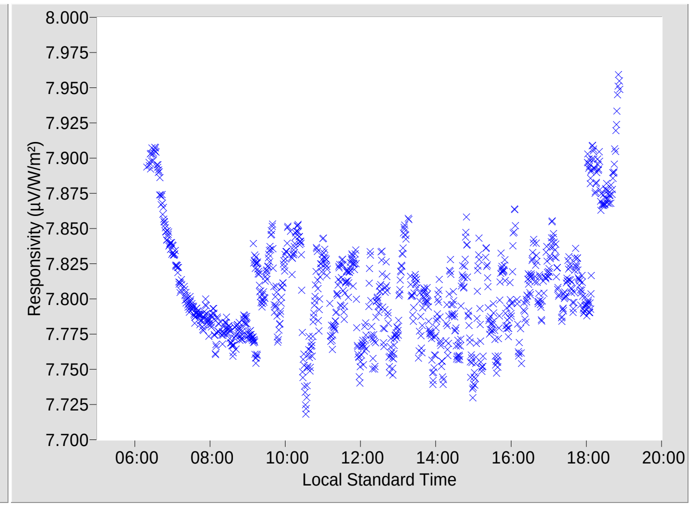


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8097	+1.07 / -1.54	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8107	0.42	97.17	7.7824	0.51	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8255	N/A	95.63	7.8490	0.61	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7646	0.40	101.85	7.7739	0.48	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7733	0.39	100.04	7.7960	0.44	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7733	0.40	98.24	7.8321	0.45	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7731	0.41	96.56	7.8039	0.52	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7774	0.40	94.92	7.8150	0.45	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7738	0.39	93.39	7.8439	0.45	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7787	0.43	91.82	7.8122	0.45	275.00
18	7.7682	0.71	155.18	7.8374	0.72	204.51	64	7.7836	0.41	90.30	7.7988	0.43	276.38
20	7.8274	0.51	142.71	7.8119	0.53	217.33	66	7.7898	0.41	88.84	7.8163	0.46	277.74
22	7.8172	0.46	134.61	7.8026	0.47	225.43	68	7.7896	0.40	87.36	7.8249	0.47	279.12
24	7.7790	0.45	128.44	7.7474	0.48	231.45	70	7.7942	0.41	85.90	7.8026	0.42	280.48
26	7.8247	0.41	123.43	7.7668	0.61	236.43	72	7.8005	0.41	84.50	7.7935	0.43	281.89
28	7.7958	0.53	119.29	7.7774	0.57	240.64	74	7.8122	0.42	83.01	7.8954	0.45	278.99
30	7.7651	0.49	115.69	7.7776	0.48	244.24	76	7.8342	0.43	81.62	7.8816	0.48	280.40
32	7.7420	0.68	112.56	7.8153	0.59	247.38	78	7.8454	0.45	80.15	7.8688	0.53	281.91
34	7.8498	0.40	109.85	7.7841	0.82	250.07	80	7.8779	0.51	78.66	7.8717	0.49	283.25
36	7.8253	0.42	107.50	7.7485	0.75	252.58	82	7.9038	0.51	77.27	7.8993	0.74	284.70
38	7.8256	0.46	104.97	7.7517	0.72	254.91	84	7.8935	N/A	75.67	N/A	N/A	N/A
40	7.7727	0.45	102.79	7.7976	0.54	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8470	0.55	100.83	7.7653	0.49	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8167	0.43	98.95	7.8214	0.60	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
29852E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

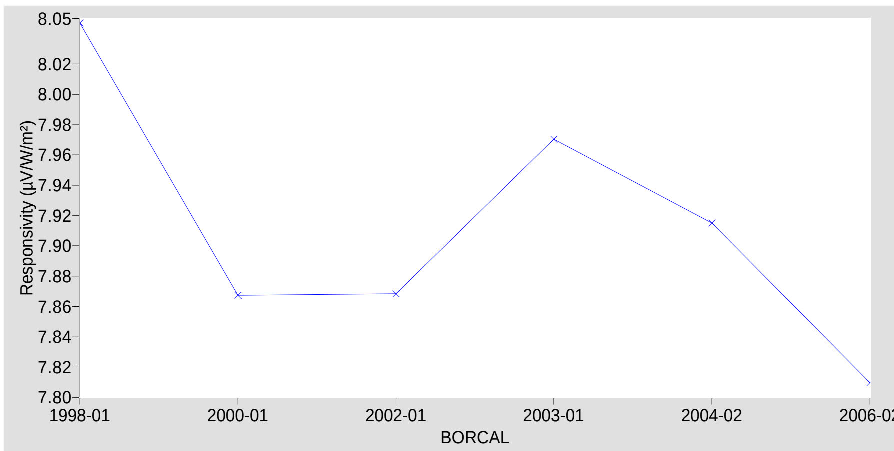
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.8097	+1.07 / -1.54 †
Average	7.8076	+1.92 / -1.51 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29853E6
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29853E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

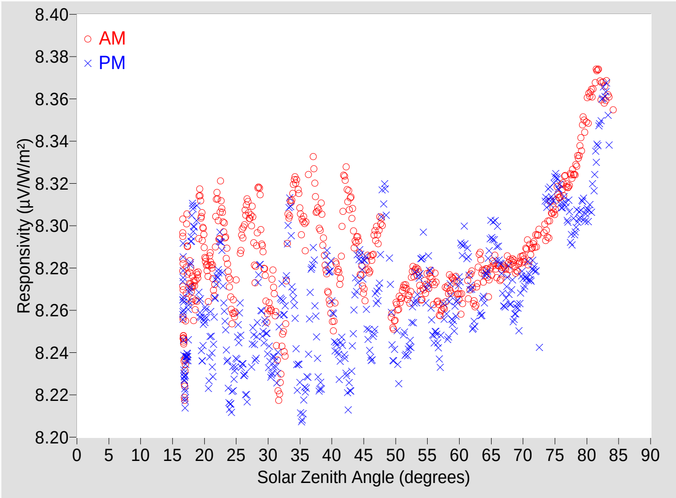


Figure 2. Responsivity vs Local Standard Time

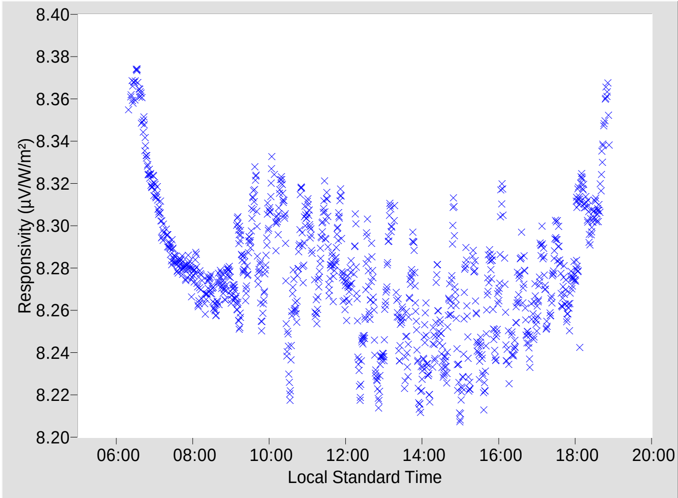


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2750	+1.07 / -1.19	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2810	0.42	97.17	8.2405	0.48	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3037	N/A	95.63	8.3129	0.50	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2592	0.39	101.85	8.2459	0.52	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2666	0.39	100.04	8.2422	0.40	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2683	0.39	98.24	8.2828	0.42	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2714	0.40	96.56	8.2477	0.49	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2689	0.39	94.92	8.2507	0.41	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2653	0.39	93.39	8.2782	0.48	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2725	0.40	91.82	8.2599	0.44	275.00
18	8.2703	0.57	155.18	8.2951	0.65	204.51	64	8.2776	0.40	90.30	8.2722	0.46	276.38
20	8.2909	0.49	142.71	8.2552	0.46	217.33	66	8.2797	0.39	88.84	8.2895	0.45	277.74
22	8.3045	0.49	134.61	8.2759	0.55	225.43	68	8.2821	0.39	87.36	8.2658	0.41	279.12
24	8.2711	0.47	128.44	8.2159	0.49	231.45	70	8.2842	0.40	85.90	8.2742	0.43	280.48
26	8.2961	0.40	123.43	8.2348	0.47	236.43	72	8.2927	0.40	84.50	8.2793	0.46	281.81
28	8.2857	0.46	119.29	8.2446	0.47	240.64	74	8.3011	0.41	83.01	8.3150	0.42	278.99
30	8.2593	0.43	115.69	8.2401	0.40	244.24	76	8.3168	0.42	81.62	8.3115	0.44	280.40
32	8.2336	0.50	112.56	8.2651	0.48	247.38	78	8.3256	0.44	80.15	8.2989	0.47	281.91
34	8.3184	0.41	109.85	8.2647	0.66	250.07	80	8.3527	0.48	78.66	8.3050	0.49	283.25
36	8.2971	0.43	107.50	8.2250	0.58	252.58	82	8.3690	0.49	77.27	8.3458	0.62	284.70
38	8.3031	0.48	104.97	8.2272	0.55	254.91	84	8.3549	N/A	75.67	N/A	N/A	N/A
40	8.2545	0.42	102.79	8.2687	0.47	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3207	0.50	100.83	8.2339	0.43	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2936	0.46	98.95	8.2775	0.51	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
29853E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

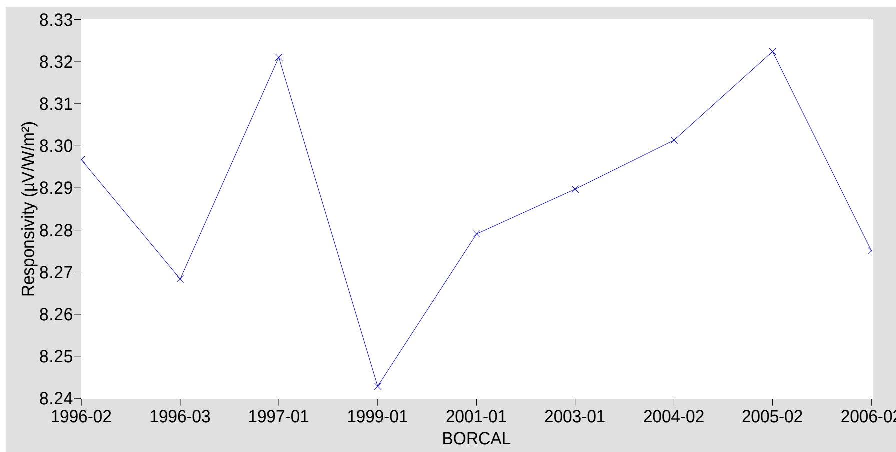
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2750	+1.07 / -1.19 †
Average	8.2785	+1.59 / -1.24 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 29912F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: SGP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29912F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

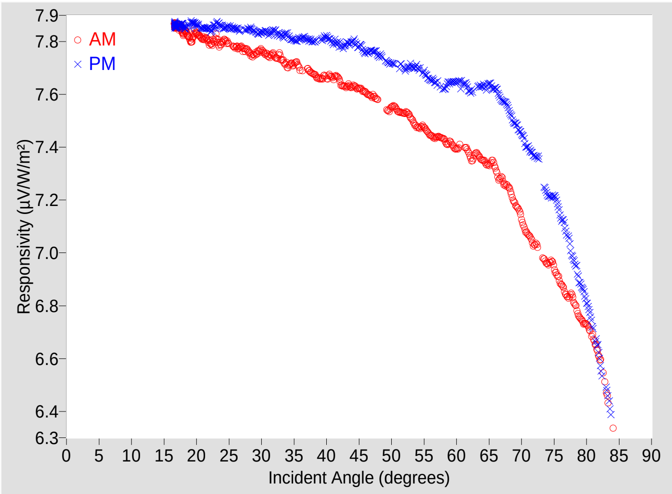


Figure 2. Responsivity vs Local Standard Time

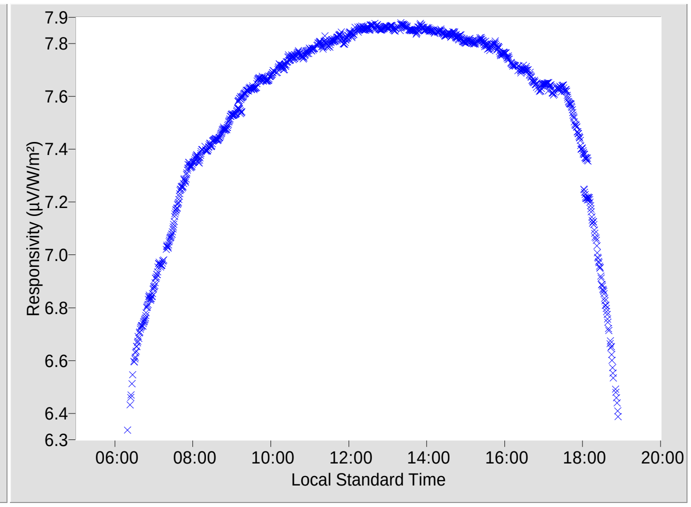


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.7033	+2.38 / -4.57	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡		RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6095	0.59	97.18	7.7601	0.59	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5827	N/A	95.64	7.7476	0.58	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5533	0.63	101.80	7.7174	0.58	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5300	0.65	100.06	7.6965	0.61	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4771	0.69	98.26	7.7018	0.63	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4461	0.72	96.58	7.6544	0.71	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4310	0.72	94.94	7.6212	0.66	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3946	0.75	93.40	7.6476	0.69	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3725	0.83	91.83	7.6113	0.73	274.97
18	7.8367	0.57	155.25	7.8590	0.49	204.58	64	7.3520	0.86	90.31	7.6328	0.74	276.39
20	7.8303	0.55	142.58	7.8640	0.51	217.20	66	7.3219	0.99	88.85	7.6221	0.88	277.75
22	7.7970	0.52	134.49	7.8470	0.50	225.32	68	7.2500	1.12	87.37	7.5439	0.99	279.13
24	7.7976	0.57	128.48	7.8541	0.51	231.49	70	7.1299	1.24	85.91	7.4509	1.08	280.49
26	7.7811	0.47	123.46	7.8493	0.50	236.46	72	7.0310	1.14	84.47	7.3662	1.04	281.90
28	7.7643	0.52	119.32	7.8479	0.49	240.56	74	6.9600	1.23	83.02	7.2222	1.40	278.95
30	7.7669	0.51	115.72	7.8358	0.49	244.17	76	6.8904	1.59	81.64	7.1367	1.86	280.41
32	7.7463	0.51	112.58	7.8410	0.52	247.32	78	6.8198	1.78	80.16	6.9723	2.21	281.83
34	7.7106	0.52	109.88	7.8259	0.53	250.09	80	6.7301	2.09	78.72	6.8157	2.47	283.26
36	7.6948	0.54	107.27	7.8124	0.52	252.60	82	6.6029	2.91	77.24	6.6002	3.06	284.73
38	7.6778	0.56	104.92	7.8008	0.52	254.93	84	6.3364	N/A	75.68	6.3876	N/A	286.03
40	7.6626	0.53	102.80	7.8163	0.55	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6546	0.59	100.85	7.7879	0.58	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6307	0.54	98.90	7.8024	0.57	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

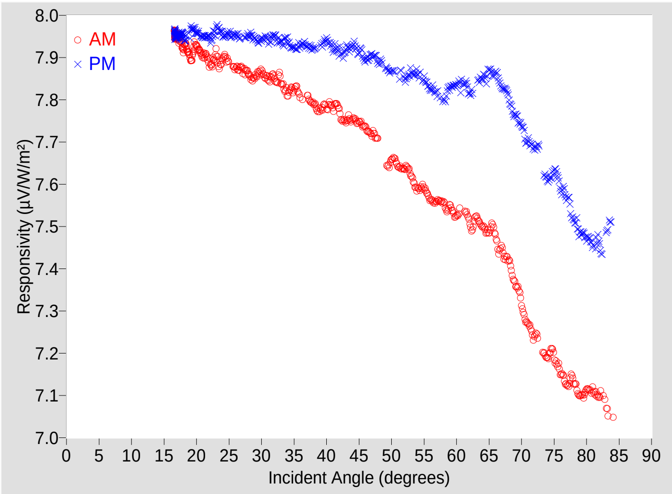


Figure 4. Responsivity vs Local Standard Time

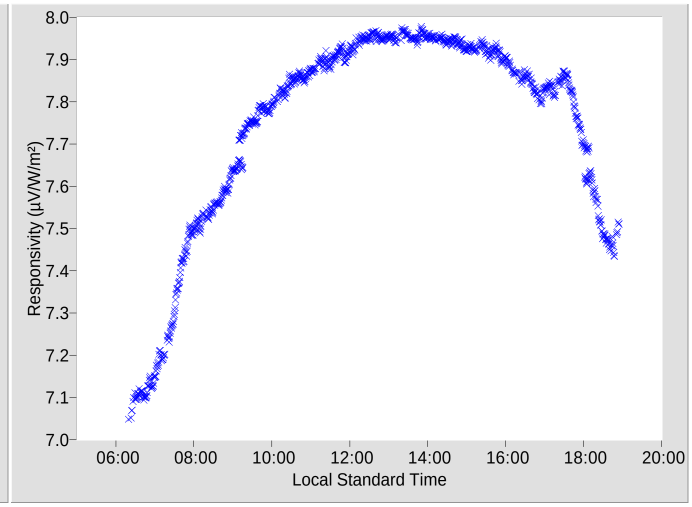


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8309	+2.17 / -4.54	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.60562 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7351	0.64	97.18	7.8958	0.65	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7093	N/A	95.64	7.8892	0.65	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6585	0.67	101.80	7.8671	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6385	0.69	100.06	7.8491	0.70	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5899	0.73	98.26	7.8615	0.71	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5641	0.75	96.58	7.8241	0.77	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5551	0.76	94.94	7.7983	0.77	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5248	0.80	93.40	7.8349	0.79	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5112	0.87	91.83	7.8142	0.84	274.97
18	7.9261	0.60	155.25	7.9501	0.52	204.58	64	7.5006	0.91	90.31	7.8534	0.89	276.39
20	7.9250	0.58	142.58	7.9597	0.54	217.20	66	7.4800	1.04	88.85	7.8629	0.96	277.75
22	7.8881	0.55	134.49	7.9468	0.55	225.32	68	7.4219	1.12	87.37	7.8040	1.08	279.13
24	7.8937	0.59	128.48	7.9543	0.55	231.49	70	7.3180	1.23	85.91	7.7392	1.17	280.49
26	7.8769	0.51	123.46	7.9524	0.54	236.46	72	7.2403	1.22	84.47	7.6864	1.21	281.90
28	7.8630	0.55	119.32	7.9521	0.54	240.56	74	7.1916	1.33	83.02	7.6115	1.62	278.95
30	7.8663	0.55	115.72	7.9434	0.54	244.17	76	7.1581	1.59	81.64	7.5888	1.89	280.41
32	7.8510	0.56	112.58	7.9508	0.56	247.32	78	7.1341	1.84	80.16	7.5158	2.25	281.83
34	7.8173	0.57	109.88	7.9402	0.58	250.09	80	7.1131	2.22	78.72	7.4729	2.60	283.26
36	7.8064	0.59	107.27	7.9299	0.57	252.60	82	7.1001	2.89	77.24	7.4568	3.34	284.73
38	7.7911	0.61	104.92	7.9207	0.58	254.93	84	7.0483	N/A	75.68	7.5104	N/A	286.03
40	7.7807	0.59	102.80	7.9399	0.61	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7733	0.64	100.85	7.9136	0.63	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7534	0.60	98.90	7.9299	0.63	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29912F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

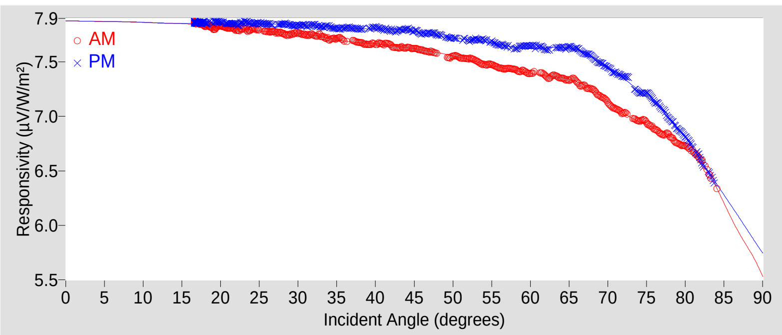
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

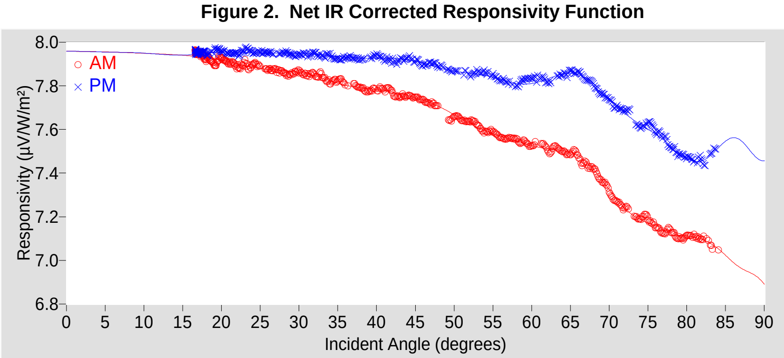


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.47	±1.47
R²	0.9999995	0.9999987
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.7°
Net IR corr. uncert. U95 (%)	±1.54	±1.54
Net IR corrected R²	0.9999996	0.9999990
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.7°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.8719	*	7.8719	*	7.8719	*	7.9558	*	7.9558	*	7.9558	*
9-18	7.8549	*	7.8568	*	7.8559	*	7.9431	*	7.9450	*	7.9440	*
18-27	7.8059	±1.53	7.8539	±1.48	7.8299	±1.66	7.8996	±1.58	7.9524	±1.54	7.9260	±1.71
27-36	7.7450	±1.56	7.8359	±1.49	7.7905	±2.04	7.8479	±1.59	7.9453	±1.54	7.8966	±2.03
36-45	7.6618	±1.54	7.8027	±1.48	7.7323	±2.28	7.7792	±1.58	7.9261	±1.54	7.8526	±2.25
45-54	7.5627	±1.70	7.7314	±1.58	7.6471	±3.06	7.6788	±1.80	7.8770	±1.59	7.7779	±3.25
54-63	7.4215	±1.66	7.6434	±1.53	7.5324	±3.33	7.5469	±1.64	7.8237	±1.56	7.6853	±3.47
63-72	7.2494	±2.59	7.5491	±2.25	7.3992	±5.80	7.4183	±2.28	7.8050	±1.87	7.6116	±5.86
72-81	6.8775	±2.81	7.0869	±4.42	6.9822	±6.77	7.1616	±1.79	7.5676	±2.10	7.3646	±5.68
81-90	6.1326	*	6.2274	*	6.1800	*	7.0087	*	7.5020	*	7.2554	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

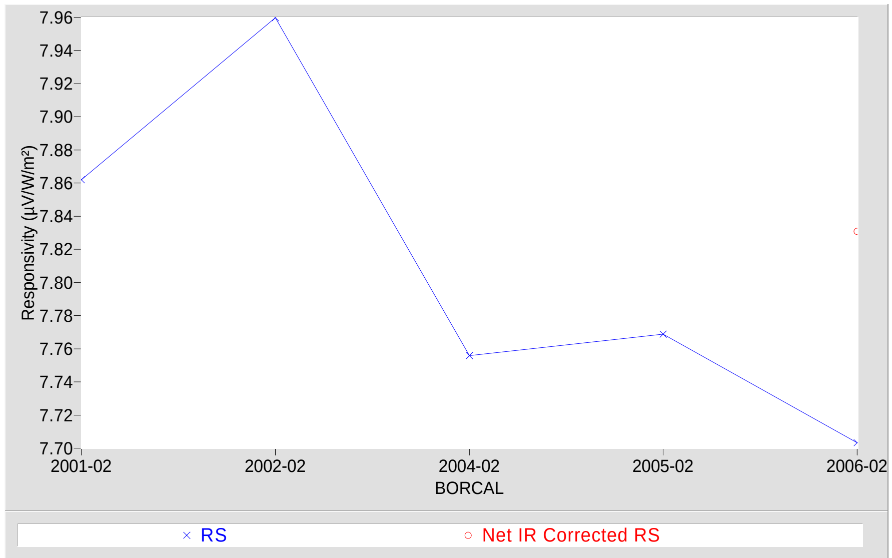
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.7033	+2.38 / -4.57
45° - 55°	7.6372	±2.53
Composite	7.7061	+2.46 / -17.63
45° (Net IR Corr.)	7.8309	+2.17 / -4.54
45° - 55° (Net IR Corr.)	7.7690	±2.63
Composite (Net IR Corr.)	7.8387	+2.14 / -10.11

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.7°, 16.6° to 83.7° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



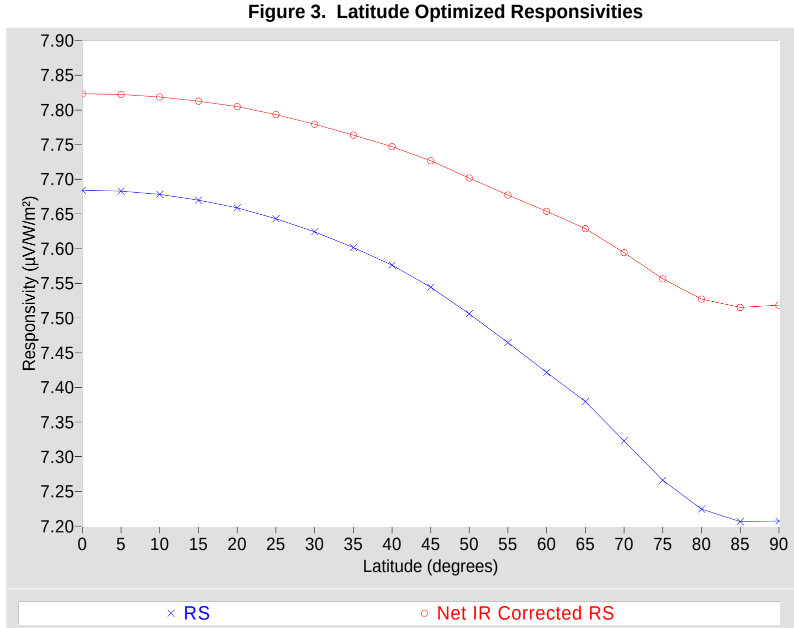
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.6844	+2.90 / -26.09	7.8233	+2.32 / -11.56
5	7.6832	+2.91 / -26.08	7.8224	+2.33 / -11.55
10	7.6783	+2.97 / -26.03	7.8188	+2.36 / -11.51
15	7.6701	+3.07 / -25.95	7.8129	+2.42 / -11.44
20	7.6589	+3.20 / -25.84	7.8048	+2.50 / -11.35
25	7.6435	+3.38 / -25.69	7.7934	+2.62 / -11.22
30	7.6242	+3.55 / -25.51	7.7794	+2.73 / -11.06
35	7.6016	+3.72 / -25.28	7.7637	+2.90 / -10.89
40	7.5761	+4.00 / -25.03	7.7472	+3.09 / -10.70
45	7.5445	+4.40 / -24.72	7.7267	+3.33 / -10.46
50	7.5060	+4.79 / -24.33	7.7020	+3.58 / -10.18
55	7.4645	+5.24 / -23.91	7.6774	+3.85 / -9.89
60	7.4217	+5.49 / -23.47	7.6539	+3.94 / -9.62
65	7.3796	+5.93 / -23.04	7.6290	+4.20 / -9.33
70	7.3229	+6.26 / -22.44	7.5943	+4.35 / -8.92
75	7.2661	+6.31 / -21.84	7.5563	+4.33 / -8.47
80	7.2247	+6.21 / -21.39	7.5272	+4.65 / -8.12
85	7.2063	+6.11 / -21.19	7.5152	+4.81 / -7.98
90	7.2072	+5.79 / -21.20	7.5185	+4.69 / -8.02

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

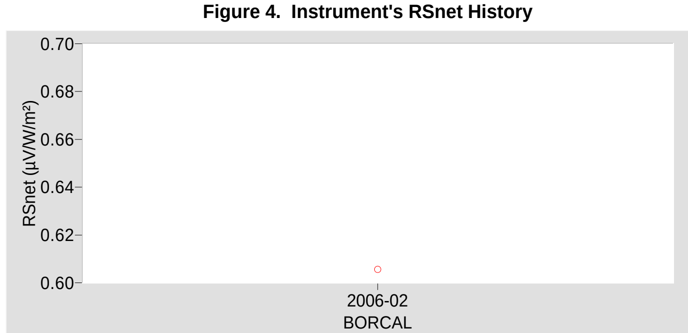
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 29915F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: TWP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

29915F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

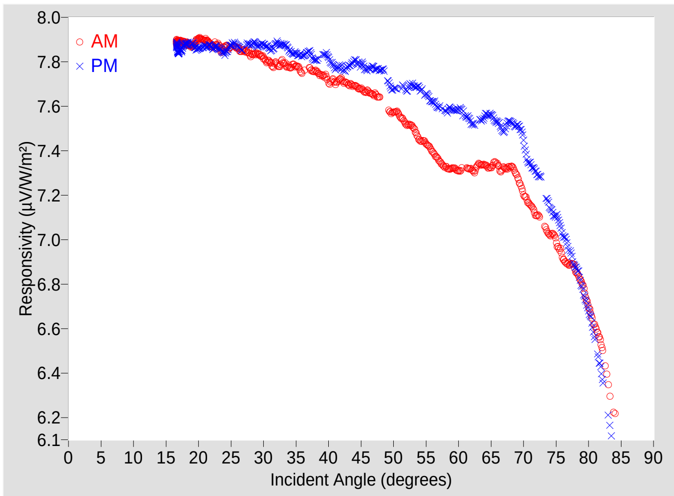


Figure 2. Responsivity vs Local Standard Time

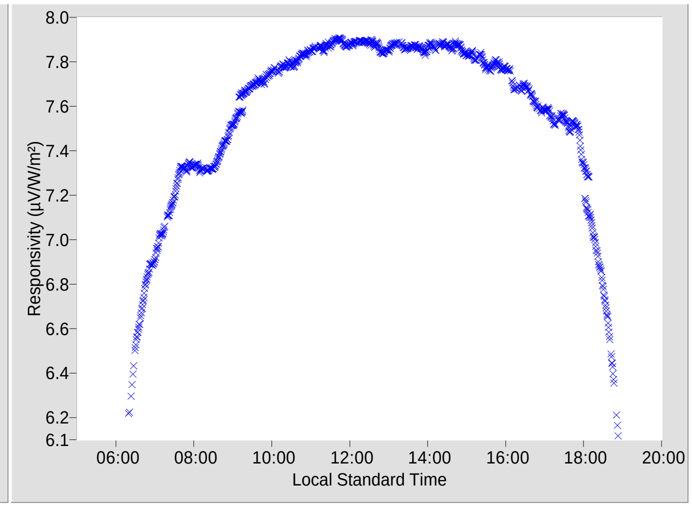


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.7338	+2.60 / -6.01	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6669	0.58	97.18	7.7670	0.60	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6410	N/A	95.64	7.7628	0.56	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5737	0.64	101.80	7.6774	0.63	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5208	0.69	100.06	7.6736	0.63	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4501	0.78	98.26	7.6805	0.66	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3960	0.84	96.58	7.6190	0.75	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3265	0.73	94.94	7.5771	0.66	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3101	0.73	93.40	7.5863	0.71	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3158	0.79	91.83	7.5226	0.74	274.97
18	7.8849	0.50	155.25	7.8799	0.55	204.58	64	7.3363	0.81	90.31	7.5553	0.76	276.39
20	7.9020	0.53	142.58	7.8595	0.52	217.20	66	7.3391	0.91	88.85	7.5280	0.93	277.75
22	7.8749	0.54	134.49	7.8668	0.50	225.32	68	7.3284	0.95	87.37	7.5295	0.88	279.13
24	7.8617	0.54	128.48	7.8404	0.56	231.49	70	7.2069	1.28	85.91	7.4447	1.47	280.49
26	7.8629	0.49	123.46	7.8707	0.53	236.46	72	7.1097	1.15	84.47	7.2969	1.08	281.90
28	7.8356	0.51	119.32	7.8769	0.49	240.56	74	7.0235	1.26	83.02	7.1533	1.50	278.95
30	7.8186	0.55	115.72	7.8781	0.50	244.17	76	6.9284	1.57	81.64	7.0245	1.92	280.41
32	7.7903	0.53	112.58	7.8835	0.56	247.32	78	6.8620	1.76	80.16	6.8758	2.15	281.83
34	7.7771	0.50	109.88	7.8503	0.58	250.09	80	6.7027	2.43	78.72	6.6790	2.73	283.26
36	7.7543	0.54	107.27	7.8293	0.53	252.60	82	6.5236	3.11	77.24	6.3985	3.49	284.73
38	7.7574	0.55	104.92	7.8071	0.59	254.93	84	6.2214	3.84	75.78	N/A	N/A	N/A
40	7.7077	0.59	102.80	7.8156	0.68	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7204	0.55	100.85	7.7725	0.56	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6920	0.55	98.90	7.8043	0.58	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

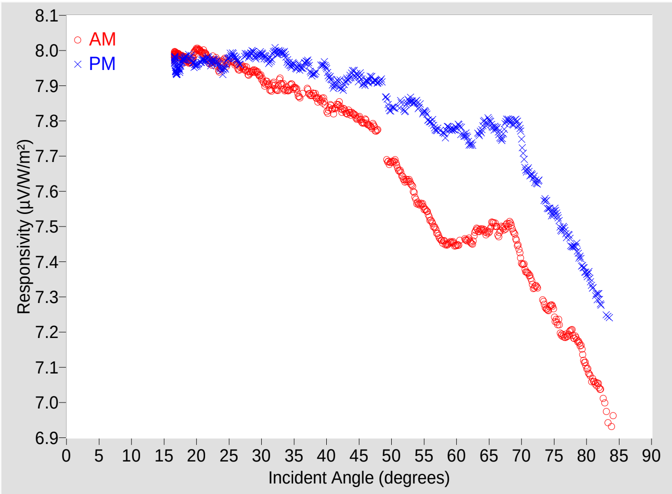

Figure 4. Responsivity vs Local Standard Time

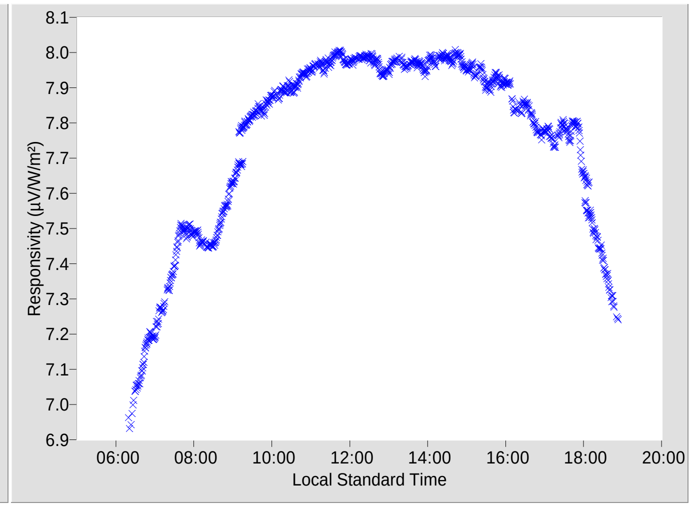

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8670	+2.40 / -5.98	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63274 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7982	0.63	97.18	7.9088	0.66	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7732	N/A	95.64	7.9108	0.64	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6836	0.67	101.80	7.8338	0.70	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6341	0.72	100.06	7.8330	0.72	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5680	0.80	98.26	7.8474	0.73	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5192	0.85	96.58	7.7963	0.80	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4562	0.78	94.94	7.7622	0.76	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4462	0.78	93.40	7.7820	0.79	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4607	0.86	91.83	7.7346	0.84	274.97
18	7.9783	0.53	155.25	7.9750	0.60	204.58	64	7.4915	0.87	90.31	7.7857	0.92	276.39
20	8.0010	0.56	142.58	7.9595	0.55	217.20	66	7.5043	0.96	88.85	7.7795	0.99	277.75
22	7.9700	0.57	134.49	7.9711	0.54	225.32	68	7.5080	1.01	87.37	7.8013	1.05	279.13
24	7.9620	0.57	128.48	7.9451	0.60	231.49	70	7.4034	1.26	85.91	7.7460	1.45	280.49
26	7.9631	0.53	123.46	7.9785	0.56	236.46	72	7.3283	1.22	84.47	7.6315	1.24	281.90
28	7.9386	0.55	119.32	7.9858	0.54	240.56	74	7.2655	1.33	83.02	7.5600	1.65	278.95
30	7.9225	0.59	115.72	7.9905	0.55	244.17	76	7.2082	1.58	81.64	7.4967	1.92	280.41
32	7.8996	0.58	112.58	7.9982	0.61	247.32	78	7.1904	1.82	80.16	7.4437	2.22	281.83
34	7.8886	0.55	109.88	7.9697	0.62	250.09	80	7.1029	2.33	78.72	7.3657	2.67	283.26
36	7.8709	0.58	107.27	7.9521	0.58	252.60	82	7.0431	2.93	77.24	7.2934	3.39	284.73
38	7.8759	0.60	104.92	7.9323	0.64	254.93	84	6.9473	4.07	75.78	N/A	N/A	N/A
40	7.8311	0.63	102.80	7.9447	0.72	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8444	0.61	100.85	7.9038	0.62	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8202	0.61	98.90	7.9374	0.63	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

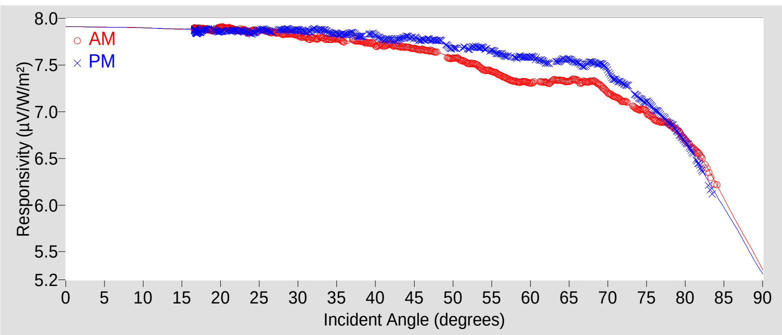
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

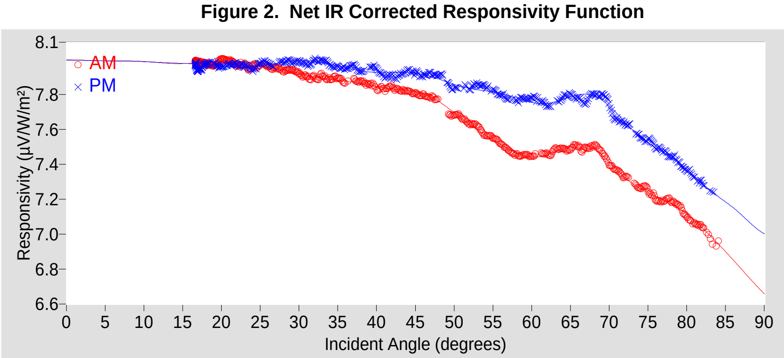


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.77	±1.77
R^2	0.9999990	0.9999979
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.77	±1.77
Net IR corrected R^2	0.9999990	0.9999981
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

	Responsivity						Net IR Corr. Responsivity					
Inc.	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.9069	*	7.9068	*	7.9068	*	7.9945	*	7.9945	*	7.9945	*
9-18	7.8909	*	7.8900	*	7.8905	*	7.9830	*	7.9822	*	7.9826	*
18-27	7.8761	±1.79	7.8615	±1.78	7.8688	±1.81	7.9740	±1.78	7.9644	±1.77	7.9692	±1.80
27-36	7.8035	±1.85	7.8695	±1.79	7.8365	±2.09	7.9110	±1.82	7.9838	±1.78	7.9474	±2.06
36-45	7.7242	±1.83	7.8031	±1.79	7.7636	±2.20	7.8468	±1.81	7.9319	±1.78	7.8894	±2.14
45-54	7.5920	±2.27	7.7199	±1.95	7.6560	±3.47	7.7133	±2.33	7.8719	±1.88	7.7926	±3.63
54-63	7.3515	±2.04	7.5925	±1.93	7.4720	±3.77	7.4826	±1.96	7.7808	±1.83	7.6317	±3.94
63-72	7.2902	±2.30	7.4976	±2.23	7.3939	±4.41	7.4667	±2.10	7.7648	±1.97	7.6157	±4.64
72-81	6.9153	±3.62	6.9893	±5.24	6.9523	±7.24	7.2123	±2.38	7.4922	±2.63	7.3523	±5.57
81-90	5.9898	*	5.9032	*	5.9465	*	6.8733	*	7.1650	*	7.0192	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

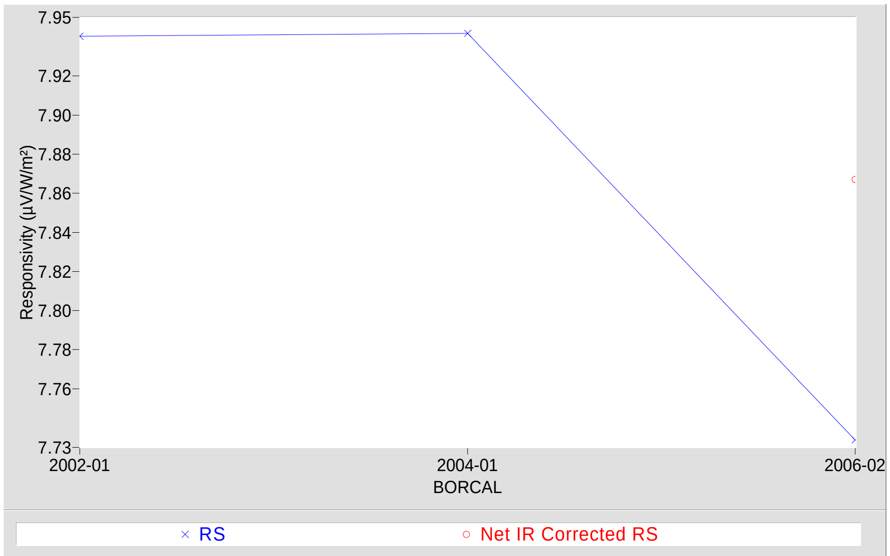
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.7338	+2.60 / -6.01
45° - 55°	7.6399	±2.97
Composite	7.7246	+2.79 / -20.97
45° (Net IR Corr.)	7.8670	+2.40 / -5.98
45° - 55° (Net IR Corr.)	7.7775	±3.03
Composite (Net IR Corr.)	7.8627	+2.45 / -11.77

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



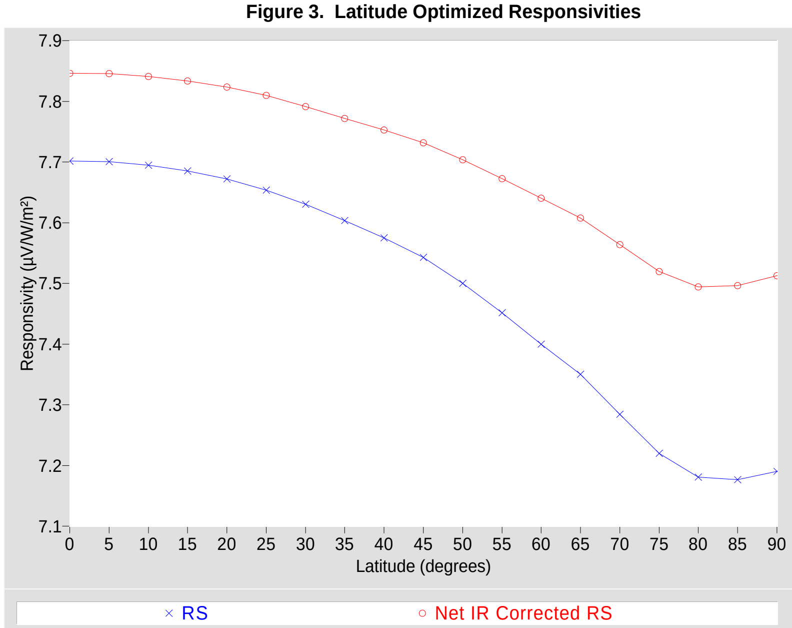
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.7018	+3.25 / -29.96	7.8464	+2.62 / -14.65
5	7.7005	+3.27 / -29.95	7.8454	+2.63 / -14.64
10	7.6948	+3.33 / -29.90	7.8411	+2.68 / -14.59
15	7.6851	+3.44 / -29.81	7.8337	+2.75 / -14.51
20	7.6719	+3.59 / -29.69	7.8237	+2.85 / -14.40
25	7.6537	+3.80 / -29.53	7.8097	+2.99 / -14.25
30	7.6301	+4.01 / -29.31	7.7915	+3.16 / -14.05
35	7.6032	+4.24 / -29.06	7.7719	+3.38 / -13.84
40	7.5751	+4.53 / -28.79	7.7529	+3.59 / -13.63
45	7.5425	+4.88 / -28.49	7.7318	+3.84 / -13.39
50	7.5002	+5.41 / -28.08	7.7036	+4.18 / -13.08
55	7.4516	+6.03 / -27.62	7.6724	+4.56 / -12.73
60	7.4000	+6.09 / -27.11	7.6403	+4.46 / -12.36
65	7.3502	+6.31 / -26.62	7.6077	+4.56 / -11.99
70	7.2839	+6.97 / -25.95	7.5638	+4.98 / -11.49
75	7.2196	+6.71 / -25.29	7.5196	+4.68 / -10.97
80	7.1809	+6.51 / -24.89	7.4940	+4.54 / -10.67
85	7.1766	+5.45 / -24.85	7.4964	+4.44 / -10.70
90	7.1901	+5.25 / -24.99	7.5126	+4.24 / -10.89

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

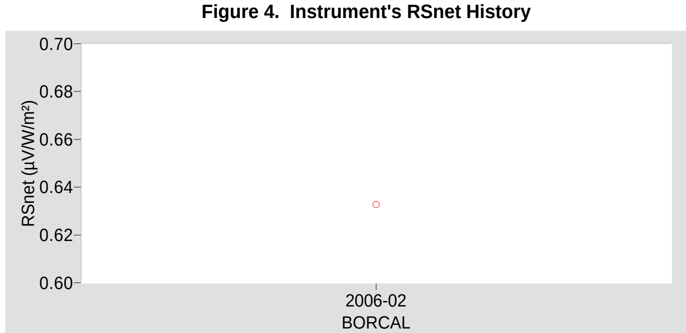
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 29934E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: TWP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29934E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

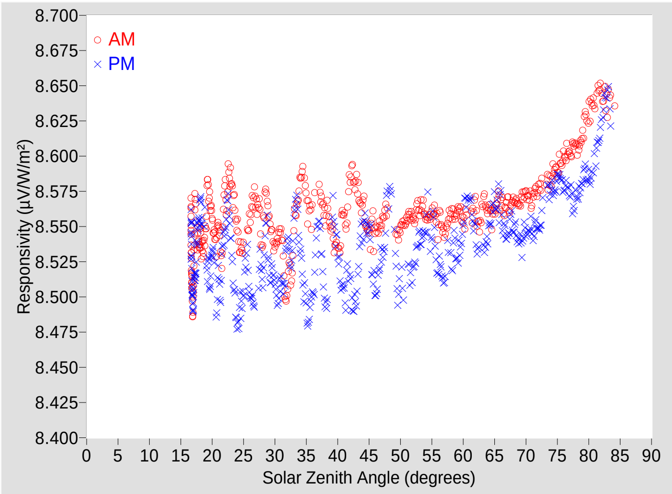


Figure 2. Responsivity vs Local Standard Time

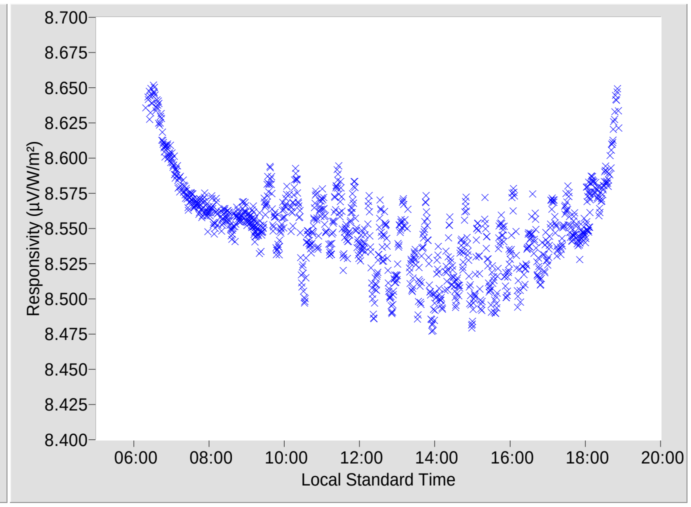


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5455	+0.94 / -1.14	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5446	0.41	97.17	8.5057	0.48	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5576	N/A	95.63	8.5720	0.47	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5488	0.38	101.85	8.5170	0.49	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5559	0.38	100.04	8.5194	0.43	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5568	0.38	98.24	8.5490	0.43	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5532	0.40	96.56	8.5198	0.48	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5589	0.39	94.92	8.5233	0.42	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5536	0.39	93.39	8.5547	0.46	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5630	0.41	91.82	8.5411	0.44	275.00
18	8.5391	0.53	155.18	8.5583	0.57	204.51	64	8.5622	0.41	90.30	8.5469	0.45	276.38
20	8.5559	0.49	142.71	8.5282	0.47	217.33	66	8.5677	0.39	88.84	8.5612	0.44	277.74
22	8.5678	0.57	134.61	8.5463	0.58	225.43	68	8.5683	0.39	87.36	8.5477	0.40	279.12
24	8.5495	0.47	128.44	8.4816	0.53	231.45	70	8.5724	0.39	85.90	8.5471	0.42	280.48
26	8.5548	0.41	123.43	8.5046	0.45	236.43	72	8.5765	0.40	84.50	8.5489	0.42	281.89
28	8.5446	0.44	119.29	8.5185	0.48	240.64	74	8.5845	0.41	83.01	8.5779	0.42	278.99
30	8.5366	0.40	115.69	8.5086	0.41	244.24	76	8.5984	0.42	81.62	8.5775	0.43	280.40
32	8.5092	0.45	112.56	8.5381	0.44	247.38	78	8.6070	0.42	80.15	8.5714	0.46	281.91
34	8.5797	0.45	109.85	8.5350	0.58	250.07	80	8.6290	0.47	78.66	8.5836	0.48	283.25
36	8.5585	0.40	107.50	8.5010	0.57	252.58	82	8.6456	0.50	77.27	8.6216	0.62	284.70
38	8.5573	0.42	104.97	8.4974	0.52	254.91	84	8.6358	N/A	75.67	N/A	N/A	N/A
40	8.5360	0.41	102.79	8.5337	0.54	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5843	0.46	100.83	8.5047	0.42	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5663	0.44	98.95	8.5477	0.49	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
29934E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

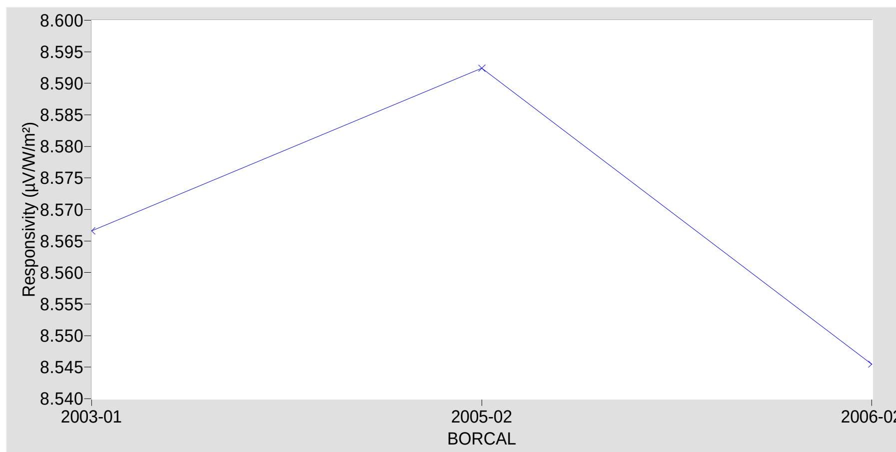
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5455	+0.94 / -1.14 †
Average	8.5520	+1.60 / -1.35 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 29935E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

29935E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

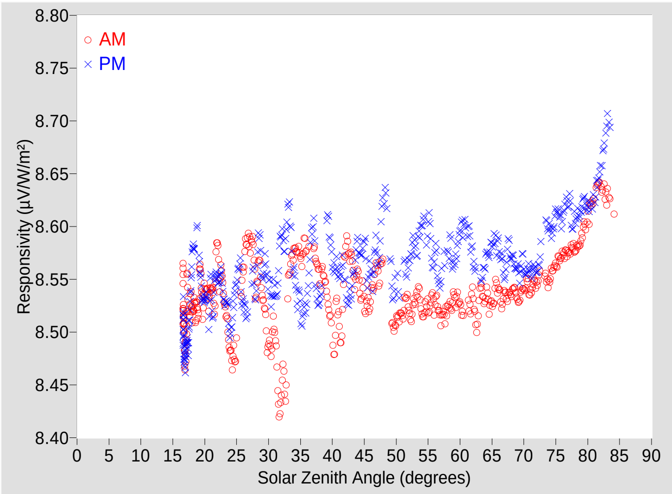


Figure 2. Responsivity vs Local Standard Time

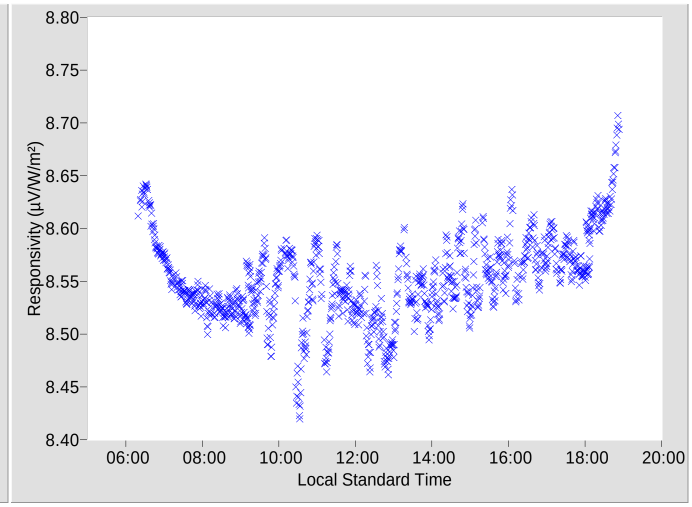


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5551	+1.33 / -1.95	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5315	0.47	97.17	8.5551	0.48	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5650	N/A	95.63	8.6262	0.57	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5106	0.39	101.85	8.5538	0.43	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5219	0.40	100.04	8.5679	0.44	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5198	0.41	98.24	8.6023	0.43	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5268	0.42	96.56	8.5716	0.56	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5227	0.42	94.92	8.5742	0.42	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5251	0.40	93.39	8.5972	0.45	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5331	0.45	91.82	8.5696	0.45	275.00
18	8.5233	0.61	155.18	8.5610	0.81	204.51	64	8.5335	0.42	90.30	8.5693	0.43	276.38
20	8.5362	0.48	142.71	8.5323	0.55	217.33	66	8.5412	0.41	88.84	8.5790	0.45	277.74
22	8.5703	0.54	134.61	8.5500	0.46	225.43	68	8.5370	0.39	87.36	8.5710	0.43	279.12
24	8.4832	0.53	128.44	8.5022	0.47	231.45	70	8.5409	0.41	85.90	8.5634	0.41	280.48
26	8.5565	0.51	123.43	8.5282	0.50	236.43	72	8.5460	0.41	84.50	8.5592	0.43	281.89
28	8.5479	0.50	119.29	8.5477	0.52	240.64	74	8.5499	0.42	83.01	8.5990	0.44	278.99
30	8.4870	0.48	115.69	8.5457	0.47	244.24	76	8.5731	0.42	81.62	8.6085	0.45	280.40
32	8.4441	0.56	112.56	8.5914	0.55	247.38	78	8.5791	0.42	80.15	8.6084	0.48	281.91
34	8.5761	0.47	109.85	8.5545	0.70	250.07	80	8.6069	0.49	78.66	8.6183	0.48	283.25
36	8.5806	0.40	107.50	8.5305	0.66	252.58	82	8.6385	0.49	77.27	8.6533	0.68	284.70
38	8.5521	0.43	104.97	8.5297	0.61	254.91	84	8.6119	N/A	75.67	N/A	N/A	N/A
40	8.4917	0.51	102.79	8.5685	0.50	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5721	0.70	100.83	8.5394	0.46	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5550	0.45	98.95	8.5808	0.46	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29935E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

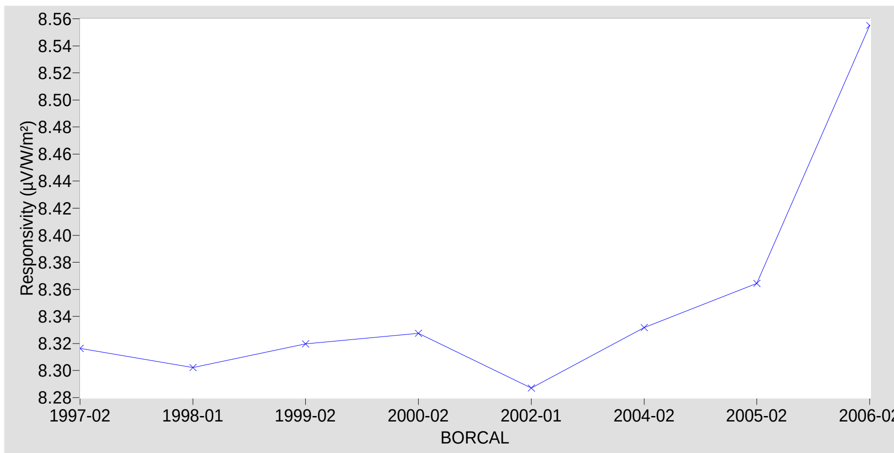
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5551	+1.33 / -1.95 †
Average	8.5559	+1.82 / -1.86 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	30585E6
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: _________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: _________________

Calibration Results

30585E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

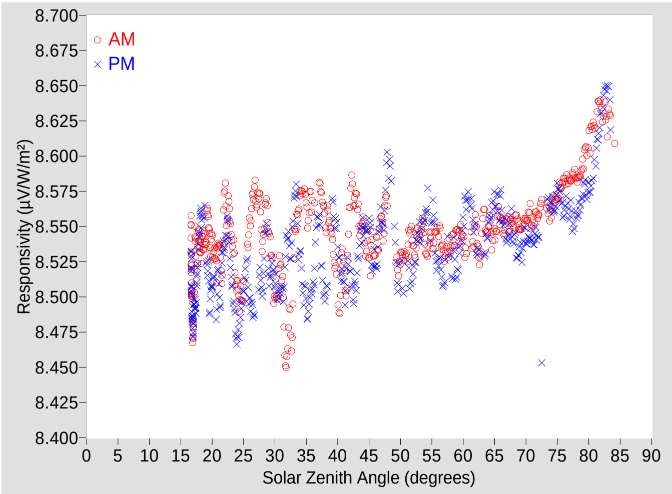


Figure 2. Responsivity vs Local Standard Time

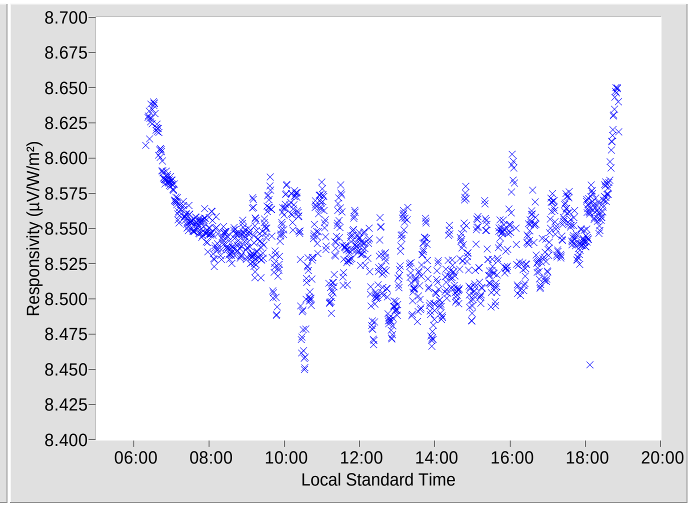


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5391	+1.11 / -1.42	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5346	0.44	97.17	8.5242	0.46	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5718	N/A	95.63	8.5950	0.49	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5279	0.39	101.85	8.5248	0.46	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5386	0.40	100.04	8.5183	0.44	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5346	0.41	98.24	8.5593	0.44	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5434	0.40	96.56	8.5234	0.52	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5377	0.39	94.92	8.5192	0.41	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5394	0.40	93.39	8.5563	0.49	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5493	0.43	91.82	8.5393	0.44	275.00
18	8.5369	0.55	155.18	8.5471	0.61	204.51	64	8.5502	0.41	90.30	8.5498	0.46	276.38
20	8.5351	0.48	142.71	8.5095	0.44	217.33	66	8.5551	0.41	88.84	8.5635	0.44	277.74
22	8.5635	0.56	134.61	8.5392	0.53	225.43	68	8.5519	0.39	87.36	8.5410	0.43	279.12
24	8.5071	0.49	128.44	8.4718	0.46	231.45	70	8.5548	0.40	85.90	8.5430	0.41	280.48
26	8.5504	0.46	123.43	8.4977	0.44	236.43	72	8.5589	0.41	84.50	8.5428	0.68	281.81
28	8.5453	0.44	119.29	8.5112	0.48	240.64	74	8.5609	0.41	83.01	8.5673	0.43	278.99
30	8.5000	0.47	115.69	8.5114	0.41	244.24	76	8.5819	0.42	81.62	8.5614	0.44	280.40
32	8.4681	0.53	112.56	8.5417	0.50	247.38	78	8.5851	0.42	80.15	8.5582	0.46	281.91
34	8.5694	0.47	109.85	8.5285	0.62	250.07	80	8.6087	0.48	78.66	8.5748	0.50	283.25
36	8.5680	0.40	107.50	8.5064	0.56	252.58	82	8.6341	0.50	77.27	8.6289	0.59	284.70
38	8.5547	0.42	104.97	8.5022	0.52	254.91	84	8.6091	N/A	75.67	N/A	N/A	N/A
40	8.4998	0.50	102.79	8.5386	0.50	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5671	0.62	100.83	8.5128	0.42	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5524	0.45	98.95	8.5475	0.43	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30585E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

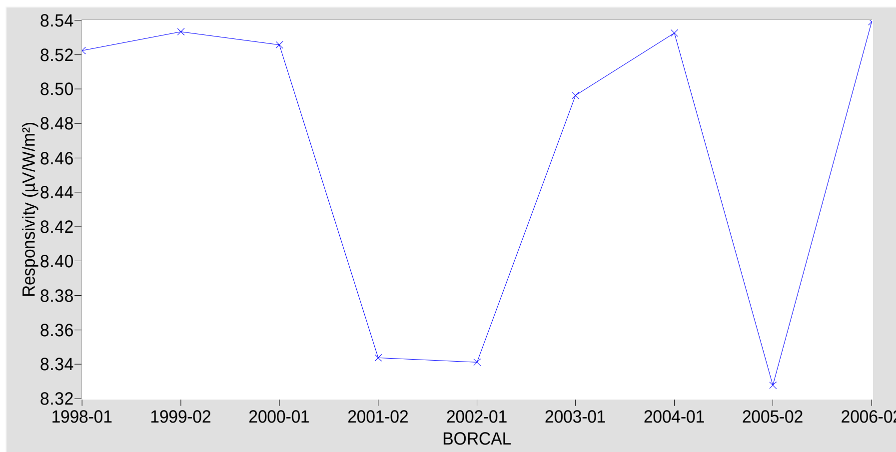
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5391	+1.11 / -1.42 †
Average	8.5438	+1.59 / -1.41 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer **Manufacturer:** Eppley

Model: PSP **Serial Number:** 30614F3

Calibration Date: 8/12/2006 **Due Date:** 8/12/2007

Customer: SGP **Calibration Site Parameters:** see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30614F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

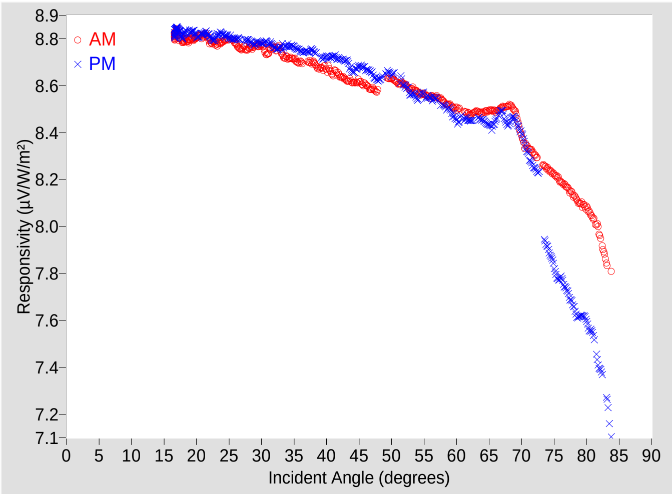


Figure 2. Responsivity vs Local Standard Time

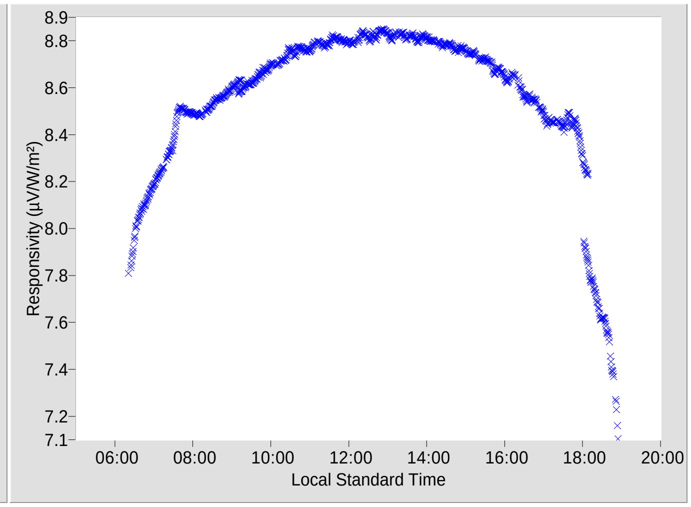


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6507	+2.16 / -2.74	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6059	0.57	97.11	8.6721	0.58	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5723	N/A	95.68	8.6253	0.60	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6311	0.62	101.84	8.6492	0.59	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6064	0.66	99.98	8.6001	0.75	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5754	0.67	98.30	8.5479	0.63	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5546	0.67	96.56	8.5468	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5345	0.70	94.97	8.5166	0.67	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5024	0.73	93.33	8.4518	0.74	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4804	0.75	91.82	8.4514	0.68	274.95
18	8.7926	0.55	155.40	8.8174	0.55	204.72	64	8.4857	0.79	90.34	8.4540	0.74	276.38
20	8.8050	0.48	142.70	8.8131	0.50	217.13	66	8.4929	0.85	88.84	8.4508	0.91	277.74
22	8.7929	0.55	134.59	8.8118	0.52	225.42	68	8.5151	0.90	87.35	8.4370	0.89	279.12
24	8.7887	0.50	128.29	8.8196	0.49	231.57	70	8.3915	1.36	85.95	8.3939	1.22	280.52
26	8.7805	0.52	123.42	8.8001	0.49	236.55	72	8.3052	1.09	84.45	8.2484	1.08	281.89
28	8.7579	0.49	119.28	8.7926	0.50	240.63	74	8.2477	1.19	83.05	7.9090	1.50	278.98
30	8.7716	0.54	115.78	8.7824	0.49	244.13	76	8.1906	1.41	81.57	7.7805	1.63	280.39
32	8.7604	0.52	112.64	8.7619	0.52	247.28	78	8.1346	1.64	80.19	7.6610	1.93	281.81
34	8.7198	0.50	109.77	8.7700	0.52	250.14	80	8.0780	1.98	78.70	7.5932	2.15	283.29
36	8.6995	0.51	107.27	8.7480	0.53	252.65	82	7.9699	2.72	77.27	7.3940	2.89	284.76
38	8.6984	0.54	104.97	8.7452	0.53	254.97	84	7.8087	N/A	75.91	7.1036	N/A	286.07
40	8.6748	0.56	102.80	8.7225	0.52	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6446	0.56	100.83	8.7145	0.55	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6155	0.54	98.94	8.6608	0.62	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

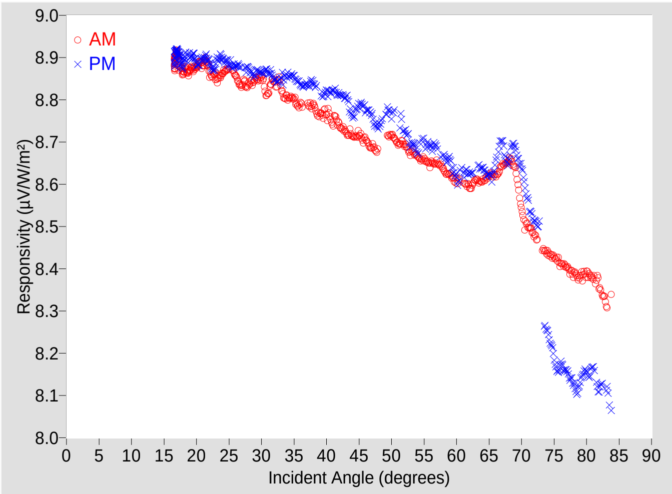

Figure 4. Responsivity vs Local Standard Time

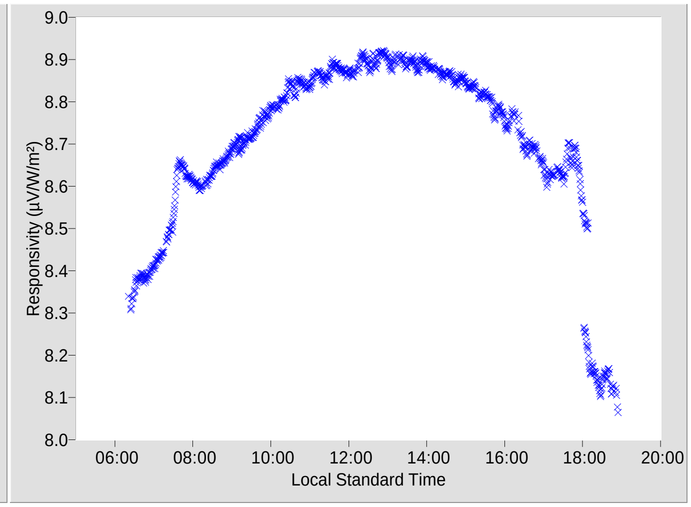

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7524	+1.94 / -2.23	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63119 µV/W/m², determination date: 06/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7062	0.60	97.11	8.7788	0.60	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6760	N/A	95.68	8.7372	0.63	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7160	0.63	101.84	8.7667	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6926	0.67	99.98	8.7260	0.77	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6669	0.68	98.30	8.6807	0.68	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6496	0.69	96.56	8.6895	0.67	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6357	0.72	94.97	8.6678	0.71	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6087	0.75	93.33	8.6130	0.79	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5942	0.78	91.82	8.6254	0.76	274.95
18	8.8683	0.56	155.40	8.8911	0.55	204.72	64	8.6078	0.82	90.34	8.6373	0.80	276.38
20	8.8782	0.50	142.70	8.8882	0.52	217.13	66	8.6219	0.88	88.84	8.6497	1.01	277.74
22	8.8689	0.57	134.59	8.8879	0.54	225.42	68	8.6559	0.93	87.35	8.6549	0.96	279.12
24	8.8634	0.52	128.29	8.8977	0.51	231.57	70	8.5457	1.33	85.95	8.6352	1.21	280.52
26	8.8575	0.54	123.42	8.8806	0.51	236.55	72	8.4780	1.12	84.45	8.5127	1.14	281.89
28	8.8355	0.50	119.28	8.8735	0.52	240.63	74	8.4382	1.23	83.05	8.2483	1.55	278.98
30	8.8511	0.57	115.78	8.8650	0.51	244.13	76	8.4111	1.43	81.57	8.1719	1.70	280.39
32	8.8416	0.55	112.64	8.8472	0.54	247.28	78	8.3894	1.67	80.19	8.1278	2.02	281.81
34	8.8060	0.52	109.77	8.8577	0.55	250.14	80	8.3872	2.03	78.70	8.1559	2.38	283.29
36	8.7877	0.54	107.27	8.8366	0.55	252.65	82	8.3592	2.63	77.27	8.1180	3.04	284.76
38	8.7855	0.55	104.97	8.8373	0.55	254.97	84	8.3391	N/A	75.91	8.0641	N/A	286.07
40	8.7680	0.58	102.80	8.8179	0.55	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7402	0.58	100.83	8.8121	0.57	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7149	0.56	98.94	8.7622	0.64	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

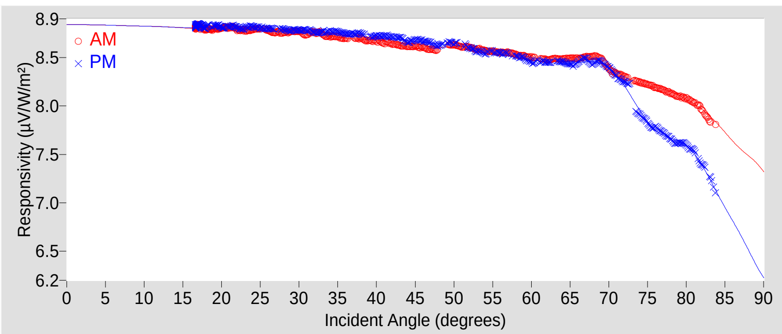
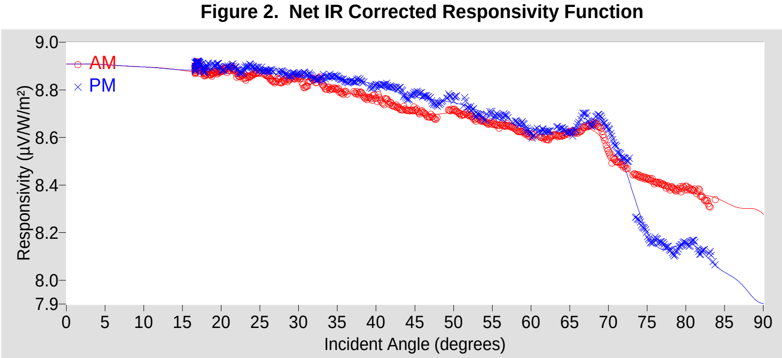


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \quad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.39	±1.39
R²	0.9999989	0.9999976
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.42	±1.42
Net IR corrected R²	0.9999992	0.9999982
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.8354	*	8.8354	*	8.8354	*	8.9054	*	8.9054	*	8.9054	*
9-18	8.8137	*	8.8157	*	8.8147	*	8.8870	*	8.8889	*	8.8879	*
18-27	8.7913	±1.40	8.8122	±1.40	8.8018	±1.45	8.8666	±1.43	8.8890	±1.42	8.8778	±1.47
27-36	8.7507	±1.44	8.7745	±1.42	8.7626	±1.59	8.8322	±1.45	8.8588	±1.44	8.8455	±1.59
36-45	8.6648	±1.50	8.7191	±1.47	8.6920	±1.87	8.7579	±1.50	8.8146	±1.48	8.7862	±1.82
45-54	8.6013	±1.40	8.6297	±1.49	8.6155	±1.58	8.6950	±1.43	8.7460	±1.47	8.7205	±1.62
54-63	8.5268	±1.52	8.5017	±1.57	8.5142	±1.78	8.6289	±1.49	8.6549	±1.50	8.6419	±1.68
63-72	8.4609	±1.73	8.4205	±1.78	8.4407	±2.58	8.5993	±1.64	8.6337	±1.64	8.6165	±2.07
72-81	8.1822	±2.12	7.8076	±4.42	7.9949	±6.87	8.4141	±1.56	8.2203	±2.60	8.3172	±3.36
81-90	7.6871	*	6.8818	*	7.2845	*	8.3253	*	8.0227	*	8.1740	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

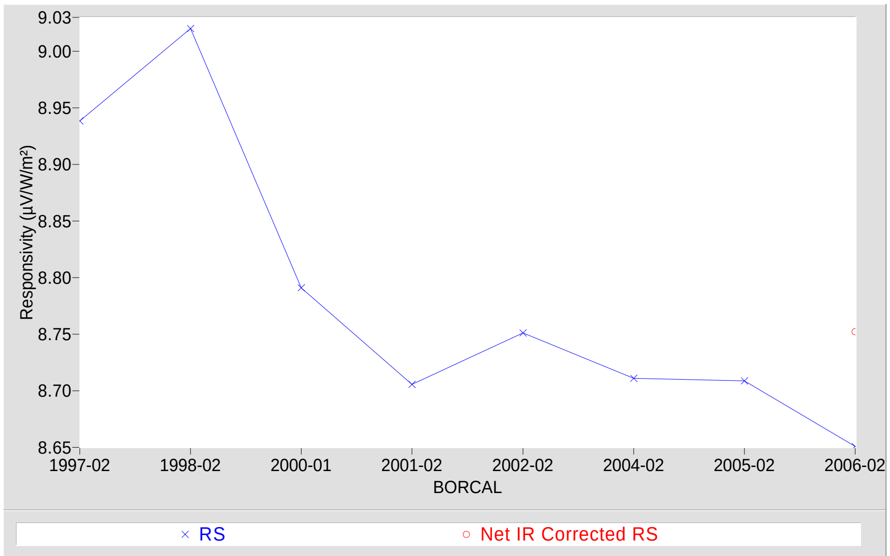
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6507	+2.16 / -2.74
45° - 55°	8.6086	±1.55
Composite	8.6807	+2.11 / -17.39
45° (Net IR Corr.)	8.7524	+1.94 / -2.23
45° - 55° (Net IR Corr.)	8.7147	±1.56
Composite (Net IR Corr.)	8.7886	+1.85 / -8.27

† Valid incident angle ranges:
- 45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
- 45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
- Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



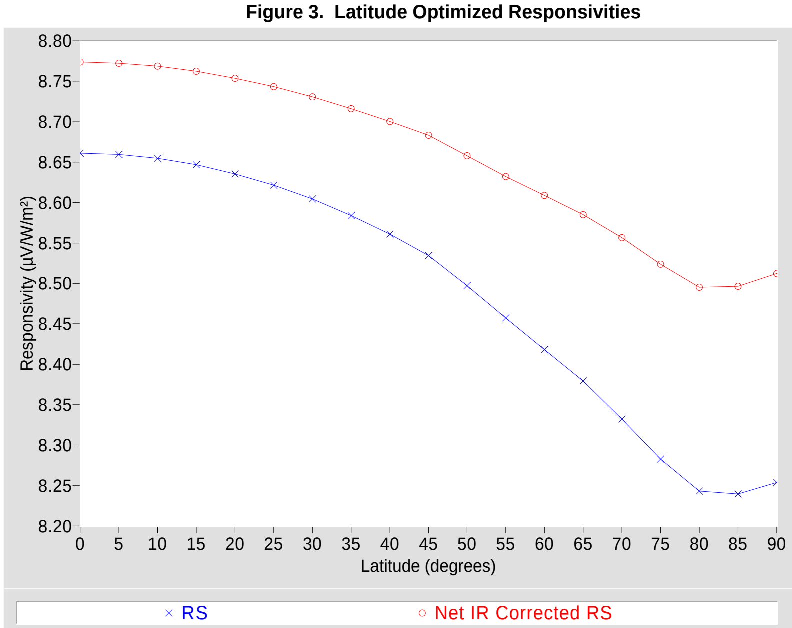
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6613	+2.49 / -26.57	8.7737	+2.10 / -9.86
5	8.6595	+2.50 / -26.56	8.7723	+2.11 / -9.85
10	8.6547	+2.55 / -26.52	8.7686	+2.14 / -9.81
15	8.6468	+2.63 / -26.45	8.7626	+2.19 / -9.75
20	8.6354	+2.75 / -26.35	8.7538	+2.27 / -9.66
25	8.6214	+2.89 / -26.23	8.7432	+2.37 / -9.55
30	8.6046	+3.00 / -26.09	8.7309	+2.44 / -9.43
35	8.5840	+3.11 / -25.91	8.7162	+2.49 / -9.27
40	8.5609	+3.31 / -25.71	8.7004	+2.63 / -9.11
45	8.5344	+3.60 / -25.48	8.6832	+2.81 / -8.93
50	8.4973	+3.86 / -25.16	8.6578	+2.97 / -8.67
55	8.4573	+3.99 / -24.80	8.6321	+2.98 / -8.40
60	8.4180	+4.24 / -24.45	8.6090	+3.08 / -8.16
65	8.3792	+4.22 / -24.10	8.5849	+2.99 / -7.91
70	8.3321	+4.16 / -23.67	8.5565	+2.82 / -7.60
75	8.2829	+4.26 / -23.22	8.5238	+2.89 / -7.26
80	8.2431	+4.04 / -22.85	8.4951	+2.54 / -6.95
85	8.2397	+3.51 / -22.82	8.4966	+2.52 / -6.96
90	8.2539	+3.35 / -22.95	8.5124	+2.36 / -7.13

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

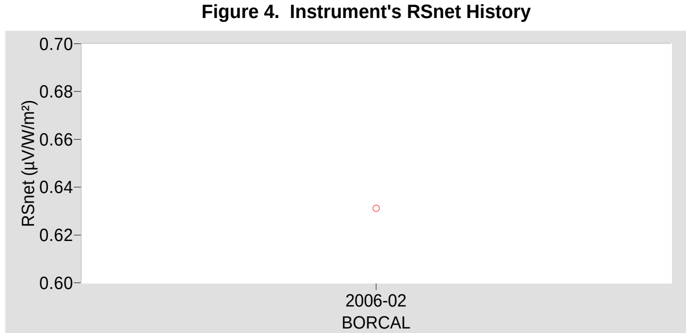
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30620F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

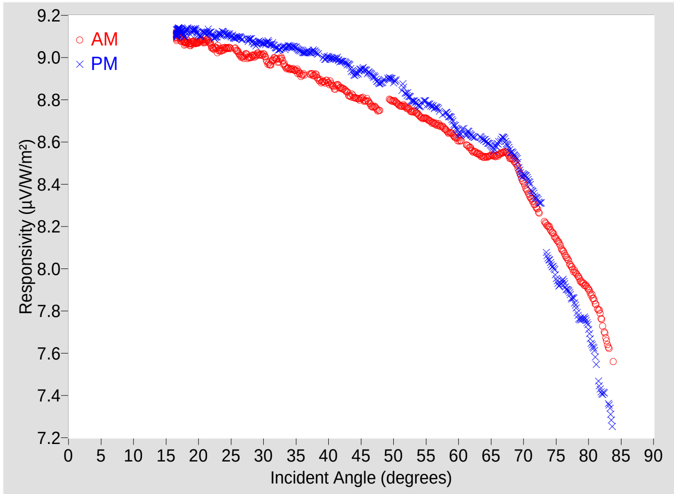

Figure 2. Responsivity vs Local Standard Time

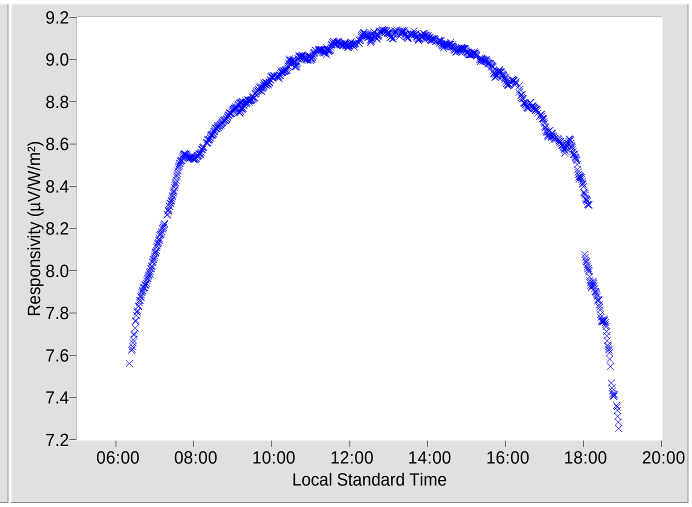

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8756	+2.84 / -3.43	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7950	0.59	97.11	8.9333	0.60	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7494	N/A	95.68	8.8797	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7945	0.62	101.84	8.8895	0.58	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7628	0.65	99.98	8.8289	0.75	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7262	0.67	98.30	8.7740	0.61	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6920	0.68	96.56	8.7677	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6598	0.71	94.97	8.7387	0.66	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6118	0.74	93.33	8.6457	0.75	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5641	0.78	91.82	8.6309	0.70	274.95
18	9.0729	0.58	155.40	9.1176	0.52	204.72	64	8.5297	0.79	90.34	8.6083	0.75	276.38
20	9.0742	0.47	142.70	9.1101	0.51	217.13	66	8.5376	0.84	88.84	8.5912	0.86	277.74
22	9.0562	0.59	134.59	9.1111	0.53	225.42	68	8.5248	0.96	87.35	8.5585	0.96	279.12
24	9.0426	0.48	128.29	9.1145	0.49	231.57	70	8.4116	1.30	85.95	8.4427	1.10	280.52
26	9.0292	0.54	123.42	9.0961	0.49	236.55	72	8.2868	1.14	84.45	8.3333	1.09	281.89
28	9.0028	0.49	119.28	9.0850	0.51	240.63	74	8.1941	1.26	83.05	8.0359	1.50	278.98
30	9.0131	0.57	115.78	9.0678	0.49	244.13	76	8.0852	1.52	81.57	7.9402	1.55	280.39
32	8.9910	0.52	112.64	9.0437	0.52	247.28	78	7.9822	1.69	80.19	7.8262	1.95	281.81
34	8.9475	0.51	109.77	9.0535	0.51	250.14	80	7.9015	2.02	78.70	7.7099	2.33	283.29
36	8.9174	0.53	107.27	9.0265	0.53	252.65	82	7.7610	2.80	77.27	7.4152	2.92	284.76
38	8.9156	0.55	104.97	9.0241	0.52	254.97	84	7.5604	N/A	75.91	N/A	N/A	N/A
40	8.8830	0.56	102.80	9.0008	0.52	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8553	0.55	100.83	8.9816	0.57	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8119	0.55	98.94	8.9228	0.61	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

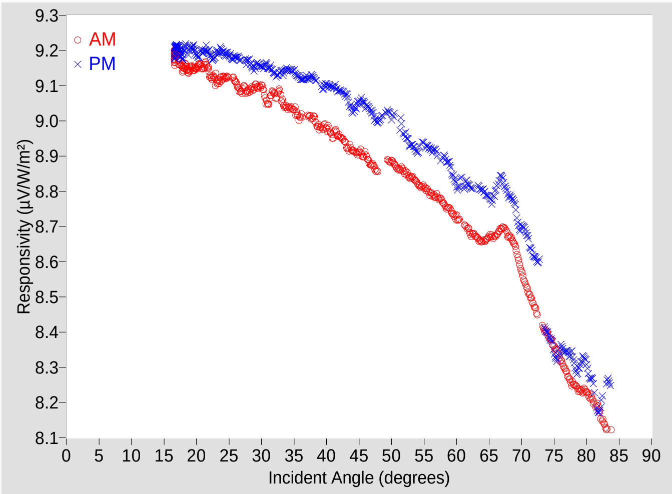

Figure 4. Responsivity vs Local Standard Time

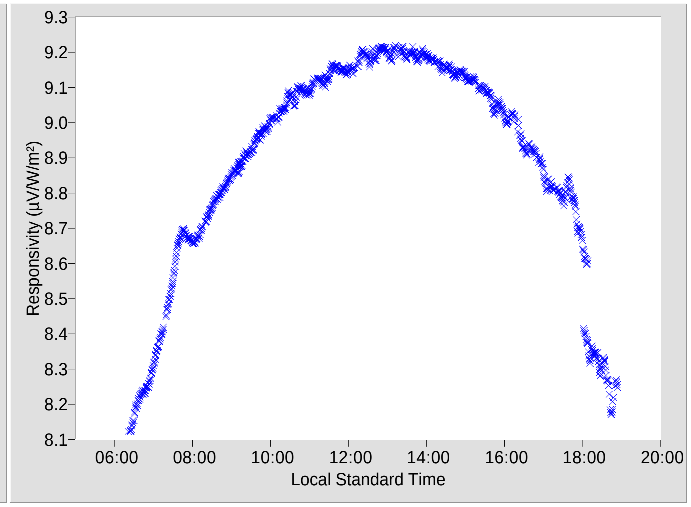

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9833	+2.60 / -3.40	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.66913 µV/W/m², determination date: 07/10/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9013	0.61	97.11	9.0465	0.62	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8593	N/A	95.68	8.9984	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8845	0.64	101.84	9.0140	0.62	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8542	0.67	99.98	8.9623	0.77	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8233	0.69	98.30	8.9149	0.66	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7927	0.70	96.56	8.9190	0.66	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7671	0.73	94.97	8.8990	0.70	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7245	0.76	93.33	8.8166	0.80	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6847	0.79	91.82	8.8153	0.76	274.95
18	9.1531	0.60	155.40	9.1958	0.54	204.72	64	8.6592	0.82	90.34	8.8026	0.80	276.38
20	9.1518	0.49	142.70	9.1897	0.52	217.13	66	8.6743	0.88	88.84	8.8021	0.96	277.74
22	9.1367	0.61	134.59	9.1918	0.54	225.42	68	8.6741	0.97	87.35	8.7895	0.98	279.12
24	9.1217	0.50	128.29	9.1972	0.51	231.57	70	8.5751	1.26	85.95	8.6985	1.11	280.52
26	9.1109	0.55	123.42	9.1814	0.51	236.55	72	8.4700	1.16	84.45	8.6135	1.15	281.89
28	9.0851	0.50	119.28	9.1708	0.53	240.63	74	8.3960	1.27	83.05	8.3955	1.54	278.98
30	9.0974	0.58	115.78	9.1553	0.51	244.13	76	8.3190	1.50	81.57	8.3551	1.71	280.39
32	9.0771	0.55	112.64	9.1341	0.54	247.28	78	8.2522	1.68	80.19	8.3211	2.02	281.81
34	9.0389	0.53	109.77	9.1464	0.53	250.14	80	8.2293	2.05	78.70	8.3064	2.39	283.29
36	9.0109	0.56	107.27	9.1204	0.55	252.65	82	8.1737	2.66	77.27	8.1828	3.05	284.76
38	9.0080	0.57	104.97	9.1217	0.54	254.97	84	8.1227	N/A	75.91	N/A	N/A	N/A
40	8.9817	0.58	102.80	9.1018	0.55	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9566	0.57	100.83	9.0851	0.59	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9172	0.58	98.94	9.0304	0.64	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

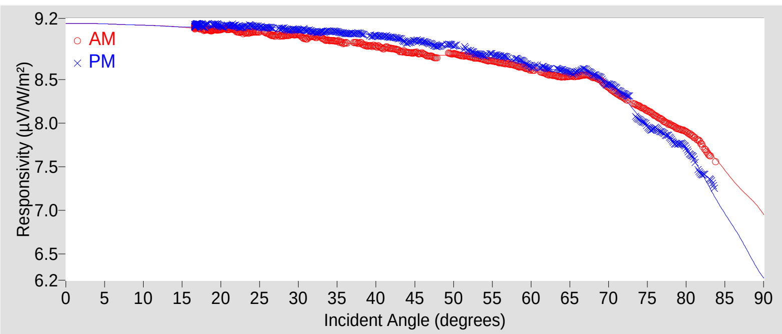
where,

- *IRR* = solar irradiance (Watts per square meter),
- *V* = radiometer output voltage (microvolts),
- *RS* = responsivity of the radiometer (µV/W/m²),
- *IRR (corr.)* = effective net infrared corrected solar irradiance (W/m²),
- *Wnet* = effective net infrared measured by pyrgeometer (W/m²),
- *RSnet* = pyranometer net infrared response (µV/W/m²), see Table 4,
- *RSc* = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

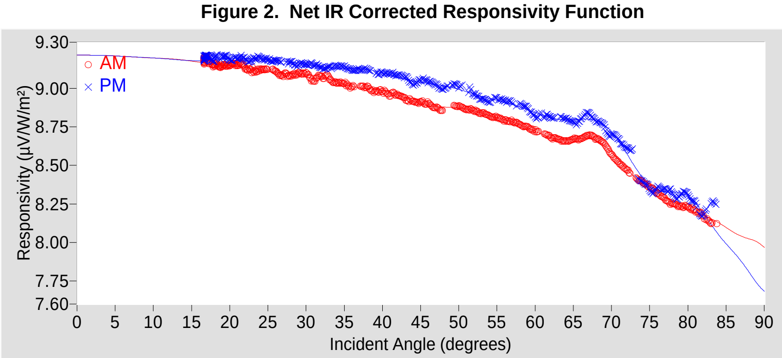


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.42	±1.42
R²	0.9999992	0.9999974
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.7°
Net IR corr. uncert. U95 (%)	±1.43	±1.43
Net IR corrected R²	0.9999994	0.9999982
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.7°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	9.1369	*	9.1369	*	9.1369	*	9.2111	*	9.2111	*	9.2111	*
9-18	9.1068	*	9.1105	*	9.1086	*	9.1844	*	9.1880	*	9.1862	*
18-27	9.0534	±1.46	9.1094	±1.43	9.0814	±1.63	9.1332	±1.46	9.1908	±1.43	9.1620	±1.62
27-36	8.9857	±1.51	9.0596	±1.45	9.0227	±1.93	9.0721	±1.49	9.1491	±1.45	9.1106	±1.89
36-45	8.8748	±1.57	8.9923	±1.53	8.9335	±2.36	8.9734	±1.54	9.0935	±1.51	9.0335	±2.26
45-54	8.7717	±1.45	8.8744	±1.59	8.8231	±2.10	8.8710	±1.48	8.9977	±1.53	8.9344	±2.18
54-63	8.6461	±1.75	8.7093	±1.74	8.6777	±2.43	8.7543	±1.66	8.8717	±1.61	8.8130	±2.53
63-72	8.4887	±1.92	8.5374	±2.14	8.5131	±2.84	8.6356	±1.74	8.7634	±1.77	8.6995	±2.90
72-81	8.0759	±3.05	7.9404	±4.30	8.0081	±5.98	8.3217	±2.17	8.3786	±2.28	8.3502	±3.52
81-90	7.4091	*	6.8962	*	7.1526	*	8.0856	*	7.9652	*	8.0254	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.8756	+2.84 / -3.43
45° - 55°	8.8131	±1.88
Composite	8.9149	+2.68 / -19.44
45° (Net IR Corr.)	8.9833	+2.60 / -3.40
45° - 55° (Net IR Corr.)	8.9256	±1.92
Composite (Net IR Corr.)	9.0289	+2.35 / -10.54

† Valid incident angle ranges:

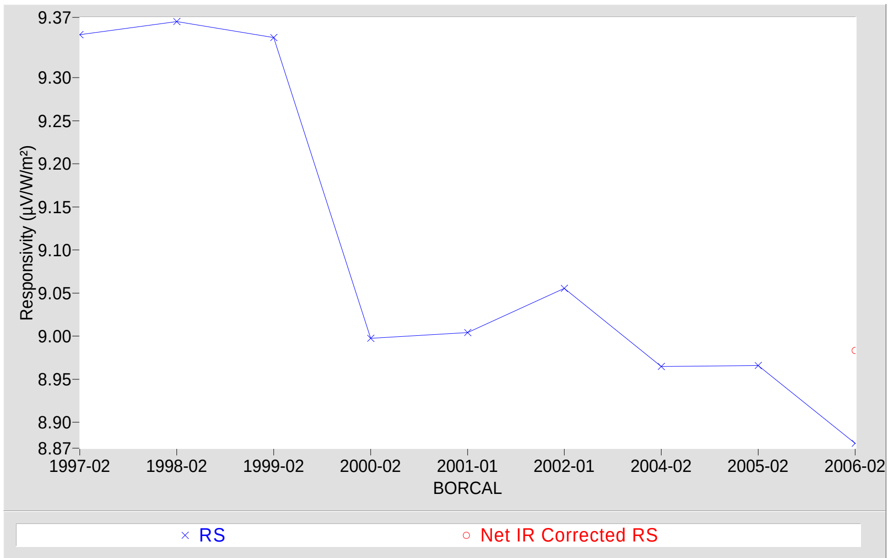
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.7°, 16.6° to 83.7° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



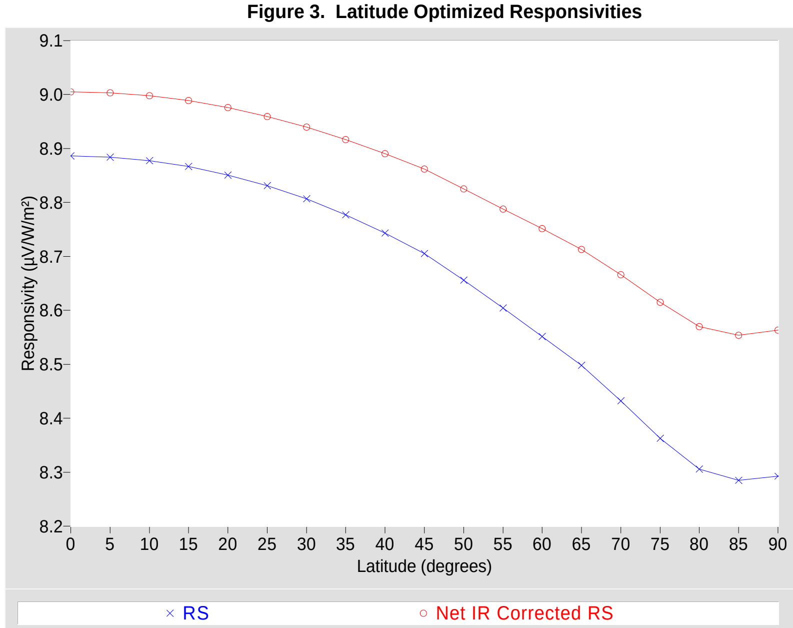
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.8862	+3.22 / -28.45	9.0049	+2.75 / -14.14
5	8.8840	+3.24 / -28.44	9.0030	+2.76 / -14.12
10	8.8775	+3.31 / -28.38	8.9976	+2.82 / -14.07
15	8.8666	+3.42 / -28.30	8.9887	+2.90 / -13.99
20	8.8508	+3.59 / -28.17	8.9757	+3.03 / -13.86
25	8.8309	+3.80 / -28.01	8.9594	+3.20 / -13.71
30	8.8067	+3.98 / -27.81	8.9398	+3.33 / -13.52
35	8.7773	+4.15 / -27.57	8.9166	+3.45 / -13.30
40	8.7434	+4.51 / -27.29	8.8904	+3.73 / -13.04
45	8.7050	+4.95 / -26.97	8.8617	+4.04 / -12.76
50	8.6562	+5.29 / -26.55	8.8251	+4.29 / -12.40
55	8.6040	+5.47 / -26.11	8.7877	+4.34 / -12.03
60	8.5513	+5.85 / -25.65	8.7513	+4.56 / -11.67
65	8.4982	+5.89 / -25.19	8.7130	+4.53 / -11.28
70	8.4322	+5.96 / -24.61	8.6663	+4.46 / -10.81
75	8.3628	+5.99 / -23.98	8.6149	+4.46 / -10.28
80	8.3059	+5.62 / -23.46	8.5700	+4.20 / -9.81
85	8.2847	+4.63 / -23.26	8.5540	+3.48 / -9.65
90	8.2926	+3.82 / -23.34	8.5636	+3.11 / -9.75

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

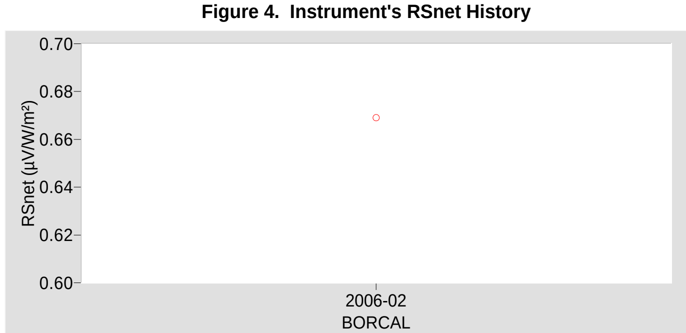
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30652F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results
30652F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

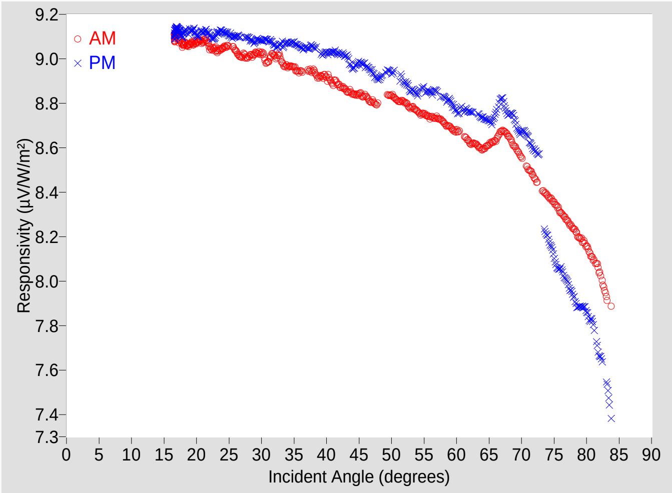


Figure 2. Responsivity vs Local Standard Time

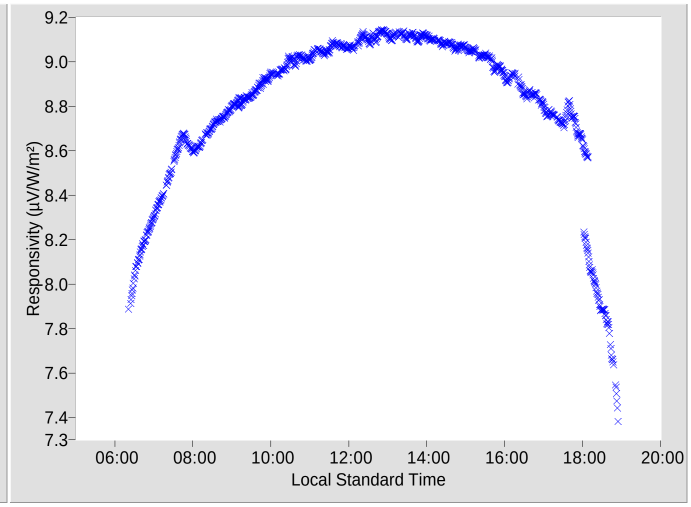


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9119	+2.52 / -3.20	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8320	0.58	97.11	8.9702	0.60	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7928	N/A	95.68	8.9098	0.61	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8350	0.62	101.84	8.9384	0.58	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8045	0.66	99.98	8.8928	0.73	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7652	0.68	98.30	8.8456	0.64	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7382	0.67	96.56	8.8491	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7155	0.71	94.97	8.8290	0.67	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6752	0.72	93.33	8.7637	0.72	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6241	0.77	91.82	8.7621	0.68	274.95
18	9.0658	0.59	155.40	9.1124	0.53	204.72	64	8.5942	0.80	90.34	8.7348	0.73	276.38
20	9.0747	0.48	142.70	9.1094	0.51	217.13	66	8.6336	0.91	88.84	8.7551	1.03	277.74
22	9.0565	0.57	134.59	9.1090	0.53	225.42	68	8.6512	0.98	87.35	8.7494	0.98	279.12
24	9.0496	0.50	128.29	9.1221	0.49	231.57	70	8.5606	1.13	85.99	8.6712	0.96	280.52
26	9.0378	0.54	123.42	9.1007	0.49	236.55	72	8.4617	1.11	84.45	8.5878	1.06	281.89
28	9.0093	0.49	119.28	9.0927	0.50	240.63	74	8.3858	1.20	83.05	8.1973	1.51	278.98
30	9.0250	0.56	115.78	9.0823	0.49	244.13	76	8.3077	1.44	81.57	8.0558	1.63	280.39
32	9.0131	0.53	112.64	9.0596	0.53	247.28	78	8.2377	1.65	80.19	7.9315	1.91	281.81
34	8.9670	0.50	109.77	9.0719	0.52	250.14	80	8.1568	2.01	78.70	7.8613	2.13	283.29
36	8.9428	0.52	107.27	9.0526	0.54	252.65	82	8.0410	2.66	77.27	7.6632	2.85	284.76
38	8.9442	0.54	104.97	9.0512	0.52	254.97	84	7.8880	N/A	75.91	7.3826	N/A	286.07
40	8.9188	0.56	102.80	9.0274	0.52	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8784	0.56	100.83	9.0210	0.55	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8437	0.54	98.94	8.9593	0.64	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

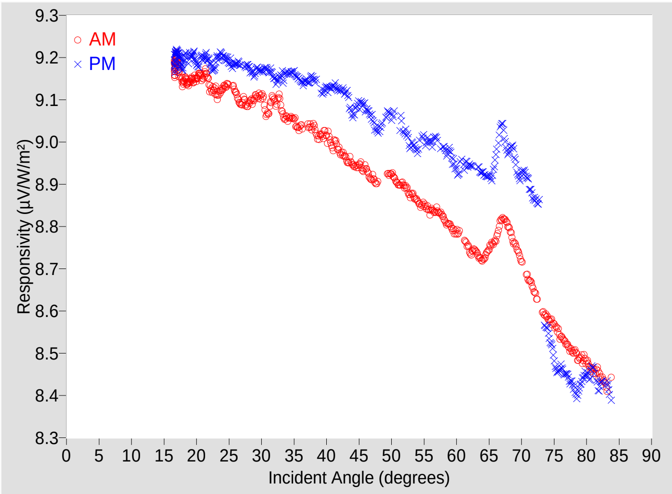

Figure 4. Responsivity vs Local Standard Time

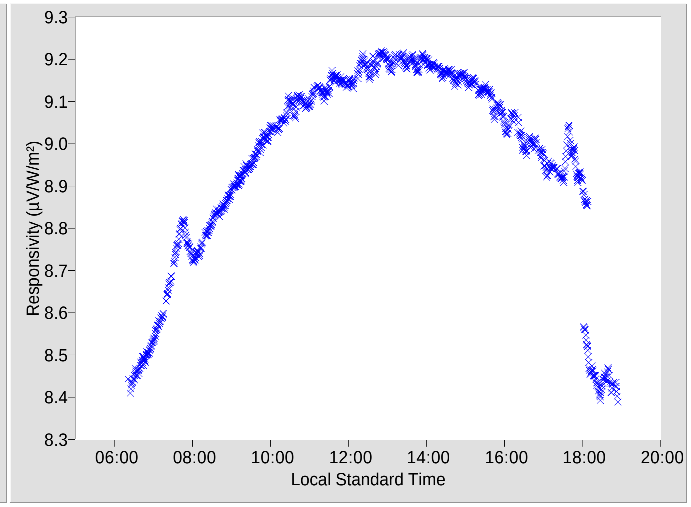

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.0183	+2.32 / -3.18	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.66095 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9370	0.61	97.11	9.0820	0.62	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9014	N/A	95.68	9.0271	0.63	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9239	0.64	101.84	9.0614	0.61	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8948	0.67	99.98	9.0246	0.75	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8611	0.68	98.30	8.9847	0.68	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8377	0.70	96.56	8.9986	0.67	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8215	0.73	94.97	8.9874	0.71	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7865	0.75	93.33	8.9325	0.77	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7433	0.80	91.82	8.9443	0.75	274.95
18	9.1450	0.61	155.40	9.1896	0.54	204.72	64	8.7220	0.83	90.34	8.9268	0.79	276.38
20	9.1513	0.49	142.70	9.1880	0.52	217.13	66	8.7687	0.96	88.84	8.9634	1.13	277.74
22	9.1360	0.59	134.59	9.1887	0.54	225.42	68	8.7986	0.99	87.35	8.9776	1.00	279.12
24	9.1278	0.53	128.29	9.2038	0.51	231.57	70	8.7217	1.11	85.99	8.9239	1.01	280.52
26	9.1185	0.55	123.42	9.1850	0.51	236.55	72	8.6426	1.13	84.45	8.8646	1.12	281.89
28	9.0905	0.51	119.28	9.1774	0.52	240.63	74	8.5852	1.23	83.05	8.5526	1.54	278.98
30	9.1082	0.58	115.78	9.1687	0.51	244.13	76	8.5386	1.45	81.57	8.4656	1.69	280.39
32	9.0982	0.56	112.64	9.1489	0.55	247.28	78	8.5045	1.67	80.19	8.4204	2.00	281.81
34	9.0573	0.52	109.77	9.1637	0.54	250.14	80	8.4806	2.03	78.70	8.4505	2.35	283.29
36	9.0351	0.54	107.27	9.1453	0.56	252.65	82	8.4486	2.60	77.27	8.4213	2.99	284.76
38	9.0355	0.56	104.97	9.1476	0.54	254.97	84	8.4433	N/A	75.91	8.3884	N/A	286.07
40	9.0164	0.58	102.80	9.1273	0.55	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9786	0.58	100.83	9.1233	0.57	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9477	0.57	98.94	9.0655	0.66	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

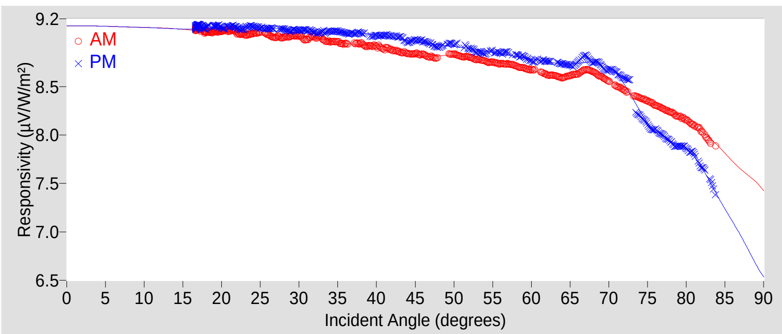
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

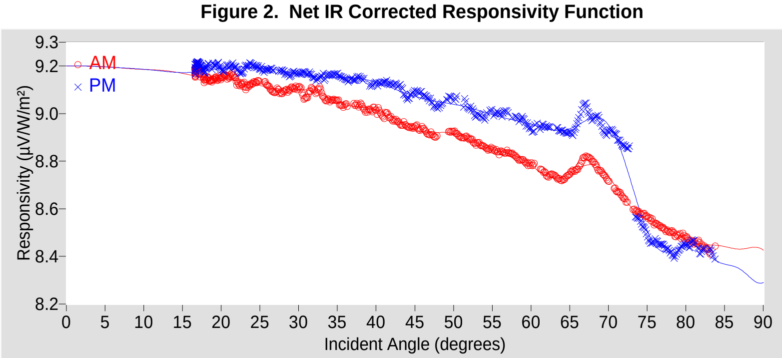


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.41	±1.41
R²	0.9999992	0.9999964
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.43	±1.43
Net IR corrected R²	0.9999995	0.9999973
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	9.1234	*	9.1234	*	9.1234	*	9.1967	*	9.1967	*	9.1967	*
9-18	9.0982	*	9.1021	*	9.1001	*	9.1749	*	9.1786	*	9.1767	*
18-27	9.0556	±1.43	9.1106	±1.41	9.0831	±1.58	9.1344	±1.45	9.1911	±1.43	9.1627	±1.59
27-36	9.0017	±1.46	9.0747	±1.42	9.0382	±1.83	9.0871	±1.47	9.1630	±1.44	9.1250	±1.80
36-45	8.9041	±1.55	9.0236	±1.49	8.9638	±2.30	9.0015	±1.53	9.1236	±1.48	9.0626	±2.22
45-54	8.8116	±1.43	8.9210	±1.49	8.8663	±2.06	8.9097	±1.47	9.0428	±1.47	8.9763	±2.16
54-63	8.6998	±1.66	8.8086	±1.55	8.7542	±2.50	8.8067	±1.60	8.9691	±1.48	8.8879	±2.62
63-72	8.6018	±1.64	8.7215	±1.72	8.6617	±2.63	8.7468	±1.58	8.9447	±1.60	8.8458	±2.92
72-81	8.2990	±2.49	8.0901	±4.53	8.1945	±6.19	8.5418	±1.77	8.5222	±2.70	8.5320	±3.79
81-90	7.7728	*	7.1686	*	7.4707	*	8.4410	*	8.3633	*	8.4022	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

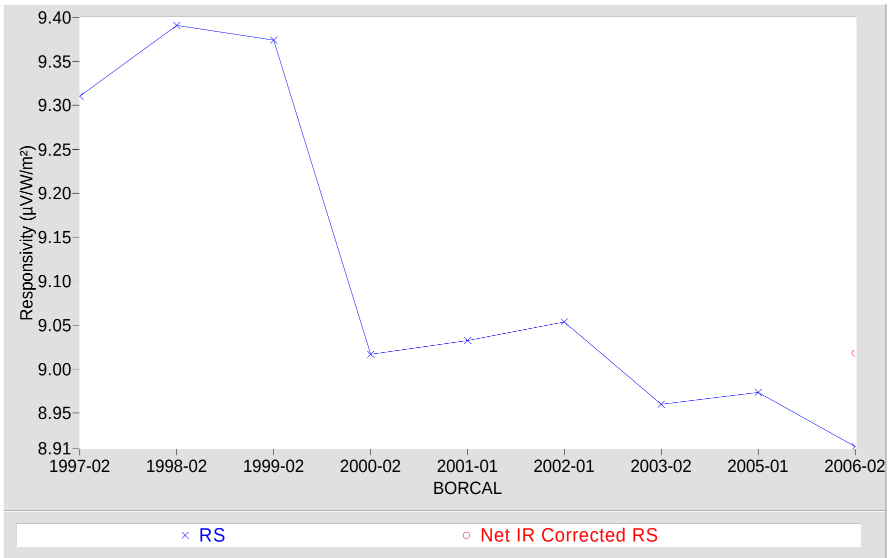
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.9119	+2.52 / -3.20
45° - 55°	8.8583	±1.85
Composite	8.9474	+2.35 / -16.77
45° (Net IR Corr.)	9.0183	+2.32 / -3.18
45° - 55° (Net IR Corr.)	8.9694	±1.89
Composite (Net IR Corr.)	9.0604	+2.07 / -7.53

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



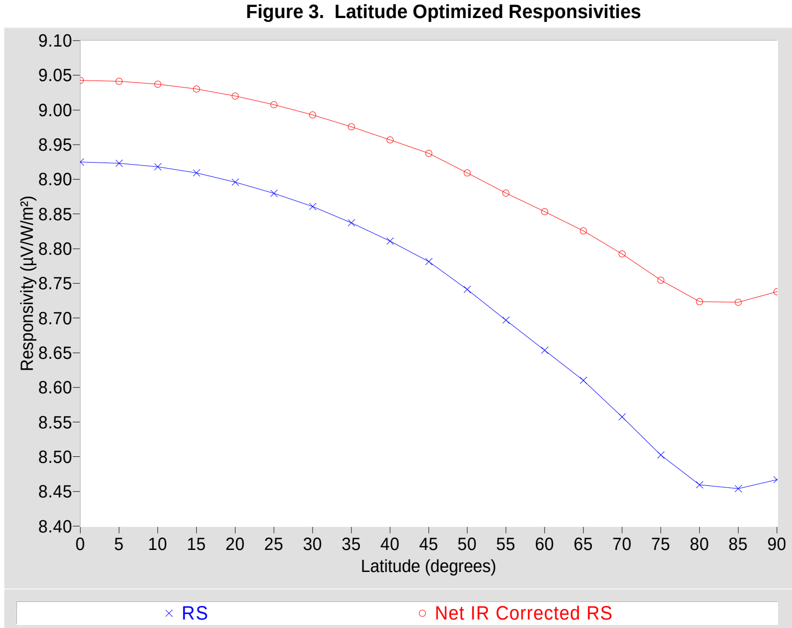
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.9251	+2.67 / -25.35	9.0429	+2.26 / -8.41
5	8.9232	+2.69 / -25.34	9.0413	+2.27 / -8.39
10	8.9179	+2.74 / -25.29	9.0372	+2.31 / -8.35
15	8.9091	+2.83 / -25.22	9.0303	+2.37 / -8.28
20	8.8961	+2.96 / -25.11	9.0201	+2.46 / -8.18
25	8.8799	+3.13 / -24.97	9.0075	+2.58 / -8.05
30	8.8606	+3.26 / -24.81	8.9929	+2.67 / -7.90
35	8.8374	+3.46 / -24.61	8.9759	+2.84 / -7.73
40	8.8109	+3.74 / -24.38	8.9570	+3.02 / -7.54
45	8.7815	+4.06 / -24.13	8.9373	+3.23 / -7.34
50	8.7413	+4.38 / -23.78	8.9093	+3.44 / -7.06
55	8.6970	+4.54 / -23.40	8.8800	+3.46 / -6.76
60	8.6537	+4.89 / -23.01	8.8536	+3.66 / -6.48
65	8.6102	+4.95 / -22.62	8.8256	+3.63 / -6.19
70	8.5573	+4.84 / -22.15	8.7923	+3.40 / -5.85
75	8.5026	+4.93 / -21.65	8.7548	+3.48 / -5.46
80	8.4596	+4.69 / -21.25	8.7235	+3.34 / -5.13
85	8.4539	+4.02 / -21.20	8.7228	+3.30 / -5.12
90	8.4672	+3.68 / -21.32	8.7378	+3.14 / -5.28

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

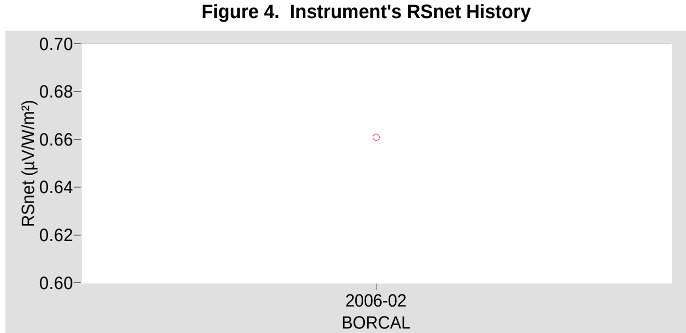
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30664F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: __________________	Date: __________________

Calibration Results

30664F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

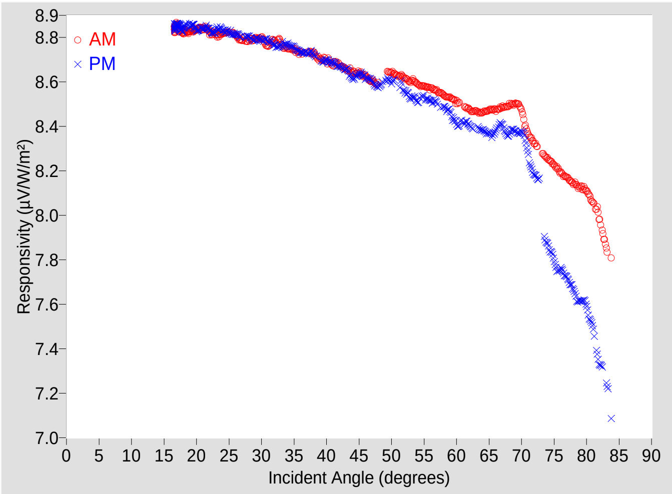


Figure 2. Responsivity vs Local Standard Time

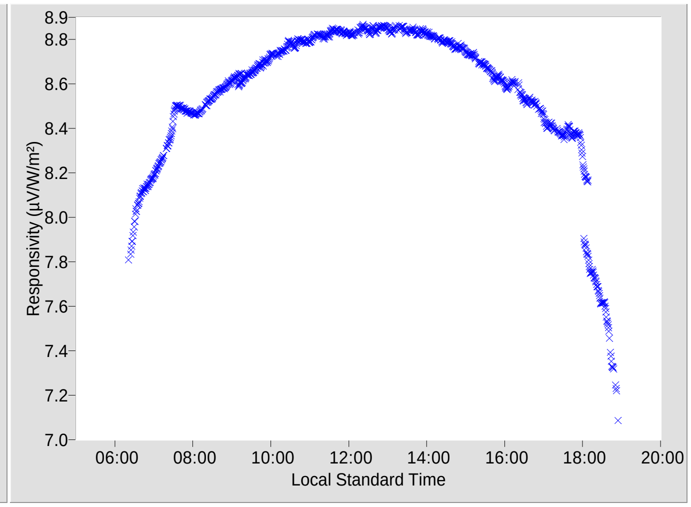


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6391	+2.36 / -3.04	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6266	0.59	97.11	8.6215	0.58	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5875	N/A	95.68	8.5801	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6425	0.61	101.84	8.6021	0.59	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6182	0.66	99.98	8.5592	0.75	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5929	0.67	98.30	8.5152	0.62	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5721	0.67	96.56	8.5148	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5432	0.70	94.97	8.4893	0.65	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5097	0.73	93.33	8.4116	0.75	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4764	0.76	91.82	8.4049	0.71	274.95
18	8.8255	0.52	155.40	8.8417	0.51	204.72	64	8.4638	0.79	90.34	8.3832	0.74	276.38
20	8.8375	0.48	142.70	8.8358	0.50	217.13	66	8.4763	0.84	88.84	8.3801	0.86	277.74
22	8.8266	0.52	134.59	8.8343	0.51	225.42	68	8.4939	0.90	87.35	8.3633	0.86	279.12
24	8.8186	0.49	128.29	8.8340	0.49	231.57	70	8.4744	1.27	85.95	8.3730	1.04	280.52
26	8.8119	0.51	123.42	8.8145	0.50	236.55	72	8.3228	1.10	84.45	8.1819	1.19	281.89
28	8.7877	0.49	119.28	8.8045	0.49	240.63	74	8.2566	1.20	83.05	7.8675	1.49	278.98
30	8.7979	0.53	115.78	8.7902	0.49	244.13	76	8.1922	1.41	81.57	7.7572	1.58	280.39
32	8.7854	0.52	112.64	8.7659	0.52	247.28	78	8.1457	1.61	80.19	7.6662	1.90	281.81
34	8.7528	0.50	109.77	8.7681	0.52	250.14	80	8.1095	1.99	78.70	7.5863	2.24	283.29
36	8.7324	0.52	107.27	8.7346	0.53	252.65	82	7.9843	2.75	77.27	7.3316	2.91	284.76
38	8.7291	0.55	104.97	8.7230	0.54	254.97	84	7.8087	N/A	75.91	7.0861	N/A	286.07
40	8.6976	0.55	102.80	8.6963	0.53	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6777	0.54	100.83	8.6700	0.56	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6467	0.54	98.94	8.6168	0.60	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

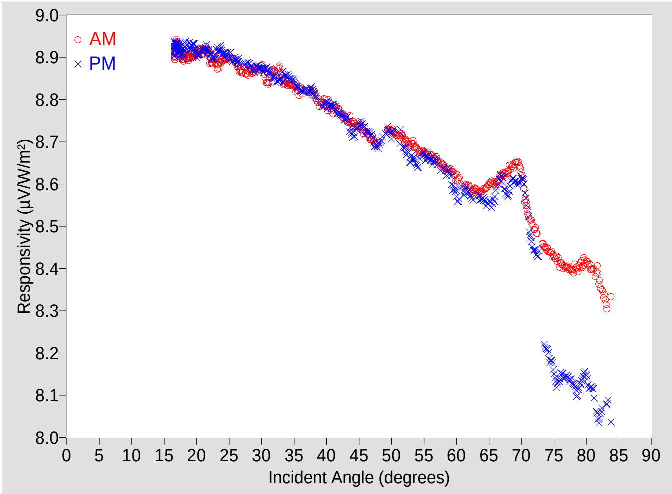

Figure 4. Responsivity vs Local Standard Time

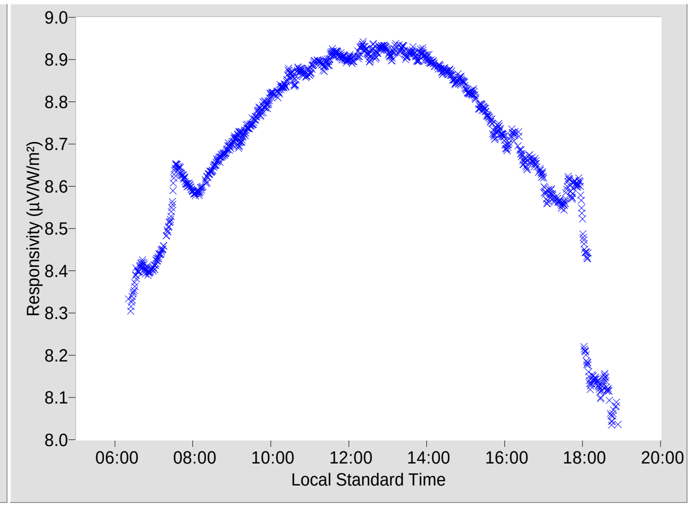

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7396	+2.16 / -2.38	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.62455 µV/W/m², determination date: 06/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7258	0.61	97.11	8.7271	0.61	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6900	N/A	95.68	8.6909	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7265	0.63	101.84	8.7184	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7035	0.67	99.98	8.6837	0.77	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6835	0.68	98.30	8.6467	0.67	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6661	0.69	96.56	8.6561	0.67	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6434	0.72	94.97	8.6389	0.70	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6149	0.76	93.33	8.5711	0.80	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5890	0.78	91.82	8.5770	0.77	274.95
18	8.9004	0.53	155.40	8.9146	0.53	204.72	64	8.5847	0.82	90.34	8.5645	0.81	276.38
20	8.9099	0.49	142.70	8.9101	0.52	217.13	66	8.6039	0.88	88.84	8.5769	0.96	277.74
22	8.9018	0.54	134.59	8.9097	0.53	225.42	68	8.6332	0.94	87.35	8.5789	0.94	279.12
24	8.8925	0.51	128.29	8.9112	0.52	231.57	70	8.6270	1.24	85.95	8.6117	1.10	280.52
26	8.8881	0.52	123.42	8.8941	0.52	236.55	72	8.4938	1.13	84.45	8.4434	1.22	281.89
28	8.8645	0.51	119.28	8.8846	0.51	240.63	74	8.4450	1.24	83.05	8.2031	1.55	278.98
30	8.8765	0.55	115.78	8.8719	0.51	244.13	76	8.4104	1.44	81.57	8.1444	1.71	280.39
32	8.8658	0.55	112.64	8.8503	0.54	247.28	78	8.3978	1.66	80.19	8.1282	2.01	281.81
34	8.8382	0.52	109.77	8.8548	0.54	250.14	80	8.4155	2.03	78.70	8.1431	2.38	283.29
36	8.8197	0.55	107.27	8.8222	0.55	252.65	82	8.3695	2.64	77.27	8.0479	3.07	284.76
38	8.8153	0.56	104.97	8.8141	0.56	254.97	84	8.3335	N/A	75.91	8.0366	N/A	286.07
40	8.7897	0.57	102.80	8.7906	0.55	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7723	0.57	100.83	8.7666	0.59	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7450	0.57	98.94	8.7172	0.63	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

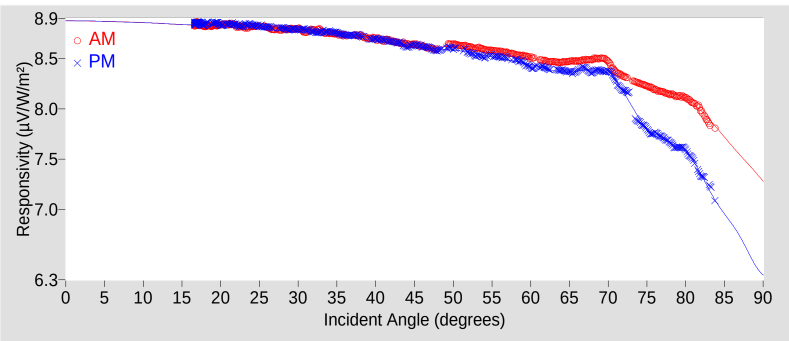
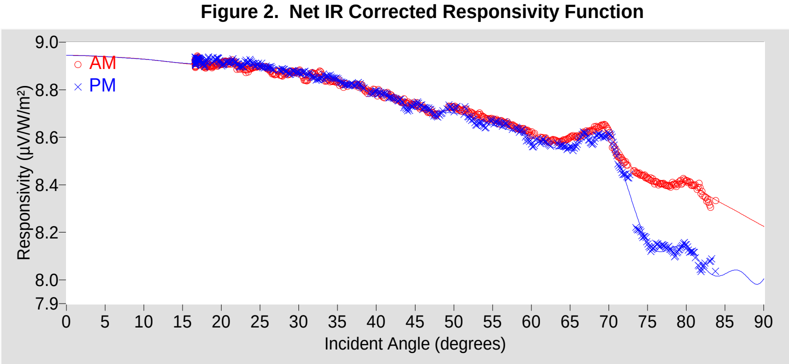


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.39	±1.39
R²	0.9999990	0.9999975
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.43	±1.43
Net IR corrected R²	0.9999993	0.9999979
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.8704	*	8.8704	*	8.8704	*	8.9397	*	8.9397	*	8.9397	*
9-18	8.8449	*	8.8460	*	8.8455	*	8.9173	*	8.9184	*	8.9179	*
18-27	8.8234	±1.40	8.8318	±1.40	8.8276	±1.43	8.8979	±1.43	8.9078	±1.43	8.9028	±1.46
27-36	8.7796	±1.43	8.7786	±1.44	8.7791	±1.51	8.8602	±1.45	8.8621	±1.46	8.8612	±1.52
36-45	8.6944	±1.51	8.6880	±1.55	8.6912	±1.70	8.7864	±1.51	8.7825	±1.55	8.7845	±1.66
45-54	8.6172	±1.40	8.5850	±1.46	8.6011	±1.58	8.7099	±1.44	8.7001	±1.45	8.7050	±1.50
54-63	8.5358	±1.58	8.4658	±1.63	8.5008	±2.22	8.6368	±1.55	8.6174	±1.54	8.6271	±1.75
63-72	8.4652	±1.56	8.3600	±1.75	8.4126	±2.85	8.6022	±1.53	8.5710	±1.63	8.5866	±1.98
72-81	8.1974	±2.16	7.7841	±4.26	7.9908	±7.39	8.4269	±1.59	8.1924	±2.39	8.3096	±3.70
81-90	7.6755	*	6.9005	*	7.2880	*	8.3070	*	8.0293	*	8.1682	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

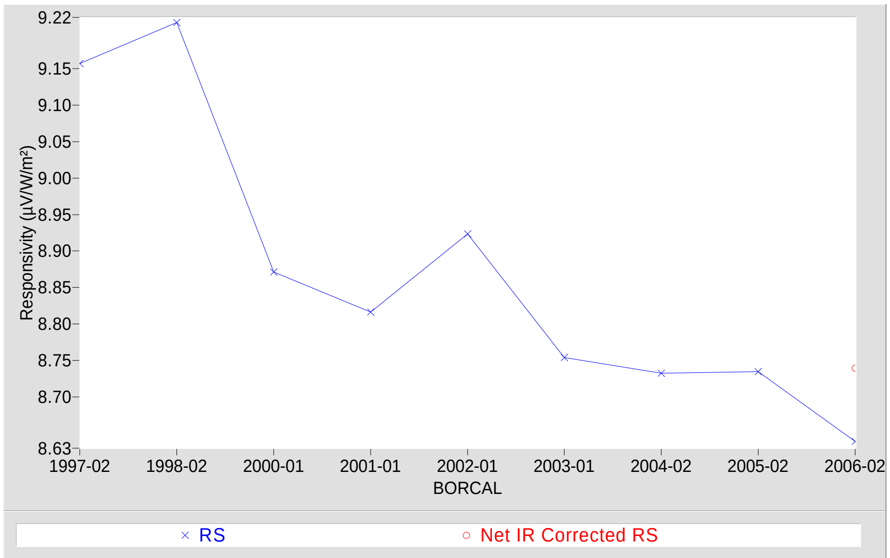
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6391	+2.36 / -3.04
45° - 55°	8.5949	±1.53
Composite	8.6920	+2.19 / -18.00
45° (Net IR Corr.)	8.7396	+2.16 / -2.38
45° - 55° (Net IR Corr.)	8.6998	±1.49
Composite (Net IR Corr.)	8.7988	+1.93 / -8.97

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



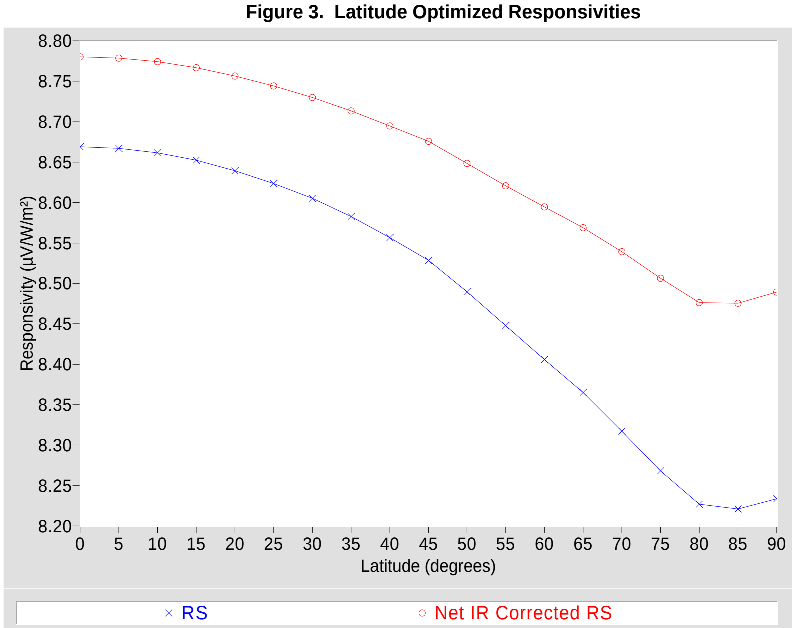
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6691	+2.77 / -25.71	8.7803	+2.36 / -9.21
5	8.6671	+2.79 / -25.69	8.7787	+2.37 / -9.19
10	8.6616	+2.85 / -25.64	8.7743	+2.41 / -9.14
15	8.6524	+2.94 / -25.56	8.7669	+2.48 / -9.07
20	8.6394	+3.08 / -25.45	8.7565	+2.58 / -8.96
25	8.6235	+3.24 / -25.31	8.7441	+2.70 / -8.83
30	8.6052	+3.35 / -25.16	8.7301	+2.77 / -8.69
35	8.5826	+3.46 / -24.96	8.7134	+2.82 / -8.52
40	8.5568	+3.58 / -24.73	8.6949	+2.89 / -8.32
45	8.5284	+3.90 / -24.48	8.6756	+3.09 / -8.12
50	8.4896	+4.10 / -24.14	8.6484	+3.21 / -7.84
55	8.4476	+4.28 / -23.76	8.6206	+3.21 / -7.55
60	8.4056	+4.25 / -23.38	8.5946	+3.10 / -7.27
65	8.3651	+4.20 / -23.01	8.5687	+2.93 / -7.00
70	8.3170	+3.96 / -22.57	8.5391	+2.50 / -6.68
75	8.2681	+4.54 / -22.11	8.5065	+2.80 / -6.33
80	8.2269	+4.39 / -21.72	8.4763	+2.64 / -6.01
85	8.2211	+3.63 / -21.66	8.4753	+2.38 / -5.99
90	8.2335	+3.49 / -21.78	8.4892	+2.25 / -6.15

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

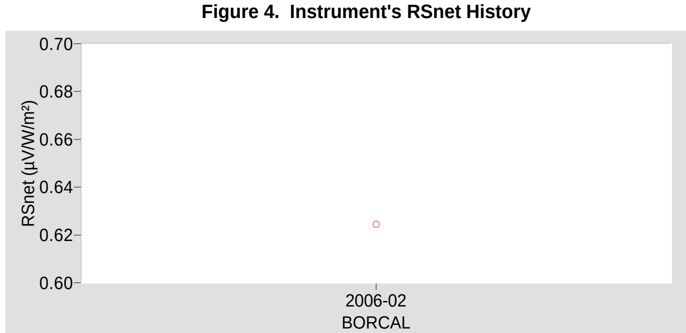
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30665F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

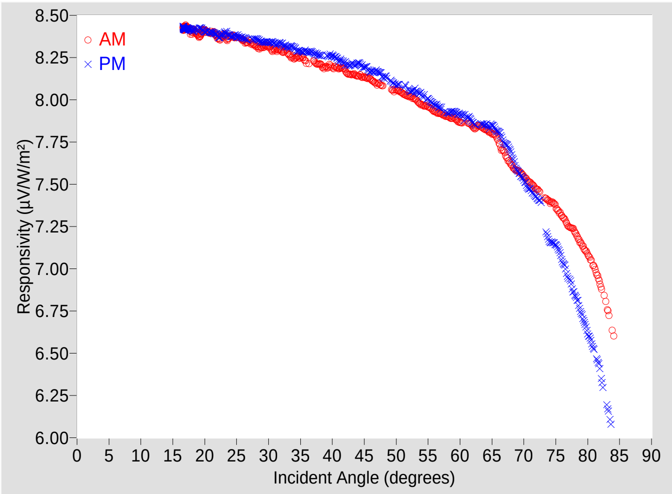

Figure 2. Responsivity vs Local Standard Time

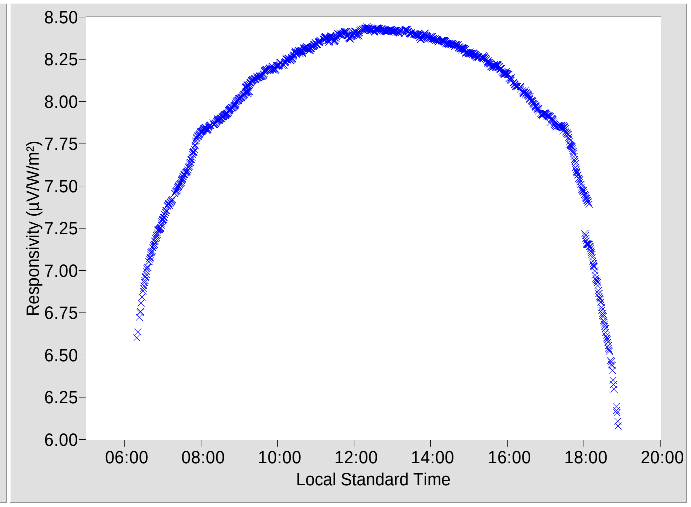

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1635	+2.75 / -4.14	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1229	0.61	97.18	8.1669	0.59	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0839	N/A	95.64	8.1329	0.61	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0583	0.62	101.80	8.0898	0.60	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0214	0.65	100.06	8.0541	0.66	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9707	0.70	98.26	8.0284	0.67	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9319	0.71	96.58	7.9705	0.73	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9008	0.70	94.94	7.9218	0.67	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8670	0.74	93.40	7.9137	0.75	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8420	0.78	91.83	7.8644	0.76	274.97
18	8.4054	0.58	155.25	8.4130	0.48	204.58	64	7.8238	0.84	90.31	7.8516	0.75	276.39
20	8.4105	0.54	142.58	8.4044	0.50	217.20	66	7.7580	1.07	88.85	7.8104	1.02	277.75
22	8.3699	0.56	134.49	8.3815	0.51	225.32	68	7.6185	1.13	87.37	7.6807	1.32	279.13
24	8.3718	0.53	128.48	8.3781	0.52	231.49	70	7.5473	1.08	85.91	7.5238	1.13	280.49
26	8.3547	0.50	123.46	8.3651	0.51	236.46	72	7.4710	1.14	84.47	7.4179	1.12	281.90
28	8.3204	0.55	119.32	8.3586	0.49	240.56	74	7.3973	1.22	83.02	7.1666	1.47	278.95
30	8.3161	0.53	115.72	8.3406	0.49	244.17	76	7.3135	1.56	81.64	7.0456	2.07	280.41
32	8.2913	0.50	112.58	8.3319	0.52	247.32	78	7.2162	1.75	80.16	6.8437	2.35	281.83
34	8.2501	0.51	109.88	8.3075	0.54	250.09	80	7.0882	2.19	78.72	6.6207	2.65	283.26
36	8.2200	0.56	107.27	8.2854	0.51	252.60	82	6.9023	2.99	77.24	6.3807	3.48	284.73
38	8.2110	0.57	104.92	8.2626	0.52	254.93	84	6.6198	3.80	75.78	N/A	N/A	N/A
40	8.1894	0.54	102.80	8.2582	0.56	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1754	0.58	100.85	8.2135	0.59	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1429	0.54	98.90	8.2157	0.57	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

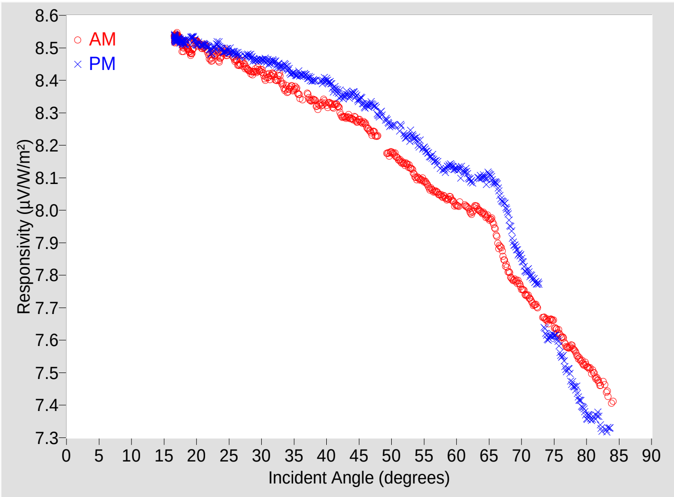

Figure 4. Responsivity vs Local Standard Time

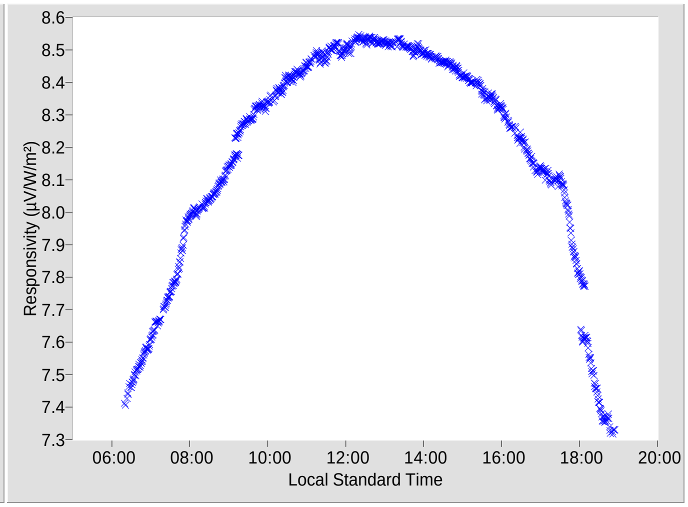

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3083	+2.52 / -4.15	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.68788 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2656	0.66	97.18	8.3210	0.64	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2276	N/A	95.64	8.2938	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1778	0.65	101.80	8.2598	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1446	0.68	100.06	8.2274	0.73	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0989	0.72	98.26	8.2098	0.73	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0659	0.74	96.58	8.1633	0.77	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0418	0.74	94.94	8.1230	0.75	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0149	0.78	93.40	8.1264	0.81	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9995	0.82	91.83	8.0948	0.85	274.97
18	8.5069	0.60	155.25	8.5165	0.51	204.58	64	7.9926	0.88	90.31	8.1021	0.88	276.39
20	8.5181	0.56	142.58	8.5131	0.53	217.20	66	7.9376	1.09	88.85	8.0839	1.04	277.75
22	8.4733	0.59	134.49	8.4949	0.55	225.32	68	7.8137	1.14	87.37	7.9761	1.29	279.13
24	8.4809	0.56	128.48	8.4919	0.55	231.49	70	7.7610	1.11	85.91	7.8513	1.19	280.49
26	8.4636	0.53	123.46	8.4823	0.54	236.46	72	7.7087	1.20	84.47	7.7816	1.23	281.90
28	8.4324	0.57	119.32	8.4770	0.53	240.56	74	7.6604	1.30	83.02	7.6087	1.63	278.95
30	8.4290	0.57	115.72	8.4628	0.53	244.17	76	7.6176	1.55	81.64	7.5590	1.97	280.41
32	8.4102	0.54	112.58	8.4566	0.55	247.32	78	7.5732	1.79	80.16	7.4611	2.27	281.83
34	8.3714	0.55	109.88	8.4373	0.58	250.09	80	7.5233	2.18	78.72	7.3672	2.64	283.26
36	8.3467	0.60	107.27	8.4188	0.56	252.60	82	7.4670	2.84	77.24	7.3532	3.39	284.73
38	8.3397	0.62	104.92	8.3988	0.57	254.93	84	7.4090	3.95	75.78	N/A	N/A	N/A
40	8.3235	0.58	102.80	8.3986	0.61	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3103	0.63	100.85	8.3563	0.63	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2823	0.60	98.90	8.3605	0.62	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (μV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (μV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (μV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

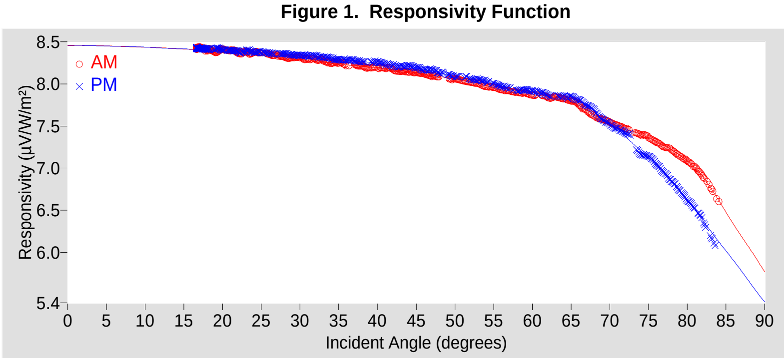
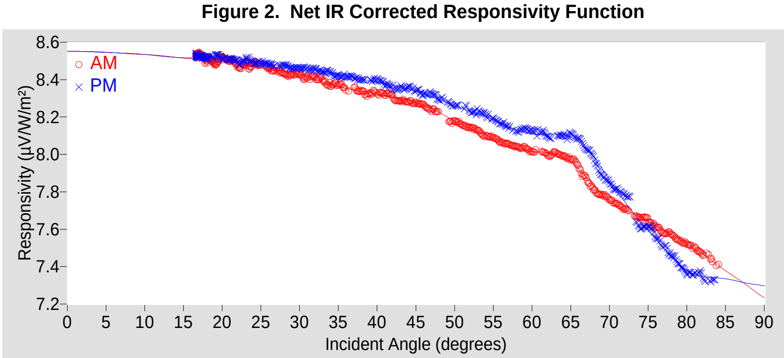


Figure 2. Net IR Corrected Responsivity Function



$$RS\,(am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\,(pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.76	±1.76
R²	0.9999993	0.9999982
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.75	±1.75
Net IR corrected R²	0.9999994	0.9999986
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

	Responsivity						Net IR Corr. Responsivity					
Inc.	AM		PM		Combined		AM		PM		Combined	
Angle	RS (μV/W/m²)	U95 (%)	RS (μV/W/m²)	U95 (%)	RS (μV/W/m²)	U95 (%)	RSc (μV/W/m²)	U95 (%)	RSc (μV/W/m²)	U95 (%)	RSc (μV/W/m²)	U95 (%)
0-9	8.4511	*	8.4512	*	8.4511	*	8.5463	*	8.5465	*	8.5464	*
9-18	8.4226	*	8.4233	*	8.4229	*	8.5227	*	8.5235	*	8.5231	*
18-27	8.3795	±1.80	8.3865	±1.79	8.3830	±1.86	8.4859	±1.78	8.4984	±1.76	8.4921	±1.83
27-36	8.2918	±1.88	8.3317	±1.81	8.3117	±2.10	8.4087	±1.83	8.4560	±1.78	8.4323	±2.04
36-45	8.1863	±1.84	8.2441	±1.84	8.2152	±2.16	8.3197	±1.79	8.3842	±1.80	8.3519	±2.09
45-54	8.0653	±1.98	8.1081	±2.02	8.0867	±2.49	8.1972	±2.01	8.2734	±1.91	8.2353	±2.61
54-63	7.8994	±1.95	7.9342	±1.99	7.9168	±2.36	8.0418	±1.85	8.1389	±1.84	8.0904	±2.45
63-72	7.6731	±2.92	7.6988	±3.41	7.6859	±4.56	7.8649	±2.54	7.9893	±2.72	7.9271	±3.93
72-81	7.2881	±3.37	6.9941	±6.06	7.1411	±9.43	7.6109	±2.16	7.5408	±3.06	7.5759	±3.96
81-90	6.4047	*	5.9570	*	6.1808	*	7.3652	*	7.3276	*	7.3464	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

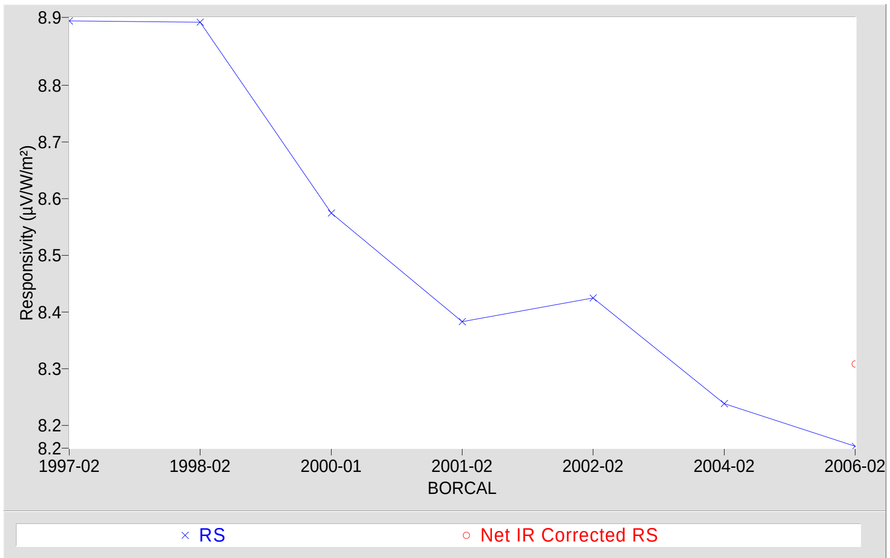
Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.1635	+2.75 / -4.14
45° - 55°	8.0728	±2.28
Composite	8.1906	+3.23 / -25.15
45° (Net IR Corr.)	8.3083	+2.52 / -4.15
45° - 55° (Net IR Corr.)	8.2223	±2.32
Composite (Net IR Corr.)	8.3407	+2.73 / -12.13

† Valid incident angle ranges:

45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



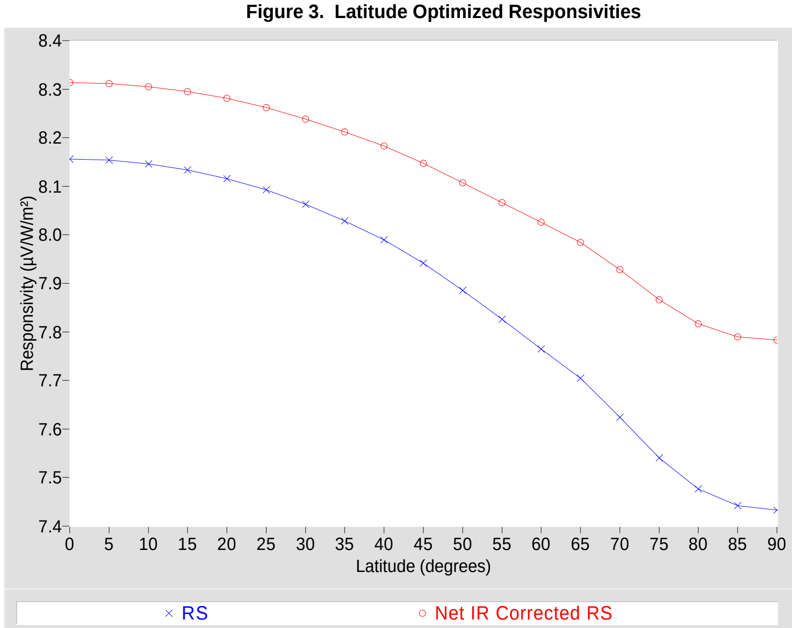
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.1562	+4.10 / -32.27	8.3134	+3.36 / -12.77
5	8.1540	+4.13 / -32.25	8.3116	+3.38 / -12.75
10	8.1462	+4.22 / -32.19	8.3053	+3.45 / -12.69
15	8.1336	+4.36 / -32.08	8.2951	+3.56 / -12.58
20	8.1159	+4.57 / -31.94	8.2810	+3.71 / -12.43
25	8.0923	+4.85 / -31.74	8.2620	+3.92 / -12.23
30	8.0631	+5.09 / -31.49	8.2386	+4.09 / -11.99
35	8.0286	+5.34 / -31.20	8.2119	+4.27 / -11.70
40	7.9896	+5.59 / -30.86	8.1830	+4.43 / -11.39
45	7.9416	+5.98 / -30.44	8.1474	+4.73 / -11.01
50	7.8857	+6.33 / -29.95	8.1070	+4.95 / -10.57
55	7.8258	+6.76 / -29.42	8.0659	+5.20 / -10.12
60	7.7649	+6.95 / -28.86	8.0261	+5.21 / -9.68
65	7.7045	+7.14 / -28.31	7.9844	+5.24 / -9.22
70	7.6240	+7.40 / -27.55	7.9282	+5.29 / -8.59
75	7.5403	+7.29 / -26.75	7.8664	+5.13 / -7.88
80	7.4763	+6.90 / -26.12	7.8167	+4.81 / -7.31
85	7.4422	+6.23 / -25.78	7.7898	+4.44 / -7.00
90	7.4327	+5.18 / -25.69	7.7833	+4.07 / -6.93

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

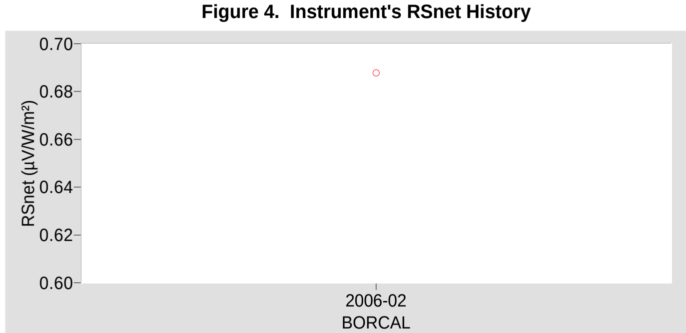
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30666F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30666F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

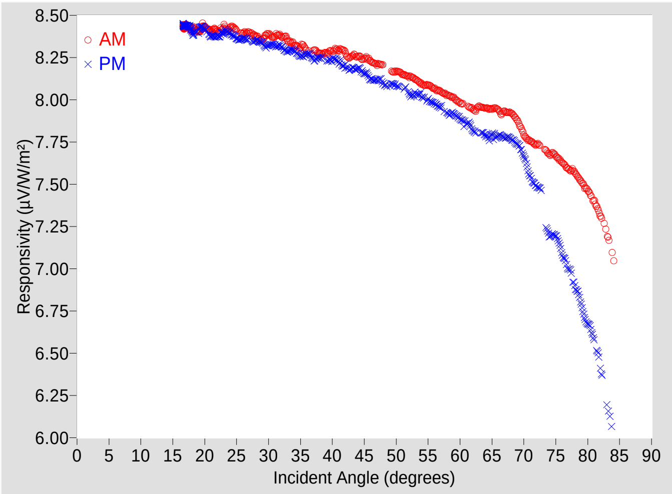


Figure 2. Responsivity vs Local Standard Time

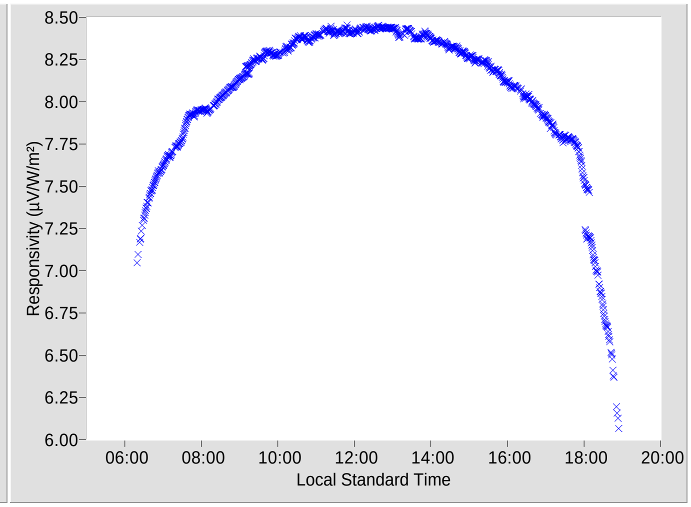


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2008	+2.87 / -4.31	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2310	0.62	97.18	8.1204	0.62	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2058	N/A	95.64	8.0945	0.63	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1680	0.62	101.80	8.0841	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1385	0.65	100.06	8.0321	0.69	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0947	0.68	98.26	8.0233	0.68	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0659	0.70	96.58	7.9775	0.70	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0286	0.71	94.94	7.9176	0.72	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9834	0.75	93.40	7.8876	0.81	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9470	0.78	91.83	7.8168	0.80	274.97
18	8.4179	0.53	155.25	8.4036	0.59	204.58	64	7.9516	0.80	90.31	7.7883	0.79	276.39
20	8.4312	0.55	142.58	8.4194	0.59	217.20	66	7.9403	0.88	88.85	7.7877	0.81	277.75
22	8.4051	0.51	134.49	8.3756	0.51	225.32	68	7.9219	0.96	87.37	7.7654	0.87	279.13
24	8.4255	0.53	128.48	8.3906	0.58	231.49	70	7.7963	1.21	85.91	7.6624	1.50	280.49
26	8.3956	0.48	123.46	8.3607	0.48	236.46	72	7.7364	1.08	84.47	7.4855	1.14	281.90
28	8.3788	0.55	119.32	8.3495	0.49	240.56	74	7.6776	1.21	83.02	7.2007	1.42	278.95
30	8.3885	0.52	115.72	8.3234	0.52	244.17	76	7.6317	1.45	81.64	7.0845	2.08	280.41
32	8.3754	0.54	112.58	8.3153	0.57	247.32	78	7.5678	1.68	80.16	6.8931	2.36	281.83
34	8.3288	0.56	109.88	8.2917	0.57	250.09	80	7.4654	2.11	78.72	6.6753	2.57	283.26
36	8.2940	0.55	107.27	8.2707	0.55	252.60	82	7.3134	2.81	77.24	6.4083	3.73	284.76
38	8.2756	0.52	104.92	8.2478	0.53	254.93	84	7.0724	3.68	75.78	6.0665	N/A	286.03
40	8.2876	0.55	102.80	8.2400	0.54	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2810	0.62	100.85	8.1962	0.65	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2565	0.56	98.90	8.1852	0.58	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

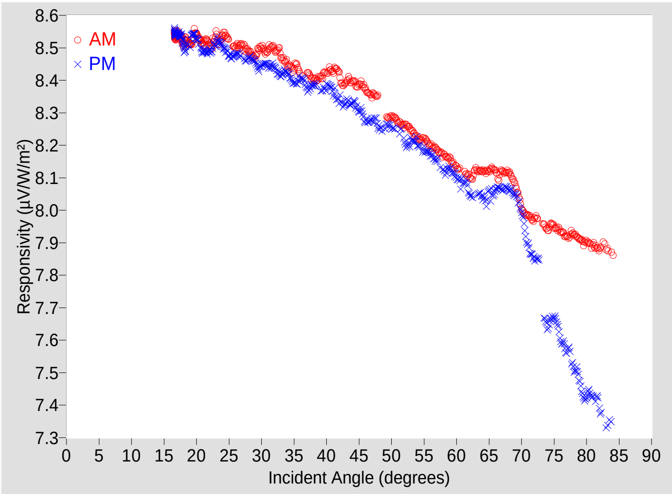

Figure 4. Responsivity vs Local Standard Time

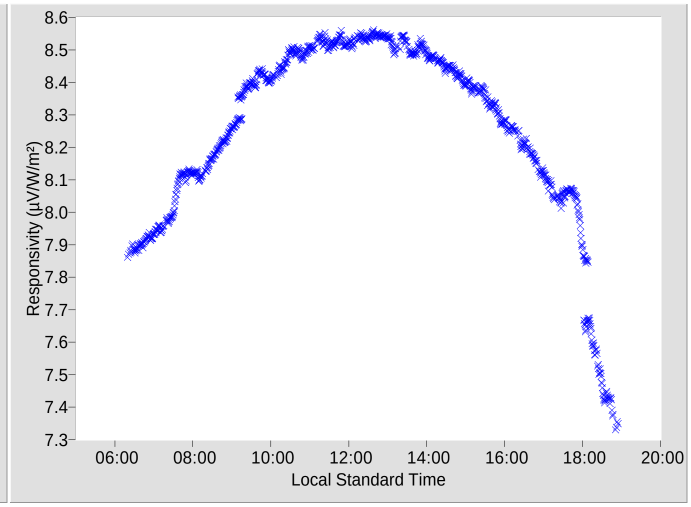

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3465	+2.54 / -3.50	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.69195 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3746	0.67	97.18	8.2755	0.67	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3504	N/A	95.64	8.2563	0.67	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2882	0.66	101.80	8.2551	0.65	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2624	0.68	100.06	8.2064	0.75	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2236	0.71	98.26	8.2058	0.74	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2007	0.74	96.58	8.1714	0.76	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1705	0.75	94.94	8.1200	0.79	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1322	0.79	93.40	8.1016	0.85	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1055	0.83	91.83	8.0486	0.88	274.97
18	8.5200	0.57	155.25	8.5077	0.62	204.58	64	8.1214	0.85	90.31	8.0403	0.90	276.39
20	8.5394	0.57	142.58	8.5287	0.62	217.20	66	8.1209	0.94	88.85	8.0627	0.95	277.75
22	8.5091	0.54	134.49	8.4897	0.55	225.32	68	8.1183	0.99	87.37	8.0626	0.99	279.13
24	8.5353	0.56	128.48	8.5050	0.63	231.49	70	8.0112	1.20	85.91	7.9919	1.44	280.49
26	8.5052	0.51	123.46	8.4786	0.53	236.46	72	7.9755	1.16	84.47	7.8513	1.24	281.90
28	8.4915	0.57	119.32	8.4686	0.53	240.56	74	7.9422	1.29	83.02	7.6455	1.63	278.95
30	8.5021	0.55	115.72	8.4463	0.56	244.17	76	7.9376	1.49	81.64	7.6010	1.97	280.41
32	8.4950	0.57	112.58	8.4407	0.59	247.32	78	7.9269	1.75	80.16	7.5142	2.28	281.83
34	8.4508	0.59	109.88	8.4223	0.60	250.09	80	7.9030	2.13	78.72	7.4262	2.62	283.26
36	8.4215	0.59	107.27	8.4049	0.60	252.60	82	7.8815	2.77	77.24	7.3909	3.43	284.76
38	8.4051	0.57	104.92	8.3848	0.59	254.93	84	7.8662	3.83	75.78	7.3494	N/A	286.03
40	8.4226	0.60	102.80	8.3813	0.59	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4167	0.66	100.85	8.3398	0.69	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3967	0.61	98.90	8.3308	0.63	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

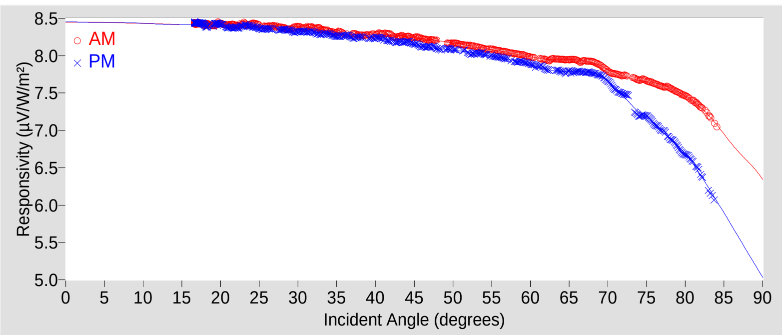
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

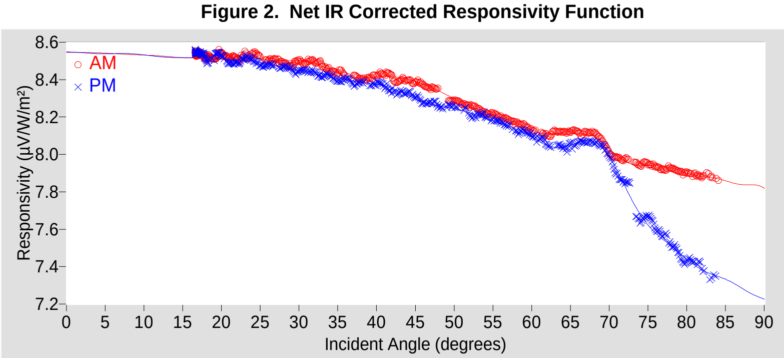


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.74	±1.74
R²	0.9999993	0.9999982
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.7°
Net IR corr. uncert. U95 (%)	±1.72	±1.72
Net IR corrected R²	0.9999993	0.9999986
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.7°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.4454	*	8.4455	*	8.4455	*	8.5413	*	8.5414	*	8.5413	*
9-18	8.4226	*	8.4219	*	8.4222	*	8.5233	*	8.5227	*	8.5230	*
18-27	8.4141	±1.75	8.3893	±1.76	8.4017	±1.83	8.5211	±1.73	8.5018	±1.73	8.5115	±1.78
27-36	8.3640	±1.81	8.3171	±1.80	8.3405	±1.99	8.4815	±1.77	8.4421	±1.76	8.4618	±1.89
36-45	8.2782	±1.75	8.2243	±1.86	8.2512	±2.13	8.4124	±1.72	8.3652	±1.81	8.3888	±2.01
45-54	8.1803	±1.93	8.0831	±1.91	8.1317	±2.62	8.3130	±1.96	8.2493	±1.81	8.2811	±2.37
54-63	8.0203	±1.97	7.9178	±2.16	7.9691	±3.14	8.1636	±1.86	8.1237	±1.96	8.1437	±2.35
63-72	7.8920	±2.16	7.7336	±2.51	7.8128	±4.50	8.0850	±1.95	8.0258	±2.12	8.0554	±2.96
72-81	7.6079	±2.62	7.0428	±6.22	7.3254	±11.20	7.9327	±1.78	7.5921	±3.19	7.7624	±5.36
81-90	6.8895	*	5.8057	*	6.3476	*	7.8556	*	7.3164	*	7.5860	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

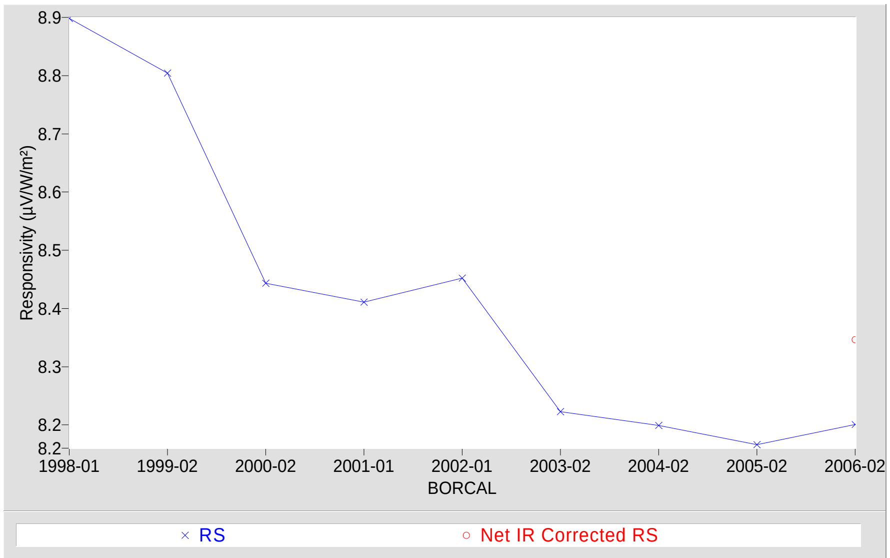
Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.2008	+2.87 / -4.31
45° - 55°	8.1195	±2.34
Composite	8.2257	+2.99 / -26.29
45° (Net IR Corr.)	8.3465	+2.54 / -3.50
45° - 55° (Net IR Corr.)	8.2700	±2.14
Composite (Net IR Corr.)	8.3772	+2.52 / -12.40

† Valid incident angle ranges:

45°:	30.0° to 60.0°,	30.0° to 60.0° (Net IR corr.)
45° - 55°:	45.0° to 55.0°,	45.0° to 55.0° (Net IR corr.)
Composite:	16.6° to 83.7°,	16.6° to 83.7° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



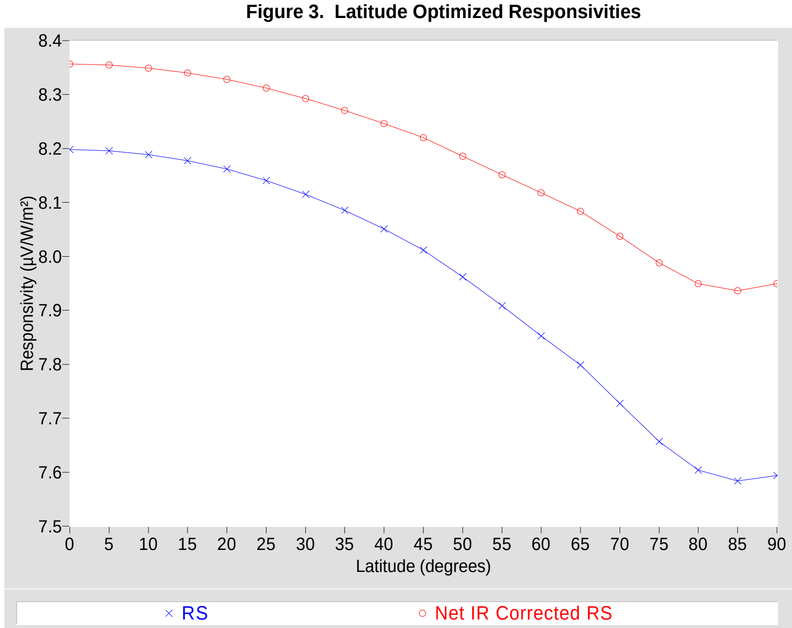
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.1981	+3.56 / -36.55	8.3567	+2.86 / -13.44
5	8.1957	+3.59 / -36.53	8.3547	+2.88 / -13.42
10	8.1886	+3.67 / -36.47	8.3492	+2.94 / -13.36
15	8.1771	+3.79 / -36.38	8.3402	+3.03 / -13.27
20	8.1617	+3.97 / -36.26	8.3283	+3.15 / -13.15
25	8.1407	+4.20 / -36.10	8.3120	+3.31 / -12.98
30	8.1153	+4.40 / -35.90	8.2925	+3.44 / -12.77
35	8.0851	+4.61 / -35.66	8.2703	+3.60 / -12.54
40	8.0508	+4.97 / -35.39	8.2462	+3.87 / -12.29
45	8.0118	+5.45 / -35.07	8.2199	+4.17 / -12.01
50	7.9621	+5.69 / -34.67	8.1859	+4.25 / -11.65
55	7.9084	+6.23 / -34.22	8.1515	+4.58 / -11.28
60	7.8529	+5.88 / -33.76	8.1180	+4.12 / -10.92
65	7.7987	+6.45 / -33.30	8.0834	+4.47 / -10.54
70	7.7274	+6.76 / -32.68	8.0371	+4.55 / -10.03
75	7.6569	+6.71 / -32.06	7.9881	+4.00 / -9.49
80	7.6040	+6.31 / -31.59	7.9494	+3.60 / -9.05
85	7.5836	+5.31 / -31.41	7.9362	+2.97 / -8.90
90	7.5936	+4.96 / -31.50	7.9492	+2.83 / -9.05

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

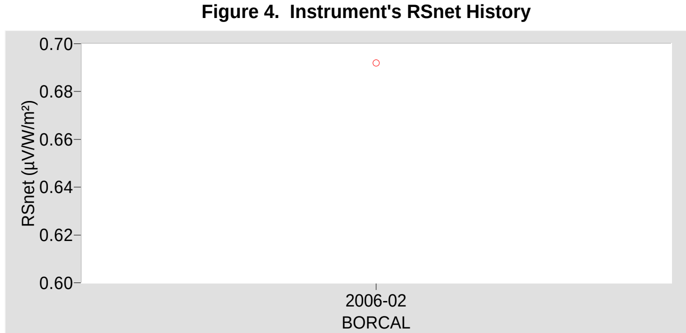
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30709F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30709F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

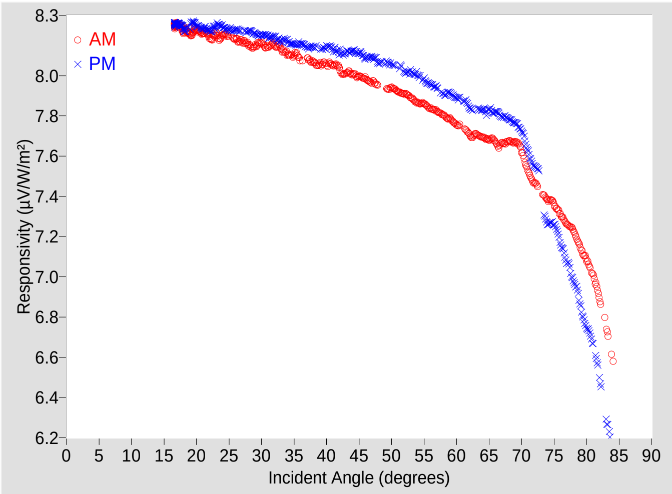


Figure 2. Responsivity vs Local Standard Time

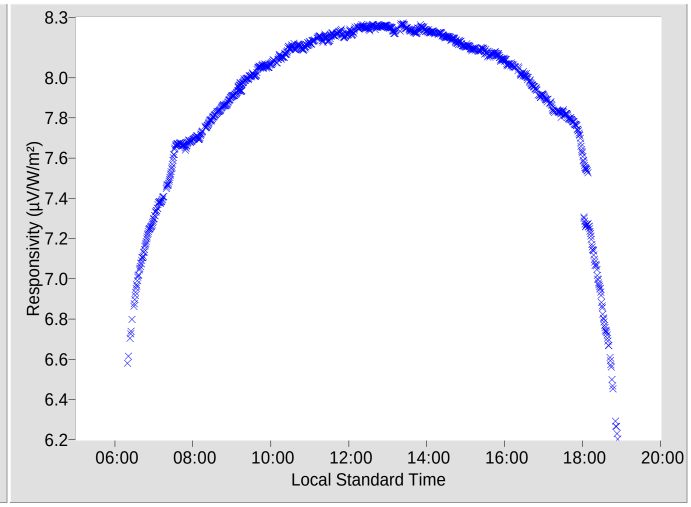


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0550	+2.40 / -4.17	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9860	0.58	97.18	8.0888	0.60	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9584	N/A	95.64	8.0637	0.59	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9395	0.62	101.80	8.0557	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9104	0.65	100.06	8.0153	0.65	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8665	0.67	98.26	8.0033	0.65	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8363	0.70	96.58	7.9561	0.68	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8035	0.73	94.94	7.9065	0.67	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7576	0.75	93.40	7.8880	0.70	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7079	0.80	91.83	7.8396	0.77	274.97
18	8.2258	0.58	155.25	8.2347	0.53	204.58	64	7.6947	0.81	90.31	7.8302	0.76	276.39
20	8.2276	0.53	142.58	8.2485	0.53	217.20	66	7.6713	0.91	88.85	7.8192	0.82	277.75
22	8.1932	0.55	134.49	8.2253	0.50	225.32	68	7.6747	0.91	87.37	7.7840	0.85	279.13
24	8.1973	0.53	128.48	8.2436	0.52	231.49	70	7.6271	1.34	85.91	7.7248	1.23	280.49
26	8.1837	0.49	123.46	8.2262	0.49	236.46	72	7.4665	1.18	84.47	7.5479	1.18	281.90
28	8.1561	0.53	119.32	8.2213	0.49	240.56	74	7.3831	1.23	83.02	7.2675	1.41	278.95
30	8.1626	0.51	115.72	8.2031	0.49	244.17	76	7.3116	1.52	81.64	7.1624	2.06	280.41
32	8.1507	0.53	112.58	8.1920	0.51	247.32	78	7.2272	1.76	80.16	6.9769	2.33	281.83
34	8.1090	0.53	109.88	8.1717	0.53	250.09	80	7.0882	2.20	78.72	6.7495	2.55	283.26
36	8.0797	0.56	107.27	8.1590	0.53	252.60	82	6.8884	3.03	77.24	6.4952	3.68	284.76
38	8.0675	0.55	104.92	8.1413	0.52	254.93	84	6.5982	3.81	75.78	N/A	N/A	N/A
40	8.0517	0.53	102.80	8.1410	0.53	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0359	0.61	100.85	8.1151	0.58	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0088	0.57	98.90	8.1239	0.55	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results
30709F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

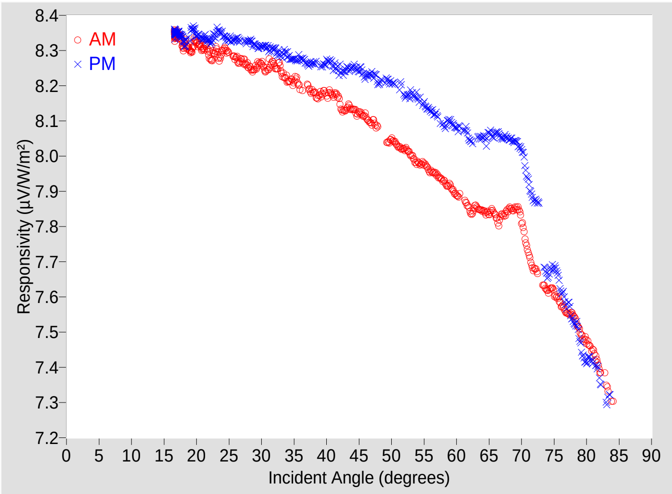


Figure 4. Responsivity vs Local Standard Time

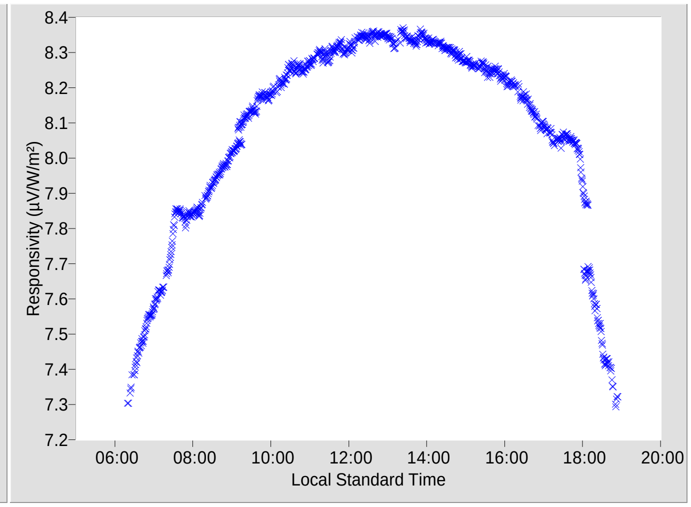


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1845	+2.18 / -4.16	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.61495 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc.	AM			PM			Inc.	AM			PM		
Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1136	0.64	97.18	8.2266	0.65	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0869	N/A	95.64	8.2075	0.65	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0464	0.66	101.80	8.2077	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0205	0.69	100.06	8.1702	0.72	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9811	0.71	98.26	8.1655	0.72	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9561	0.74	96.58	8.1284	0.74	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9295	0.76	94.94	8.0864	0.75	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8898	0.79	93.40	8.0782	0.79	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8487	0.84	91.83	8.0456	0.85	274.97
18	8.3166	0.61	155.25	8.3272	0.56	204.58	64	7.8455	0.87	90.31	8.0541	0.89	276.39
20	8.3237	0.56	142.58	8.3457	0.57	217.20	66	7.8318	0.96	88.85	8.0636	0.93	277.75
22	8.2856	0.58	134.49	8.3267	0.54	225.32	68	7.8492	0.99	87.37	8.0482	0.99	279.13
24	8.2949	0.56	128.48	8.3453	0.57	231.49	70	7.8181	1.32	85.91	8.0176	1.25	280.49
26	8.2810	0.52	123.46	8.3310	0.53	236.46	72	7.6790	1.23	84.47	7.8730	1.26	281.90
28	8.2563	0.56	119.32	8.3271	0.53	240.56	74	7.6183	1.31	83.02	7.6628	1.62	278.95
30	8.2636	0.55	115.72	8.3123	0.53	244.17	76	7.5834	1.54	81.64	7.6214	1.99	280.41
32	8.2569	0.56	112.58	8.3035	0.56	247.32	78	7.5464	1.80	80.16	7.5288	2.28	281.83
34	8.2174	0.57	109.88	8.2878	0.57	250.09	80	7.4772	2.19	78.72	7.4168	2.63	283.26
36	8.1930	0.60	107.27	8.2783	0.58	252.60	82	7.3933	2.87	77.24	7.3685	3.44	284.76
38	8.1826	0.60	104.92	8.2631	0.57	254.93	84	7.3037	3.96	75.78	N/A	N/A	N/A
40	8.1717	0.58	102.80	8.2665	0.59	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1564	0.66	100.85	8.2427	0.63	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1334	0.62	98.90	8.2533	0.60	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30709F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

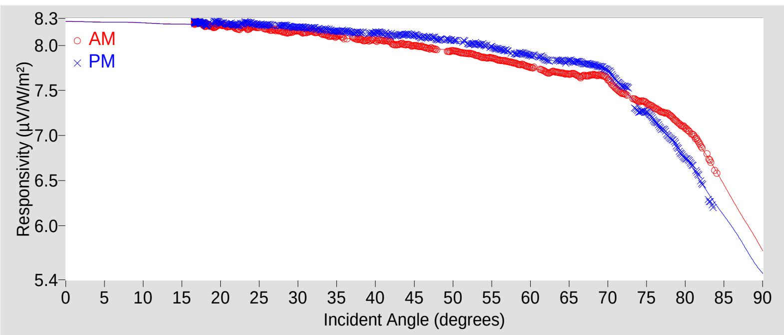
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

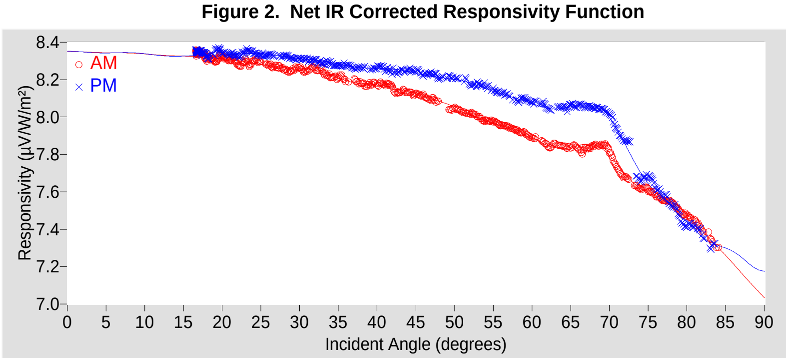


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.78	±1.78
R^2	0.9999993	0.9999980
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.76	±1.76
Net IR corrected R^2	0.9999993	0.9999982
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.2603	*	8.2602	*	8.2603	*	8.3455	*	8.3454	*	8.3454	*
9-18	8.2399	*	8.2407	*	8.2403	*	8.3294	*	8.3303	*	8.3299	*
18-27	8.2028	±1.81	8.2358	±1.78	8.2193	±1.87	8.2979	±1.78	8.3358	±1.76	8.3168	±1.86
27-36	8.1423	±1.85	8.1949	±1.82	8.1686	±2.14	8.2468	±1.80	8.3060	±1.78	8.2764	±2.08
36-45	8.0469	±1.84	8.1336	±1.80	8.0902	±2.24	8.1661	±1.80	8.2588	±1.77	8.2125	±2.17
45-54	7.9434	±1.92	8.0550	±1.88	7.9992	±2.67	8.0613	±1.94	8.2027	±1.81	8.1320	±2.79
54-63	7.7910	±2.08	7.9132	±2.03	7.8521	±3.18	7.9184	±1.96	8.0961	±1.88	8.0072	±3.28
63-72	7.6514	±2.10	7.7718	±2.40	7.7116	±3.43	7.8229	±1.95	8.0315	±2.07	7.9272	±3.62
72-81	7.2873	±3.50	7.1176	±6.08	7.2025	±8.50	7.5759	±2.36	7.6064	±3.38	7.5912	±4.54
81-90	6.3768	*	6.0449	*	6.2109	*	7.2355	*	7.2809	*	7.2582	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

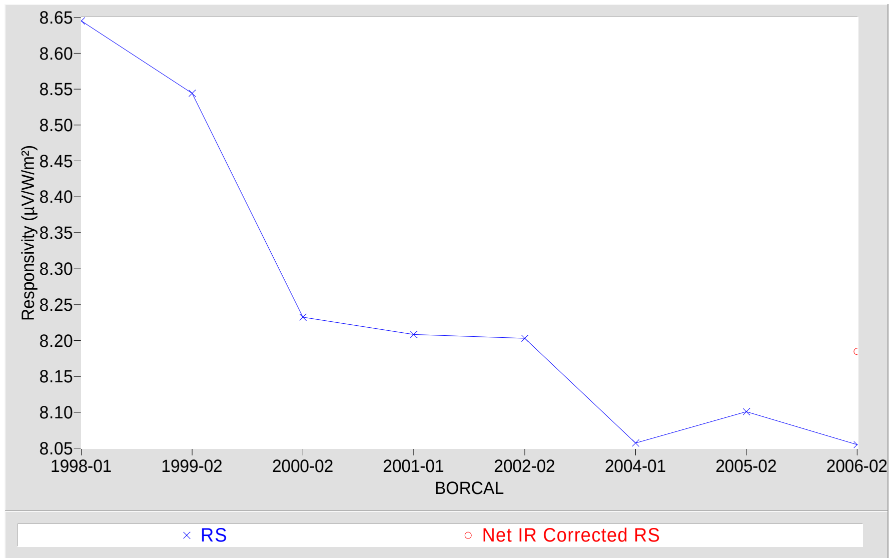
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.0550	+2.40 / -4.17
45° - 55°	7.9880	±2.37
Composite	8.0648	+2.78 / -22.82
45° (Net IR Corr.)	8.1845	+2.18 / -4.16
45° - 55° (Net IR Corr.)	8.1217	±2.41
Composite (Net IR Corr.)	8.1991	+2.46 / -11.07

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



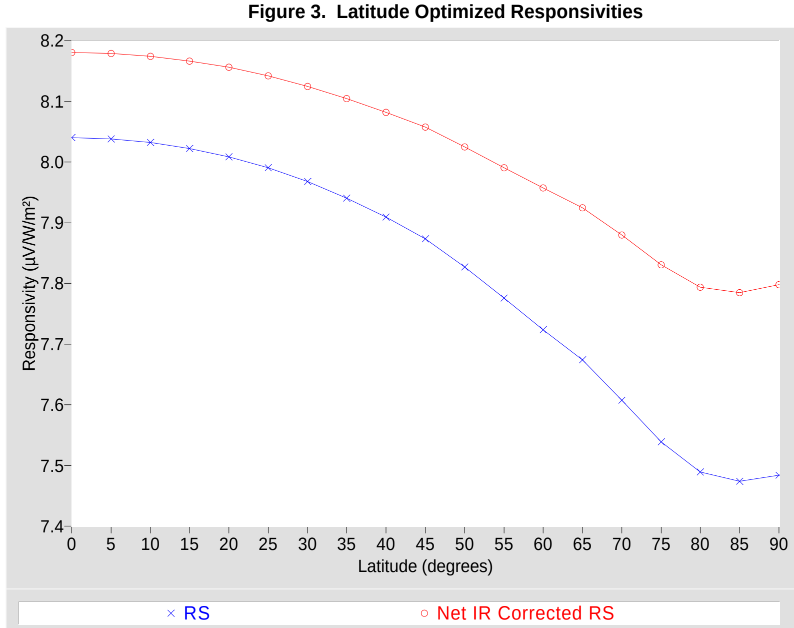
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.0401	+3.33 / -30.62	8.1807	+2.73 / -13.59
5	8.0382	+3.36 / -30.60	8.1791	+2.74 / -13.57
10	8.0321	+3.42 / -30.55	8.1743	+2.79 / -13.52
15	8.0220	+3.53 / -30.46	8.1665	+2.87 / -13.44
20	8.0085	+3.69 / -30.34	8.1561	+2.97 / -13.33
25	7.9903	+3.88 / -30.18	8.1420	+3.10 / -13.18
30	7.9678	+4.05 / -29.99	8.1247	+3.22 / -13.00
35	7.9404	+4.23 / -29.75	8.1044	+3.40 / -12.78
40	7.9091	+4.51 / -29.47	8.0820	+3.65 / -12.54
45	7.8734	+4.95 / -29.15	8.0575	+3.93 / -12.28
50	7.8271	+5.46 / -28.73	8.0250	+4.25 / -11.93
55	7.7759	+5.70 / -28.26	7.9907	+4.34 / -11.55
60	7.7236	+5.88 / -27.78	7.9573	+4.36 / -11.19
65	7.6740	+6.24 / -27.31	7.9245	+4.58 / -10.82
70	7.6072	+6.58 / -26.67	7.8796	+4.73 / -10.32
75	7.5386	+6.88 / -26.01	7.8305	+4.96 / -9.77
80	7.4891	+6.45 / -25.52	7.7937	+4.60 / -9.35
85	7.4737	+5.49 / -25.36	7.7848	+4.10 / -9.24
90	7.4840	+4.83 / -25.47	7.7977	+3.94 / -9.39

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

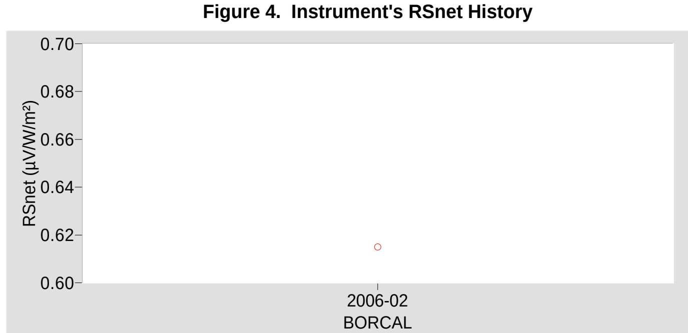
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 30775F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: SGP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

30775F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

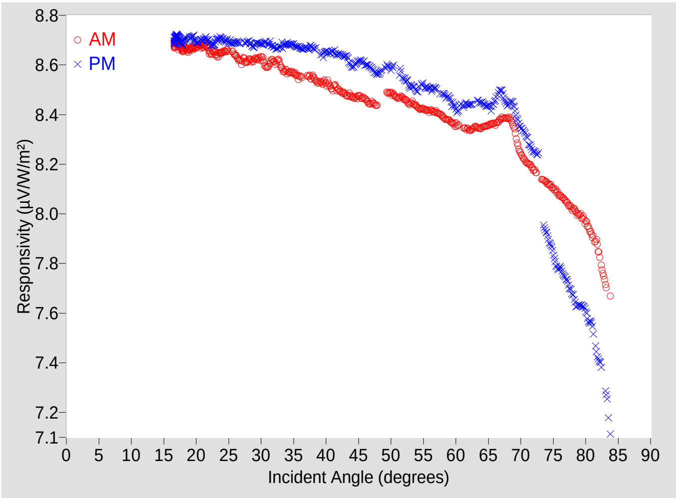


Figure 2. Responsivity vs Local Standard Time

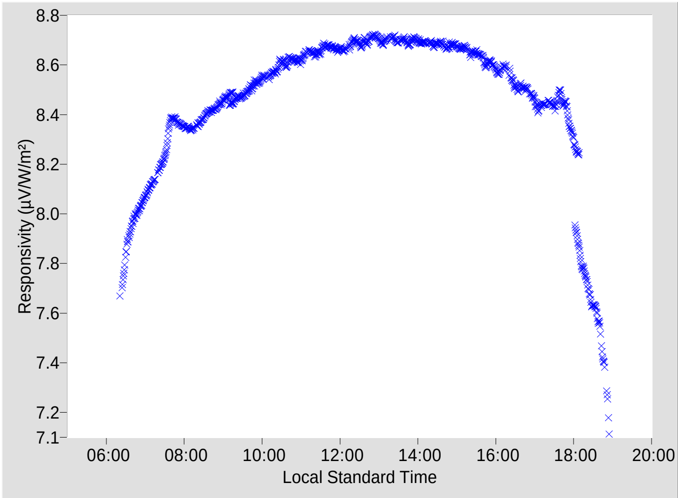


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5441	+2.30 / -2.67	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4634	0.57	97.11	8.6049	0.58	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4363	N/A	95.68	8.5643	0.58	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4863	0.62	101.84	8.5889	0.59	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4631	0.66	99.98	8.5450	0.75	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4341	0.67	98.30	8.4992	0.63	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4162	0.67	96.56	8.5046	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3927	0.70	94.97	8.4840	0.66	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3594	0.73	93.33	8.4224	0.74	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3400	0.75	91.82	8.4402	0.69	274.95
18	8.6625	0.54	155.40	8.6947	0.53	204.72	64	8.3472	0.79	90.34	8.4479	0.73	276.38
20	8.6729	0.47	142.70	8.6945	0.50	217.13	66	8.3639	0.85	88.84	8.4556	0.91	277.74
22	8.6572	0.54	134.59	8.6934	0.52	225.42	68	8.3853	0.93	87.35	8.4402	0.89	279.12
24	8.6520	0.50	128.29	8.7041	0.49	231.57	70	8.2459	1.29	85.95	8.3458	1.14	280.52
26	8.6404	0.56	123.42	8.6916	0.48	236.55	72	8.1769	1.09	84.45	8.2505	1.04	281.89
28	8.6170	0.49	119.28	8.6925	0.50	240.63	74	8.1263	1.19	83.05	7.9187	1.50	278.98
30	8.6265	0.54	115.78	8.6854	0.49	244.13	76	8.0737	1.41	81.57	7.7821	1.64	280.39
32	8.6138	0.51	112.64	8.6716	0.52	247.28	78	8.0222	1.62	80.19	7.6754	1.91	281.81
34	8.5735	0.50	109.77	8.6847	0.52	250.14	80	7.9667	2.01	78.70	7.6055	2.16	283.29
36	8.5509	0.52	107.27	8.6687	0.52	252.65	82	7.8495	2.75	77.27	7.4100	2.89	284.76
38	8.5502	0.53	104.97	8.6676	0.52	254.97	84	7.6689	N/A	75.91	7.1132	N/A	286.07
40	8.5303	0.55	102.80	8.6523	0.54	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4994	0.55	100.83	8.6421	0.55	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4723	0.54	98.94	8.5936	0.61	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

30775F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

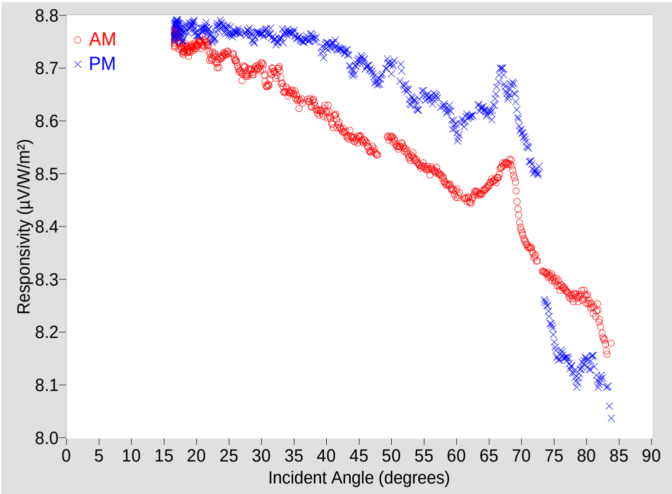


Figure 4. Responsivity vs Local Standard Time

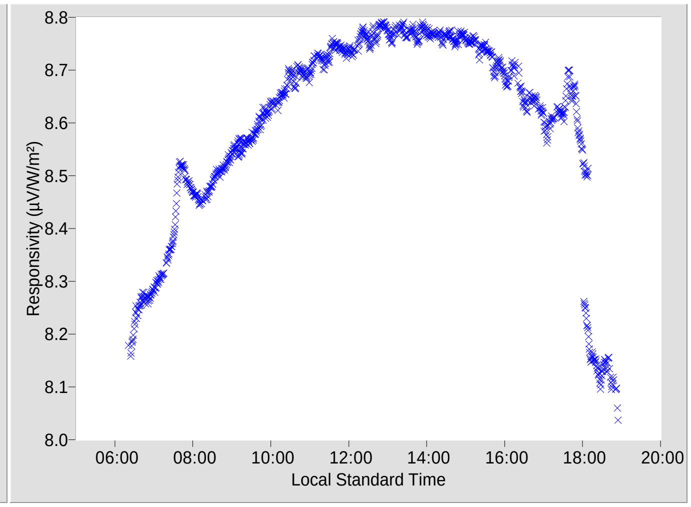


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6418	+2.11 / -2.66	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.60686 µV/W/m², determination date: 06/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc.	AM			PM			Inc.	AM			PM		
Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5598	0.59	97.11	8.7075	0.60	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5359	N/A	95.68	8.6719	0.61	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5679	0.64	101.84	8.7019	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5460	0.67	99.98	8.6660	0.77	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5221	0.68	98.30	8.6269	0.68	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5076	0.69	96.56	8.6418	0.67	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4900	0.72	94.97	8.6295	0.70	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4617	0.75	93.33	8.5774	0.79	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4495	0.79	91.82	8.6075	0.76	274.95
18	8.7352	0.56	155.40	8.7656	0.54	204.72	64	8.4646	0.83	90.34	8.6241	0.80	276.38
20	8.7433	0.49	142.70	8.7667	0.51	217.13	66	8.4879	0.90	88.84	8.6468	1.01	277.74
22	8.7302	0.56	134.59	8.7666	0.54	225.42	68	8.5207	0.95	87.35	8.6497	0.96	279.12
24	8.7237	0.52	128.29	8.7792	0.51	231.57	70	8.3942	1.25	85.95	8.5778	1.15	280.52
26	8.7145	0.57	123.42	8.7689	0.51	236.55	72	8.3430	1.12	84.45	8.5046	1.12	281.89
28	8.6916	0.51	119.28	8.7703	0.52	240.63	74	8.3095	1.23	83.05	8.2448	1.56	278.98
30	8.7030	0.56	115.78	8.7648	0.51	244.13	76	8.2857	1.44	81.57	8.1584	1.71	280.39
32	8.6918	0.54	112.64	8.7536	0.54	247.28	78	8.2672	1.67	80.19	8.1243	2.02	281.81
34	8.6564	0.52	109.77	8.7690	0.54	250.14	80	8.2640	2.04	78.70	8.1465	2.37	283.29
36	8.6357	0.56	107.27	8.7539	0.54	252.65	82	8.2238	2.65	77.27	8.1061	3.04	284.76
38	8.6340	0.55	104.97	8.7561	0.55	254.97	84	8.1789	N/A	75.91	8.0368	N/A	286.07
40	8.6199	0.58	102.80	8.7439	0.57	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5913	0.58	100.83	8.7360	0.58	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5678	0.57	98.94	8.6911	0.63	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30775F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

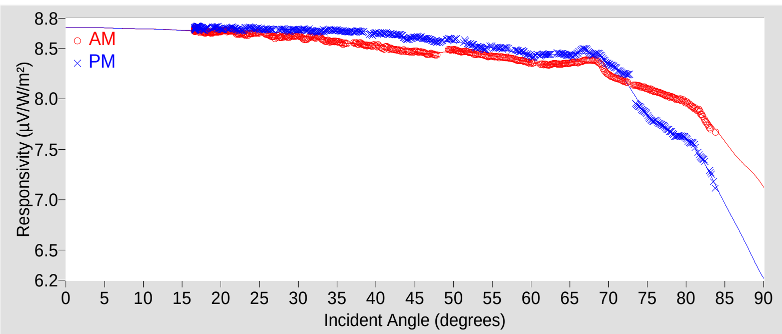
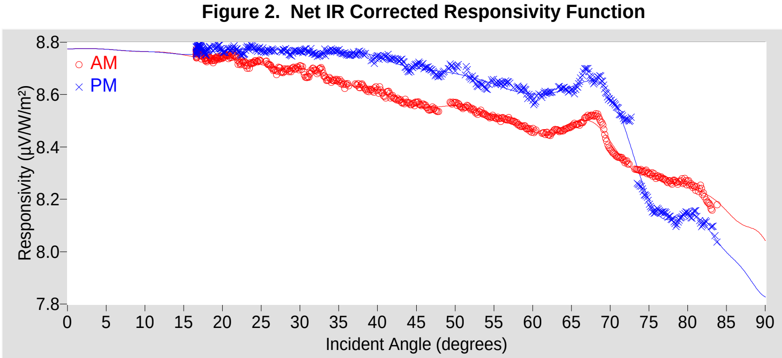


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.40	±1.40
R²	0.9999988	0.9999974
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.43	±1.43
Net IR corrected R²	0.9999990	0.9999980
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.7052	*	8.7051	*	8.7051	*	8.7725	*	8.7724	*	8.7724	*
9-18	8.6857	*	8.6884	*	8.6871	*	8.7562	*	8.7587	*	8.7574	*
18-27	8.6561	±1.42	8.6957	±1.40	8.6759	±1.52	8.7284	±1.44	8.7696	±1.43	8.7490	±1.54
27-36	8.6056	±1.46	8.6817	±1.40	8.6437	±1.81	8.6840	±1.47	8.7628	±1.43	8.7234	±1.79
36-45	8.5191	±1.50	8.6461	±1.46	8.5826	±2.26	8.6086	±1.50	8.7379	±1.47	8.6733	±2.19
45-54	8.4597	±1.41	8.5697	±1.46	8.5147	±1.91	8.5498	±1.44	8.6815	±1.45	8.6156	±2.00
54-63	8.3856	±1.52	8.4693	±1.48	8.4275	±2.08	8.4838	±1.50	8.6167	±1.46	8.5502	±2.20
63-72	8.3263	±1.75	8.4121	±1.83	8.3692	±2.66	8.4595	±1.66	8.6171	±1.67	8.5383	±2.88
72-81	8.0643	±2.06	7.8144	±4.26	7.9393	±5.86	8.2873	±1.54	8.2111	±2.52	8.2492	±3.33
81-90	7.5328	*	6.8869	*	7.2099	*	8.1464	*	7.9838	*	8.0651	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.5441	+2.30 / -2.67
45° - 55°	8.5090	±1.73
Composite	8.5691	+2.07 / -16.14
45° (Net IR Corr.)	8.6418	+2.11 / -2.66
45° - 55° (Net IR Corr.)	8.6110	±1.78
Composite (Net IR Corr.)	8.6729	+1.84 / -7.29

† Valid incident angle ranges:

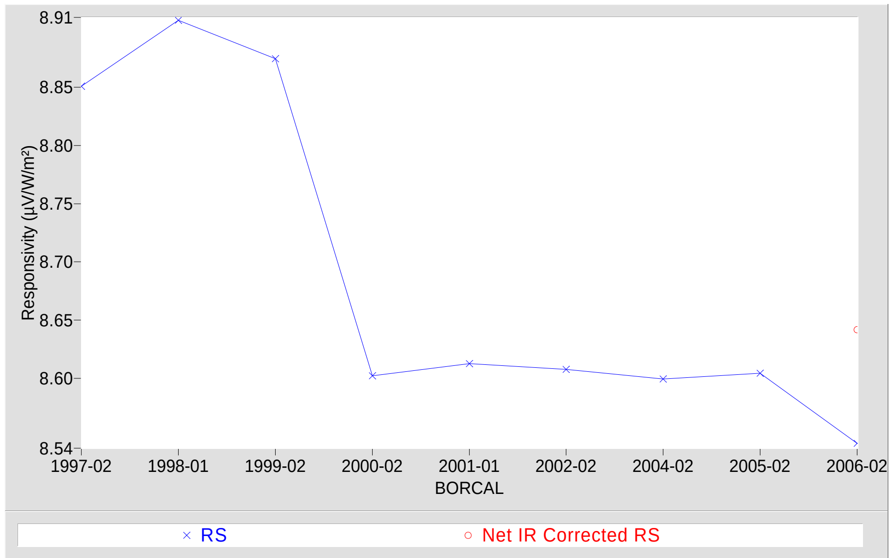
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



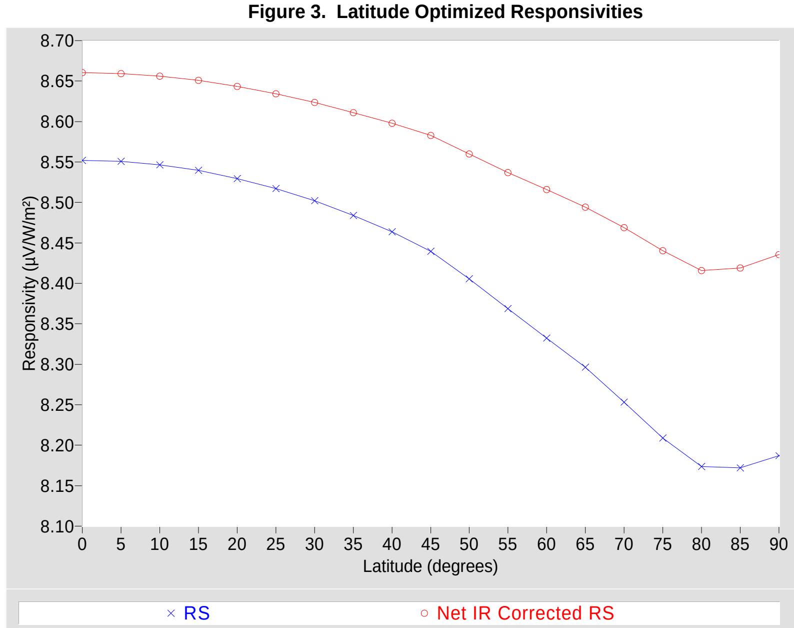
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5522	+2.31 / -25.67	8.6603	+1.95 / -9.41
5	8.5507	+2.32 / -25.65	8.6591	+1.96 / -9.40
10	8.5465	+2.36 / -25.62	8.6560	+1.99 / -9.36
15	8.5396	+2.43 / -25.56	8.6509	+2.03 / -9.31
20	8.5295	+2.53 / -25.47	8.6433	+2.09 / -9.23
25	8.5171	+2.65 / -25.36	8.6343	+2.17 / -9.14
30	8.5023	+2.75 / -25.23	8.6237	+2.24 / -9.03
35	8.4840	+2.90 / -25.07	8.6111	+2.36 / -8.90
40	8.4637	+3.12 / -24.89	8.5978	+2.49 / -8.76
45	8.4397	+3.38 / -24.68	8.5828	+2.64 / -8.60
50	8.4057	+3.70 / -24.37	8.5600	+2.85 / -8.36
55	8.3688	+3.99 / -24.04	8.5369	+3.00 / -8.12
60	8.3325	+4.35 / -23.71	8.5160	+3.22 / -7.89
65	8.2964	+4.38 / -23.38	8.4942	+3.16 / -7.66
70	8.2531	+4.37 / -22.98	8.4689	+3.04 / -7.39
75	8.2088	+4.46 / -22.56	8.4404	+3.12 / -7.08
80	8.1734	+4.15 / -22.23	8.4157	+3.15 / -6.82
85	8.1721	+3.68 / -22.21	8.4191	+3.11 / -6.85
90	8.1872	+3.50 / -22.36	8.4358	+2.93 / -7.03

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

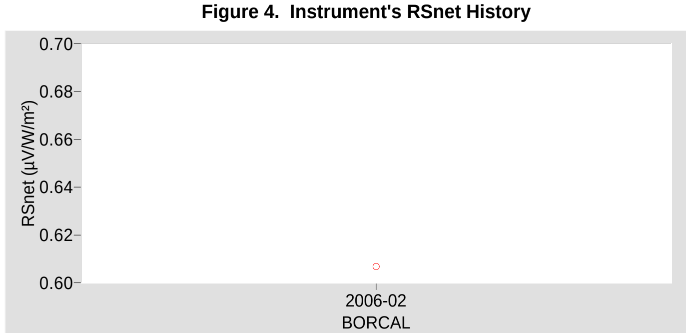
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30778F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30778F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

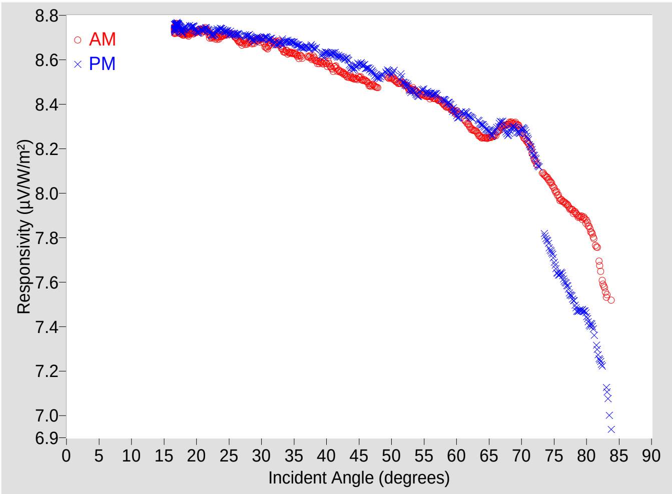


Figure 2. Responsivity vs Local Standard Time

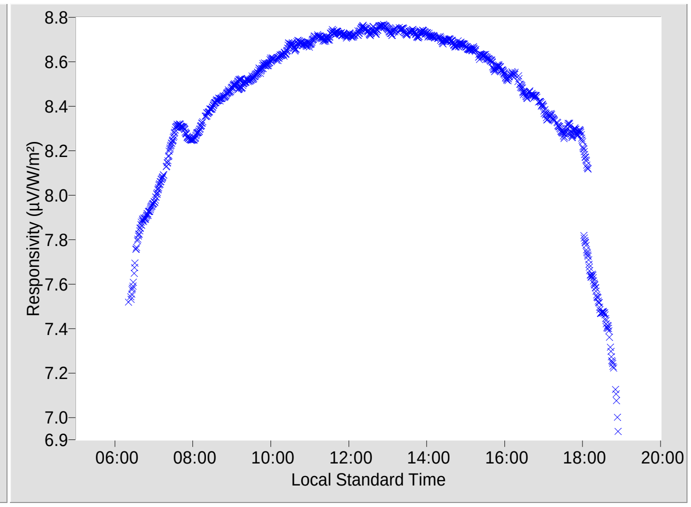


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5504	+2.32 / -2.74	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5059	0.59	97.11	8.5678	0.59	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4760	N/A	95.68	8.5198	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5182	0.62	101.84	8.5411	0.58	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4887	0.67	99.98	8.4945	0.76	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4541	0.67	98.30	8.4428	0.63	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4328	0.67	96.56	8.4468	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4025	0.72	94.97	8.4214	0.67	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3615	0.74	93.33	8.3504	0.75	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3006	0.81	91.82	8.3456	0.71	274.95
18	8.7185	0.54	155.40	8.7347	0.54	204.72	64	8.2506	0.81	90.34	8.3059	0.77	276.38
20	8.7276	0.47	142.70	8.7288	0.50	217.13	66	8.2645	0.89	88.84	8.2863	0.87	277.74
22	8.7139	0.55	134.59	8.7264	0.52	225.42	68	8.3122	0.90	87.35	8.2672	0.90	279.12
24	8.7096	0.50	128.29	8.7341	0.49	231.57	70	8.2764	1.12	85.95	8.2856	0.93	280.52
26	8.7011	0.55	123.42	8.7148	0.49	236.55	72	8.1501	1.21	84.45	8.1630	1.22	281.89
28	8.6777	0.49	119.28	8.7073	0.51	240.63	74	8.0681	1.24	83.05	7.7790	1.53	278.98
30	8.6889	0.55	115.78	8.6958	0.49	244.13	76	7.9697	1.45	81.57	7.6381	1.67	280.39
32	8.6774	0.50	112.64	8.6761	0.52	247.28	78	7.9190	1.63	80.19	7.5178	1.94	281.81
34	8.6350	0.50	109.77	8.6826	0.52	250.14	80	7.8697	2.02	78.70	7.4460	2.17	283.29
36	8.6137	0.52	107.27	8.6586	0.53	252.65	82	7.6722	3.01	77.22	7.2501	2.91	284.76
38	8.6068	0.54	104.97	8.6531	0.53	254.97	84	7.5187	N/A	75.91	6.9369	N/A	286.07
40	8.5854	0.56	102.80	8.6307	0.54	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5493	0.56	100.83	8.6141	0.56	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5188	0.54	98.94	8.5618	0.62	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

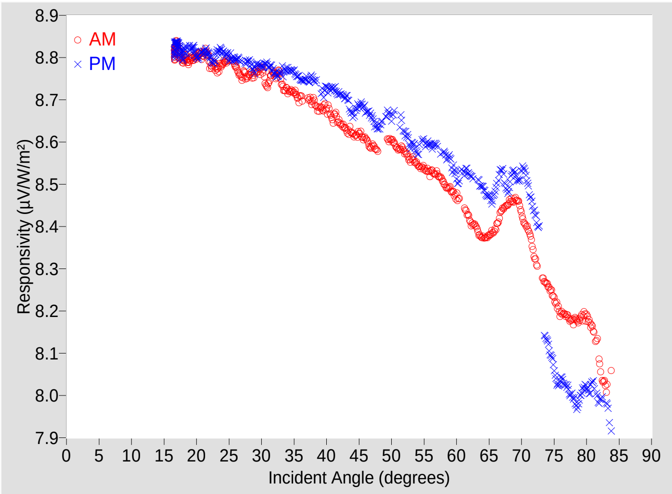


Figure 4. Responsivity vs Local Standard Time

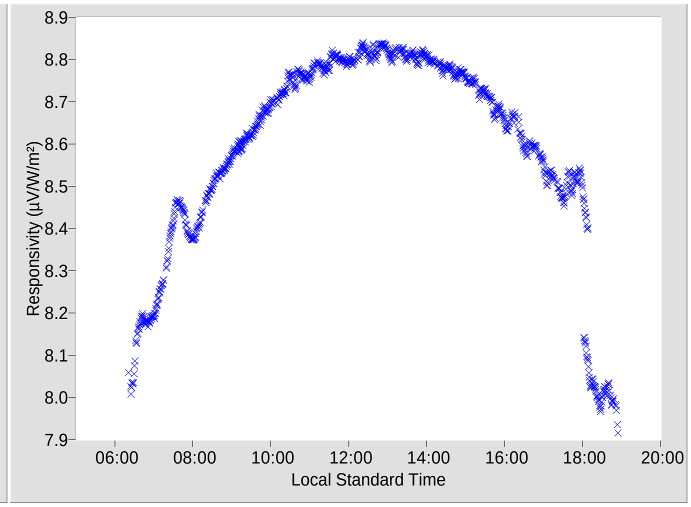


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6539	+2.13 / -2.66	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64306 µV/W/m², determination date: 06/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6080	0.61	97.11	8.6766	0.62	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5816	N/A	95.68	8.6339	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6047	0.64	101.84	8.6608	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5765	0.68	99.98	8.6228	0.78	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5474	0.69	98.30	8.5782	0.68	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5296	0.69	96.56	8.5922	0.67	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5056	0.73	94.97	8.5755	0.71	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4698	0.76	93.33	8.5146	0.80	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4166	0.82	91.82	8.5229	0.77	274.95
18	8.7956	0.56	155.40	8.8099	0.55	204.72	64	8.3750	0.83	90.34	8.4926	0.83	276.38
20	8.8022	0.49	142.70	8.8053	0.52	217.13	66	8.3959	0.94	88.84	8.4889	0.97	277.74
22	8.7913	0.57	134.59	8.8039	0.53	225.42	68	8.4557	0.94	87.35	8.4892	0.97	279.12
24	8.7857	0.52	128.29	8.8136	0.51	231.57	70	8.4336	1.11	85.95	8.5315	1.01	280.52
26	8.7796	0.55	123.42	8.7968	0.51	236.55	72	8.3261	1.22	84.45	8.4322	1.23	281.89
28	8.7567	0.51	119.28	8.7898	0.53	240.63	74	8.2621	1.26	83.05	8.1246	1.57	278.98
30	8.7699	0.57	115.78	8.7800	0.51	244.13	76	8.1944	1.46	81.57	8.0368	1.72	280.39
32	8.7601	0.53	112.64	8.7630	0.54	247.28	78	8.1785	1.67	80.19	7.9934	2.04	281.81
34	8.7229	0.52	109.77	8.7720	0.54	250.14	80	8.1848	2.05	78.70	8.0192	2.39	283.29
36	8.7036	0.55	107.27	8.7489	0.55	252.65	82	8.0726	2.77	77.22	7.9877	3.05	284.76
38	8.6956	0.55	104.97	8.7469	0.55	254.97	84	8.0591	N/A	75.91	7.9155	N/A	286.07
40	8.6803	0.58	102.80	8.7279	0.57	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6467	0.58	100.83	8.7136	0.58	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6200	0.57	98.94	8.6652	0.64	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30778F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

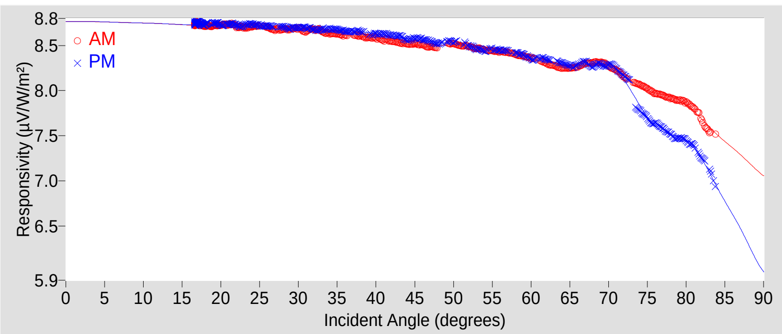
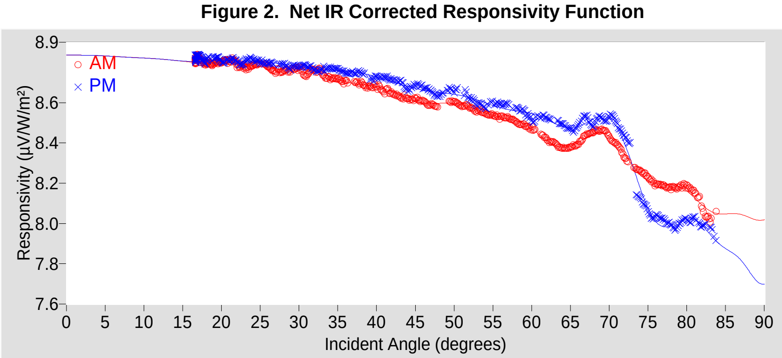


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.45	±1.45
R²	0.9999990	0.9999964
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.46	±1.46
Net IR corrected R²	0.9999992	0.9999973
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.7606	*	8.7606	*	8.7606	*	8.8319	*	8.8319	*	8.8319	*
9-18	8.7369	*	8.7381	*	8.7375	*	8.8115	*	8.8126	*	8.8121	*
18-27	8.7131	±1.46	8.7275	±1.46	8.7203	±1.49	8.7898	±1.47	8.8057	±1.46	8.7977	±1.50
27-36	8.6679	±1.51	8.6880	±1.48	8.6780	±1.65	8.7509	±1.50	8.7740	±1.47	8.7625	±1.62
36-45	8.5728	±1.58	8.6243	±1.55	8.5986	±1.96	8.6677	±1.55	8.7216	±1.53	8.6946	±1.89
45-54	8.4939	±1.47	8.5242	±1.55	8.5091	±1.68	8.5894	±1.49	8.6427	±1.50	8.6161	±1.74
54-63	8.3866	±1.79	8.4004	±1.66	8.3935	±2.15	8.4906	±1.70	8.5565	±1.56	8.5236	±2.25
63-72	8.2692	±1.58	8.2786	±1.69	8.2739	±1.96	8.4103	±1.53	8.4957	±1.56	8.4530	±1.99
72-81	7.9820	±2.66	7.6758	±4.77	7.8289	±6.95	8.2184	±1.89	8.0962	±2.93	8.1573	±3.90
81-90	7.4054	*	6.6964	*	7.0509	*	8.0526	*	7.8587	*	7.9557	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.5504	+2.32 / -2.74
45° - 55°	8.5011	±1.62
Composite	8.5832	+2.27 / -18.36
45° (Net IR Corr.)	8.6539	+2.13 / -2.66
45° - 55° (Net IR Corr.)	8.6092	±1.65
Composite (Net IR Corr.)	8.6931	+1.97 / -8.96

† Valid incident angle ranges:

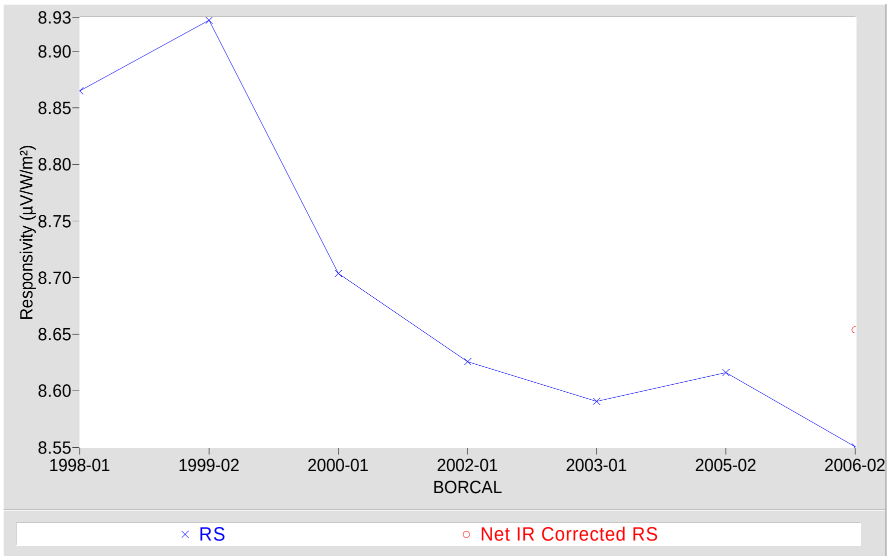
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



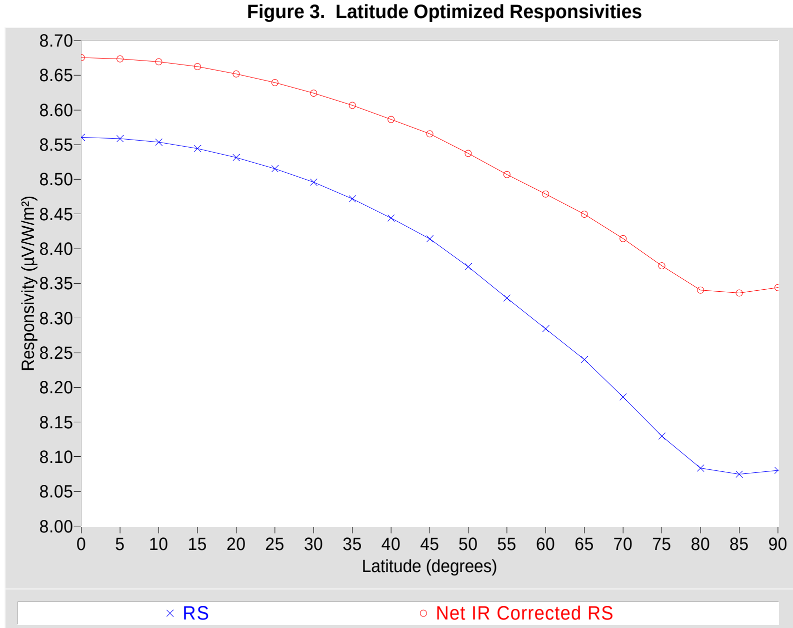
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5608	+2.80 / -28.41	8.6753	+2.36 / -11.16
5	8.5589	+2.82 / -28.40	8.6738	+2.37 / -11.15
10	8.5536	+2.87 / -28.35	8.6696	+2.41 / -11.10
15	8.5445	+2.97 / -28.27	8.6624	+2.48 / -11.03
20	8.5314	+3.10 / -28.16	8.6521	+2.58 / -10.92
25	8.5152	+3.28 / -28.03	8.6394	+2.70 / -10.79
30	8.4958	+3.41 / -27.86	8.6245	+2.79 / -10.64
35	8.4720	+3.55 / -27.66	8.6067	+2.87 / -10.46
40	8.4442	+3.71 / -27.42	8.5864	+2.97 / -10.25
45	8.4140	+4.06 / -27.16	8.5656	+3.19 / -10.03
50	8.3740	+4.36 / -26.82	8.5375	+3.40 / -9.74
55	8.3289	+4.54 / -26.42	8.5070	+3.45 / -9.42
60	8.2842	+4.84 / -26.02	8.4788	+3.59 / -9.12
65	8.2400	+4.80 / -25.63	8.4496	+3.47 / -8.81
70	8.1860	+4.74 / -25.14	8.4147	+3.29 / -8.44
75	8.1298	+4.90 / -24.62	8.3753	+3.43 / -8.01
80	8.0837	+4.53 / -24.19	8.3404	+3.16 / -7.63
85	8.0746	+3.87 / -24.10	8.3362	+2.78 / -7.59
90	8.0805	+3.11 / -24.16	8.3438	+2.69 / -7.67

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

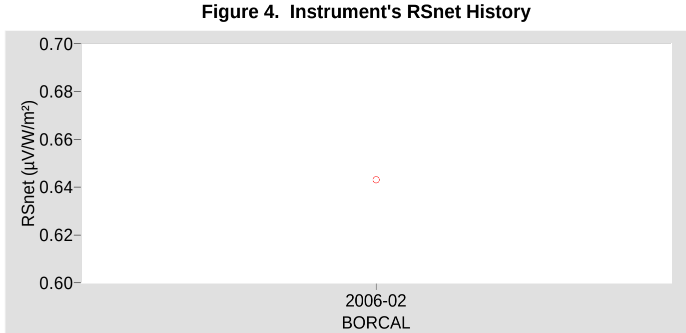
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30812F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

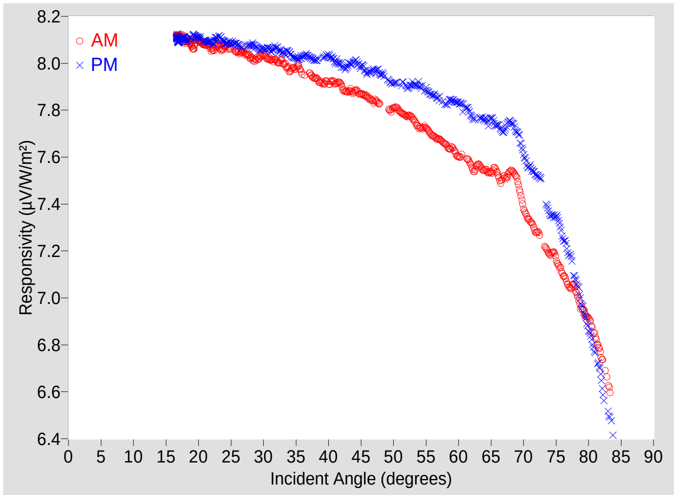

Figure 2. Responsivity vs Local Standard Time

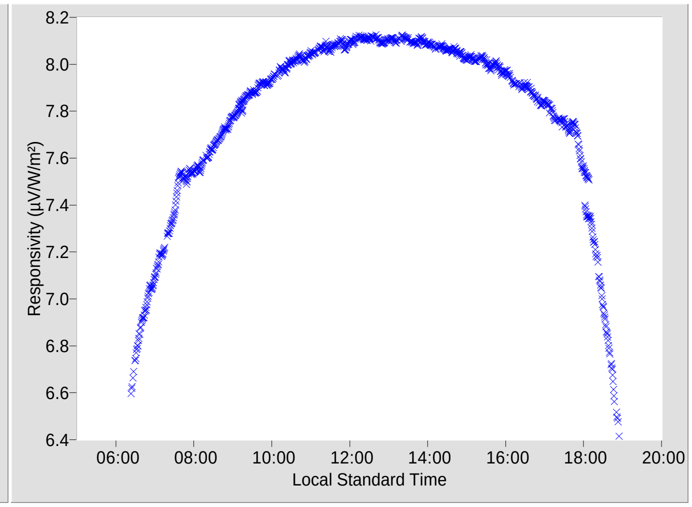

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9282	+2.38 / -4.64	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8578	0.60	97.18	7.9594	0.61	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8257	N/A	95.64	7.9541	0.59	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8098	0.63	101.80	7.9143	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7766	0.66	100.06	7.8977	0.61	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7274	0.70	98.26	7.9040	0.65	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6925	0.73	96.58	7.8639	0.71	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6546	0.74	94.94	7.8246	0.67	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6027	0.77	93.40	7.8305	0.74	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5619	0.83	91.83	7.7720	0.77	274.97
18	8.0981	0.56	155.25	8.1032	0.49	204.58	64	7.5448	0.83	90.31	7.7605	0.76	276.39
20	8.0976	0.55	142.58	8.1080	0.51	217.20	66	7.5310	0.96	88.85	7.7358	0.87	277.75
22	8.0619	0.52	134.49	8.0904	0.51	225.32	68	7.5413	0.94	87.37	7.7509	0.87	279.13
24	8.0680	0.55	128.48	8.0881	0.53	231.49	70	7.3860	1.48	85.91	7.6145	1.33	280.49
26	8.0491	0.48	123.46	8.0800	0.51	236.46	72	7.2807	1.15	84.47	7.5209	1.05	281.90
28	8.0277	0.54	119.32	8.0770	0.49	240.56	74	7.1882	1.23	83.02	7.3624	1.42	278.95
30	8.0374	0.51	115.72	8.0624	0.49	244.17	76	7.1070	1.60	81.64	7.2573	1.94	280.41
32	8.0099	0.50	112.58	8.0663	0.53	247.32	78	7.0328	1.81	80.16	7.0770	2.36	281.83
34	7.9732	0.53	109.88	8.0441	0.54	250.09	80	6.9144	2.15	78.72	6.8670	2.58	283.26
36	7.9551	0.56	107.27	8.0292	0.53	252.60	82	6.7483	2.91	77.24	6.6448	3.14	284.73
38	7.9360	0.57	104.92	8.0130	0.52	254.93	84	N/A	N/A	N/A	6.4145	N/A	286.03
40	7.9145	0.52	102.80	8.0308	0.56	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9058	0.58	100.85	7.9905	0.61	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8807	0.54	98.90	8.0093	0.58	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

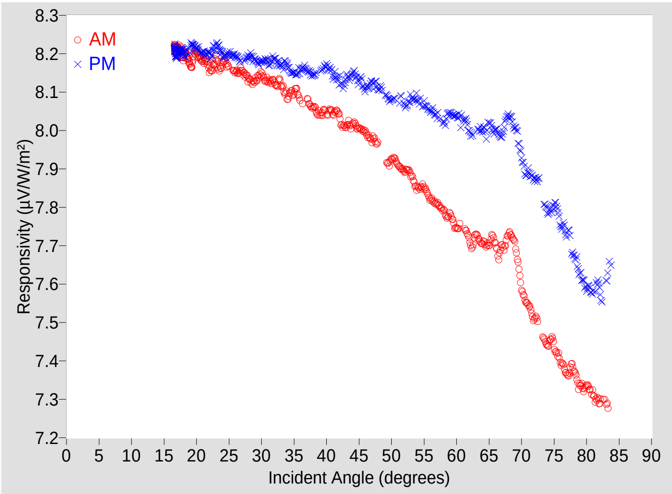

Figure 4. Responsivity vs Local Standard Time

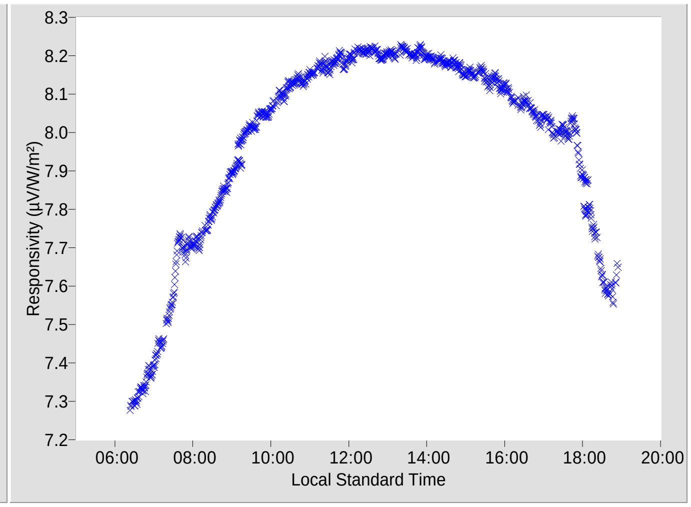

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0685	+2.15 / -4.60	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.66610 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9961	0.64	97.18	8.1087	0.66	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9649	N/A	95.64	8.1099	0.65	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9255	0.66	101.80	8.0790	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8960	0.69	100.06	8.0655	0.69	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8515	0.73	98.26	8.0797	0.72	269.18
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8222	0.76	96.58	8.0505	0.76	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7911	0.78	94.94	8.0195	0.75	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7459	0.81	93.40	8.0365	0.80	273.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7145	0.87	91.83	7.9951	0.85	274.97
18	8.1964	0.58	155.25	8.2034	0.52	204.58	64	7.7082	0.88	90.31	8.0030	0.90	276.39
20	8.2017	0.58	142.58	8.2133	0.54	217.20	66	7.7049	1.01	88.85	8.0005	0.95	277.75
22	8.1621	0.56	134.49	8.2002	0.55	225.32	68	7.7303	1.02	87.37	8.0370	1.03	279.13
24	8.1737	0.57	128.48	8.1983	0.57	231.49	70	7.5928	1.42	85.91	7.9316	1.33	280.49
26	8.1546	0.52	123.46	8.1935	0.55	236.46	72	7.5108	1.21	84.47	7.8730	1.21	281.90
28	8.1362	0.56	119.32	8.1916	0.54	240.56	74	7.4430	1.32	83.02	7.7906	1.60	278.95
30	8.1468	0.54	115.72	8.1807	0.54	244.17	76	7.4015	1.58	81.64	7.7545	1.90	280.41
32	8.1250	0.54	112.58	8.1870	0.56	247.32	78	7.3785	1.84	80.16	7.6748	2.28	281.83
34	8.0906	0.57	109.88	8.1698	0.59	250.09	80	7.3356	2.19	78.72	7.5898	2.60	283.26
36	8.0778	0.60	107.27	8.1584	0.58	252.60	82	7.2952	2.86	77.24	7.5869	3.32	284.73
38	8.0607	0.61	104.92	8.1448	0.57	254.93	84	N/A	N/A	N/A	7.6494	N/A	286.03
40	8.0444	0.58	102.80	8.1668	0.61	257.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0363	0.64	100.85	8.1287	0.65	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0157	0.60	98.90	8.1494	0.64	260.97	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

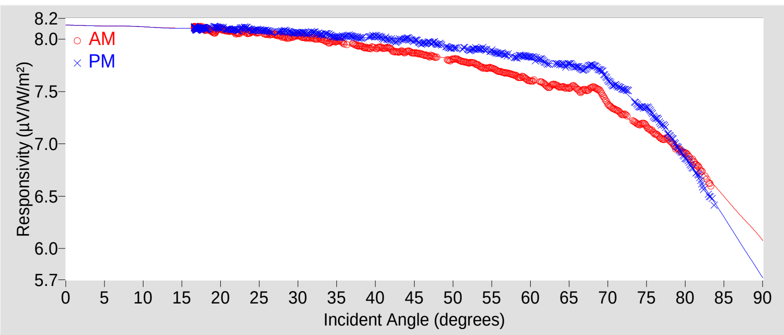
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

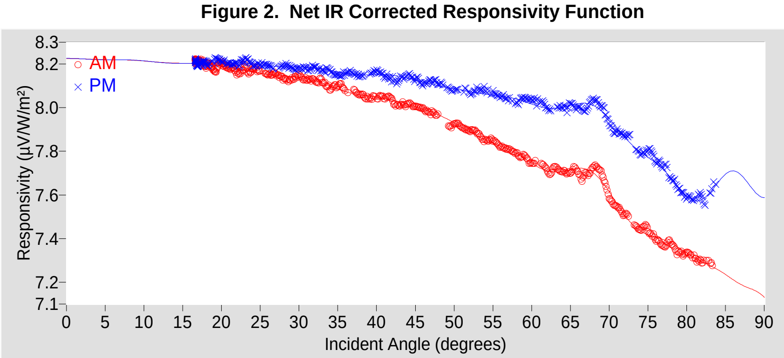


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.53	±1.53
R²	0.9999990	0.9999983
Valid incidence angle range	16.6° to 83.3°	16.6° to 83.7°
Net IR corr. uncert. U95 (%)	±1.55	±1.55
Net IR corrected R²	0.9999991	0.9999987
Corr. valid inc. angle range	16.6° to 83.3°	16.6° to 83.7°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.1291	*	8.1291	*	8.1291	*	8.2214	*	8.2213	*	8.2214	*
9-18	8.1099	*	8.1103	*	8.1101	*	8.2069	*	8.2073	*	8.2071	*
18-27	8.0724	±1.57	8.0933	±1.54	8.0829	±1.62	8.1754	±1.58	8.2016	±1.55	8.1885	±1.63
27-36	8.0101	±1.62	8.0602	±1.55	8.0352	±1.88	8.1233	±1.61	8.1806	±1.56	8.1519	±1.85
36-45	7.9154	±1.61	8.0125	±1.55	7.9640	±2.08	8.0446	±1.60	8.1482	±1.56	8.0964	±2.03
45-54	7.8118	±1.73	7.9326	±1.63	7.8722	±2.65	7.9395	±1.79	8.0927	±1.59	8.0161	±2.84
54-63	7.6431	±1.92	7.8341	±1.70	7.7386	±3.42	7.7810	±1.81	8.0325	±1.60	7.9067	±3.56
63-72	7.4880	±2.20	7.7042	±2.11	7.5961	±4.62	7.6738	±1.98	7.9856	±1.76	7.8297	±4.77
72-81	7.0919	±3.26	7.1997	±5.06	7.1458	±7.05	7.4054	±1.99	7.7285	±2.40	7.5669	±5.32
81-90	6.4562	*	6.2401	*	6.3481	*	7.2242	*	7.6387	*	7.4314	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.9282	+2.38 / -4.64
45° - 55°	7.8621	±2.29
Composite	7.9415	+2.57 / -18.57
45° (Net IR Corr.)	8.0685	+2.15 / -4.60
45° - 55° (Net IR Corr.)	8.0070	±2.37
Composite (Net IR Corr.)	8.0867	+2.14 / -10.25

† Valid incident angle ranges:

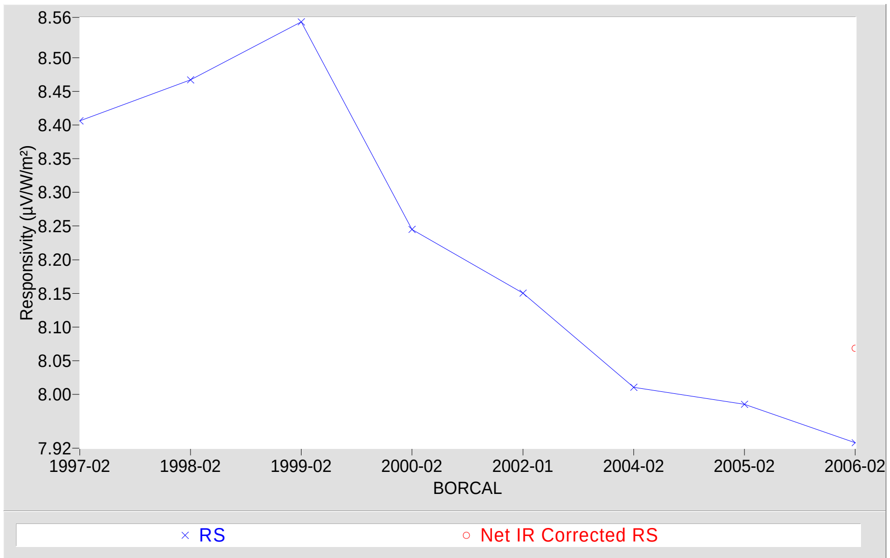
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.3°, 16.6° to 83.3° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



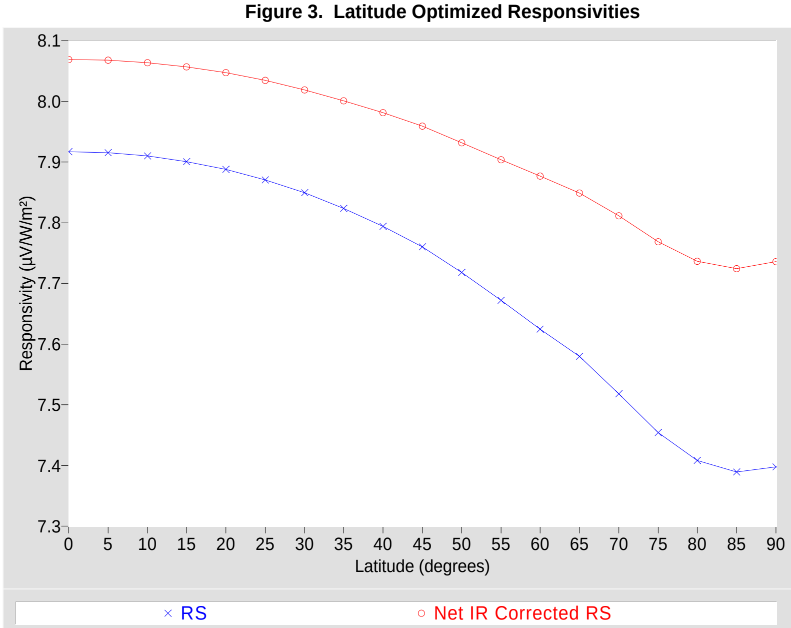
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.9171	+3.15 / -26.32	8.0691	+2.49 / -11.39
5	7.9155	+3.17 / -26.30	8.0679	+2.50 / -11.38
10	7.9099	+3.23 / -26.25	8.0637	+2.54 / -11.33
15	7.9005	+3.34 / -26.16	8.0567	+2.61 / -11.26
20	7.8878	+3.49 / -26.04	8.0473	+2.71 / -11.15
25	7.8705	+3.68 / -25.88	8.0345	+2.84 / -11.01
30	7.8492	+3.85 / -25.68	8.0188	+2.95 / -10.84
35	7.8236	+4.03 / -25.44	8.0008	+3.05 / -10.64
40	7.7942	+4.28 / -25.15	7.9810	+3.22 / -10.42
45	7.7604	+4.61 / -24.83	7.9593	+3.46 / -10.18
50	7.7180	+4.93 / -24.42	7.9317	+3.64 / -9.87
55	7.6719	+5.36 / -23.96	7.9037	+3.89 / -9.56
60	7.6246	+5.51 / -23.49	7.8766	+3.89 / -9.25
65	7.5795	+5.95 / -23.04	7.8491	+4.15 / -8.93
70	7.5180	+6.17 / -22.41	7.8112	+4.20 / -8.50
75	7.4542	+6.36 / -21.75	7.7687	+4.29 / -8.01
80	7.4082	+6.39 / -21.26	7.7366	+4.38 / -7.63
85	7.3889	+5.66 / -21.06	7.7245	+4.13 / -7.49
90	7.3978	+5.06 / -21.15	7.7359	+3.99 / -7.62

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

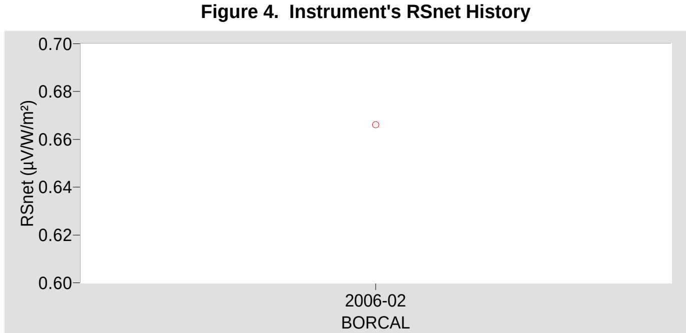
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30823F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30823F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

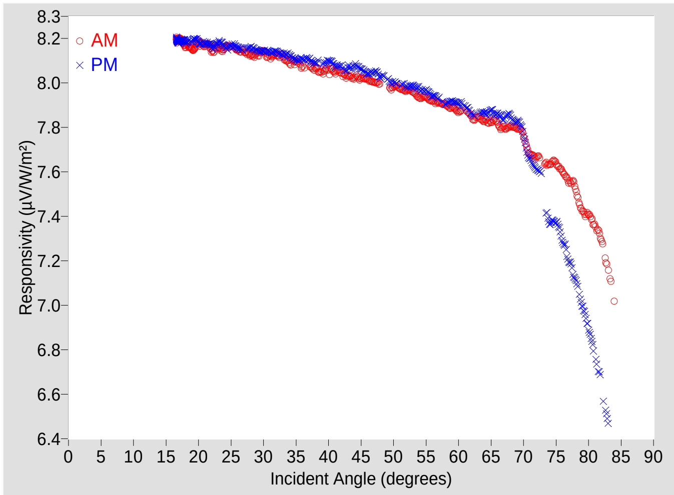


Figure 2. Responsivity vs Local Standard Time

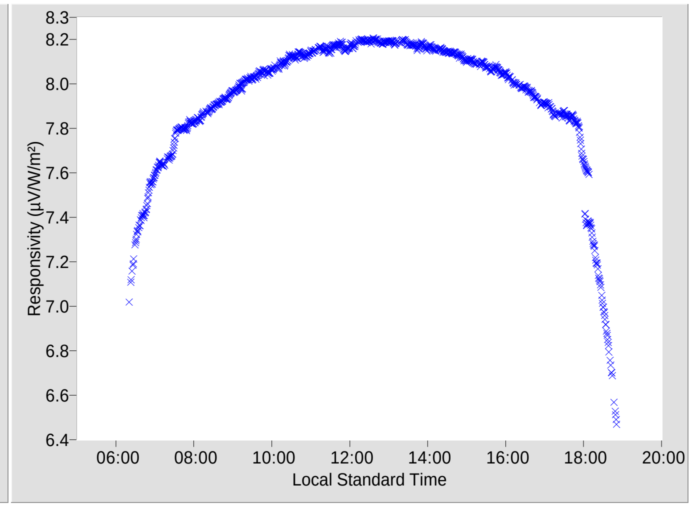


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0407	+1.86 / -2.61	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0182	0.55	97.14	8.0409	0.57	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9947	N/A	95.65	8.0279	0.60	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9827	0.62	101.81	8.0023	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9656	0.63	100.01	7.9819	0.59	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9333	0.67	98.27	7.9721	0.62	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9188	0.68	96.59	7.9412	0.66	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9021	0.70	94.95	7.9067	0.66	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8722	0.74	93.36	7.9060	0.68	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8471	0.80	91.79	7.8611	0.74	274.98
18	8.1737	0.55	155.29	8.1860	0.48	204.62	64	7.8313	0.81	90.32	7.8663	0.75	276.40
20	8.1793	0.54	142.61	8.1847	0.50	217.23	66	7.8184	0.90	88.81	7.8593	0.83	277.76
22	8.1504	0.53	134.51	8.1674	0.51	225.35	68	7.8042	0.91	87.33	7.8510	0.86	279.10
24	8.1591	0.51	128.37	8.1648	0.54	231.51	70	7.7630	1.21	85.92	7.7648	1.42	280.50
26	8.1501	0.48	123.49	8.1594	0.51	236.49	72	7.6670	1.08	84.48	7.6111	1.07	281.91
28	8.1263	0.50	119.23	8.1582	0.50	240.58	74	7.6343	1.20	83.03	7.3735	1.41	278.96
30	8.1437	0.51	115.74	8.1427	0.49	244.18	76	7.6013	1.49	81.60	7.2860	1.98	280.42
32	8.1261	0.50	112.60	8.1422	0.50	247.24	78	7.5232	1.82	80.16	7.1151	2.27	281.79
34	8.0921	0.52	109.73	8.1246	0.53	250.10	80	7.4083	2.03	78.68	6.8942	2.58	283.27
36	8.0713	0.55	107.28	8.1082	0.52	252.62	82	7.2902	2.81	77.25	6.6283	3.43	284.73
38	8.0659	0.55	104.94	8.0904	0.53	254.94	84	7.0189	N/A	75.79	N/A	N/A	N/A
40	8.0554	0.54	102.74	8.0994	0.54	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0443	0.56	100.86	8.0754	0.56	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0257	0.54	98.92	8.0792	0.56	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

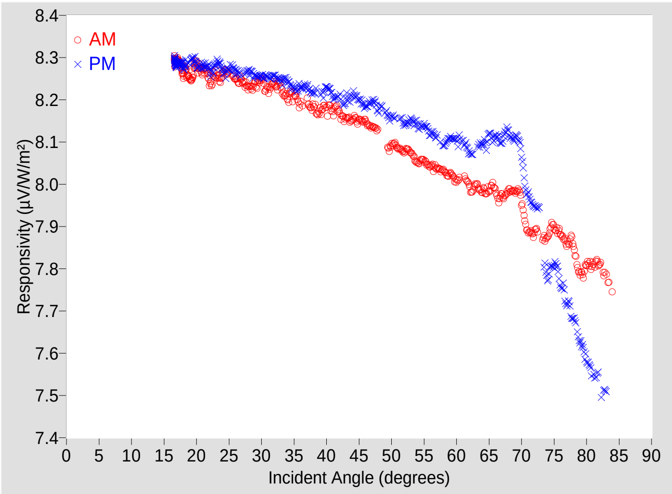


Figure 4. Responsivity vs Local Standard Time

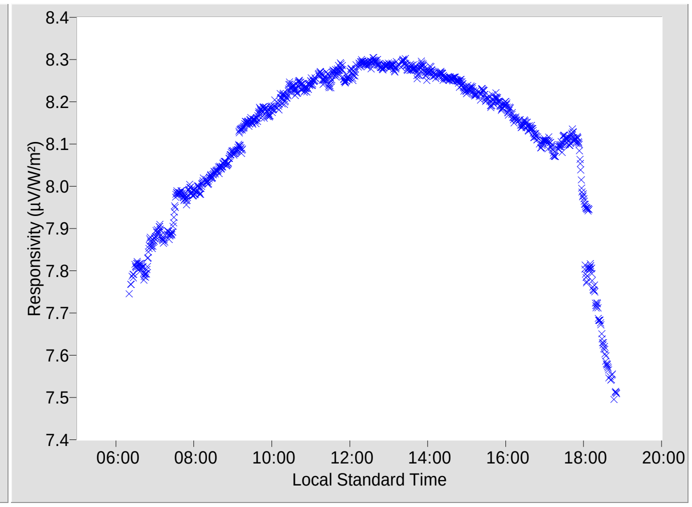


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1746	+1.64 / -2.65	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63457 µV/W/m², determination date: 06/08/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1499	0.60	97.14	8.1828	0.63	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1265	N/A	95.65	8.1764	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0929	0.66	101.81	8.1590	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0789	0.67	100.01	8.1420	0.67	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0513	0.70	98.27	8.1396	0.69	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0430	0.72	96.59	8.1191	0.73	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0322	0.74	94.95	8.0925	0.74	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0094	0.78	93.36	8.1025	0.78	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9927	0.84	91.79	8.0739	0.83	274.98
18	8.2671	0.58	155.29	8.2815	0.52	204.62	64	7.9868	0.86	90.32	8.0973	0.88	276.40
20	8.2787	0.57	142.61	8.2851	0.53	217.23	66	7.9837	0.96	88.81	8.1115	0.92	277.76
22	8.2457	0.56	134.51	8.2721	0.55	225.35	68	7.9846	0.98	87.33	8.1233	0.99	279.10
24	8.2598	0.54	128.37	8.2696	0.58	231.51	70	7.9596	1.22	85.92	8.0676	1.39	280.50
26	8.2508	0.52	123.49	8.2673	0.55	236.49	72	7.8865	1.17	84.48	7.9470	1.21	281.91
28	8.2305	0.53	119.23	8.2671	0.54	240.58	74	7.8764	1.31	83.03	7.7819	1.62	278.96
30	8.2480	0.55	115.74	8.2554	0.53	244.18	76	7.8834	1.52	81.60	7.7599	1.93	280.42
32	8.2362	0.56	112.60	8.2570	0.54	247.24	78	7.8528	1.83	80.16	7.6814	2.23	281.79
34	8.2050	0.56	109.73	8.2446	0.58	250.10	80	7.8113	2.16	78.68	7.5839	2.63	283.27
36	8.1884	0.59	107.28	8.2313	0.57	252.62	82	7.8102	2.78	77.25	7.5254	3.40	284.73
38	8.1844	0.60	104.94	8.2160	0.58	254.94	84	7.7454	N/A	75.79	N/A	N/A	N/A
40	8.1785	0.59	102.74	8.2289	0.60	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1689	0.61	100.86	8.2076	0.61	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1542	0.59	98.92	8.2128	0.61	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30823F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

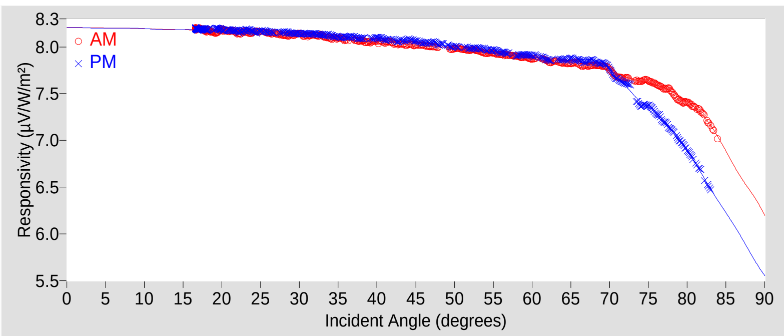
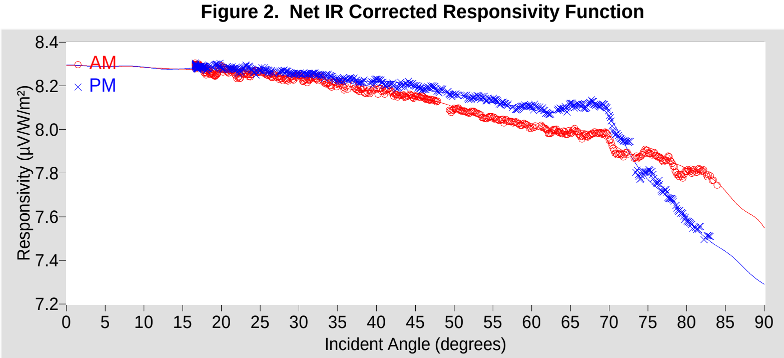


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.53	±1.53
R^2	0.9999992	0.9999987
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.0°
Net IR corr. uncert. U95 (%)	±1.54	±1.54
Net IR corrected R^2	0.9999994	0.9999990
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.0°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.2031	*	8.2032	*	8.2032	*	8.2909	*	8.2910	*	8.2910	*
9-18	8.1871	*	8.1882	*	8.1876	*	8.2793	*	8.2806	*	8.2800	*
18-27	8.1604	±1.54	8.1714	±1.54	8.1659	±1.58	8.2586	±1.55	8.2746	±1.54	8.2666	±1.57
27-36	8.1206	±1.58	8.1396	±1.56	8.1301	±1.69	8.2290	±1.57	8.2541	±1.55	8.2416	±1.66
36-45	8.0516	±1.56	8.0888	±1.55	8.0702	±1.70	8.1745	±1.55	8.2181	±1.55	8.1963	±1.67
45-54	7.9859	±1.60	8.0128	±1.63	7.9993	±1.85	8.1072	±1.65	8.1652	±1.58	8.1362	±1.97
54-63	7.8926	±1.65	7.9141	±1.66	7.9034	±1.89	8.0244	±1.59	8.1031	±1.57	8.0637	±2.00
63-72	7.7941	±1.76	7.8190	±2.12	7.8065	±2.75	7.9710	±1.63	8.0871	±1.84	8.0290	±2.50
72-81	7.5650	±2.47	7.2356	±5.43	7.4003	±8.64	7.8635	±1.63	7.7396	±2.77	7.8015	±3.68
81-90	6.8102	*	6.1582	*	6.4842	*	7.6944	*	7.4208	*	7.5576	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

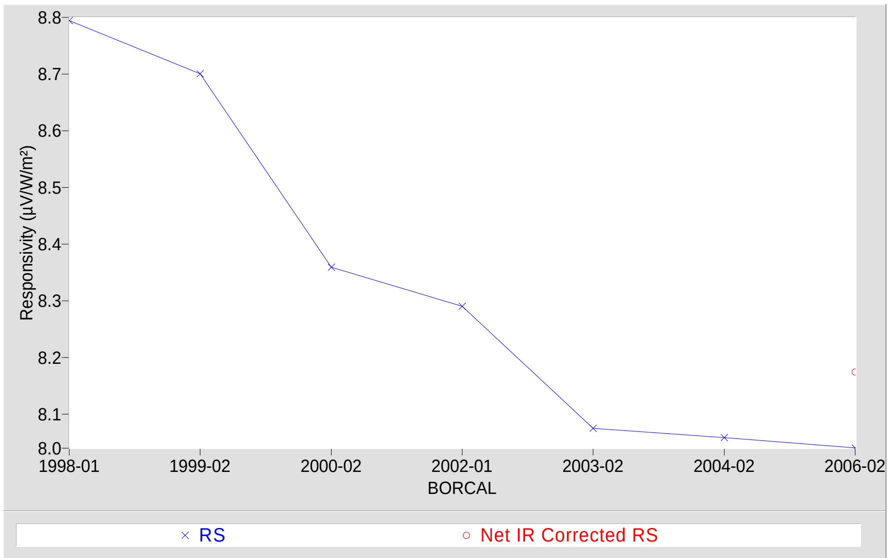
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.0407	+1.86 / -2.61
45° - 55°	7.9913	±1.74
Composite	8.0530	+2.26 / -20.34
45° (Net IR Corr.)	8.1746	+1.64 / -2.65
45° - 55° (Net IR Corr.)	8.1292	±1.79
Composite (Net IR Corr.)	8.1915	+1.89 / -8.88

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.0°, 16.6° to 83.0° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



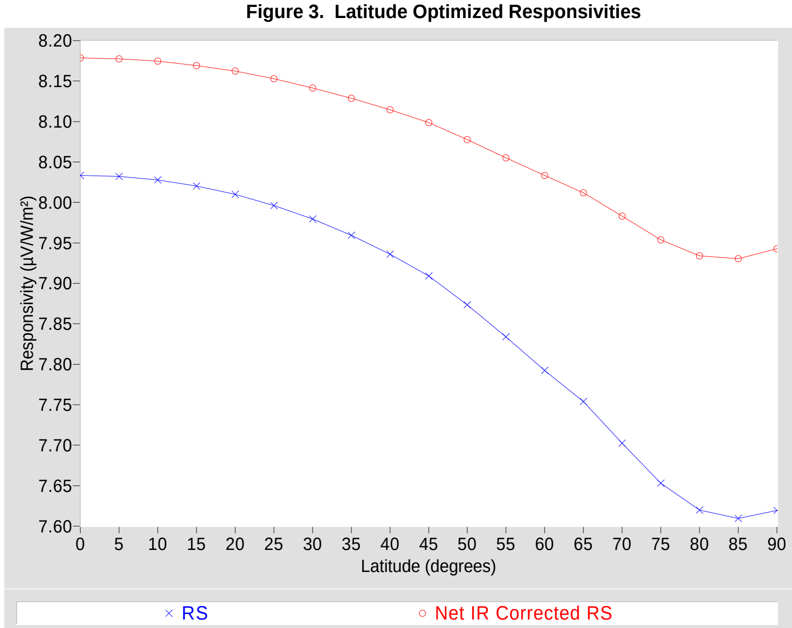
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.0334	+2.67 / -29.34	8.1785	+2.10 / -10.67
5	8.0322	+2.68 / -29.33	8.1776	+2.11 / -10.66
10	8.0278	+2.73 / -29.29	8.1745	+2.14 / -10.63
15	8.0202	+2.81 / -29.22	8.1692	+2.19 / -10.57
20	8.0100	+2.92 / -29.13	8.1623	+2.25 / -10.50
25	7.9963	+3.06 / -29.01	8.1528	+2.32 / -10.40
30	7.9795	+3.18 / -28.86	8.1413	+2.40 / -10.27
35	7.9594	+3.30 / -28.68	8.1286	+2.44 / -10.13
40	7.9361	+3.51 / -28.47	8.1145	+2.57 / -9.98
45	7.9090	+3.69 / -28.23	8.0988	+2.68 / -9.80
50	7.8734	+3.95 / -27.90	8.0775	+2.81 / -9.57
55	7.8337	+4.25 / -27.54	8.0552	+2.96 / -9.32
60	7.7923	+4.31 / -27.15	8.0332	+2.88 / -9.08
65	7.7539	+4.61 / -26.79	8.0120	+3.03 / -8.84
70	7.7027	+4.69 / -26.31	7.9833	+2.96 / -8.52
75	7.6529	+4.76 / -25.83	7.9537	+2.98 / -8.18
80	7.6199	+4.47 / -25.51	7.9339	+2.92 / -7.96
85	7.6096	+3.87 / -25.41	7.9303	+2.96 / -7.91
90	7.6193	+3.60 / -25.50	7.9426	+2.83 / -8.05

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

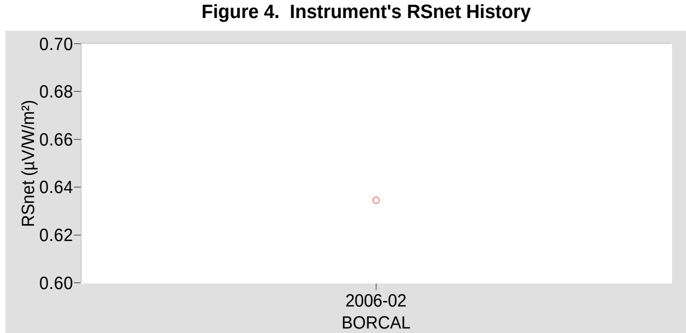
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30888F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

30888F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

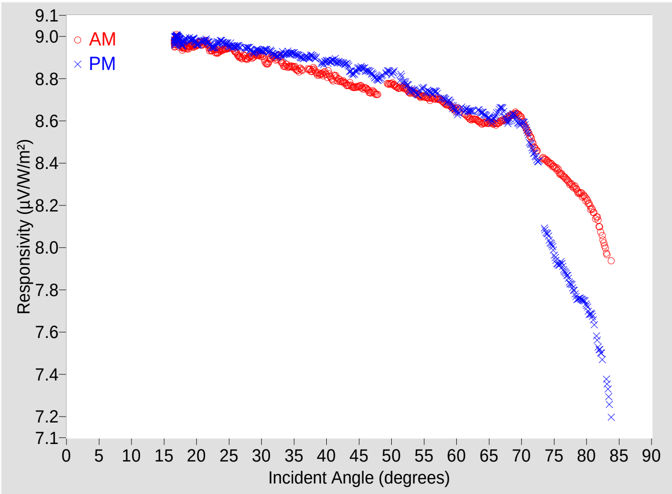


Figure 2. Responsivity vs Local Standard Time

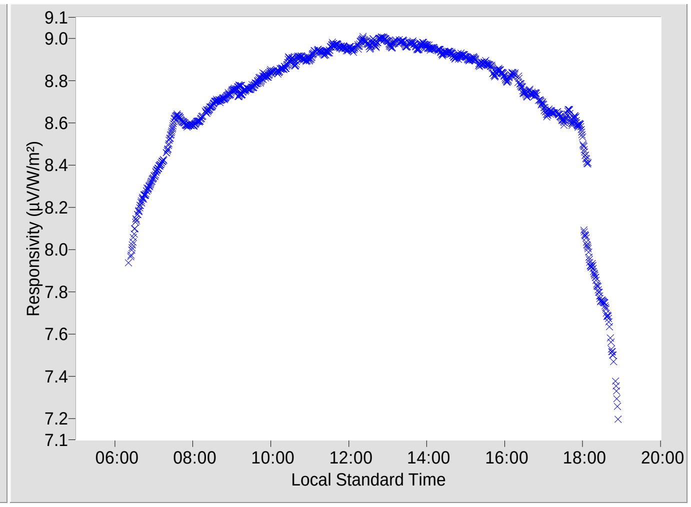


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8063	+2.05 / -2.28	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7551	0.57	97.11	8.8424	0.58	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7241	N/A	95.68	8.7975	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7759	0.62	101.84	8.8272	0.58	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7554	0.65	99.98	8.7823	0.75	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7260	0.67	98.30	8.7300	0.63	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7069	0.67	96.56	8.7349	0.61	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6891	0.70	94.97	8.7074	0.67	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6545	0.73	93.33	8.6432	0.73	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6124	0.76	91.82	8.6470	0.68	274.95
18	8.9504	0.56	155.40	8.9729	0.55	204.72	64	8.5893	0.79	90.34	8.6378	0.75	276.38
20	8.9606	0.48	142.70	8.9672	0.50	217.13	66	8.5870	0.84	88.84	8.6249	0.87	277.74
22	8.9463	0.57	134.59	8.9654	0.53	225.42	68	8.6171	0.91	87.35	8.5989	0.91	279.12
24	8.9369	0.49	128.29	8.9735	0.50	231.57	70	8.6140	1.12	85.95	8.5897	1.00	280.52
26	8.9275	0.54	123.42	8.9530	0.49	236.55	72	8.4744	1.17	84.45	8.4382	1.22	281.89
28	8.8988	0.49	119.28	8.9447	0.50	240.63	74	8.4097	1.19	83.05	8.0583	1.50	278.98
30	8.9112	0.55	115.78	8.9313	0.48	244.13	76	8.3486	1.41	81.57	7.9236	1.63	280.39
32	8.8999	0.53	112.64	8.9112	0.52	247.28	78	8.2909	1.63	80.19	7.8016	1.92	281.81
34	8.8605	0.50	109.77	8.9212	0.52	250.14	80	8.2254	1.99	78.70	7.7246	2.17	283.29
36	8.8421	0.51	107.27	8.9024	0.53	252.65	82	8.1010	2.69	77.27	7.5128	2.93	284.76
38	8.8430	0.53	104.97	8.9022	0.52	254.97	84	7.9381	N/A	75.91	7.1966	N/A	286.07
40	8.8239	0.56	102.80	8.8813	0.53	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7925	0.55	100.83	8.8762	0.55	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7630	0.54	98.94	8.8253	0.61	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

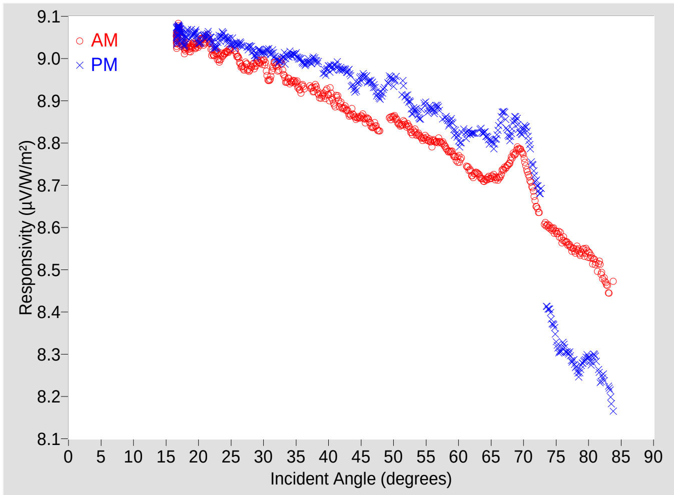


Figure 4. Responsivity vs Local Standard Time

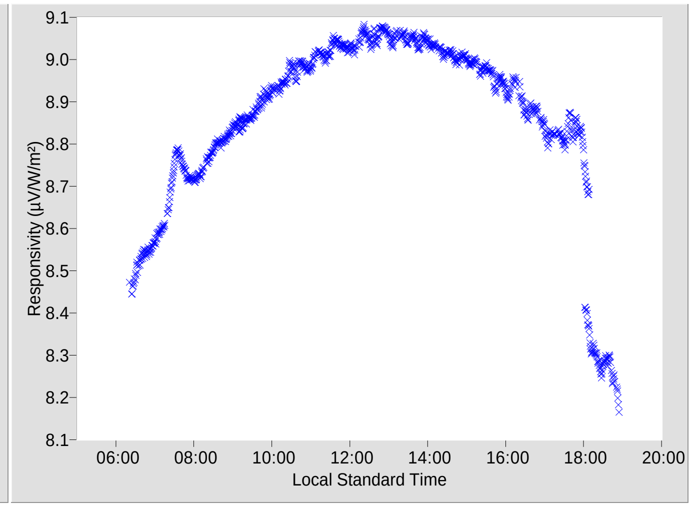


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9088	+1.85 / -2.25	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63655 µV/W/m², determination date: 06/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8562	0.59	97.11	8.9501	0.60	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8286	N/A	95.68	8.9104	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8615	0.63	101.84	8.9457	0.62	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8423	0.67	99.98	8.9093	0.76	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8183	0.68	98.30	8.8640	0.68	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8027	0.69	96.56	8.8789	0.66	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7911	0.72	94.97	8.8600	0.71	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7617	0.75	93.33	8.8057	0.78	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7272	0.79	91.82	8.8224	0.75	274.95
18	9.0266	0.58	155.40	9.0473	0.55	204.72	64	8.7125	0.82	90.34	8.8226	0.81	276.38
20	9.0344	0.50	142.70	9.0429	0.51	217.13	66	8.7171	0.88	88.84	8.8255	0.98	277.74
22	9.0229	0.59	134.59	9.0422	0.54	225.42	68	8.7591	0.96	87.35	8.8186	0.97	279.12
24	9.0122	0.51	128.29	9.0522	0.52	231.57	70	8.7696	1.10	85.95	8.8330	1.04	280.52
26	9.0052	0.55	123.42	9.0342	0.51	236.55	72	8.6487	1.18	84.45	8.7047	1.23	281.89
28	8.9771	0.51	119.28	9.0263	0.52	240.63	74	8.6018	1.23	83.05	8.4004	1.55	278.98
30	8.9914	0.57	115.78	9.0146	0.51	244.13	76	8.5710	1.43	81.57	8.3184	1.69	280.39
32	8.9818	0.56	112.64	8.9972	0.54	247.28	78	8.5478	1.66	80.19	8.2724	2.01	281.81
34	8.9475	0.52	109.77	9.0097	0.54	250.14	80	8.5373	2.03	78.70	8.2920	2.36	283.29
36	8.9311	0.54	107.27	8.9917	0.55	252.65	82	8.4936	2.61	77.27	8.2429	3.02	284.76
38	8.9309	0.55	104.97	8.9950	0.54	254.97	84	8.4729	N/A	75.91	8.1653	N/A	286.07
40	8.9179	0.58	102.80	8.9775	0.56	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8889	0.57	100.83	8.9747	0.57	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8632	0.57	98.94	8.9276	0.64	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30888F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

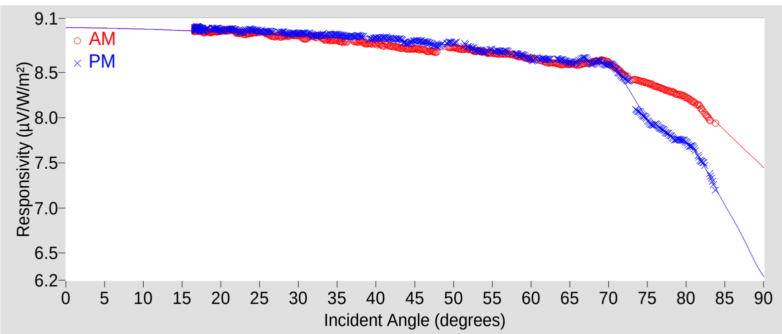
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I) \quad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

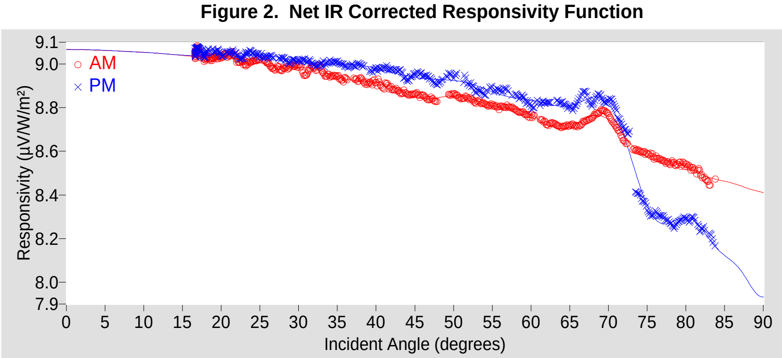


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.40	±1.40
R^2	0.9999992	0.9999968
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.42	±1.42
Net IR corrected R^2	0.9999993	0.9999975
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.9922	*	8.9922	*	8.9922	*	9.0628	*	9.0628	*	9.0628	*
9-18	8.9706	*	8.9724	*	8.9715	*	9.0445	*	9.0461	*	9.0453	*
18-27	8.9433	±1.42	8.9662	±1.41	8.9547	±1.48	9.0192	±1.44	9.0437	±1.42	9.0314	±1.49
27-36	8.8914	±1.45	8.9252	±1.42	8.9083	±1.63	8.9736	±1.45	9.0103	±1.43	8.9919	±1.61
36-45	8.8118	±1.50	8.8788	±1.46	8.8453	±1.90	8.9056	±1.49	8.9751	±1.46	8.9404	±1.84
45-54	8.7500	±1.41	8.8056	±1.46	8.7778	±1.62	8.8445	±1.43	8.9229	±1.44	8.8837	±1.69
54-63	8.6756	±1.59	8.6919	±1.55	8.6837	±1.89	8.7785	±1.54	8.8465	±1.48	8.8125	±1.99
63-72	8.5917	±1.51	8.6000	±1.74	8.5959	±2.18	8.7314	±1.48	8.8150	±1.60	8.7732	±1.91
72-81	8.3429	±2.30	7.9564	±4.64	8.1497	±7.20	8.5768	±1.66	8.3725	±2.81	8.4747	±3.67
81-90	7.8143	*	6.9543	*	7.3843	*	8.4579	*	8.1049	*	8.2814	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

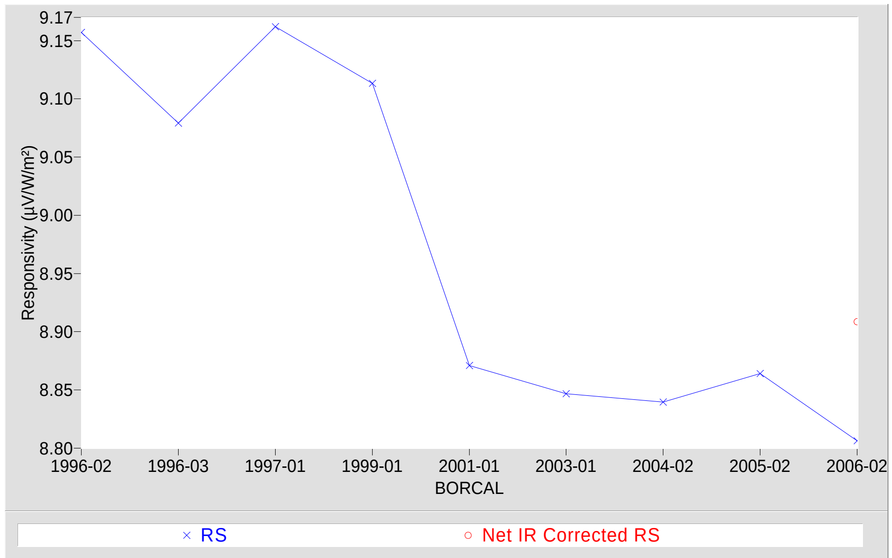
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.8063	+2.05 / -2.28
45° - 55°	8.7714	±1.56
Composite	8.8358	+2.08 / -17.75
45° (Net IR Corr.)	8.9088	+1.85 / -2.25
45° - 55° (Net IR Corr.)	8.8784	±1.60
Composite (Net IR Corr.)	8.9446	+1.83 / -8.71

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



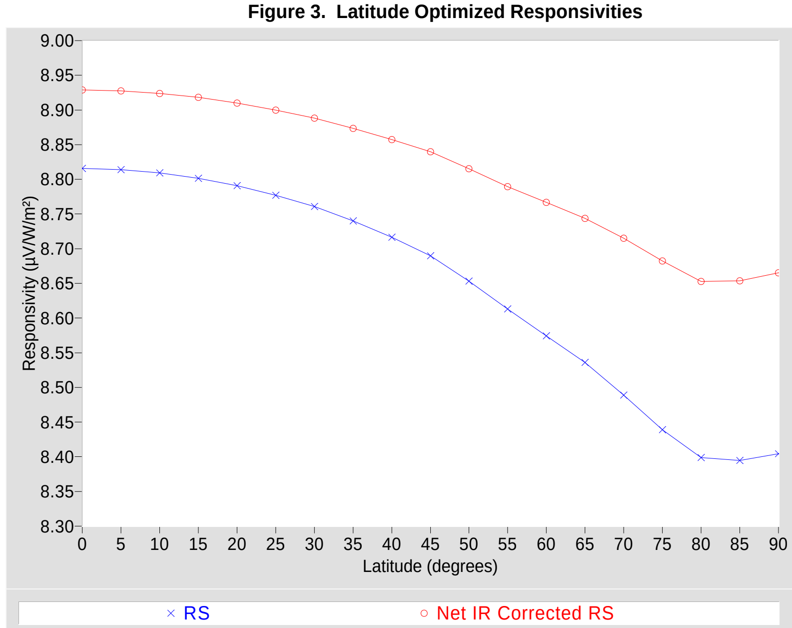
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.8156	+2.49 / -27.61	8.9290	+2.10 / -11.03
5	8.8139	+2.51 / -27.59	8.9276	+2.11 / -11.01
10	8.8092	+2.55 / -27.56	8.9240	+2.14 / -10.98
15	8.8016	+2.63 / -27.49	8.9183	+2.19 / -10.92
20	8.7907	+2.74 / -27.40	8.9101	+2.26 / -10.84
25	8.7771	+2.87 / -27.29	8.9000	+2.35 / -10.74
30	8.7607	+2.97 / -27.15	8.8880	+2.41 / -10.62
35	8.7402	+3.07 / -26.98	8.8735	+2.46 / -10.48
40	8.7165	+3.24 / -26.79	8.8572	+2.57 / -10.31
45	8.6898	+3.53 / -26.56	8.8399	+2.74 / -10.14
50	8.6533	+3.78 / -26.25	8.8152	+2.90 / -9.89
55	8.6132	+3.85 / -25.91	8.7895	+2.85 / -9.63
60	8.5744	+4.16 / -25.57	8.7669	+3.01 / -9.40
65	8.5360	+4.19 / -25.24	8.7435	+2.96 / -9.16
70	8.4887	+4.24 / -24.82	8.7150	+2.89 / -8.86
75	8.4391	+4.46 / -24.38	8.6821	+3.09 / -8.52
80	8.3988	+4.04 / -24.02	8.6530	+2.79 / -8.22
85	8.3948	+3.46 / -23.98	8.6538	+2.67 / -8.23
90	8.4045	+3.03 / -24.07	8.6652	+2.55 / -8.35

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

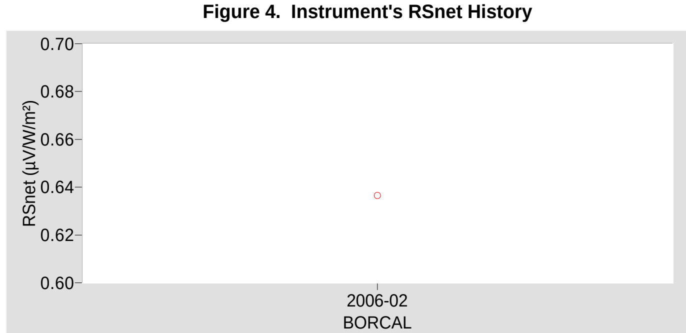
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30890F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30890F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

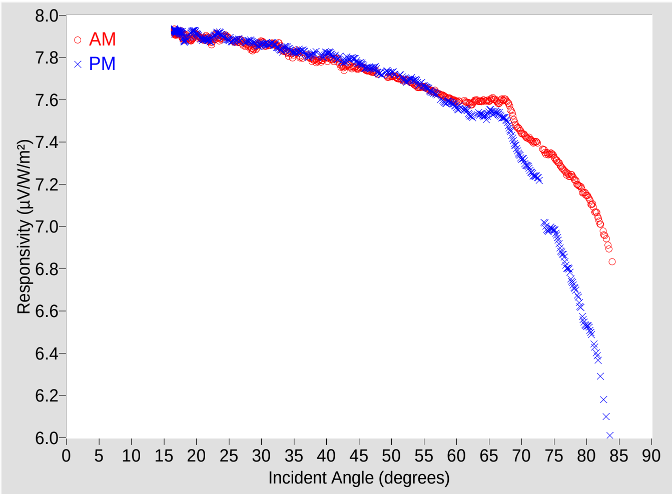


Figure 2. Responsivity vs Local Standard Time

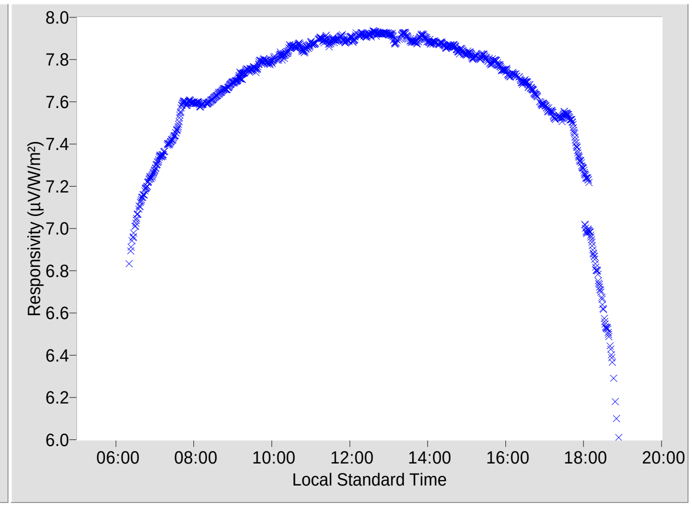


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.7616	+2.02 / -3.00	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7430	0.56	97.14	7.7499	0.58	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7253	N/A	95.65	7.7267	0.61	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7106	0.62	101.81	7.7275	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6929	0.64	100.01	7.6927	0.63	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6623	0.67	98.27	7.6813	0.66	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6454	0.70	96.59	7.6395	0.66	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6194	0.70	94.95	7.5900	0.68	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5924	0.72	93.36	7.5624	0.70	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5820	0.77	91.79	7.5278	0.74	274.98
18	7.8983	0.54	155.29	7.8938	0.58	204.62	64	7.5955	0.80	90.32	7.5277	0.76	276.40
20	7.9064	0.53	142.61	7.9139	0.56	217.23	66	7.5979	0.87	88.81	7.5406	0.82	277.76
22	7.8819	0.54	134.51	7.8828	0.52	225.35	68	7.5771	1.16	87.33	7.4786	1.20	279.10
24	7.8966	0.52	128.37	7.9029	0.54	231.51	70	7.4456	1.07	85.92	7.3239	1.12	280.50
26	7.8755	0.48	123.49	7.8818	0.50	236.49	72	7.4001	1.10	84.48	7.2384	1.09	281.91
28	7.8564	0.54	119.23	7.8792	0.48	240.58	74	7.3444	1.21	83.03	6.9854	1.41	278.96
30	7.8745	0.55	115.74	7.8619	0.49	244.18	76	7.2882	1.50	81.60	6.8890	2.04	280.42
32	7.8618	0.50	112.60	7.8627	0.54	247.24	78	7.2313	1.68	80.16	6.7229	2.26	281.79
34	7.8216	0.55	109.73	7.8449	0.53	250.10	80	7.1484	2.09	78.68	6.5301	2.38	283.27
36	7.8014	0.56	107.28	7.8337	0.55	252.62	82	7.0222	2.76	77.25	6.3287	3.46	284.69
38	7.7882	0.56	104.94	7.8165	0.55	254.94	84	6.8338	N/A	75.79	N/A	N/A	N/A
40	7.7949	0.54	102.74	7.8214	0.55	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7736	0.63	100.86	7.7929	0.58	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7539	0.55	98.92	7.7969	0.57	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

30890F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

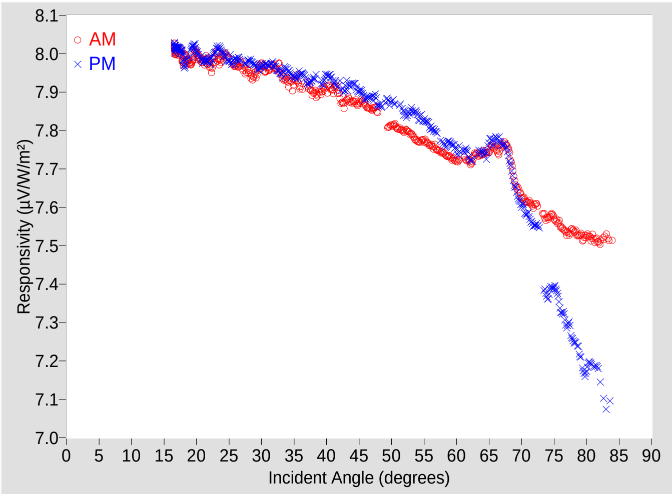


Figure 4. Responsivity vs Local Standard Time

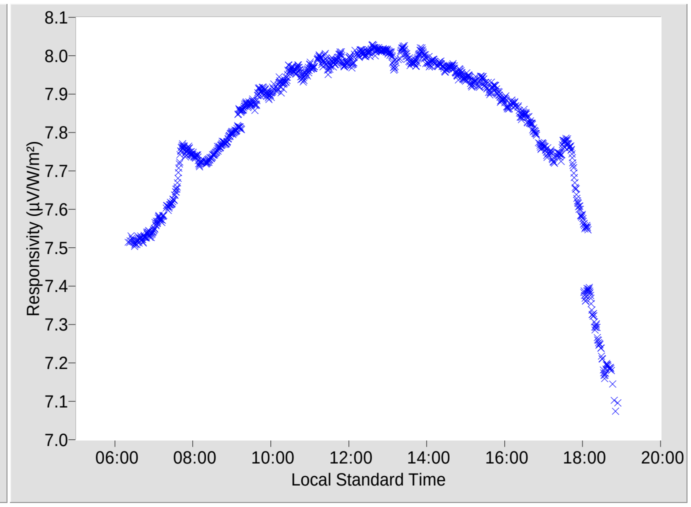


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8870	+1.77 / -2.69	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.59445 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8664	0.62	97.14	7.8829	0.64	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8487	N/A	95.65	7.8659	0.67	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8138	0.66	101.81	7.8744	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7991	0.68	100.01	7.8426	0.70	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7729	0.70	98.27	7.8382	0.72	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7618	0.73	96.59	7.8061	0.74	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7413	0.74	94.95	7.7640	0.77	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7209	0.77	93.36	7.7464	0.80	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7184	0.83	91.79	7.7271	0.84	274.98
18	7.9858	0.58	155.29	7.9833	0.61	204.62	64	7.7411	0.86	90.32	7.7441	0.91	276.40
20	7.9995	0.56	142.61	8.0079	0.60	217.23	66	7.7528	0.93	88.81	7.7768	0.94	277.76
22	7.9712	0.58	134.51	7.9808	0.56	225.35	68	7.7461	1.17	87.33	7.7337	1.23	279.10
24	7.9910	0.56	128.37	8.0011	0.58	231.51	70	7.6297	1.11	85.92	7.6076	1.20	280.50
26	7.9699	0.52	123.49	7.9830	0.55	236.49	72	7.6057	1.18	84.48	7.5530	1.23	281.91
28	7.9540	0.57	119.23	7.9812	0.53	240.58	74	7.5712	1.30	83.03	7.3680	1.64	278.96
30	7.9722	0.58	115.74	7.9674	0.54	244.18	76	7.5525	1.54	81.60	7.3329	2.00	280.42
32	7.9650	0.55	112.60	7.9702	0.57	247.24	78	7.5401	1.77	80.16	7.2534	2.28	281.79
34	7.9273	0.59	109.73	7.9573	0.58	250.10	80	7.5260	2.18	78.68	7.1762	2.66	283.27
36	7.9111	0.60	107.28	7.9490	0.60	252.62	82	7.5094	2.82	77.25	7.1625	3.46	284.69
38	7.8992	0.61	104.94	7.9341	0.60	254.94	84	7.5144	N/A	75.79	N/A	N/A	N/A
40	7.9102	0.59	102.74	7.9427	0.61	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8903	0.68	100.86	7.9168	0.63	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8742	0.60	98.92	7.9221	0.63	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30890F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

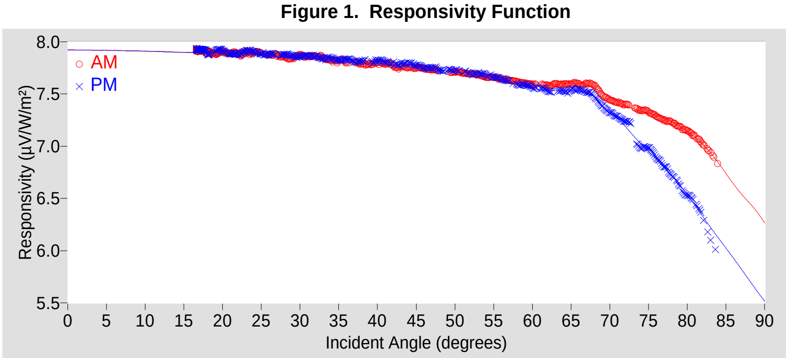
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

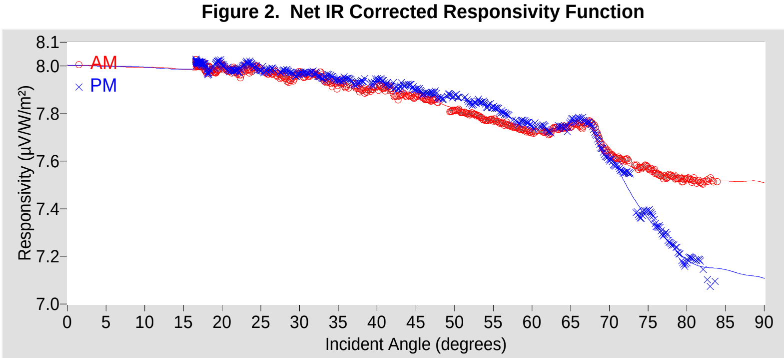


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.53	±1.53
R^2	0.9999991	0.9999976
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.57	±1.57
Net IR corrected R^2	0.9999991	0.9999981
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.9181	*	7.9181	*	7.9181	*	8.0003	*	8.0004	*	8.0003	*
9-18	7.9033	*	7.9033	*	7.9033	*	7.9898	*	7.9899	*	7.9898	*
18-27	7.8902	±1.55	7.8952	±1.54	7.8927	±1.57	7.9822	±1.58	7.9919	±1.57	7.9871	±1.60
27-36	7.8516	±1.59	7.8603	±1.56	7.8560	±1.69	7.9531	±1.61	7.9677	±1.58	7.9604	±1.69
36-45	7.7818	±1.57	7.8098	±1.57	7.7958	±1.70	7.8969	±1.59	7.9310	±1.59	7.9139	±1.70
45-54	7.7140	±1.61	7.7244	±1.63	7.7192	±1.77	7.8277	±1.68	7.8672	±1.62	7.8475	±1.91
54-63	7.6177	±1.63	7.5946	±1.81	7.6062	±2.04	7.7411	±1.62	7.7716	±1.71	7.7564	±1.94
63-72	7.5450	±2.01	7.4544	±2.54	7.4997	±4.11	7.7107	±1.85	7.7056	±2.14	7.7081	±2.78
72-81	7.2737	±2.43	6.8490	±5.38	7.0613	±9.52	7.5532	±1.65	7.3210	±2.78	7.4371	±4.39
81-90	6.6913	*	5.9730	*	6.3322	*	7.5149	*	7.1376	*	7.3263	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

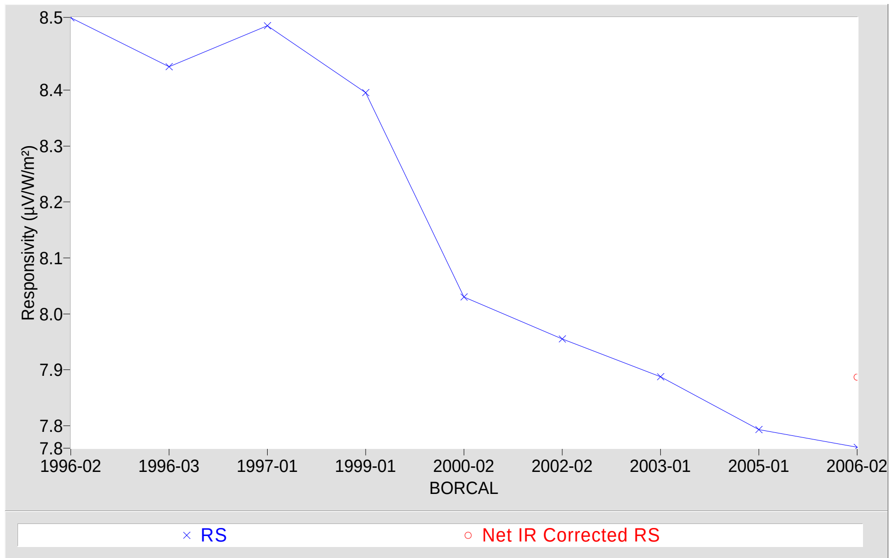
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.7616	+2.02 / -3.00
45° - 55°	7.7116	±1.70
Composite	7.7698	+2.29 / -20.60
45° (Net IR Corr.)	7.8870	+1.77 / -2.69
45° - 55° (Net IR Corr.)	7.8407	±1.78
Composite (Net IR Corr.)	7.8995	+1.99 / -9.60

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



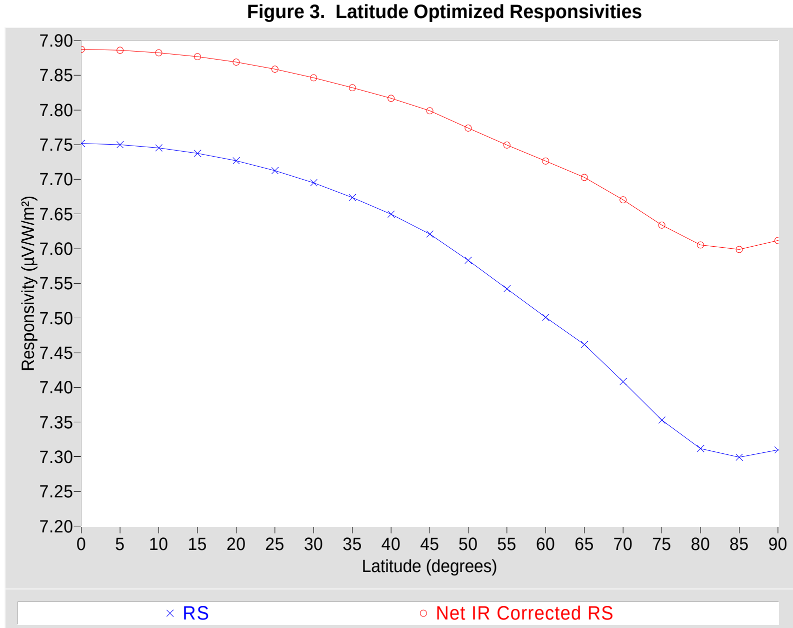
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.7517	+2.68 / -27.60	7.8875	+2.15 / -9.90
5	7.7501	+2.70 / -27.59	7.8862	+2.17 / -9.89
10	7.7453	+2.75 / -27.54	7.8827	+2.20 / -9.85
15	7.7374	+2.84 / -27.47	7.8769	+2.25 / -9.78
20	7.7268	+2.96 / -27.37	7.8693	+2.32 / -9.70
25	7.7124	+3.12 / -27.24	7.8589	+2.42 / -9.58
30	7.6950	+3.27 / -27.07	7.8465	+2.50 / -9.44
35	7.6736	+3.43 / -26.87	7.8319	+2.62 / -9.27
40	7.6498	+3.63 / -26.64	7.8167	+2.78 / -9.10
45	7.6210	+3.99 / -26.36	7.7987	+2.98 / -8.89
50	7.5831	+4.27 / -26.00	7.7740	+3.15 / -8.60
55	7.5424	+4.55 / -25.60	7.7495	+3.25 / -8.32
60	7.5013	+4.66 / -25.19	7.7265	+3.25 / -8.05
65	7.4618	+4.92 / -24.79	7.7030	+3.37 / -7.78
70	7.4084	+4.94 / -24.25	7.6705	+3.24 / -7.39
75	7.3530	+5.08 / -23.68	7.6342	+3.32 / -6.96
80	7.3117	+4.81 / -23.25	7.6053	+3.07 / -6.62
85	7.2992	+4.44 / -23.12	7.5991	+2.70 / -6.54
90	7.3097	+4.26 / -23.23	7.6120	+2.56 / -6.70

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

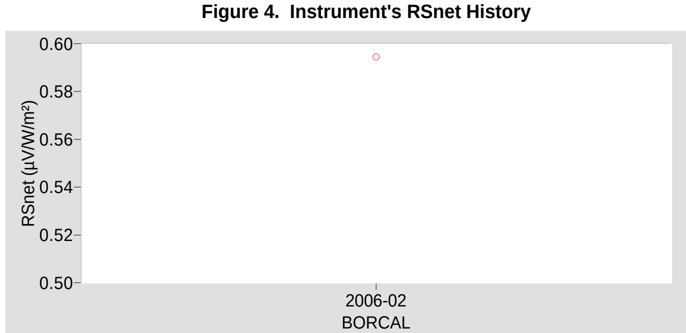
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30891F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30891F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

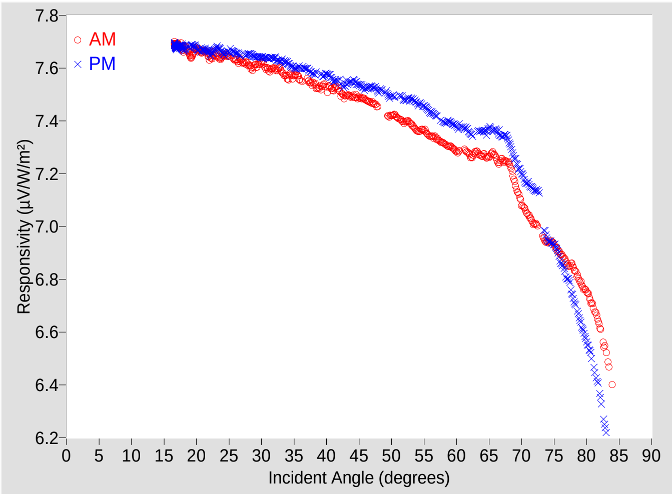


Figure 2. Responsivity vs Local Standard Time

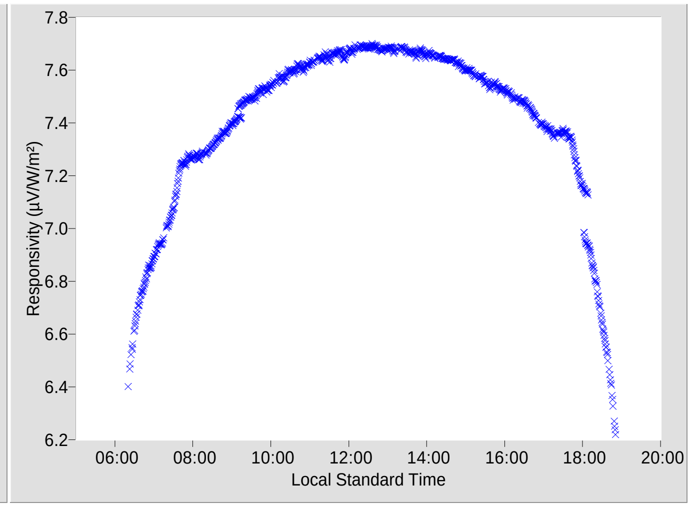


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.5117	+2.29 / -3.53	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4809	0.56	97.14	7.5224	0.57	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4533	N/A	95.65	7.5136	0.58	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4215	0.62	101.81	7.4932	0.60	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3960	0.65	100.01	7.4789	0.60	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3624	0.68	98.27	7.4654	0.63	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3421	0.72	96.59	7.4323	0.67	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3165	0.72	94.95	7.3950	0.66	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2840	0.74	93.36	7.3782	0.69	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2709	0.79	91.79	7.3542	0.73	274.98
18	7.6747	0.55	155.29	7.6773	0.50	204.62	64	7.2711	0.82	90.32	7.3620	0.75	276.40
20	7.6709	0.53	142.61	7.6755	0.51	217.23	66	7.2638	0.92	88.81	7.3649	0.82	277.76
22	7.6434	0.52	134.51	7.6587	0.51	225.35	68	7.2383	1.09	87.33	7.3270	1.04	279.10
24	7.6438	0.53	128.37	7.6580	0.54	231.51	70	7.0893	1.23	85.92	7.2031	1.12	280.50
26	7.6327	0.49	123.49	7.6574	0.51	236.49	72	7.0099	1.13	84.48	7.1372	1.03	281.91
28	7.6129	0.52	119.23	7.6535	0.49	240.58	74	6.9407	1.23	83.03	6.9516	1.43	278.96
30	7.6221	0.52	115.74	7.6407	0.49	244.18	76	6.8974	1.52	81.60	6.8649	1.82	280.42
32	7.5976	0.50	112.60	7.6390	0.50	247.24	78	6.8443	1.72	80.16	6.7269	2.16	281.79
34	7.5640	0.53	109.73	7.6201	0.54	250.10	80	6.7538	2.13	78.68	6.5642	2.40	283.27
36	7.5535	0.55	107.28	7.6003	0.51	252.65	82	6.6243	2.87	77.25	6.3637	3.30	284.76
38	7.5412	0.56	104.94	7.5781	0.54	254.94	84	6.4012	N/A	75.79	N/A	N/A	N/A
40	7.5250	0.56	102.74	7.5775	0.54	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5117	0.60	100.86	7.5502	0.58	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4928	0.54	98.92	7.5517	0.55	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

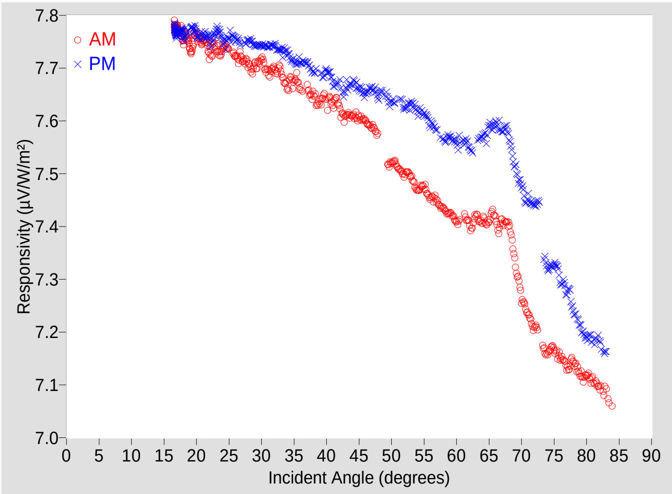

Figure 4. Responsivity vs Local Standard Time

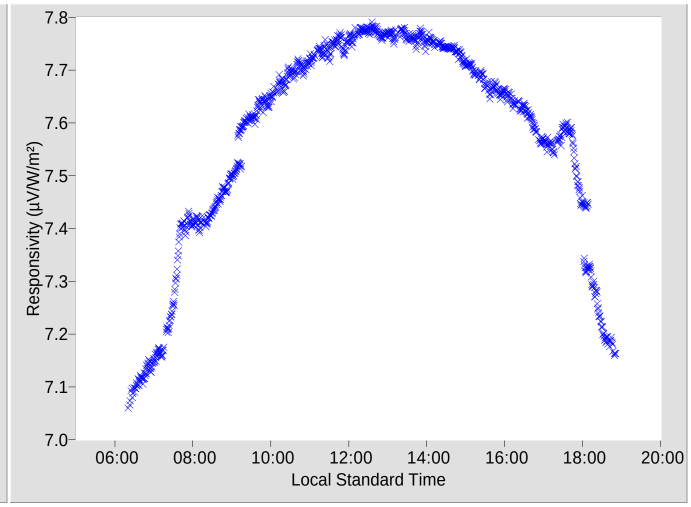

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.6332	+2.09 / -3.53	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.57550 µV/W/m², determination date: 06/08/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6004	0.62	97.14	7.6512	0.64	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5728	N/A	95.65	7.6483	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5214	0.66	101.81	7.6354	0.68	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4987	0.68	100.01	7.6240	0.69	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4695	0.72	98.27	7.6172	0.72	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4548	0.75	96.59	7.5936	0.75	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4345	0.76	94.95	7.5635	0.76	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4084	0.79	93.36	7.5564	0.80	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4029	0.85	91.79	7.5473	0.84	274.98
18	7.7595	0.58	155.29	7.7639	0.53	204.62	64	7.4121	0.88	90.32	7.5715	0.90	276.40
20	7.7611	0.58	142.61	7.7666	0.54	217.23	66	7.4138	0.97	88.81	7.5936	0.95	277.76
22	7.7298	0.56	134.51	7.7537	0.56	225.35	68	7.4019	1.11	87.33	7.5739	1.12	279.10
24	7.7351	0.56	128.37	7.7531	0.59	231.51	70	7.2676	1.23	85.92	7.4778	1.21	280.50
26	7.7241	0.53	123.49	7.7553	0.56	236.49	72	7.2090	1.21	84.48	7.4418	1.23	281.91
28	7.7075	0.55	119.23	7.7523	0.54	240.58	74	7.1603	1.33	83.03	7.3219	1.64	278.96
30	7.7167	0.56	115.74	7.7429	0.54	244.18	76	7.1533	1.56	81.60	7.2946	1.90	280.42
32	7.6974	0.55	112.60	7.7432	0.55	247.24	78	7.1432	1.82	80.16	7.2405	2.24	281.79
34	7.6663	0.57	109.73	7.7289	0.58	250.10	80	7.1193	2.23	78.68	7.1897	2.65	283.27
36	7.6597	0.60	107.28	7.7123	0.57	252.65	82	7.0960	2.89	77.25	7.1814	3.42	284.76
38	7.6486	0.61	104.94	7.6920	0.59	254.94	84	7.0600	N/A	75.79	N/A	N/A	N/A
40	7.6366	0.61	102.74	7.6949	0.61	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6247	0.65	100.86	7.6701	0.64	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6093	0.60	98.92	7.6729	0.62	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

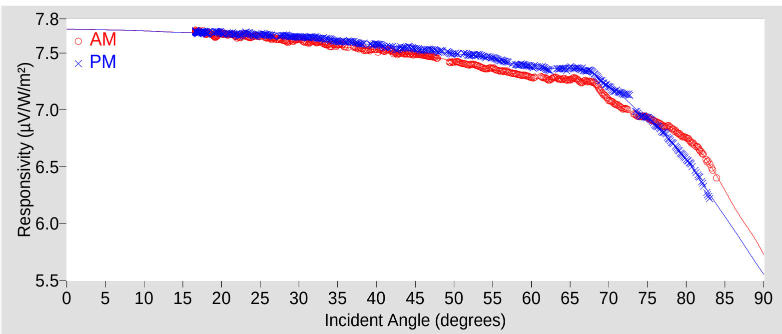
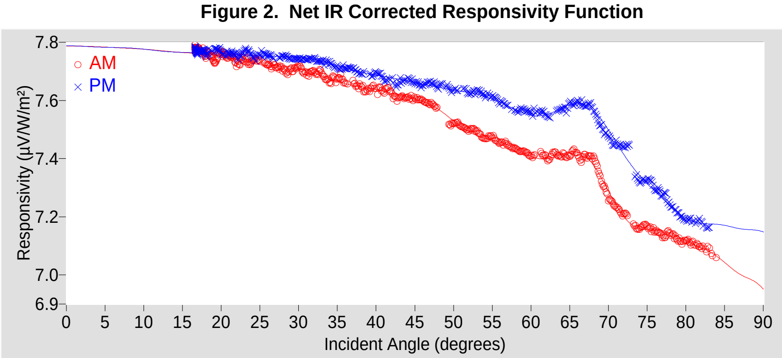


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.49	±1.49
R^2	0.9999993	0.9999989
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.0°
Net IR corr. uncert. U95 (%)	±1.56	±1.56
Net IR corrected R^2	0.9999993	0.9999992
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.0°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.7041	*	7.7041	*	7.7041	*	7.7837	*	7.7837	*	7.7837	*
9-18	7.6851	*	7.6854	*	7.6853	*	7.7688	*	7.7692	*	7.7690	*
18-27	7.6506	±1.53	7.6641	±1.50	7.6573	±1.57	7.7397	±1.58	7.7577	±1.56	7.7487	±1.61
27-36	7.5980	±1.57	7.6359	±1.53	7.6169	±1.77	7.6962	±1.60	7.7399	±1.57	7.7180	±1.78
36-45	7.5229	±1.55	7.5692	±1.55	7.5461	±1.82	7.6344	±1.59	7.6865	±1.59	7.6605	±1.82
45-54	7.4328	±1.68	7.5013	±1.56	7.4671	±2.19	7.5429	±1.78	7.6395	±1.58	7.5912	±2.38
54-63	7.3120	±1.64	7.4010	±1.65	7.3565	±2.40	7.4314	±1.63	7.5724	±1.62	7.5019	±2.56
63-72	7.2033	±2.29	7.3038	±2.16	7.2536	±3.79	7.3637	±2.09	7.5469	±1.87	7.4553	±3.97
72-81	6.8811	±2.51	6.8300	±4.55	6.8556	±6.31	7.1518	±1.67	7.2871	±2.19	7.2194	±3.45
81-90	6.2310	*	6.0100	*	6.1205	*	7.0330	*	7.1663	*	7.0996	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.5117	+2.29 / -3.53
45° - 55°	7.4586	±1.93
Composite	7.5362	+2.41 / -17.66
45° (Net IR Corr.)	7.6332	+2.09 / -3.53
45° - 55° (Net IR Corr.)	7.5836	±2.03
Composite (Net IR Corr.)	7.6618	+2.05 / -7.84

† Valid incident angle ranges:

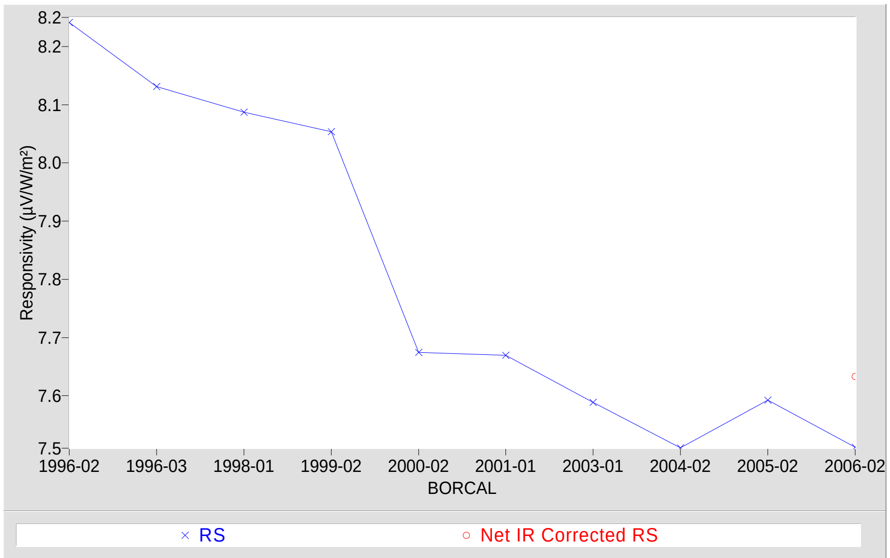
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.0°, 16.6° to 83.0° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



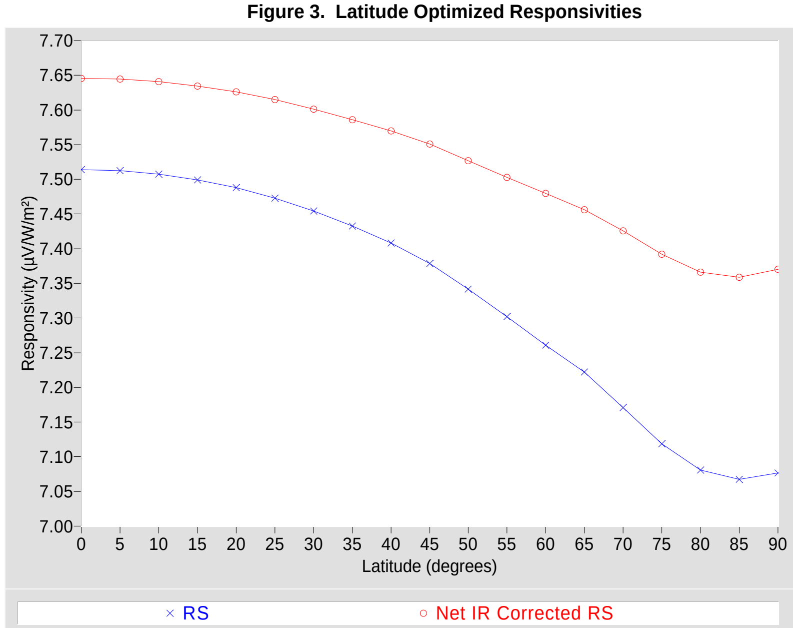
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.5138	+3.00 / -24.81	7.6454	+2.43 / -8.90
5	7.5125	+3.01 / -24.80	7.6445	+2.44 / -8.89
10	7.5076	+3.07 / -24.75	7.6408	+2.48 / -8.84
15	7.4993	+3.17 / -24.67	7.6345	+2.54 / -8.77
20	7.4879	+3.31 / -24.55	7.6260	+2.63 / -8.67
25	7.4729	+3.49 / -24.40	7.6149	+2.75 / -8.54
30	7.4544	+3.64 / -24.21	7.6013	+2.84 / -8.38
35	7.4325	+3.79 / -23.99	7.5860	+2.93 / -8.19
40	7.4080	+3.96 / -23.74	7.5698	+3.01 / -8.00
45	7.3787	+4.19 / -23.44	7.5511	+3.17 / -7.78
50	7.3417	+4.52 / -23.05	7.5270	+3.37 / -7.49
55	7.3019	+4.89 / -22.63	7.5029	+3.58 / -7.20
60	7.2610	+4.91 / -22.20	7.4798	+3.47 / -6.92
65	7.2220	+4.96 / -21.78	7.4564	+3.40 / -6.63
70	7.1708	+5.20 / -21.22	7.4256	+3.47 / -6.26
75	7.1187	+5.39 / -20.64	7.3919	+3.59 / -5.84
80	7.0809	+5.20 / -20.22	7.3659	+3.47 / -5.52
85	7.0676	+4.47 / -20.07	7.3588	+3.51 / -5.43
90	7.0767	+4.28 / -20.18	7.3703	+3.37 / -5.58

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

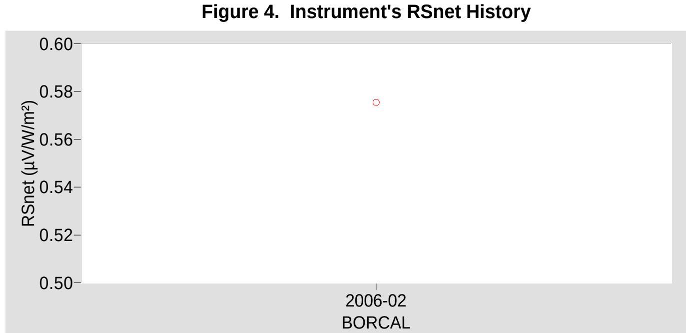
Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 30894F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: SGP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ____________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ____________________

Calibration Results

30894F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

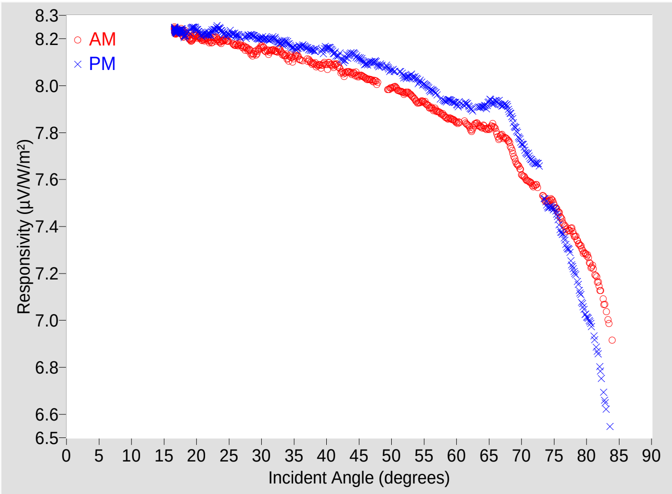


Figure 2. Responsivity vs Local Standard Time

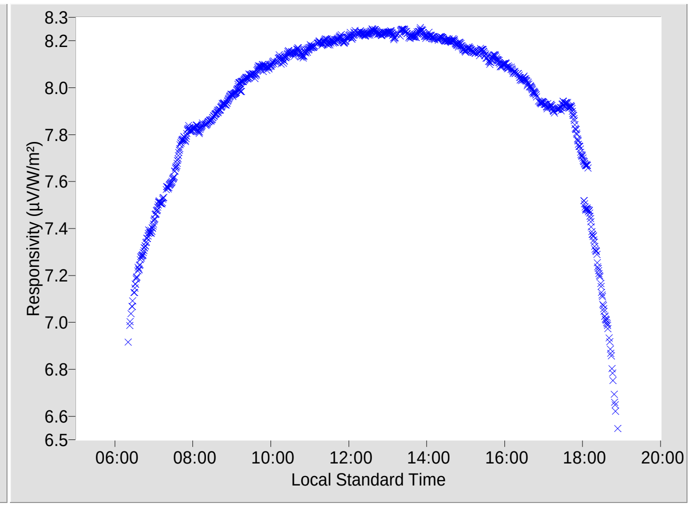


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0786	+2.15 / -3.39	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0323	0.55	97.14	8.0915	0.58	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0051	N/A	95.65	8.0865	0.58	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9914	0.62	101.81	8.0655	0.60	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9689	0.64	100.01	8.0370	0.61	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9301	0.67	98.27	8.0221	0.66	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9061	0.72	96.59	7.9798	0.66	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8745	0.71	94.95	7.9366	0.66	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8440	0.73	93.36	7.9204	0.68	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8201	0.80	91.79	7.9071	0.72	274.98
18	8.2212	0.54	155.29	8.2227	0.52	204.62	64	7.8261	0.81	90.32	7.9119	0.74	276.40
20	8.2125	0.51	142.61	8.2399	0.53	217.23	66	7.8101	0.95	88.81	7.9320	0.79	277.76
22	8.1932	0.49	134.51	8.2208	0.50	225.35	68	7.7600	1.11	87.33	7.9005	1.03	279.10
24	8.1894	0.50	128.37	8.2273	0.55	231.51	70	7.6286	1.12	85.92	7.7564	1.16	280.50
26	8.1754	0.48	123.49	8.2156	0.51	236.49	72	7.5747	1.09	84.48	7.6700	1.04	281.91
28	8.1539	0.55	119.23	8.2143	0.49	240.69	74	7.5073	1.21	83.03	7.4882	1.40	278.96
30	8.1656	0.54	115.74	8.2017	0.49	244.18	76	7.4434	1.58	81.60	7.3817	1.91	280.42
32	8.1493	0.50	112.60	8.2023	0.52	247.24	78	7.3721	1.69	80.16	7.2186	2.22	281.79
34	8.1192	0.54	109.73	8.1829	0.54	250.10	80	7.2780	2.10	78.68	7.0169	2.34	283.27
36	8.1099	0.54	107.28	8.1677	0.52	252.62	82	7.1414	2.79	77.25	6.7992	3.44	284.76
38	8.0949	0.54	104.94	8.1496	0.52	254.94	84	6.9156	N/A	75.79	N/A	N/A	N/A
40	8.0874	0.54	102.74	8.1621	0.55	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0748	0.62	100.86	8.1259	0.60	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0535	0.54	98.92	8.1391	0.56	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

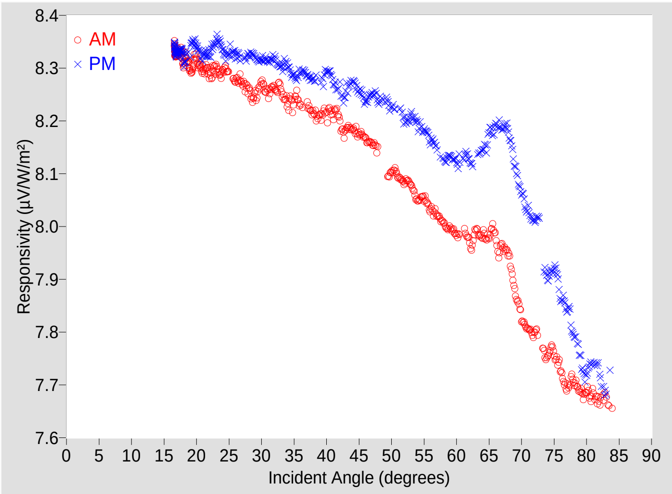

Figure 4. Responsivity vs Local Standard Time

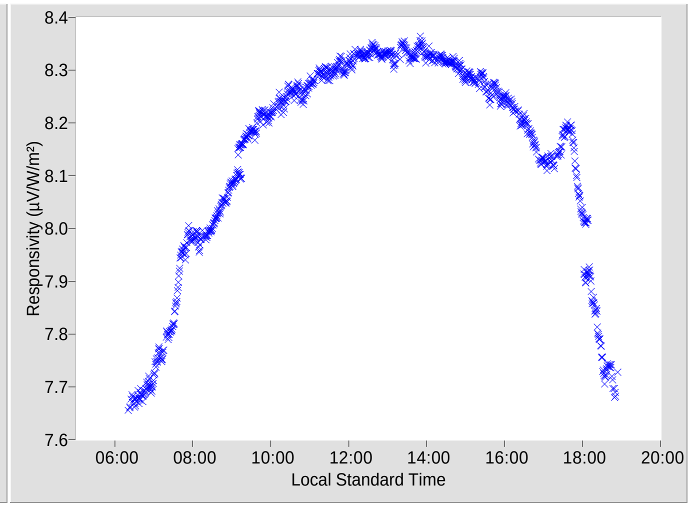

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2150	+1.94 / -3.37	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64666 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1666	0.60	97.14	8.2361	0.63	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1393	N/A	95.65	8.2378	0.64	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1037	0.66	101.81	8.2253	0.67	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0844	0.67	100.01	8.2001	0.68	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0504	0.71	98.27	8.1927	0.72	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0327	0.75	96.59	8.1611	0.72	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0072	0.75	94.95	8.1259	0.74	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9838	0.77	93.36	8.1206	0.78	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9684	0.84	91.79	8.1240	0.82	274.98
18	8.3164	0.56	155.29	8.3200	0.54	204.62	64	7.9845	0.86	90.32	8.1473	0.88	276.40
20	8.3138	0.54	142.61	8.3422	0.57	217.23	66	7.9786	0.99	88.81	8.1890	0.93	277.76
22	8.2903	0.53	134.51	8.3275	0.54	225.35	68	7.9438	1.11	87.33	8.1780	1.09	279.10
24	8.2920	0.53	128.37	8.3341	0.60	231.51	70	7.8290	1.13	85.92	8.0650	1.19	280.50
26	8.2780	0.52	123.49	8.3256	0.55	236.49	72	7.7985	1.17	84.48	8.0122	1.19	281.91
28	8.2602	0.57	119.23	8.3246	0.53	240.58	74	7.7541	1.30	83.03	7.9043	1.59	278.96
30	8.2719	0.57	115.74	8.3165	0.53	244.18	76	7.7308	1.56	81.60	7.8646	1.89	280.42
32	8.2615	0.56	112.60	8.3193	0.55	247.24	78	7.7080	1.77	80.16	7.7957	2.20	281.79
34	8.2342	0.58	109.73	8.3052	0.59	250.10	80	7.6887	2.17	78.68	7.7197	2.57	283.27
36	8.2292	0.58	107.28	8.2932	0.57	252.62	82	7.6713	2.80	77.25	7.7180	3.31	284.76
38	8.2157	0.59	104.94	8.2775	0.57	254.94	84	7.6559	N/A	75.79	N/A	N/A	N/A
40	8.2128	0.59	102.74	8.2941	0.61	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2017	0.66	100.86	8.2606	0.64	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1844	0.60	98.92	8.2753	0.61	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

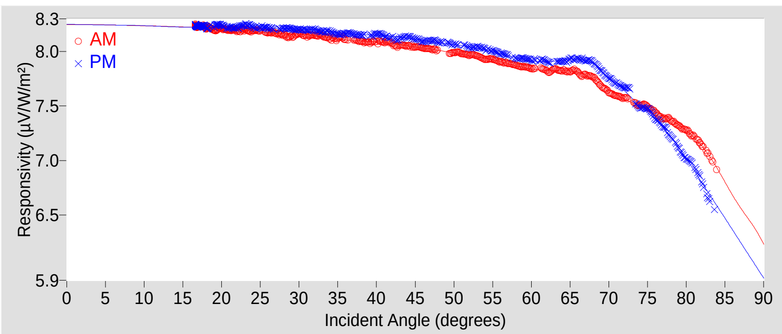
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

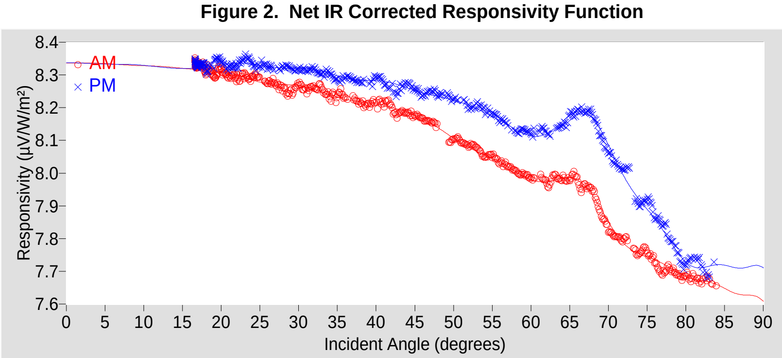


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.49	±1.49
R²	0.9999994	0.9999989
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.51	±1.51
Net IR corrected R²	0.9999995	0.9999992
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.2449	*	8.2449	*	8.2449	*	8.3344	*	8.3344	*	8.3344	*
9-18	8.2293	*	8.2296	*	8.2295	*	8.3233	*	8.3238	*	8.3235	*
18-27	8.1959	±1.52	8.2256	±1.50	8.2107	±1.60	8.2960	±1.53	8.3308	±1.51	8.3134	±1.61
27-36	8.1462	±1.53	8.1980	±1.52	8.1721	±1.75	8.2567	±1.53	8.3146	±1.52	8.2856	±1.72
36-45	8.0823	±1.54	8.1464	±1.52	8.1144	±1.82	8.2075	±1.53	8.2782	±1.52	8.2429	±1.78
45-54	7.9952	±1.61	8.0699	±1.59	8.0326	±2.11	8.1188	±1.67	8.2253	±1.56	8.1721	±2.26
54-63	7.8723	±1.65	7.9471	±1.65	7.9097	±2.26	8.0065	±1.60	8.1397	±1.58	8.0731	±2.40
63-72	7.7453	±2.17	7.8634	±2.19	7.8044	±3.58	7.9256	±1.92	8.1365	±1.85	8.0311	±3.81
72-81	7.4256	±2.61	7.3355	±4.86	7.3805	±6.83	7.7297	±1.66	7.8491	±2.30	7.7894	±3.31
81-90	6.7440	*	6.4152	*	6.5796	*	7.6451	*	7.7145	*	7.6798	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

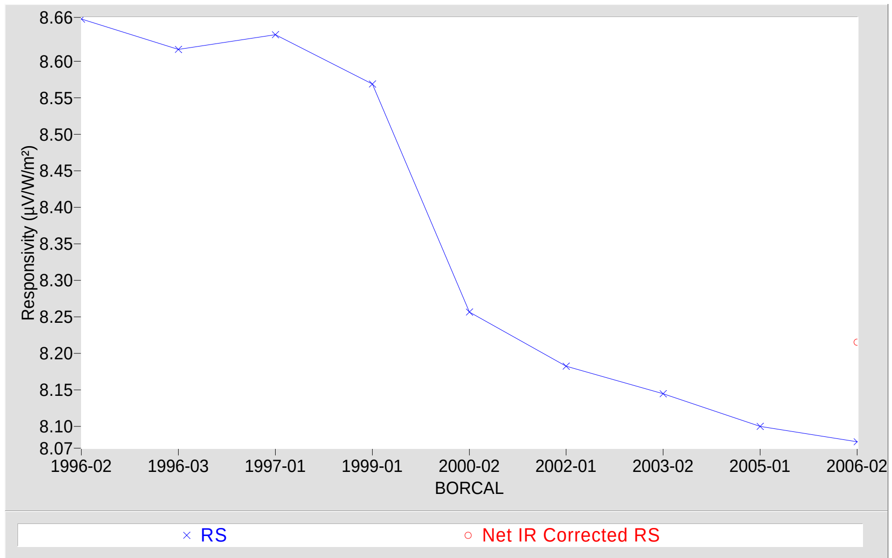
Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.0786	+2.15 / -3.39
45° - 55°	8.0235	±1.91
Composite	8.0872	+2.32 / -18.03
45° (Net IR Corr.)	8.2150	+1.94 / -3.37
45° - 55° (Net IR Corr.)	8.1639	±1.97
Composite (Net IR Corr.)	8.2284	+2.00 / -7.02

† Valid incident angle ranges:

45°:	30.0° to 60.0°,	30.0° to 60.0° (Net IR corr.)
45° - 55°:	45.0° to 55.0°,	45.0° to 55.0° (Net IR corr.)
Composite:	16.6° to 83.6°,	16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



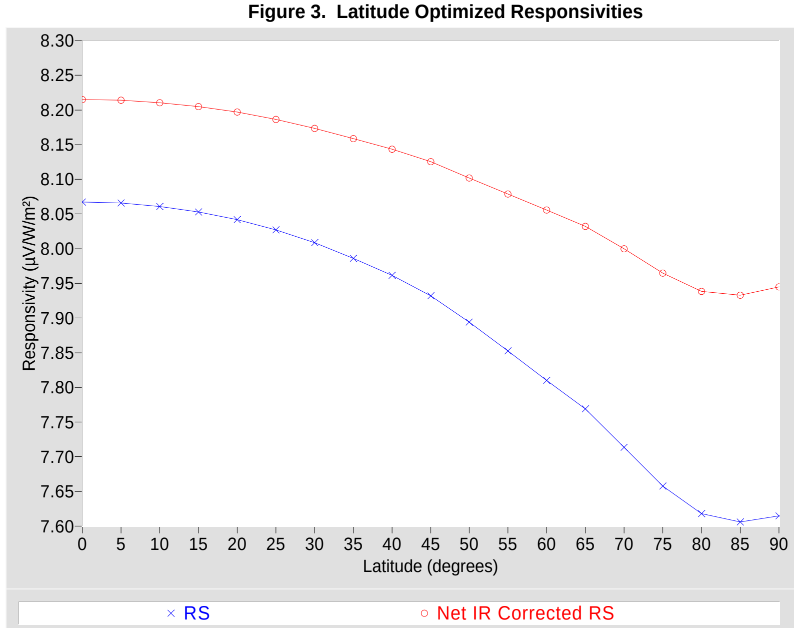
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.0672	+2.70 / -25.28	8.2151	+2.12 / -7.35
5	8.0657	+2.72 / -25.27	8.2140	+2.13 / -7.34
10	8.0610	+2.77 / -25.22	8.2106	+2.16 / -7.30
15	8.0530	+2.86 / -25.15	8.2049	+2.21 / -7.24
20	8.0420	+2.98 / -25.05	8.1972	+2.28 / -7.15
25	8.0270	+3.14 / -24.91	8.1865	+2.38 / -7.03
30	8.0085	+3.29 / -24.73	8.1735	+2.49 / -6.89
35	7.9862	+3.45 / -24.53	8.1587	+2.64 / -6.72
40	7.9616	+3.69 / -24.29	8.1435	+2.80 / -6.55
45	7.9320	+4.05 / -24.01	8.1256	+2.99 / -6.35
50	7.8940	+4.35 / -23.64	8.1021	+3.14 / -6.09
55	7.8528	+4.72 / -23.24	8.0786	+3.35 / -5.83
60	7.8101	+4.80 / -22.83	8.0559	+3.29 / -5.57
65	7.7689	+5.09 / -22.42	8.0323	+3.44 / -5.30
70	7.7137	+5.25 / -21.86	8.0001	+3.42 / -4.94
75	7.6578	+5.39 / -21.29	7.9647	+3.50 / -4.54
80	7.6181	+4.99 / -20.88	7.9385	+3.48 / -4.24
85	7.6059	+4.50 / -20.76	7.9330	+3.54 / -4.18
90	7.6149	+4.38 / -20.85	7.9447	+3.41 / -4.31

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

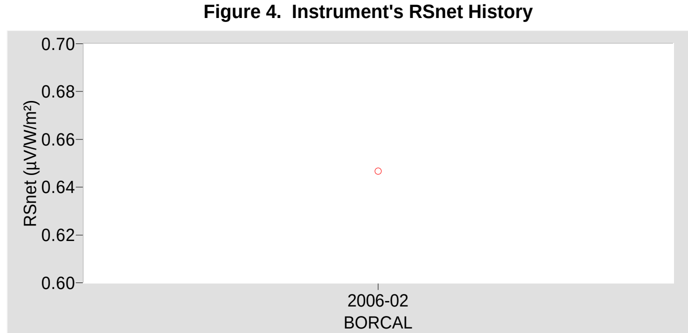
Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30902F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30902F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

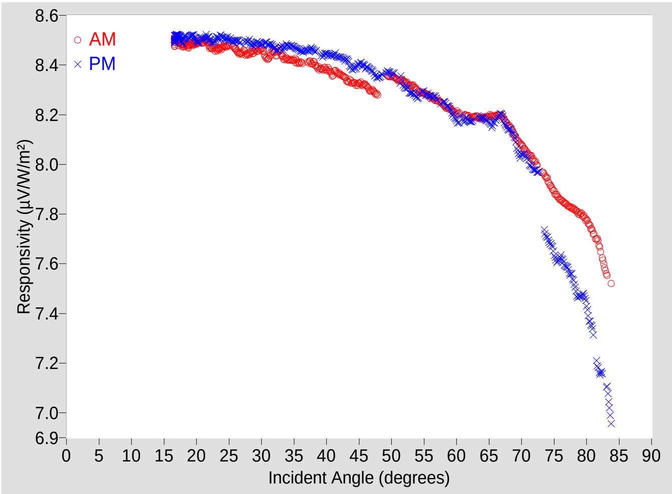


Figure 2. Responsivity vs Local Standard Time

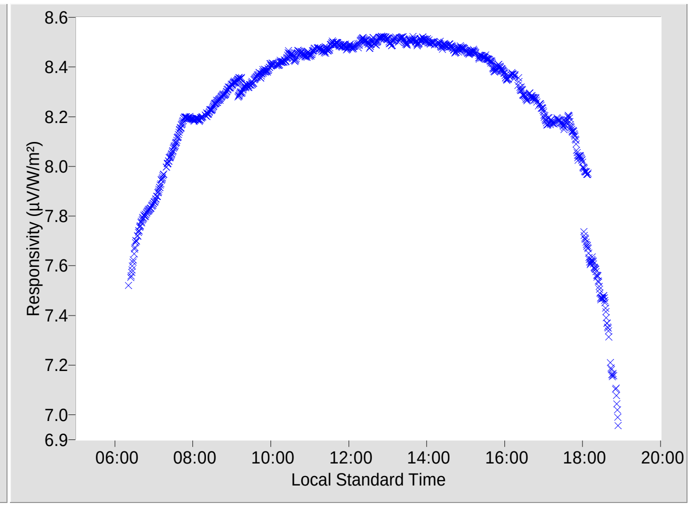


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3654	+2.06 / -2.68	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3190	0.58	97.11	8.3939	0.58	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2853	N/A	95.68	8.3500	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3544	0.61	101.84	8.3635	0.59	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3318	0.65	99.98	8.3132	0.72	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2998	0.67	98.30	8.2719	0.63	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2704	0.68	96.56	8.2738	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2401	0.71	94.97	8.2512	0.66	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2072	0.73	93.33	8.1756	0.73	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1895	0.76	91.82	8.1745	0.69	274.95
18	8.4820	0.53	155.40	8.5026	0.51	204.72	64	8.1870	0.79	90.34	8.1862	0.73	276.38
20	8.4884	0.47	142.70	8.4997	0.50	217.13	66	8.1951	0.84	88.84	8.1782	0.84	277.74
22	8.4783	0.55	134.59	8.5053	0.52	225.42	68	8.1563	1.01	87.35	8.1424	0.96	279.12
24	8.4706	0.49	128.29	8.5111	0.49	231.57	70	8.0795	1.07	85.95	8.0385	1.02	280.52
26	8.4642	0.51	123.42	8.4985	0.49	236.55	72	8.0109	1.10	84.45	7.9778	1.01	281.89
28	8.4444	0.49	119.28	8.4943	0.51	240.63	74	7.9395	1.26	83.05	7.7009	1.47	278.98
30	8.4631	0.55	115.78	8.4847	0.49	244.13	76	7.8570	1.42	81.57	7.6246	1.55	280.39
32	8.4489	0.54	112.64	8.4678	0.52	247.28	78	7.8219	1.61	80.19	7.5304	1.96	281.81
34	8.4238	0.50	109.77	8.4793	0.52	250.14	80	7.7745	2.01	78.70	7.4293	2.31	283.29
36	8.4090	0.51	107.27	8.4582	0.52	252.65	82	7.6704	2.70	77.27	7.1647	2.90	284.76
38	8.4073	0.54	104.97	8.4593	0.52	254.97	84	7.5208	N/A	75.91	6.9563	N/A	286.07
40	8.3839	0.55	102.80	8.4439	0.53	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3642	0.54	100.83	8.4310	0.56	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3298	0.55	98.94	8.3869	0.60	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

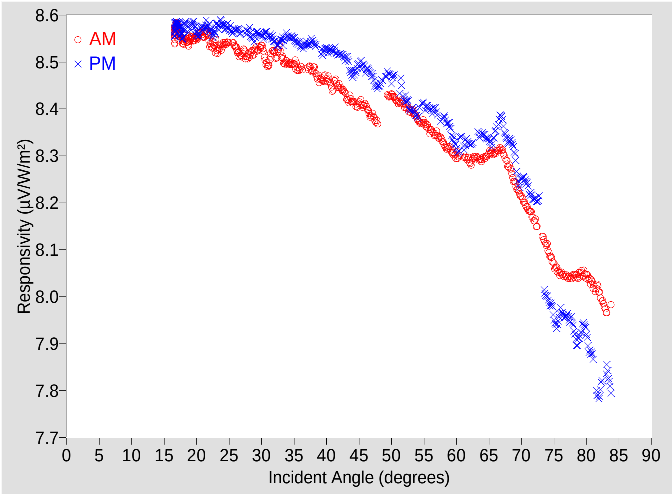

Figure 4. Responsivity vs Local Standard Time

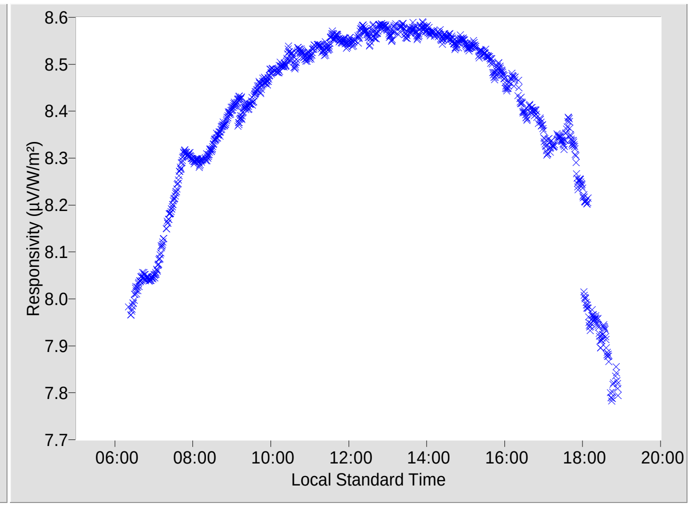

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.4540	+1.88 / -2.39	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.55035 µV/W/m², determination date: 07/10/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4064	0.61	97.11	8.4870	0.61	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3757	N/A	95.68	8.4476	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4284	0.64	101.84	8.4660	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4070	0.66	99.98	8.4229	0.75	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3796	0.69	98.30	8.3877	0.68	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3532	0.70	96.56	8.3983	0.67	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3283	0.73	94.97	8.3831	0.70	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2999	0.75	93.33	8.3162	0.79	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2888	0.79	91.82	8.3262	0.77	274.95
18	8.5480	0.55	155.40	8.5669	0.53	204.72	64	8.2935	0.83	90.34	8.3460	0.80	276.38
20	8.5522	0.49	142.70	8.5651	0.52	217.13	66	8.3076	0.88	88.84	8.3517	0.95	277.74
22	8.5446	0.57	134.59	8.5717	0.54	225.42	68	8.2790	1.02	87.35	8.3324	1.00	279.12
24	8.5357	0.51	128.29	8.5791	0.51	231.57	70	8.2140	1.08	85.95	8.2488	1.09	280.52
26	8.5313	0.52	123.42	8.5687	0.51	236.55	72	8.1616	1.14	84.45	8.2083	1.11	281.89
28	8.5120	0.51	119.28	8.5649	0.53	240.63	74	8.1056	1.28	83.05	7.9967	1.55	278.98
30	8.5324	0.57	115.78	8.5567	0.51	244.13	76	8.0493	1.45	81.57	7.9658	1.73	280.39
32	8.5198	0.57	112.64	8.5421	0.54	247.28	78	8.0440	1.68	80.19	7.9375	2.05	281.81
34	8.4990	0.52	109.77	8.5557	0.55	250.14	80	8.0441	2.06	78.70	7.9199	2.43	283.29
36	8.4859	0.54	107.27	8.5354	0.55	252.65	82	8.0099	2.65	77.27	7.7960	3.11	284.76
38	8.4833	0.56	104.97	8.5395	0.55	254.97	84	7.9832	N/A	75.91	7.7938	N/A	286.07
40	8.4651	0.58	102.80	8.5271	0.56	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4476	0.57	100.83	8.5162	0.59	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4165	0.58	98.94	8.4753	0.62	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

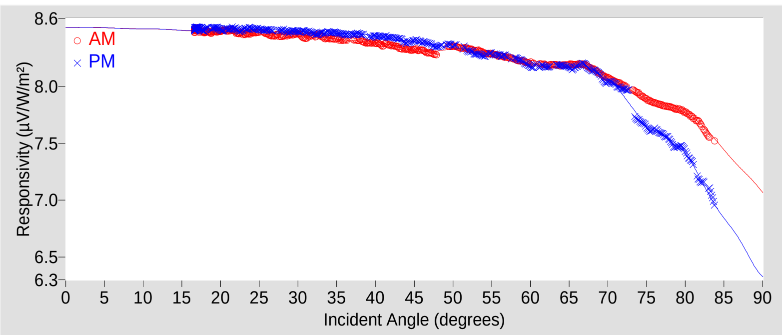
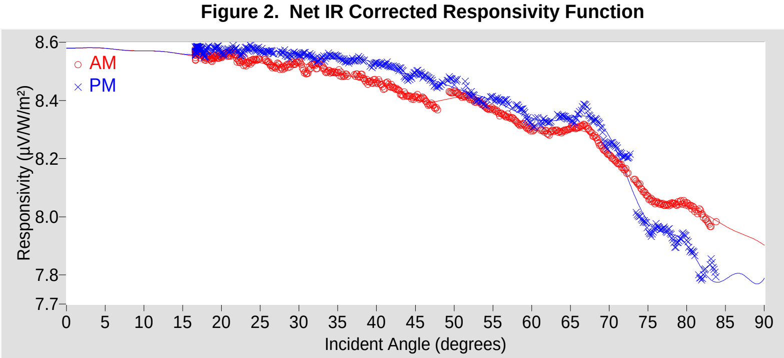


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.41	±1.41
R²	0.9999992	0.9999967
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.45	±1.45
Net IR corrected R²	0.9999994	0.9999973
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.5167	*	8.5167	*	8.5167	*	8.5777	*	8.5777	*	8.5777	*
9-18	8.4992	*	8.5008	*	8.5000	*	8.5631	*	8.5646	*	8.5638	*
18-27	8.4758	±1.42	8.5037	±1.41	8.4897	±1.48	8.5414	±1.46	8.5706	±1.45	8.5560	±1.52
27-36	8.4442	±1.43	8.4793	±1.42	8.4617	±1.58	8.5152	±1.46	8.5529	±1.46	8.5340	±1.59
36-45	8.3774	±1.51	8.4371	±1.47	8.4073	±1.89	8.4585	±1.52	8.5204	±1.49	8.4895	±1.85
45-54	8.3208	±1.42	8.3490	±1.52	8.3349	±1.63	8.4025	±1.45	8.4504	±1.51	8.4265	±1.64
54-63	8.2380	±1.58	8.2290	±1.58	8.2335	±1.82	8.3270	±1.56	8.3627	±1.53	8.3448	±1.75
63-72	8.1460	±1.73	8.1265	±1.92	8.1362	±2.64	8.2667	±1.63	8.3123	±1.72	8.2895	±2.12
72-81	7.8699	±2.17	7.6256	±3.90	7.7478	±6.13	8.0722	±1.64	7.9854	±2.24	8.0288	±2.81
81-90	7.4079	*	6.8011	*	7.1045	*	7.9643	*	7.7958	*	7.8801	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.3654	+2.06 / -2.68
45° - 55°	8.3290	±1.57
Composite	8.3818	+2.07 / -16.59
45° (Net IR Corr.)	8.4540	+1.88 / -2.39
45° - 55° (Net IR Corr.)	8.4215	±1.60
Composite (Net IR Corr.)	8.4759	+1.86 / -8.37

† Valid incident angle ranges:

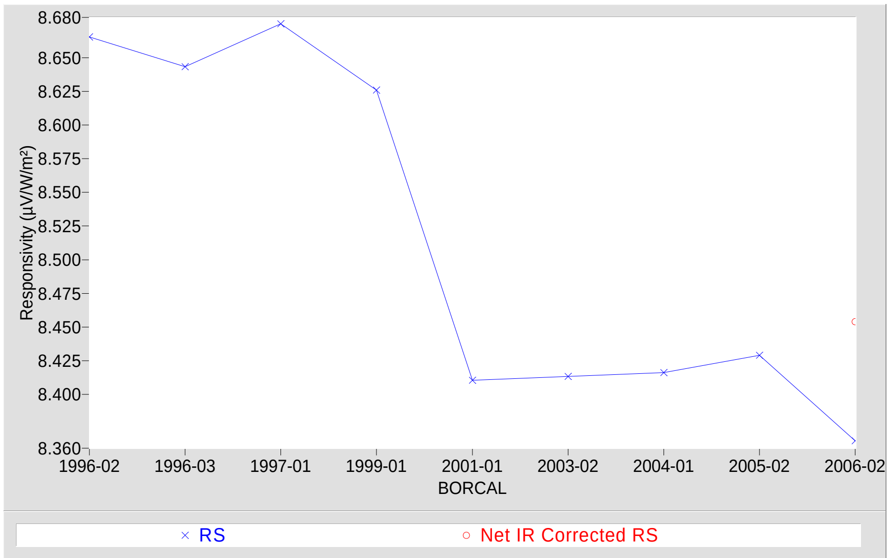
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



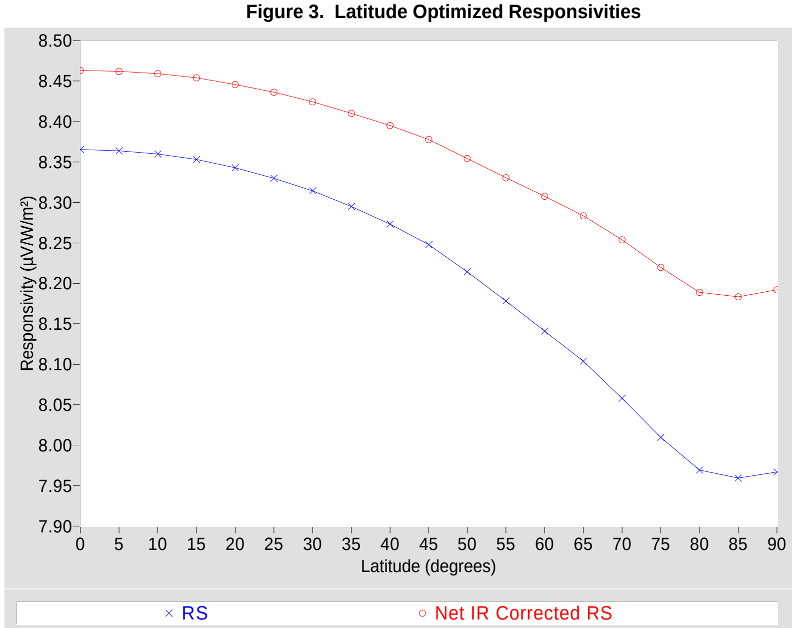
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.3653	+2.34 / -23.37	8.4633	+2.01 / -8.33
5	8.3639	+2.35 / -23.36	8.4622	+2.02 / -8.32
10	8.3598	+2.39 / -23.32	8.4591	+2.05 / -8.28
15	8.3530	+2.46 / -23.26	8.4539	+2.09 / -8.23
20	8.3427	+2.56 / -23.16	8.4460	+2.16 / -8.14
25	8.3299	+2.69 / -23.04	8.4361	+2.25 / -8.04
30	8.3145	+2.79 / -22.90	8.4246	+2.31 / -7.91
35	8.2950	+2.94 / -22.72	8.4103	+2.44 / -7.76
40	8.2734	+3.17 / -22.52	8.3951	+2.59 / -7.60
45	8.2481	+3.46 / -22.28	8.3778	+2.76 / -7.41
50	8.2144	+3.75 / -21.96	8.3543	+2.96 / -7.15
55	8.1781	+3.93 / -21.62	8.3305	+3.02 / -6.89
60	8.1411	+4.25 / -21.26	8.3076	+3.21 / -6.64
65	8.1040	+4.27 / -20.90	8.2834	+3.15 / -6.38
70	8.0581	+4.31 / -20.45	8.2538	+3.08 / -6.05
75	8.0096	+4.30 / -19.97	8.2197	+2.99 / -5.67
80	7.9692	+4.03 / -19.57	8.1890	+2.83 / -5.33
85	7.9595	+3.32 / -19.47	8.1834	+2.46 / -5.27
90	7.9668	+3.07 / -19.54	8.1922	+2.37 / -5.36

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

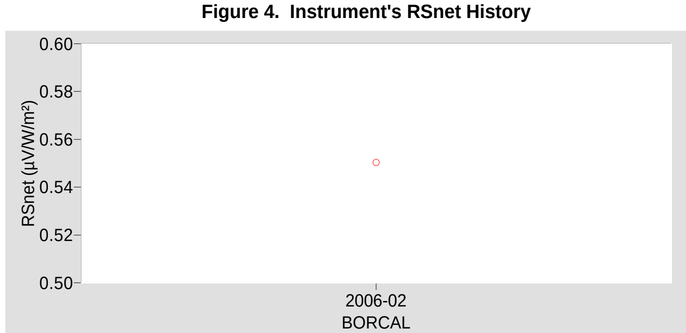
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30929F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

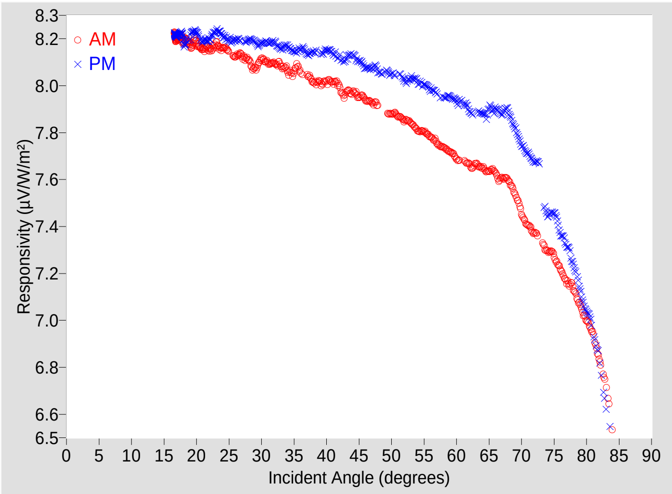

Figure 2. Responsivity vs Local Standard Time

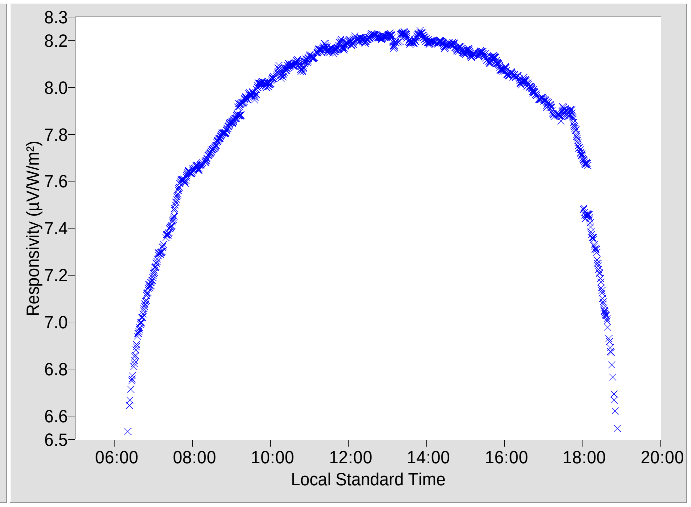

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0279	+2.57 / -4.66	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9398	0.57	97.14	8.0756	0.60	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9149	N/A	95.65	8.0593	0.61	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8810	0.62	101.81	8.0502	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8526	0.65	100.01	8.0209	0.63	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8111	0.68	98.27	8.0177	0.66	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7822	0.74	96.59	7.9825	0.65	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7375	0.71	94.95	7.9503	0.63	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6884	0.75	93.36	7.9322	0.69	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6619	0.78	91.79	7.8902	0.76	274.98
18	8.1937	0.52	155.29	8.1941	0.62	204.62	64	7.6514	0.83	90.32	7.8816	0.78	276.40
20	8.1832	0.56	142.61	8.2280	0.58	217.23	66	7.6276	0.92	88.81	7.8976	0.82	277.76
22	8.1567	0.51	134.51	8.1978	0.53	225.35	68	7.5929	1.01	87.33	7.8899	1.00	279.10
24	8.1592	0.53	128.37	8.2131	0.57	231.51	70	7.4591	1.30	85.92	7.7488	1.13	280.50
26	8.1263	0.48	123.49	8.1953	0.50	236.49	72	7.3727	1.12	84.48	7.6751	1.03	281.91
28	8.1105	0.61	119.23	8.1948	0.49	240.58	74	7.2954	1.24	83.03	7.4515	1.40	278.96
30	8.1131	0.58	115.74	8.1811	0.50	244.18	76	7.2180	1.60	81.60	7.3676	1.83	280.42
32	8.0953	0.50	112.60	8.1859	0.54	247.24	78	7.1352	1.77	80.16	7.2353	2.17	281.79
34	8.0624	0.56	109.73	8.1670	0.53	250.10	80	7.0011	2.18	78.68	7.0388	2.36	283.27
36	8.0575	0.57	107.28	8.1563	0.55	252.62	82	6.8308	2.97	77.25	6.8182	3.33	284.74
38	8.0156	0.56	104.94	8.1432	0.53	254.94	84	6.5346	N/A	75.79	N/A	N/A	N/A
40	8.0175	0.54	102.74	8.1520	0.54	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9950	0.68	100.86	8.1190	0.60	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9707	0.56	98.92	8.1328	0.58	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

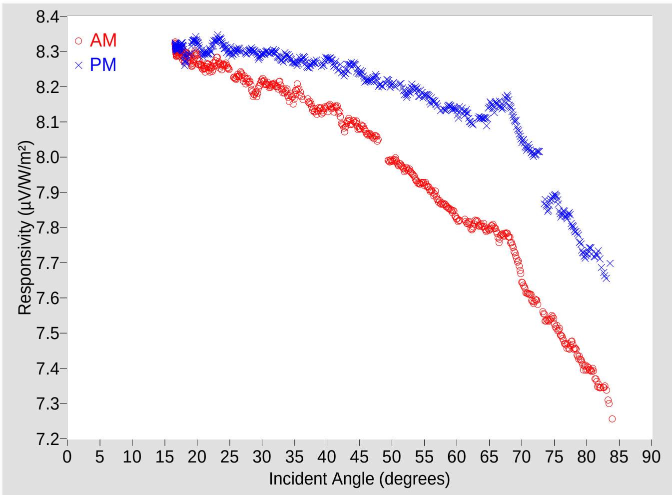

Figure 4. Responsivity vs Local Standard Time

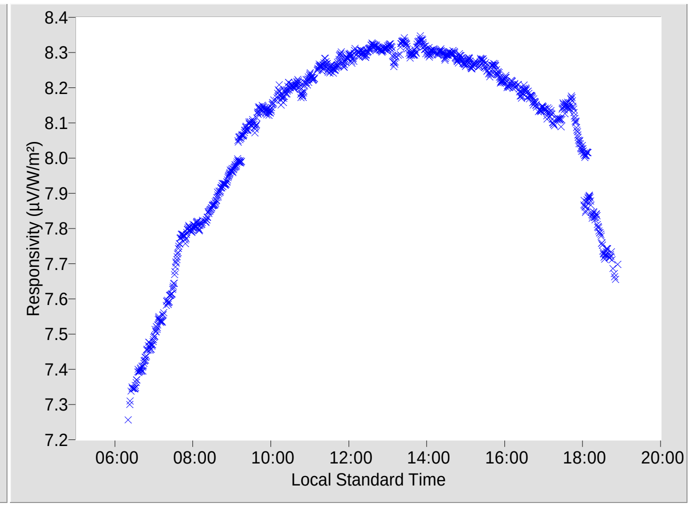

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1609	+2.36 / -4.63	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63036 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡		RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0706	0.63	97.14	8.2166	0.64	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0457	N/A	95.65	8.2069	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9904	0.66	101.81	8.2059	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9651	0.68	100.01	8.1799	0.70	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9283	0.71	98.27	8.1840	0.72	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9056	0.77	96.59	8.1592	0.72	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8668	0.75	94.95	8.1348	0.73	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8247	0.80	93.36	8.1274	0.79	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8065	0.83	91.79	8.1016	0.84	274.98
18	8.2866	0.55	155.29	8.2890	0.63	204.62	64	7.8058	0.88	90.32	8.1110	0.91	276.40
20	8.2820	0.59	142.61	8.3277	0.61	217.23	66	7.7919	0.97	88.81	8.1481	0.93	277.76
22	8.2514	0.54	134.51	8.3018	0.57	225.35	68	7.7721	1.04	87.33	8.1604	1.08	279.10
24	8.2592	0.55	128.37	8.3173	0.61	231.51	70	7.6544	1.27	85.92	8.0496	1.19	280.50
26	8.2264	0.52	123.49	8.3025	0.54	236.49	72	7.5908	1.19	84.48	8.0087	1.19	281.91
28	8.2141	0.62	119.23	8.3030	0.53	240.58	74	7.5360	1.31	83.03	7.8571	1.61	278.96
30	8.2167	0.61	115.74	8.2930	0.55	244.18	76	7.4983	1.58	81.60	7.8383	1.86	280.42
32	8.2047	0.54	112.60	8.3000	0.57	247.24	78	7.4627	1.81	80.16	7.7979	2.19	281.79
34	8.1745	0.59	109.73	8.2861	0.58	250.10	80	7.4014	2.20	78.68	7.7239	2.56	283.27
36	8.1738	0.61	107.28	8.2786	0.59	252.62	82	7.3475	2.86	77.25	7.7102	3.31	284.74
38	8.1333	0.61	104.94	8.2680	0.58	254.94	84	7.2563	N/A	75.79	N/A	N/A	N/A
40	8.1397	0.59	102.74	8.2806	0.59	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1188	0.73	100.86	8.2504	0.64	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0983	0.61	98.92	8.2655	0.62	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

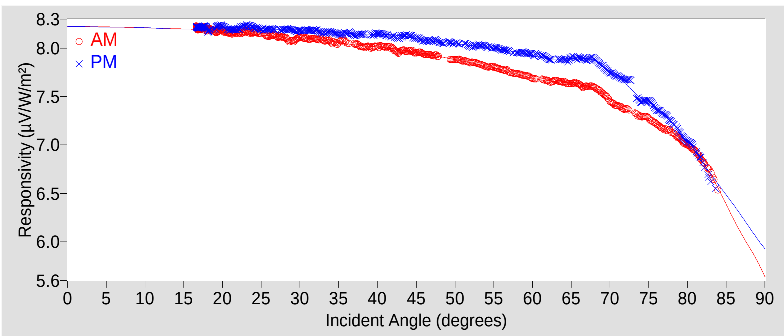
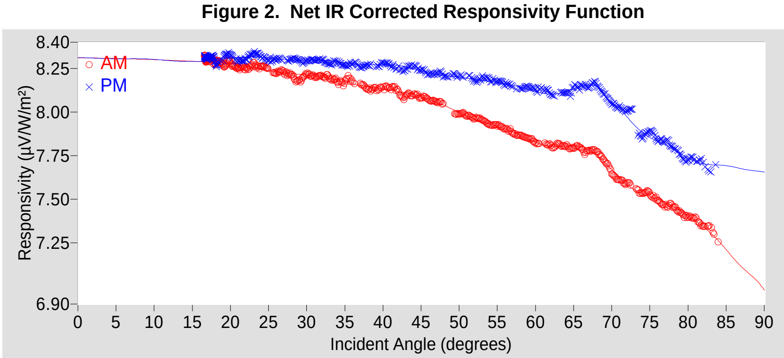


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.52	±1.52
R²	0.9999993	0.9999979
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.53	±1.53
Net IR corrected R²	0.9999994	0.9999983
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.2200	*	8.2199	*	8.2199	*	8.3072	*	8.3071	*	8.3071	*
9-18	8.2024	*	8.2027	*	8.2026	*	8.2941	*	8.2945	*	8.2943	*
18-27	8.1617	±1.57	8.2068	±1.52	8.1842	±1.72	8.2593	±1.57	8.3093	±1.53	8.2843	±1.73
27-36	8.0941	±1.58	8.1804	±1.53	8.1372	±1.97	8.2017	±1.57	8.2942	±1.54	8.2479	±1.92
36-45	8.0078	±1.60	8.1380	±1.54	8.0729	±2.27	8.1299	±1.59	8.2665	±1.54	8.1982	±2.20
45-54	7.8924	±1.73	8.0527	±1.61	7.9726	±2.87	8.0130	±1.79	8.2042	±1.57	8.1086	±3.03
54-63	7.7316	±1.83	7.9501	±1.69	7.8409	±3.52	7.8625	±1.74	8.1378	±1.59	8.0002	±3.63
63-72	7.5701	±2.29	7.8449	±2.08	7.7075	±4.98	7.7458	±2.01	8.1112	±1.80	7.9285	±5.22
72-81	7.1948	±3.19	7.3325	±4.63	7.2637	±6.71	7.4913	±2.01	7.8331	±2.20	7.6622	±5.61
81-90	6.3085	*	6.4285	*	6.3685	*	7.1869	*	7.6852	*	7.4361	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.0279	+2.57 / -4.66
45° - 55°	7.9630	±2.42
Composite	8.0416	+2.61 / -17.70
45° (Net IR Corr.)	8.1609	+2.36 / -4.63
45° - 55° (Net IR Corr.)	8.1000	±2.48
Composite (Net IR Corr.)	8.1792	+2.27 / -11.04

† Valid incident angle ranges:

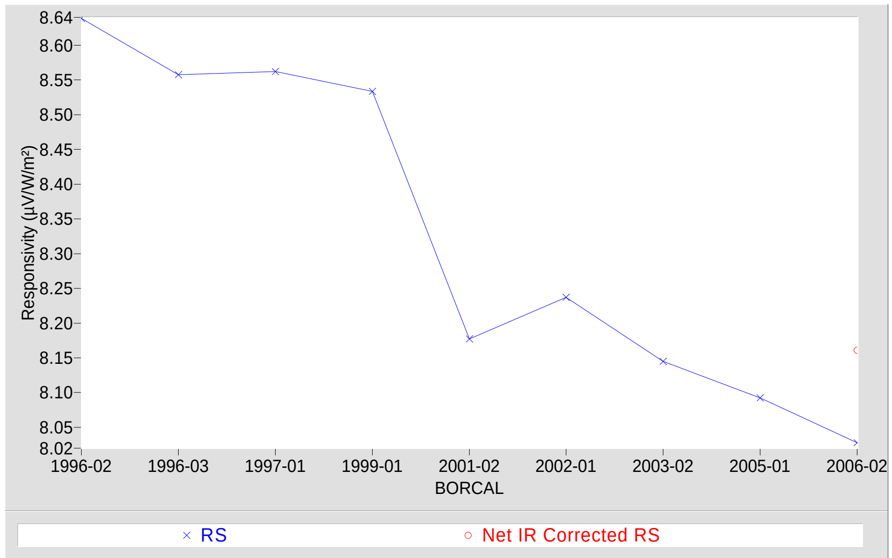
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



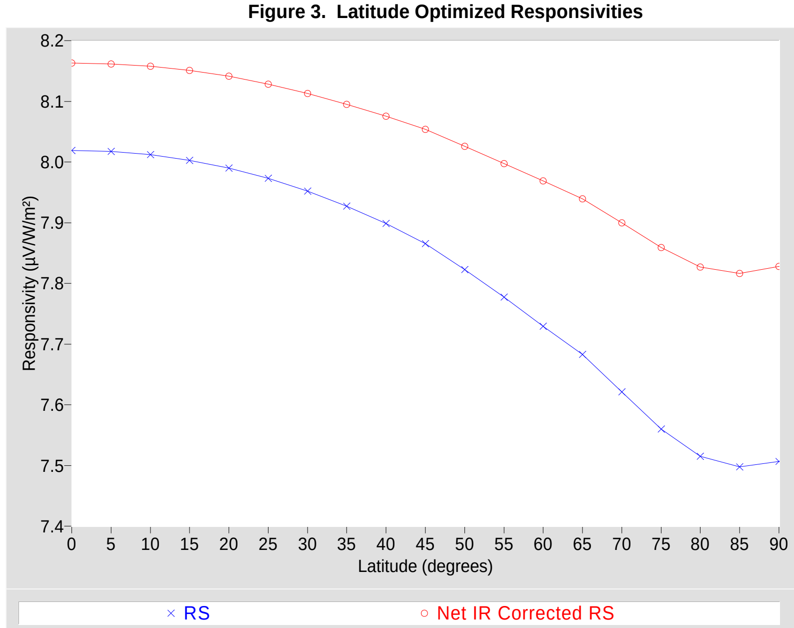
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.0192	+2.98 / -27.66	8.1633	+2.42 / -13.90
5	8.0173	+3.00 / -27.64	8.1617	+2.43 / -13.89
10	8.0119	+3.06 / -27.60	8.1577	+2.47 / -13.85
15	8.0028	+3.17 / -27.51	8.1508	+2.54 / -13.77
20	7.9901	+3.31 / -27.40	8.1414	+2.64 / -13.67
25	7.9729	+3.50 / -27.24	8.1283	+2.77 / -13.54
30	7.9519	+3.68 / -27.05	8.1127	+2.94 / -13.37
35	7.9269	+3.91 / -26.82	8.0950	+3.13 / -13.18
40	7.8985	+4.26 / -26.56	8.0757	+3.35 / -12.98
45	7.8652	+4.67 / -26.25	8.0539	+3.60 / -12.74
50	7.8229	+5.02 / -25.85	8.0257	+3.79 / -12.44
55	7.7775	+5.46 / -25.42	7.9975	+4.07 / -12.13
60	7.7295	+5.70 / -24.95	7.9689	+4.14 / -11.82
65	7.6827	+6.17 / -24.50	7.9391	+4.46 / -11.49
70	7.6209	+6.27 / -23.89	7.8997	+4.39 / -11.05
75	7.5599	+6.49 / -23.27	7.8588	+4.54 / -10.59
80	7.5150	+6.45 / -22.81	7.8270	+4.54 / -10.23
85	7.4977	+5.64 / -22.64	7.8163	+4.59 / -10.11
90	7.5065	+5.41 / -22.73	7.8277	+4.44 / -10.24

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

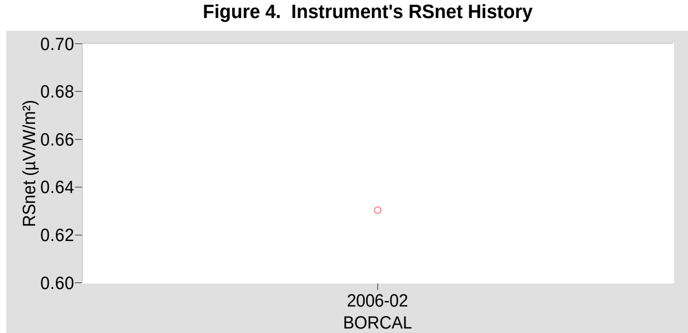
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30933F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

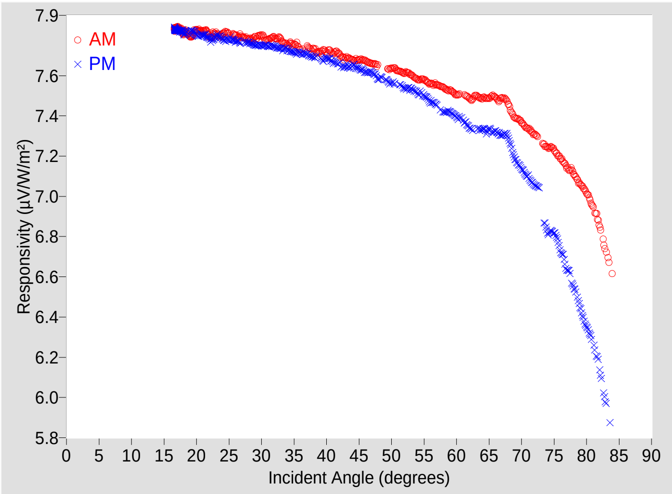

Figure 2. Responsivity vs Local Standard Time

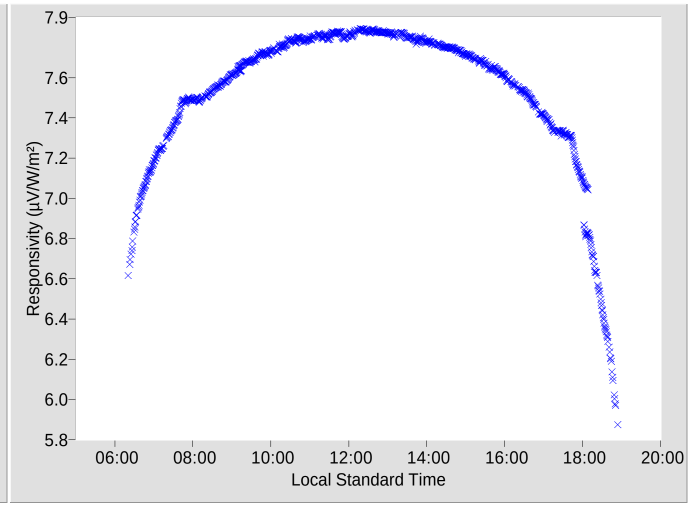

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.6559	+2.46 / -3.87	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6742	0.56	97.14	7.6168	0.57	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6451	N/A	95.65	7.5850	0.60	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6375	0.62	101.81	7.5637	0.59	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6142	0.64	100.01	7.5365	0.61	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5823	0.67	98.27	7.5129	0.65	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5601	0.69	96.59	7.4688	0.67	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5408	0.71	94.95	7.4192	0.68	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5054	0.74	93.36	7.3931	0.71	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4861	0.78	91.79	7.3396	0.77	274.98
18	7.8166	0.55	155.29	7.8144	0.51	204.62	64	7.4896	0.81	90.32	7.3338	0.75	276.40
20	7.8251	0.53	142.61	7.8049	0.51	217.23	66	7.4918	0.88	88.81	7.3211	0.82	277.76
22	7.8002	0.53	134.51	7.7836	0.54	225.35	68	7.4525	1.12	87.33	7.2885	1.21	279.10
24	7.8063	0.50	128.37	7.7828	0.53	231.51	70	7.3694	1.04	85.92	7.1383	1.07	280.50
26	7.8031	0.49	123.49	7.7716	0.52	236.49	72	7.3076	1.12	84.48	7.0549	1.09	281.91
28	7.7832	0.49	119.23	7.7644	0.49	240.58	74	7.2435	1.21	83.03	6.8246	1.45	278.96
30	7.8011	0.52	115.74	7.7500	0.49	244.18	76	7.1901	1.53	81.60	6.7271	2.08	280.42
32	7.7884	0.49	112.60	7.7462	0.50	247.24	78	7.1151	1.73	80.16	6.5533	2.31	281.79
34	7.7546	0.51	109.73	7.7293	0.52	250.10	80	7.0160	2.16	78.68	6.3509	2.49	283.27
36	7.7307	0.56	107.28	7.7110	0.51	252.62	82	6.8547	3.01	77.25	6.1328	3.62	284.76
38	7.7320	0.55	104.94	7.6920	0.53	254.94	84	6.6164	N/A	75.79	N/A	N/A	N/A
40	7.7186	0.53	102.74	7.6871	0.55	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7059	0.59	100.86	7.6554	0.60	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6782	0.55	98.92	7.6516	0.56	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

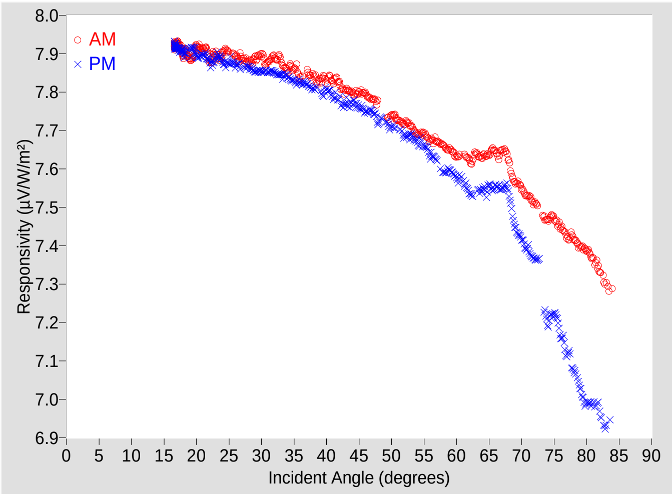

Figure 4. Responsivity vs Local Standard Time

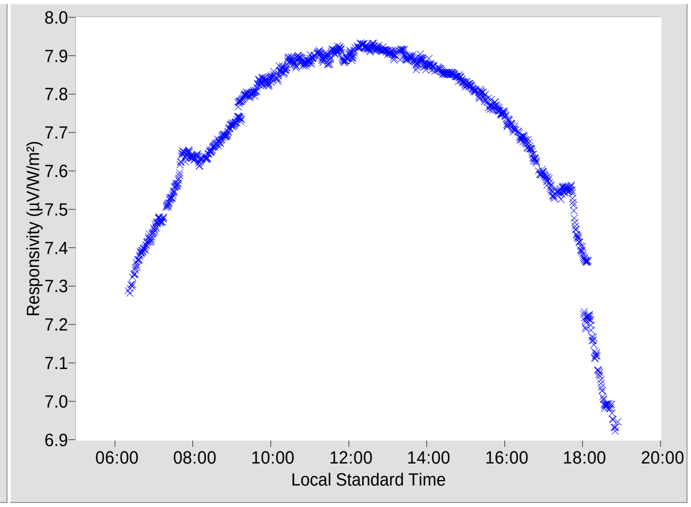

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.7798	+2.16 / -3.16	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.58687 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7960	0.62	97.14	7.7481	0.63	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7669	N/A	95.65	7.7223	0.67	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7394	0.66	101.81	7.7087	0.67	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7190	0.68	100.01	7.6845	0.69	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6914	0.71	98.27	7.6678	0.73	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6750	0.73	96.59	7.6334	0.75	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6612	0.75	94.95	7.5909	0.77	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6323	0.78	93.36	7.5748	0.81	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6207	0.84	91.79	7.5365	0.86	274.98
18	7.9030	0.58	155.29	7.9027	0.55	204.62	64	7.6333	0.86	90.32	7.5474	0.90	276.40
20	7.9171	0.57	142.61	7.8978	0.54	217.23	66	7.6447	0.94	88.81	7.5543	0.95	277.76
22	7.8883	0.57	134.51	7.8805	0.57	225.35	68	7.6193	1.13	87.33	7.5403	1.26	279.10
24	7.8995	0.55	128.37	7.8797	0.58	231.51	70	7.5512	1.10	85.92	7.4184	1.17	280.50
26	7.8963	0.53	123.49	7.8714	0.57	236.49	72	7.5107	1.19	84.48	7.3655	1.25	281.91
28	7.8796	0.53	119.23	7.8651	0.54	240.58	74	7.4675	1.31	83.03	7.2023	1.67	278.96
30	7.8975	0.56	115.74	7.8542	0.54	244.18	76	7.4510	1.55	81.60	7.1653	2.04	280.42
32	7.8902	0.54	112.60	7.8523	0.55	247.24	78	7.4200	1.80	80.16	7.0771	2.32	281.79
34	7.8590	0.56	109.73	7.8402	0.57	250.10	80	7.3887	2.20	78.68	6.9887	2.70	283.27
36	7.8389	0.60	107.28	7.8249	0.57	252.62	82	7.3357	2.88	77.25	6.9667	3.51	284.76
38	7.8415	0.60	104.94	7.8081	0.59	254.94	84	7.2883	N/A	75.79	N/A	N/A	N/A
40	7.8324	0.59	102.74	7.8068	0.60	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8211	0.64	100.86	7.7777	0.65	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7970	0.60	98.92	7.7752	0.63	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

IRR = *V / RS* [1]

IRR (corr.) = *(V - Wnet * RSnet) / RSc* [2]

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

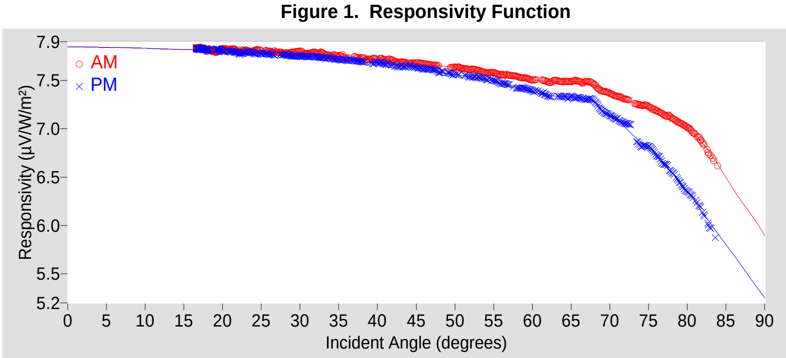
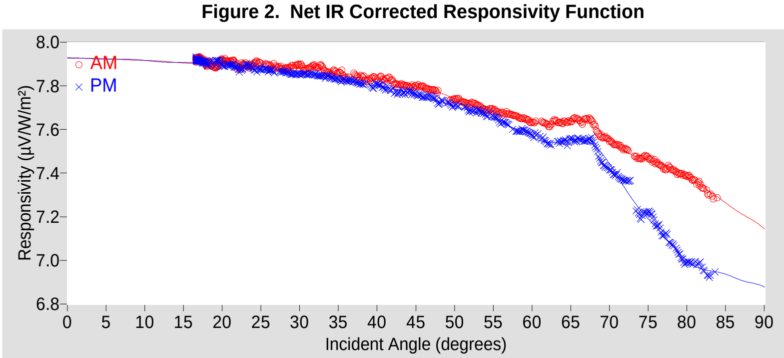


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I)$$ [3]

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.59	±1.59
R²	0.9999995	0.9999982
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.59	±1.59
Net IR corrected R²	0.9999996	0.9999987
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	7.8429	*	7.8431	*	7.8430	*	7.9241	*	7.9243	*	7.9242	*
9-18	7.8245	*	7.8245	*	7.8245	*	7.9098	*	7.9100	*	7.9099	*
18-27	7.8082	±1.59	7.7896	±1.61	7.7989	±1.65	7.8991	±1.59	7.8851	±1.60	7.8921	±1.62
27-36	7.7800	±1.63	7.7453	±1.62	7.7627	±1.76	7.8803	±1.62	7.8513	±1.61	7.8658	±1.70
36-45	7.7129	±1.63	7.6772	±1.66	7.6951	±1.83	7.8266	±1.61	7.7968	±1.63	7.8117	±1.75
45-54	7.6380	±1.67	7.5730	±1.76	7.6055	±2.17	7.7502	±1.71	7.7140	±1.69	7.7321	±1.97
54-63	7.5327	±1.71	7.4216	±1.94	7.4772	±2.82	7.6545	±1.65	7.5964	±1.78	7.6254	±2.13
63-72	7.4415	±1.96	7.2579	±2.51	7.3497	±4.72	7.6051	±1.79	7.5058	±2.06	7.5555	±3.25
72-81	7.1663	±2.76	6.6798	±5.58	6.9230	±10.65	7.4423	±1.81	7.1459	±2.89	7.2941	±5.35
81-90	6.4355	*	5.7479	*	6.0917	*	7.2533	*	6.9271	*	7.0902	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

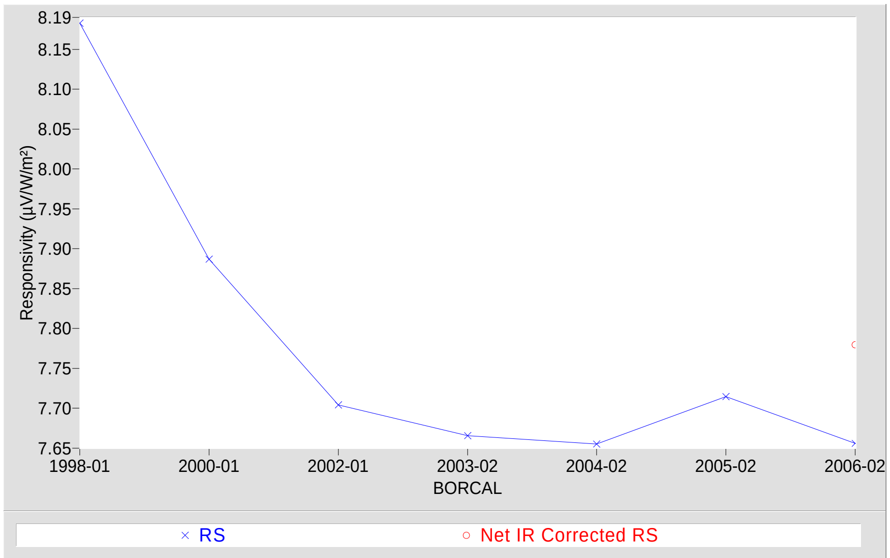
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.6559	+2.46 / -3.87
45° - 55°	7.5962	±2.00
Composite	7.6691	+2.51 / -22.27
45° (Net IR Corr.)	7.7798	+2.16 / -3.16
45° - 55° (Net IR Corr.)	7.7237	±1.85
Composite (Net IR Corr.)	7.7972	+2.13 / -10.99

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



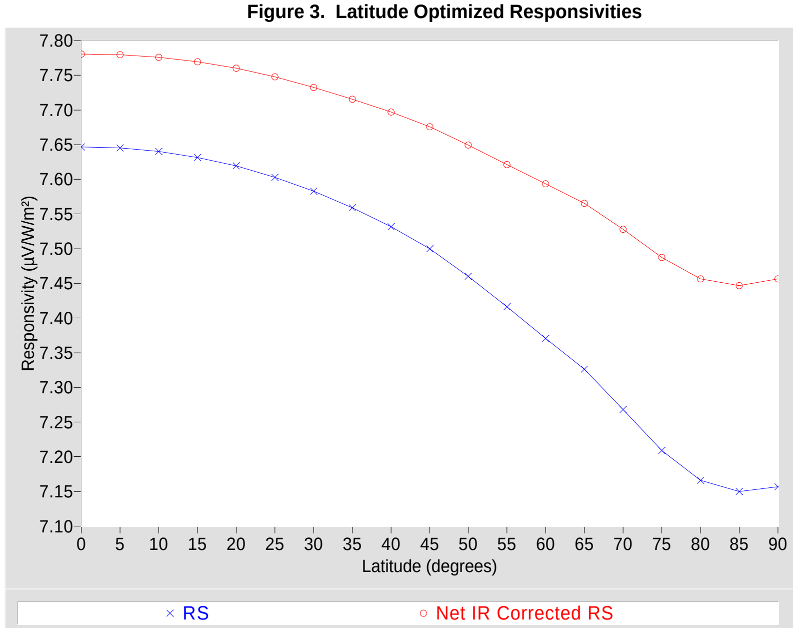
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.6465	+3.08 / -29.93	7.7807	+2.48 / -11.54
5	7.6452	+3.10 / -29.92	7.7797	+2.49 / -11.52
10	7.6402	+3.15 / -29.88	7.7760	+2.53 / -11.48
15	7.6315	+3.26 / -29.80	7.7694	+2.60 / -11.41
20	7.6193	+3.40 / -29.68	7.7602	+2.69 / -11.30
25	7.6031	+3.59 / -29.53	7.7479	+2.82 / -11.16
30	7.5830	+3.75 / -29.35	7.7328	+2.92 / -10.99
35	7.5590	+3.94 / -29.12	7.7155	+3.04 / -10.79
40	7.5318	+4.14 / -28.87	7.6968	+3.17 / -10.58
45	7.5001	+4.51 / -28.57	7.6758	+3.40 / -10.34
50	7.4604	+4.81 / -28.19	7.6493	+3.59 / -10.03
55	7.4164	+5.31 / -27.76	7.6213	+3.88 / -9.70
60	7.3706	+5.21 / -27.31	7.5937	+3.67 / -9.38
65	7.3264	+5.51 / -26.88	7.5655	+3.79 / -9.05
70	7.2682	+5.71 / -26.29	7.5281	+3.81 / -8.60
75	7.2089	+5.95 / -25.69	7.4875	+3.58 / -8.11
80	7.1659	+5.76 / -25.24	7.4566	+3.36 / -7.74
85	7.1500	+5.09 / -25.07	7.4469	+3.05 / -7.62
90	7.1570	+4.87 / -25.15	7.4564	+2.94 / -7.74

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

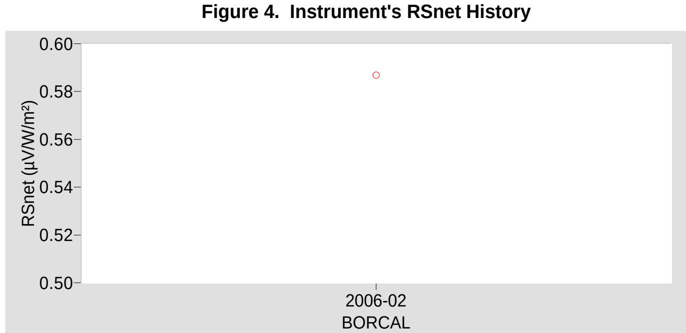
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 30940F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: SGP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30940F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

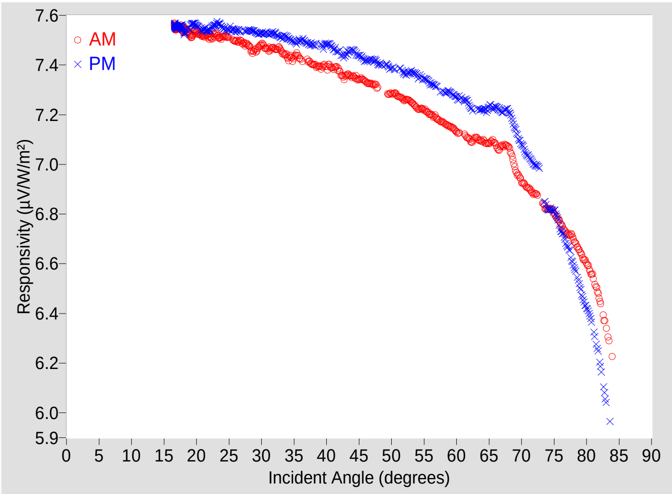


Figure 2. Responsivity vs Local Standard Time

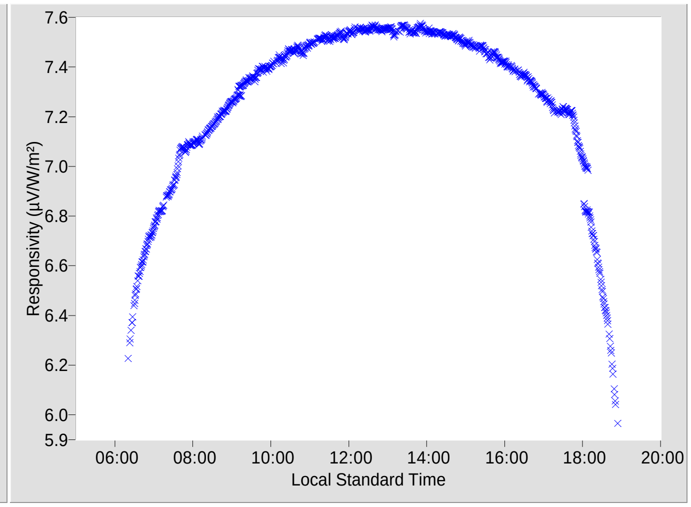


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.3899	+2.50 / -3.97	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.3338	0.56	97.14	7.4169	0.58	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3059	N/A	95.65	7.4039	0.58	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2854	0.62	101.81	7.3867	0.60	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2603	0.65	100.01	7.3653	0.61	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2263	0.68	98.27	7.3556	0.66	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2015	0.72	96.59	7.3242	0.65	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1681	0.72	94.95	7.2919	0.66	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1312	0.75	93.36	7.2677	0.70	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.0989	0.80	91.79	7.2350	0.77	274.98
18	7.5405	0.54	155.29	7.5406	0.54	204.62	64	7.0956	0.82	90.32	7.2205	0.75	276.40
20	7.5332	0.52	142.61	7.5596	0.53	217.23	66	7.0797	0.91	88.81	7.2298	0.81	277.76
22	7.5128	0.50	134.51	7.5409	0.51	225.35	68	7.0664	1.12	87.33	7.2147	0.99	279.10
24	7.5121	0.51	128.37	7.5501	0.54	231.51	70	6.9333	1.11	85.92	7.0812	1.17	280.50
26	7.4978	0.47	123.49	7.5392	0.51	236.49	72	6.8822	1.11	84.48	6.9976	1.07	281.91
28	7.4788	0.56	119.23	7.5392	0.48	240.58	74	6.8197	1.24	83.03	6.8230	1.42	278.96
30	7.4829	0.54	115.74	7.5283	0.49	244.18	76	6.7645	1.55	81.60	6.7348	1.88	280.42
32	7.4667	0.50	112.60	7.5289	0.52	247.24	78	6.6997	1.73	80.16	6.5948	2.21	281.79
34	7.4311	0.55	109.73	7.5098	0.53	250.10	80	6.6018	2.15	78.68	6.4225	2.40	283.27
36	7.4230	0.55	107.28	7.4990	0.53	252.62	82	6.4580	2.96	77.25	6.2010	3.54	284.76
38	7.4021	0.55	104.94	7.4799	0.53	254.94	84	6.2268	N/A	75.79	N/A	N/A	N/A
40	7.3929	0.54	102.74	7.4846	0.55	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3752	0.63	100.86	7.4508	0.60	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3536	0.55	98.92	7.4605	0.56	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

30940F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

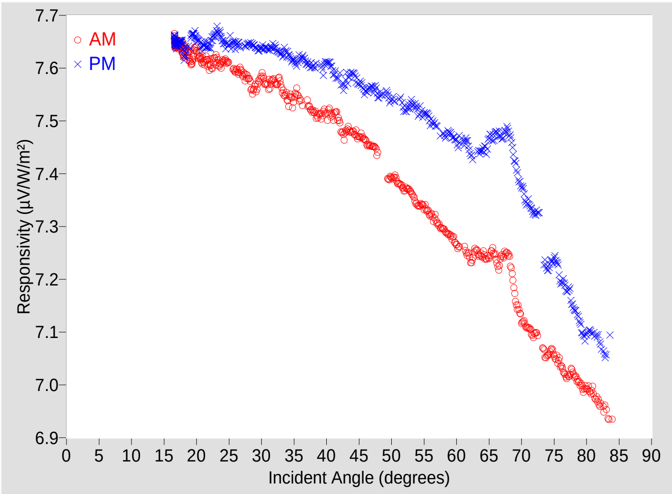


Figure 4. Responsivity vs Local Standard Time

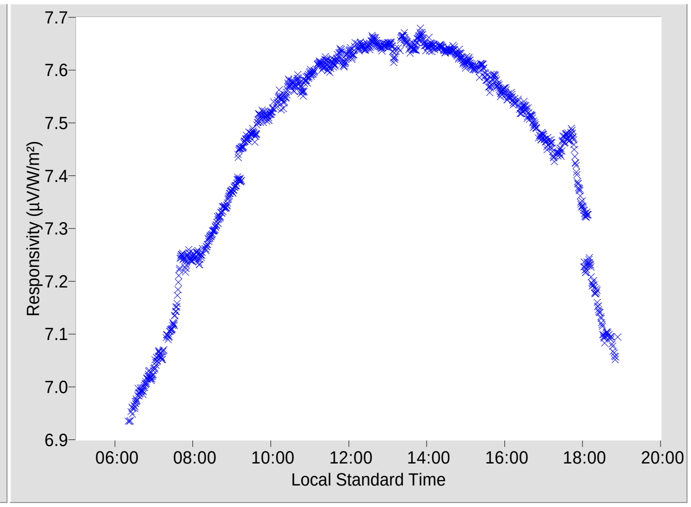


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.5204	+2.28 / -3.94	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.61870 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4622	0.63	97.14	7.5553	0.65	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4344	N/A	95.65	7.5487	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3928	0.67	101.81	7.5396	0.68	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3708	0.69	100.01	7.5214	0.70	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3413	0.72	98.27	7.5189	0.73	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3226	0.76	96.59	7.4976	0.74	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2950	0.76	94.95	7.4730	0.76	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2649	0.80	93.36	7.4592	0.81	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2409	0.85	91.79	7.4426	0.87	274.98
18	7.6316	0.56	155.29	7.6337	0.57	204.62	64	7.2471	0.88	90.32	7.4457	0.90	276.40
20	7.6301	0.56	142.61	7.6574	0.57	217.23	66	7.2410	0.97	88.81	7.4757	0.95	277.76
22	7.6057	0.54	134.51	7.6430	0.55	225.35	68	7.2423	1.14	87.33	7.4802	1.10	279.10
24	7.6103	0.54	128.37	7.6523	0.59	231.51	70	7.1250	1.14	85.92	7.3765	1.23	280.50
26	7.5960	0.52	123.49	7.6445	0.56	236.49	72	7.0962	1.20	84.48	7.3250	1.24	281.91
28	7.5805	0.59	119.23	7.6454	0.53	240.58	74	7.0557	1.34	83.03	7.2211	1.65	278.96
30	7.5846	0.58	115.74	7.6381	0.54	244.18	76	7.0396	1.58	81.60	7.1968	1.93	280.42
32	7.5740	0.56	112.60	7.6408	0.56	247.24	78	7.0211	1.83	80.16	7.1469	2.26	281.79
34	7.5412	0.60	109.73	7.6268	0.59	250.10	80	6.9948	2.24	78.68	7.0950	2.67	283.27
36	7.5372	0.60	107.28	7.6191	0.59	252.62	82	6.9650	2.92	77.25	7.0801	3.46	284.76
38	7.5177	0.60	104.94	7.6023	0.58	254.94	84	6.9352	N/A	75.79	N/A	N/A	N/A
40	7.5129	0.60	102.74	7.6108	0.61	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4967	0.68	100.86	7.5798	0.65	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4789	0.62	98.92	7.5907	0.62	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

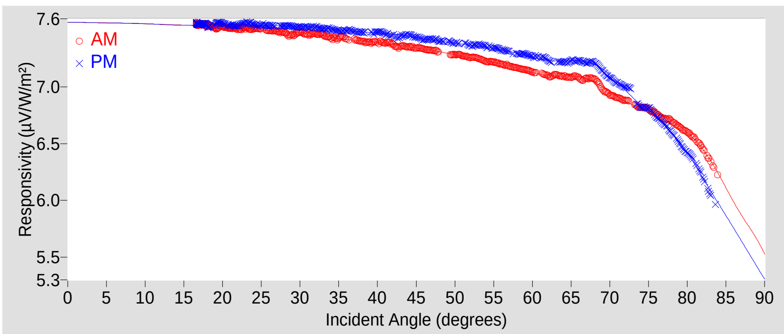
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

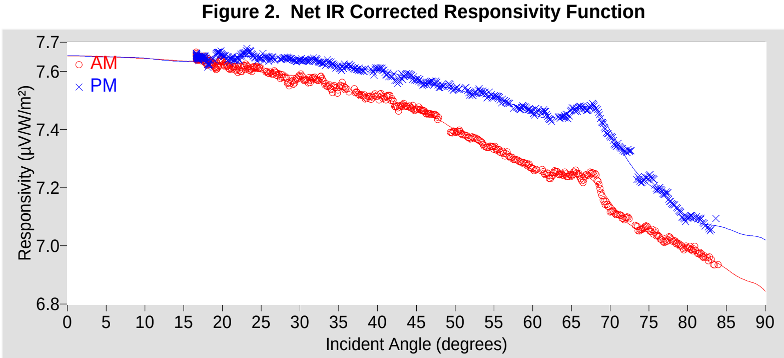


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.54	±1.54
R²	0.9999992	0.9999988
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.57	±1.57
Net IR corrected R²	0.9999993	0.9999992
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	7.5649	*	7.5649	*	7.5649	*	7.6505	*	7.6505	*	7.6505	*
9-18	7.5485	*	7.5486	*	7.5485	*	7.6384	*	7.6387	*	7.6386	*
18-27	7.5170	±1.56	7.5466	±1.54	7.5318	±1.64	7.6128	±1.59	7.6472	±1.57	7.6300	±1.67
27-36	7.4638	±1.60	7.5247	±1.56	7.4942	±1.90	7.5694	±1.61	7.6364	±1.58	7.6029	±1.87
36-45	7.3870	±1.61	7.4722	±1.58	7.4296	±2.09	7.5069	±1.61	7.5983	±1.59	7.5526	±2.04
45-54	7.2921	±1.70	7.3932	±1.63	7.3426	±2.46	7.4104	±1.78	7.5418	±1.61	7.4761	±2.64
54-63	7.1619	±1.79	7.2904	±1.74	7.2261	±2.90	7.2903	±1.72	7.4746	±1.64	7.3825	±3.03
63-72	7.0347	±2.11	7.1763	±2.18	7.1055	±3.80	7.2072	±1.89	7.4377	±1.87	7.3224	±4.05
72-81	6.7450	±2.73	6.6961	±4.76	6.7206	±6.62	7.0359	±1.73	7.1875	±2.17	7.1117	±3.62
81-90	6.0511	*	5.8105	*	5.9308	*	6.9133	*	7.0536	*	6.9835	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

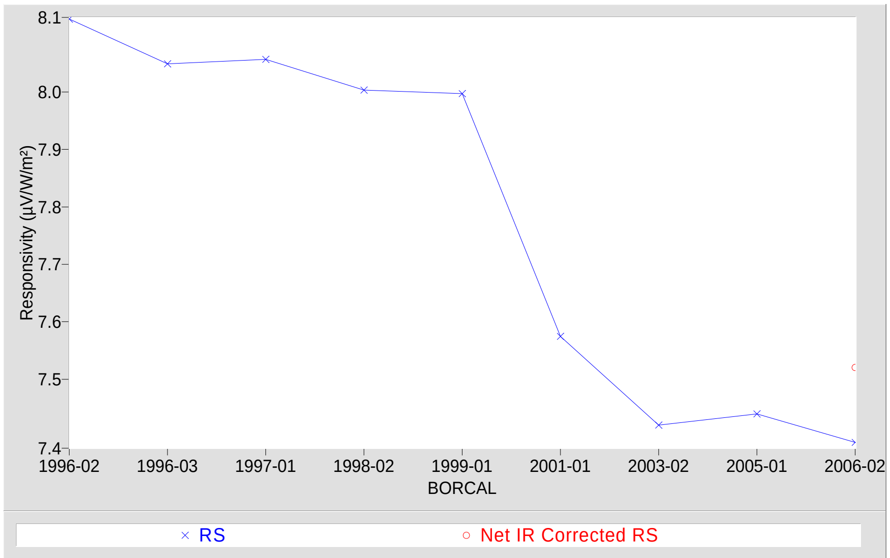
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.3899	+2.50 / -3.97
45° - 55°	7.3342	±2.14
Composite	7.4056	+2.48 / -18.60
45° (Net IR Corr.)	7.5204	+2.28 / -3.94
45° - 55° (Net IR Corr.)	7.4686	±2.22
Composite (Net IR Corr.)	7.5407	+2.15 / -8.04

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



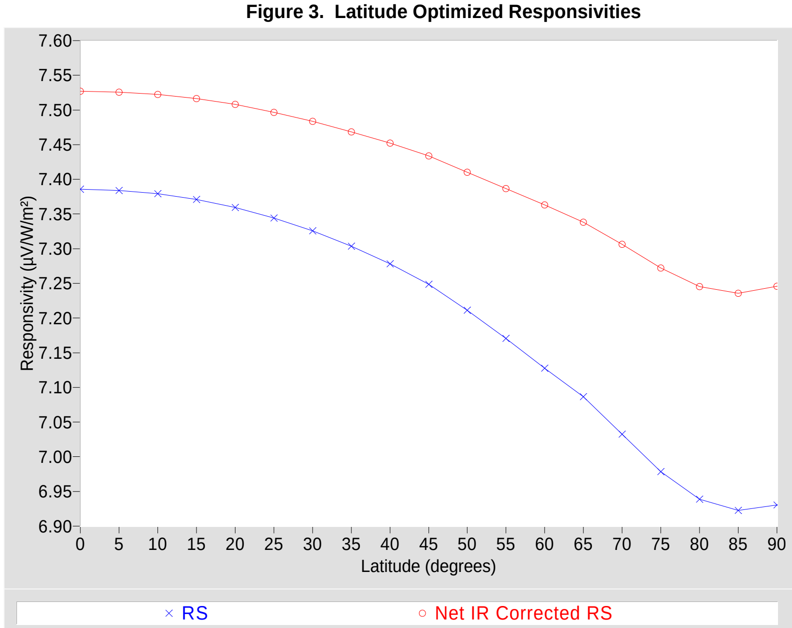
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.3856	+2.93 / -26.69	7.5271	+2.31 / -8.92
5	7.3840	+2.94 / -26.67	7.5259	+2.32 / -8.90
10	7.3791	+3.00 / -26.62	7.5222	+2.35 / -8.86
15	7.3708	+3.10 / -26.54	7.5162	+2.42 / -8.79
20	7.3594	+3.24 / -26.42	7.5079	+2.50 / -8.69
25	7.3441	+3.42 / -26.27	7.4968	+2.62 / -8.55
30	7.3255	+3.59 / -26.08	7.4834	+2.74 / -8.39
35	7.3033	+3.76 / -25.86	7.4683	+2.91 / -8.21
40	7.2780	+4.04 / -25.60	7.4520	+3.11 / -8.01
45	7.2486	+4.43 / -25.30	7.4339	+3.32 / -7.79
50	7.2112	+4.82 / -24.91	7.4104	+3.54 / -7.51
55	7.1705	+5.24 / -24.49	7.3866	+3.79 / -7.22
60	7.1278	+5.39 / -24.04	7.3630	+3.77 / -6.93
65	7.0864	+5.65 / -23.59	7.3384	+3.88 / -6.62
70	7.0324	+5.77 / -23.01	7.3064	+3.82 / -6.22
75	6.9786	+5.91 / -22.42	7.2723	+3.90 / -5.80
80	6.9389	+5.80 / -21.97	7.2454	+3.84 / -5.46
85	6.9226	+4.90 / -21.79	7.2356	+3.70 / -5.34
90	6.9303	+4.59 / -21.88	7.2459	+3.57 / -5.47

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

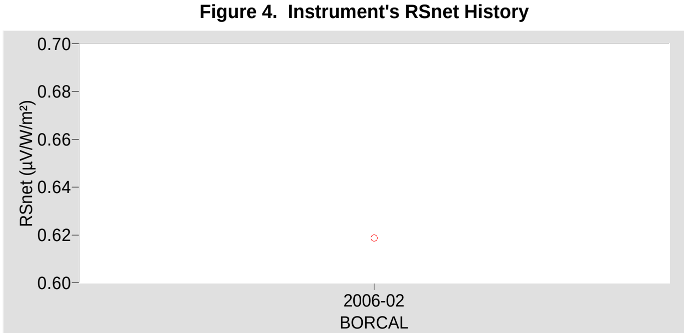
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30945F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results
30945F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

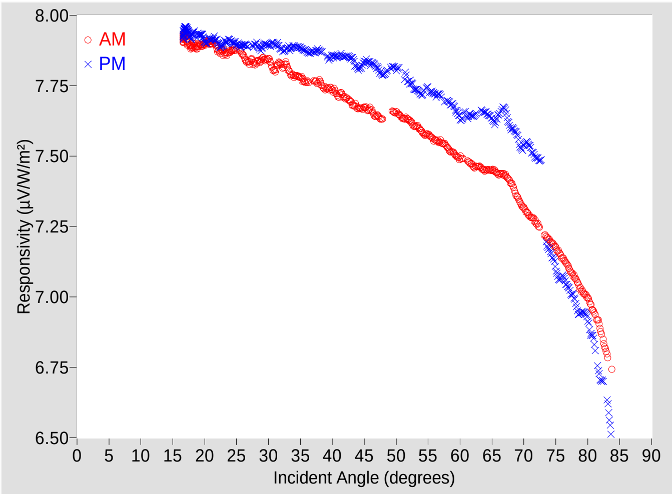


Figure 2. Responsivity vs Local Standard Time

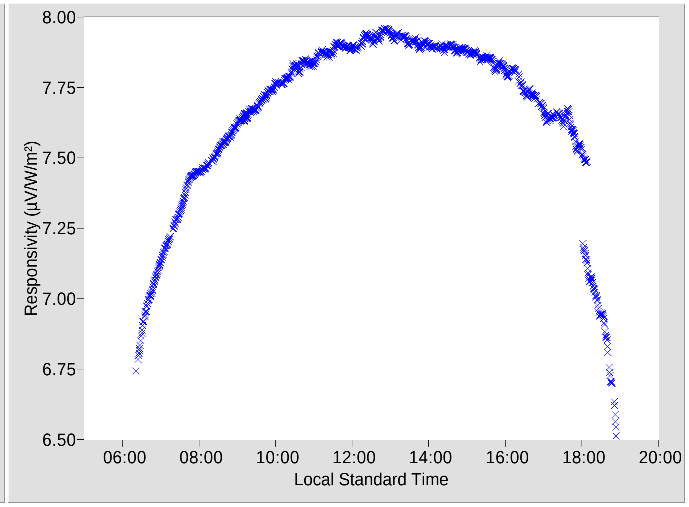


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.7528	+2.49 / -3.85	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6649	0.58	97.11	7.8312	0.59	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6330	N/A	95.68	7.7890	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6544	0.63	101.84	7.8114	0.58	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6275	0.67	99.98	7.7638	0.71	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5888	0.69	98.30	7.7217	0.63	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5572	0.69	96.56	7.7197	0.62	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5324	0.72	94.97	7.6961	0.66	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4934	0.74	93.33	7.6354	0.73	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4665	0.77	91.82	7.6427	0.70	274.95
18	7.8909	0.58	155.40	7.9289	0.55	204.72	64	7.4503	0.80	90.34	7.6542	0.75	276.38
20	7.8986	0.48	142.70	7.9089	0.52	217.13	66	7.4369	0.86	88.84	7.6445	0.87	277.74
22	7.8817	0.58	134.59	7.9052	0.54	225.42	68	7.4035	1.05	87.35	7.5997	1.00	279.12
24	7.8722	0.50	128.29	7.9087	0.49	231.57	70	7.3166	1.10	85.95	7.5389	0.96	280.52
26	7.8590	0.56	123.42	7.8944	0.49	236.55	72	7.2605	1.11	84.45	7.4936	1.03	281.89
28	7.8317	0.50	119.28	7.8970	0.52	240.63	74	7.2021	1.23	83.05	7.1658	1.50	278.98
30	7.8428	0.56	115.78	7.8949	0.50	244.13	76	7.1382	1.48	81.57	7.0723	1.59	280.39
32	7.8250	0.54	112.64	7.8791	0.54	247.28	78	7.0691	1.73	80.19	6.9874	1.93	281.81
34	7.7861	0.51	109.77	7.8886	0.51	250.14	80	6.9960	2.08	78.70	6.9140	2.25	283.29
36	7.7642	0.52	107.27	7.8709	0.52	252.65	82	6.8846	2.78	77.27	6.7078	2.90	284.76
38	7.7625	0.55	104.97	7.8722	0.52	254.97	84	6.7427	N/A	75.91	N/A	N/A	N/A
40	7.7368	0.56	102.80	7.8559	0.53	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7082	0.56	100.83	7.8532	0.55	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6717	0.55	98.94	7.8120	0.61	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

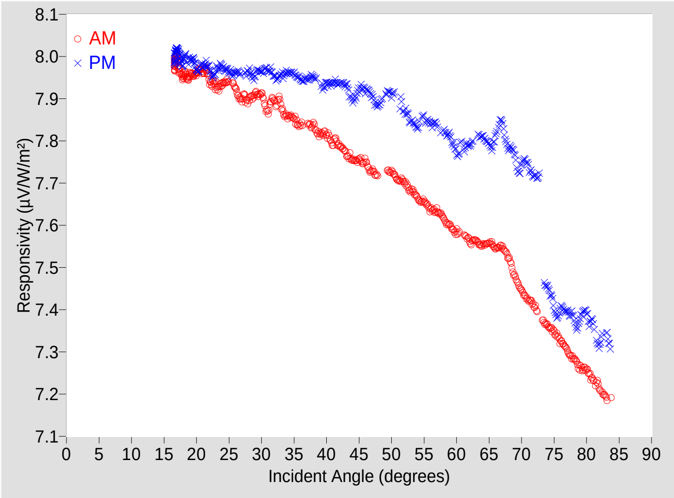

Figure 4. Responsivity vs Local Standard Time

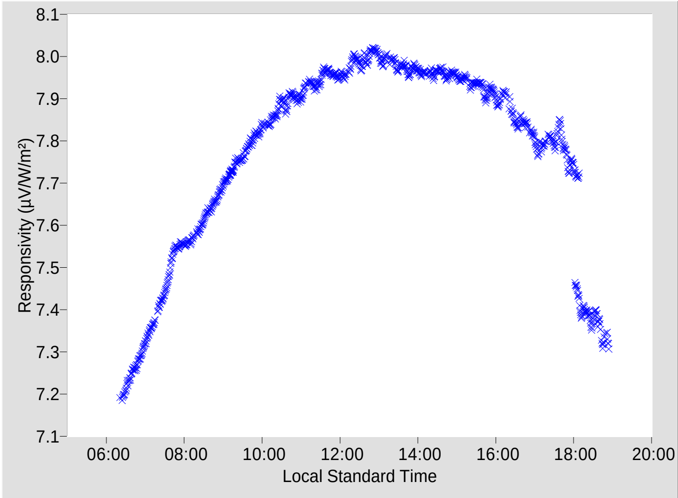

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8388	+2.31 / -3.84	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.53402 µV/W/m², determination date: 07/10/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc.	AM			PM			Inc.	AM			PM		
Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7497	0.61	97.11	7.9216	0.62	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7207	N/A	95.68	7.8837	0.63	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7262	0.65	101.84	7.9108	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7004	0.69	99.98	7.8703	0.74	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6662	0.70	98.30	7.8341	0.69	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6376	0.72	96.56	7.8405	0.69	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6181	0.75	94.97	7.8241	0.71	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5834	0.77	93.33	7.7718	0.80	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5627	0.80	91.82	7.7899	0.79	274.95
18	7.9549	0.60	155.40	7.9912	0.56	204.72	64	7.5536	0.84	90.34	7.8093	0.82	276.38
20	7.9605	0.50	142.70	7.9724	0.54	217.13	66	7.5460	0.90	88.84	7.8128	0.99	277.74
22	7.9459	0.60	134.59	7.9696	0.56	225.42	68	7.5227	1.06	87.35	7.7841	1.04	279.12
24	7.9353	0.52	128.29	7.9748	0.52	231.57	70	7.4471	1.10	85.95	7.7430	1.06	280.52
26	7.9242	0.57	123.42	7.9625	0.51	236.55	72	7.4067	1.16	84.45	7.7172	1.14	281.89
28	7.8973	0.52	119.28	7.9655	0.54	240.63	74	7.3632	1.28	83.05	7.4528	1.59	278.98
30	7.9101	0.59	115.78	7.9647	0.53	244.13	76	7.3248	1.51	81.57	7.4034	1.76	280.39
32	7.8937	0.57	112.64	7.9512	0.56	247.28	78	7.2846	1.75	80.19	7.3824	2.09	281.81
34	7.8591	0.54	109.77	7.9628	0.54	250.14	80	7.2576	2.13	78.70	7.3901	2.47	283.29
36	7.8388	0.55	107.27	7.9459	0.55	252.65	82	7.2140	2.74	77.27	7.3204	3.17	284.76
38	7.8363	0.57	104.97	7.9501	0.55	254.97	84	7.1914	N/A	75.91	N/A	N/A	N/A
40	7.8156	0.59	102.80	7.9366	0.57	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7890	0.59	100.83	7.9358	0.58	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7558	0.58	98.94	7.8979	0.64	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

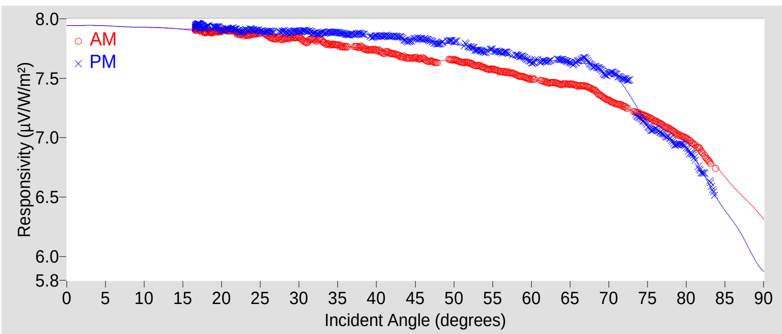
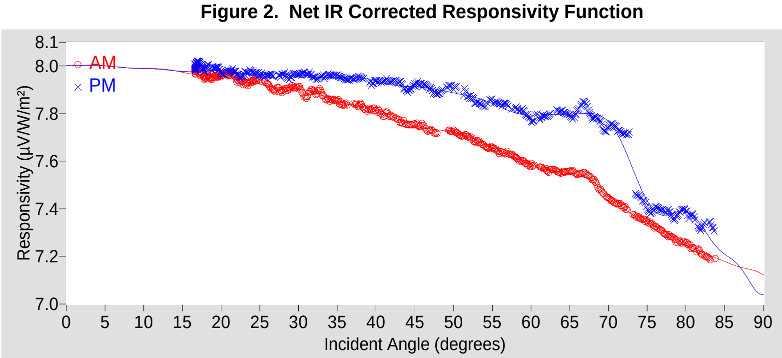


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.46	±1.46
R²	0.9999995	0.9999951
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.7°
Net IR corr. uncert. U95 (%)	±1.51	±1.51
Net IR corrected R²	0.9999996	0.9999963
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.7°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.9404	*	7.9405	*	7.9405	*	7.9997	*	7.9997	*	7.9997	*
9-18	7.9180	*	7.9212	*	7.9196	*	7.9800	*	7.9831	*	7.9815	*
18-27	7.8793	±1.49	7.9077	±1.46	7.8935	±1.59	7.9429	±1.53	7.9726	±1.51	7.9578	±1.63
27-36	7.8195	±1.53	7.8879	±1.46	7.8537	±1.88	7.8885	±1.56	7.9593	±1.51	7.9239	±1.88
36-45	7.7274	±1.60	7.8544	±1.49	7.7909	±2.44	7.8061	±1.61	7.9351	±1.53	7.8706	±2.38
45-54	7.6404	±1.51	7.7927	±1.53	7.7165	±2.51	7.7197	±1.58	7.8911	±1.54	7.8054	±2.62
54-63	7.5242	±1.69	7.6827	±1.58	7.6035	±2.99	7.6106	±1.67	7.8124	±1.56	7.7115	±3.10
63-72	7.3939	±1.92	7.6023	±1.86	7.4981	±3.87	7.5111	±1.78	7.7826	±1.66	7.6469	±3.94
72-81	7.1243	±2.51	7.0967	±4.15	7.1105	±5.74	7.3205	±1.87	7.4465	±2.44	7.3835	±4.46
81-90	6.6357	*	6.3440	*	6.4899	*	7.1757	*	7.1971	*	7.1864	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.7528	+2.49 / -3.85
45° - 55°	7.7085	±2.17
Composite	7.7778	+2.33 / -15.96
45° (Net IR Corr.)	7.8388	+2.31 / -3.84
45° - 55° (Net IR Corr.)	7.7983	±2.24
Composite (Net IR Corr.)	7.8687	+2.08 / -8.64

† Valid incident angle ranges:

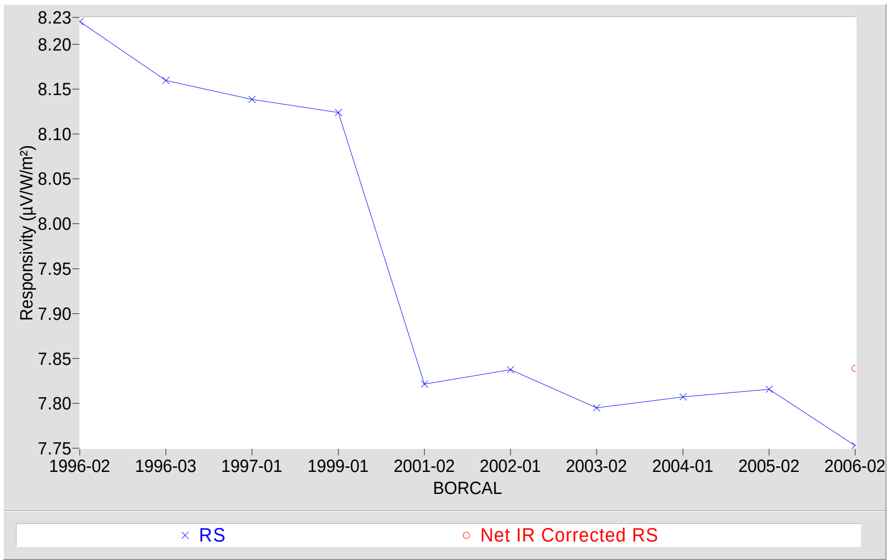
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.7°, 16.6° to 83.7° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



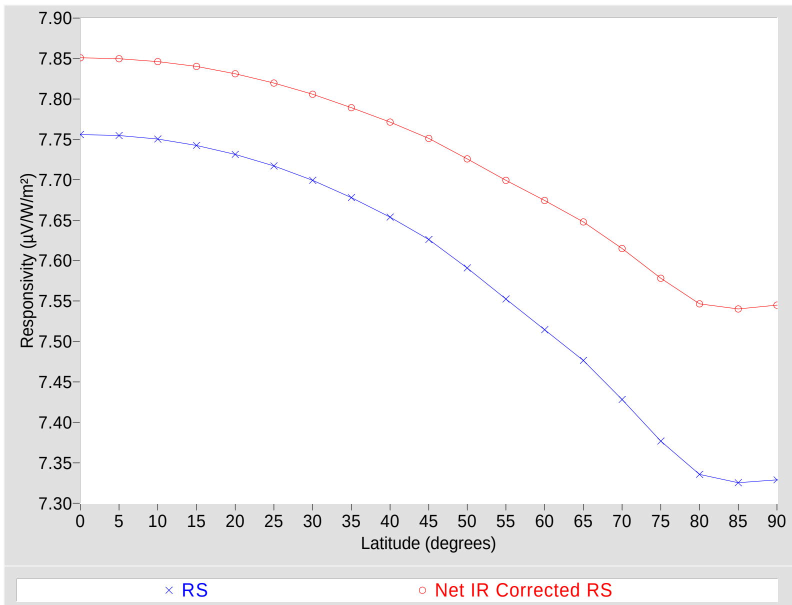
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.7561	+2.84 / -23.22	7.8508	+2.46 / -10.22
5	7.7548	+2.85 / -23.21	7.8498	+2.47 / -10.20
10	7.7503	+2.90 / -23.16	7.8462	+2.51 / -10.16
15	7.7426	+2.99 / -23.09	7.8401	+2.58 / -10.09
20	7.7314	+3.12 / -22.98	7.8311	+2.67 / -9.99
25	7.7171	+3.29 / -22.83	7.8197	+2.80 / -9.86
30	7.6995	+3.43 / -22.66	7.8057	+2.89 / -9.70
35	7.6779	+3.58 / -22.44	7.7891	+2.98 / -9.51
40	7.6539	+3.75 / -22.20	7.7712	+3.10 / -9.31
45	7.6260	+4.06 / -21.91	7.7510	+3.30 / -9.07
50	7.5910	+4.32 / -21.55	7.7257	+3.48 / -8.78
55	7.5527	+4.68 / -21.16	7.6992	+3.70 / -8.47
60	7.5146	+5.07 / -20.76	7.6742	+3.95 / -8.18
65	7.4764	+5.16 / -20.35	7.6479	+3.97 / -7.86
70	7.4284	+5.48 / -19.84	7.6152	+4.16 / -7.48
75	7.3768	+5.63 / -19.28	7.5780	+4.27 / -7.03
80	7.3357	+5.28 / -18.83	7.5464	+4.03 / -6.65
85	7.3253	+4.72 / -18.71	7.5402	+3.77 / -6.58
90	7.3289	+4.35 / -18.75	7.5451	+3.71 / -6.64

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

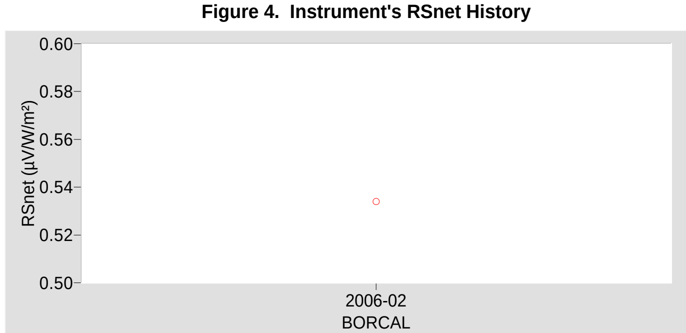
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer **Manufacturer:** Eppley

Model: PSP **Serial Number:** 30949F3

Calibration Date: 8/12/2006 **Due Date:** 8/12/2007

Customer: SGP **Calibration Site Parameters:** see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30949F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

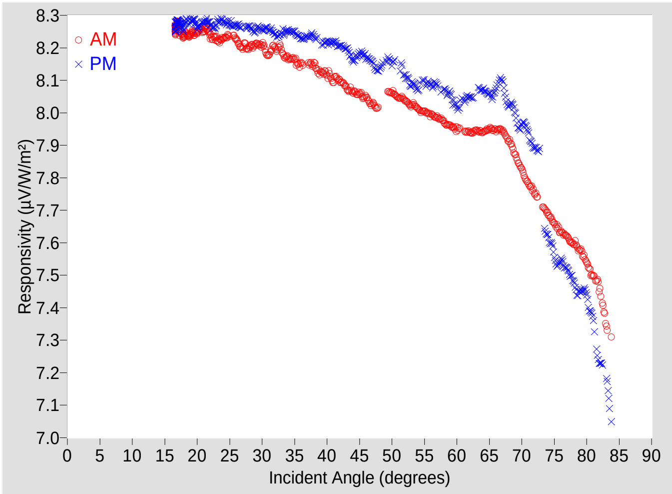


Figure 2. Responsivity vs Local Standard Time

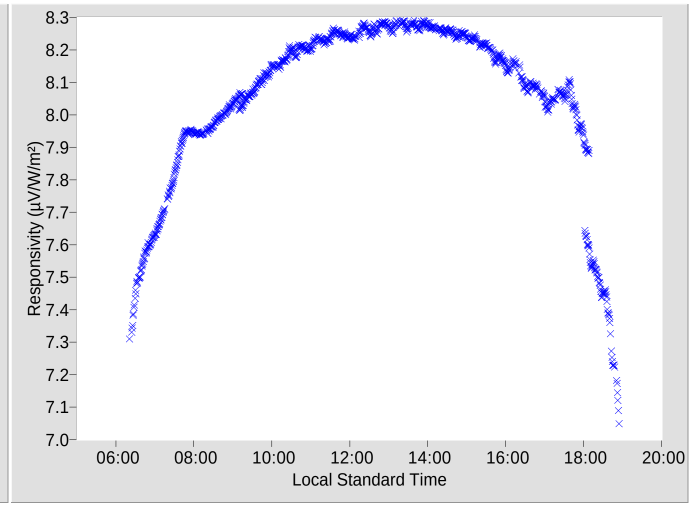


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1206	+2.30 / -2.63	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A
18	8.2382	0.53	155.40	8.2695	0.52	204.72
20	8.2480	0.48	142.70	8.2666	0.51	217.13
22	8.2401	0.54	134.59	8.2732	0.51	225.42
24	8.2301	0.50	128.29	8.2817	0.49	231.57
26	8.2267	0.54	123.42	8.2690	0.49	236.55
28	8.2006	0.49	119.28	8.2652	0.49	240.63
30	8.2086	0.54	115.78	8.2566	0.49	244.13
32	8.1999	0.52	112.64	8.2411	0.52	247.28
34	8.1691	0.50	109.77	8.2518	0.51	250.14
36	8.1495	0.52	107.27	8.2296	0.53	252.65
38	8.1475	0.55	104.97	8.2328	0.53	254.97
40	8.1196	0.56	102.80	8.2174	0.53	257.09
42	8.0981	0.55	100.83	8.2060	0.55	259.07
44	8.0657	0.55	98.94	8.1611	0.60	261.00

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
46	8.0475	0.59	97.11	8.1725	0.58	262.74
48	8.0140	N/A	95.68	8.1335	0.58	264.46
50	8.0627	0.62	101.84	8.1547	0.59	266.12
52	8.0384	0.66	99.98	8.1135	0.73	267.66
54	8.0143	0.67	98.30	8.0754	0.63	269.21
56	7.9942	0.67	96.56	8.0866	0.62	270.67
58	7.9728	0.70	94.97	8.0724	0.65	272.19
60	7.9509	0.72	93.33	8.0184	0.72	273.58
62	7.9407	0.75	91.82	8.0480	0.69	274.95
64	7.9416	0.79	90.34	8.0708	0.73	276.38
66	7.9477	0.85	88.84	8.0738	0.87	277.74
68	7.9139	1.01	87.35	8.0222	1.00	279.12
70	7.8282	1.13	85.95	7.9635	0.95	280.52
72	7.7517	1.10	84.45	7.8921	1.03	281.89
74	7.6909	1.22	83.05	7.6188	1.44	278.98
76	7.6324	1.41	81.57	7.5455	1.54	280.39
78	7.5991	1.63	80.19	7.4804	1.86	281.81
80	7.5382	2.05	78.70	7.4333	2.19	283.29
82	7.4561	2.72	77.27	7.2315	2.84	284.76
84	7.3101	N/A	75.91	7.0493	N/A	286.07
86	N/A	N/A	N/A	N/A	N/A	N/A
88	N/A	N/A	N/A	N/A	N/A	N/A
90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

30949F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

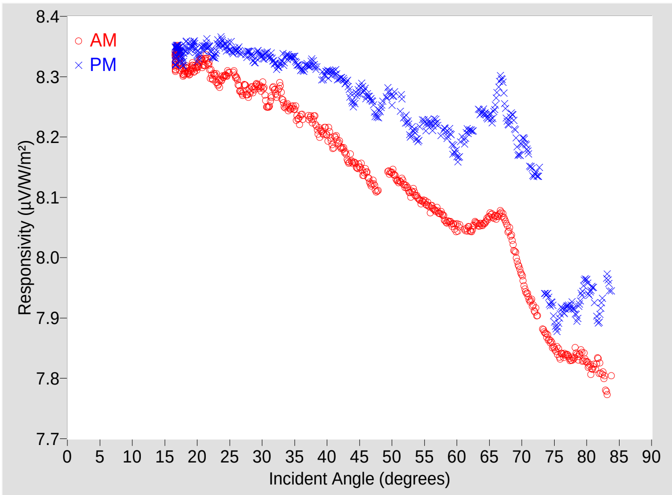


Figure 4. Responsivity vs Local Standard Time

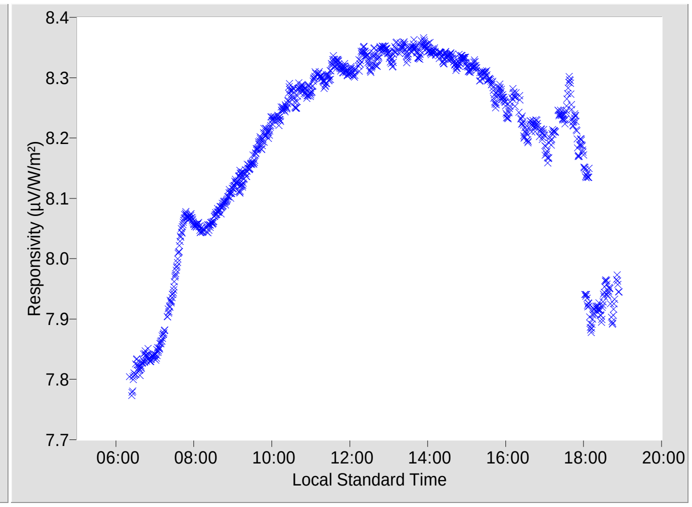


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2154	+2.10 / -2.61	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.58852 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1410	0.61	97.11	8.2720	0.61	262.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1106	N/A	95.68	8.2379	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1418	0.64	101.84	8.2642	0.64	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1188	0.68	99.98	8.2309	0.76	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0996	0.68	98.30	8.1993	0.69	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0828	0.70	96.56	8.2197	0.68	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0671	0.72	94.97	8.2135	0.70	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0500	0.75	93.33	8.1687	0.78	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0468	0.79	91.82	8.2102	0.78	274.95
18	8.3087	0.55	155.40	8.3382	0.54	204.72	64	8.0555	0.83	90.34	8.2417	0.81	276.38
20	8.3162	0.50	142.70	8.3366	0.53	217.13	66	8.0679	0.88	88.84	8.2593	0.98	277.74
22	8.3109	0.56	134.59	8.3442	0.53	225.42	68	8.0451	1.02	87.35	8.2254	1.03	279.12
24	8.2997	0.52	128.29	8.3545	0.51	231.57	70	7.9720	1.12	85.95	8.1884	1.03	280.52
26	8.2985	0.55	123.42	8.3440	0.52	236.55	72	7.9128	1.14	84.45	8.1385	1.12	281.89
28	8.2729	0.51	119.28	8.3407	0.51	240.63	74	7.8685	1.26	83.05	7.9351	1.54	278.98
30	8.2827	0.56	115.78	8.3336	0.51	244.13	76	7.8380	1.46	81.57	7.9104	1.73	280.39
32	8.2757	0.56	112.64	8.3207	0.54	247.28	78	7.8371	1.69	80.21	7.9158	2.02	281.81
34	8.2495	0.52	109.77	8.3336	0.54	250.14	80	7.8265	2.08	78.70	7.9579	2.40	283.29
36	8.2317	0.56	107.27	8.3122	0.55	252.65	82	7.8191	2.68	77.27	7.9065	3.07	284.76
38	8.2288	0.57	104.97	8.3186	0.55	254.97	84	7.8046	N/A	75.91	7.9449	N/A	286.07
40	8.2064	0.58	102.80	8.3063	0.56	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1873	0.58	100.83	8.2970	0.58	259.07	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1584	0.58	98.94	8.2557	0.63	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30949F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

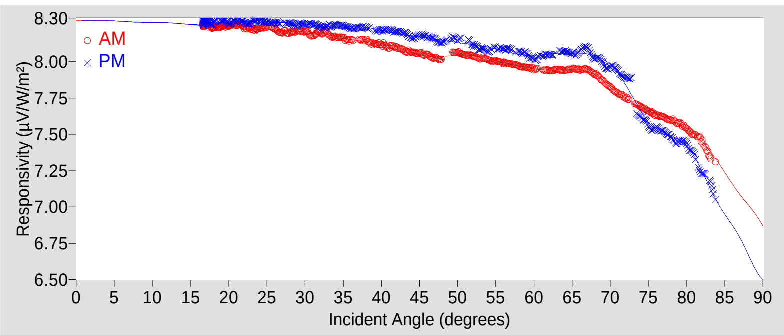
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

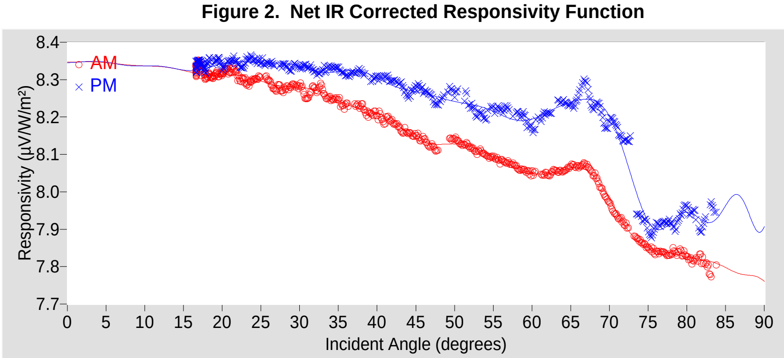


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.38	±1.38
R²	0.9999994	0.9999967
Valid incidence angle range	16.6° to 83.8°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.44	±1.44
Net IR corrected R²	0.9999996	0.9999976
Corr. valid inc. angle range	16.6° to 83.8°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.2794	*	8.2793	*	8.2794	*	8.3447	*	8.3446	*	8.3446	*
9-18	8.2607	*	8.2631	*	8.2619	*	8.3290	*	8.3313	*	8.3301	*
18-27	8.2360	±1.39	8.2722	±1.39	8.2541	±1.49	8.3061	±1.45	8.3438	±1.44	8.3249	±1.53
27-36	8.1934	±1.43	8.2515	±1.40	8.2224	±1.70	8.2693	±1.46	8.3301	±1.45	8.2997	±1.70
36-45	8.1142	±1.51	8.2110	±1.44	8.1626	±2.14	8.2010	±1.53	8.3000	±1.47	8.2505	±2.09
45-54	8.0391	±1.39	8.1382	±1.44	8.0887	±1.88	8.1265	±1.45	8.2467	±1.46	8.1866	±1.99
54-63	7.9720	±1.47	8.0607	±1.43	8.0163	±1.96	8.0671	±1.48	8.2037	±1.45	8.1354	±2.10
63-72	7.8980	±1.77	8.0228	±1.77	7.9604	±3.02	8.0271	±1.68	8.2217	±1.61	8.1244	±3.21
72-81	7.6346	±2.05	7.5685	±3.30	7.6016	±4.44	7.8510	±1.54	7.9534	±1.90	7.9022	±3.03
81-90	7.1990	*	6.9126	*	7.0558	*	7.7940	*	7.9401	*	7.8671	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.1206	+2.30 / -2.63
45° - 55°	8.0837	±1.71
Composite	8.1533	+2.06 / -13.18
45° (Net IR Corr.)	8.2154	+2.10 / -2.61
45° - 55° (Net IR Corr.)	8.1826	±1.79
Composite (Net IR Corr.)	8.2539	+1.84 / -5.55

† Valid incident angle ranges:

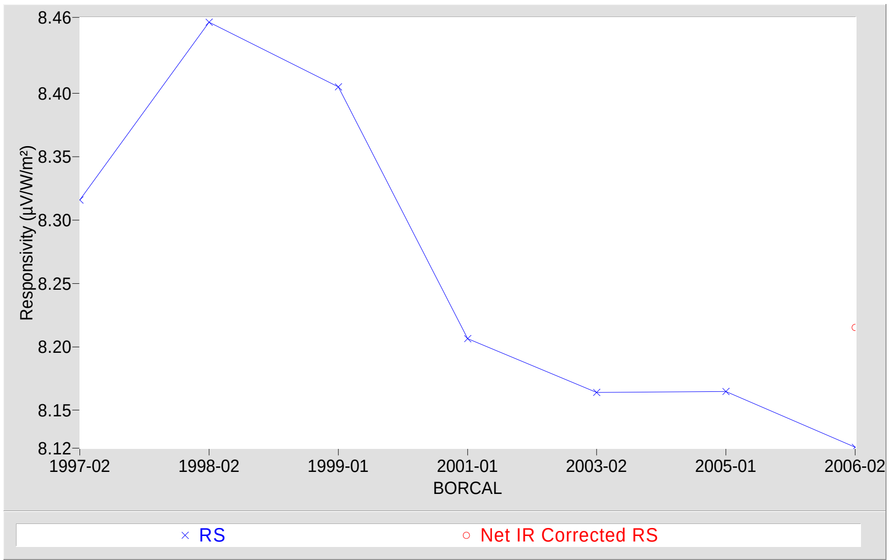
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



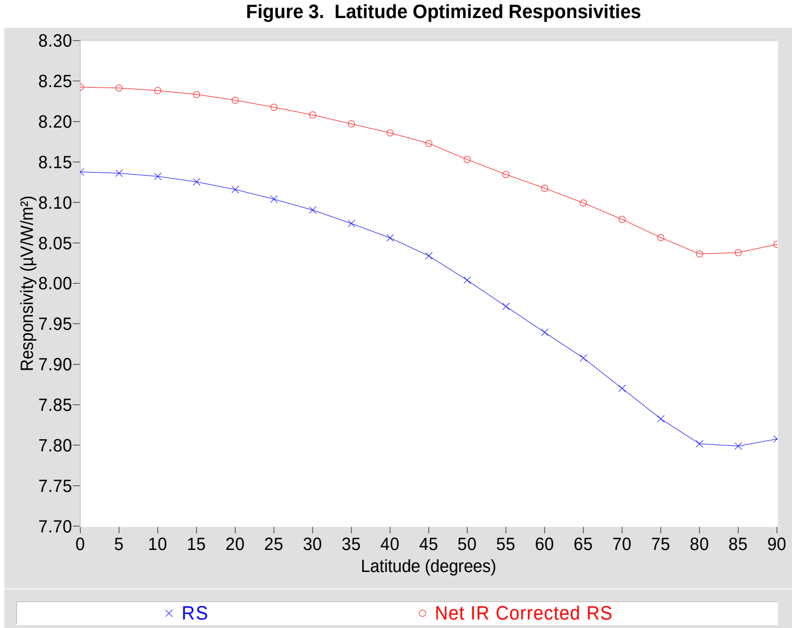
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.1377	+2.27 / -19.28	8.2425	+1.93 / -5.87
5	8.1362	+2.28 / -19.27	8.2413	+1.94 / -5.86
10	8.1322	+2.32 / -19.23	8.2383	+1.97 / -5.82
15	8.1256	+2.39 / -19.16	8.2335	+2.01 / -5.77
20	8.1160	+2.49 / -19.07	8.2263	+2.07 / -5.69
25	8.1041	+2.62 / -18.95	8.2177	+2.15 / -5.59
30	8.0905	+2.70 / -18.81	8.2082	+2.23 / -5.49
35	8.0741	+2.88 / -18.65	8.1972	+2.34 / -5.37
40	8.0562	+3.08 / -18.47	8.1862	+2.45 / -5.24
45	8.0342	+3.33 / -18.25	8.1728	+2.59 / -5.09
50	8.0038	+3.60 / -17.94	8.1533	+2.75 / -4.88
55	7.9716	+3.77 / -17.61	8.1344	+2.79 / -4.66
60	7.9396	+4.03 / -17.28	8.1174	+2.92 / -4.47
65	7.9079	+3.99 / -16.94	8.0994	+2.80 / -4.27
70	7.8703	+3.98 / -16.55	8.0792	+2.69 / -4.05
75	7.8325	+3.97 / -16.15	8.0568	+2.77 / -3.80
80	7.8017	+3.75 / -15.82	8.0364	+2.99 / -3.57
85	7.7989	+3.63 / -15.79	8.0382	+2.98 / -3.59
90	7.8077	+3.50 / -15.88	8.0483	+2.86 / -3.71

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

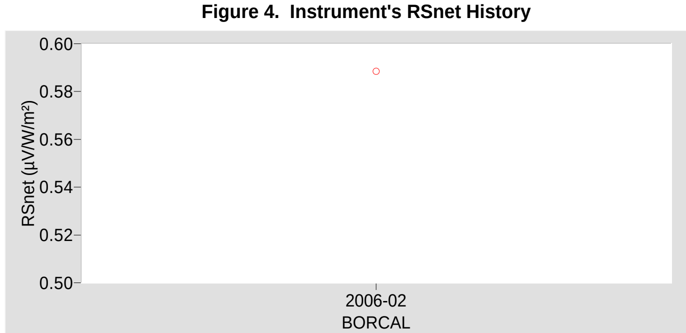
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30951F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ____________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ____________________

Calibration Results

30951F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

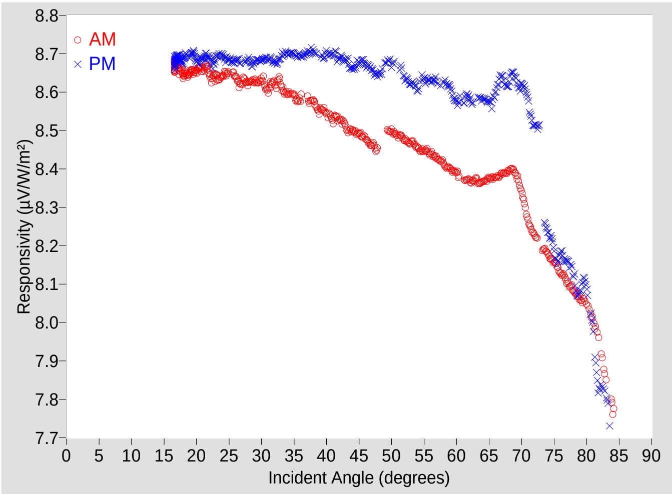


Figure 2. Responsivity vs Local Standard Time

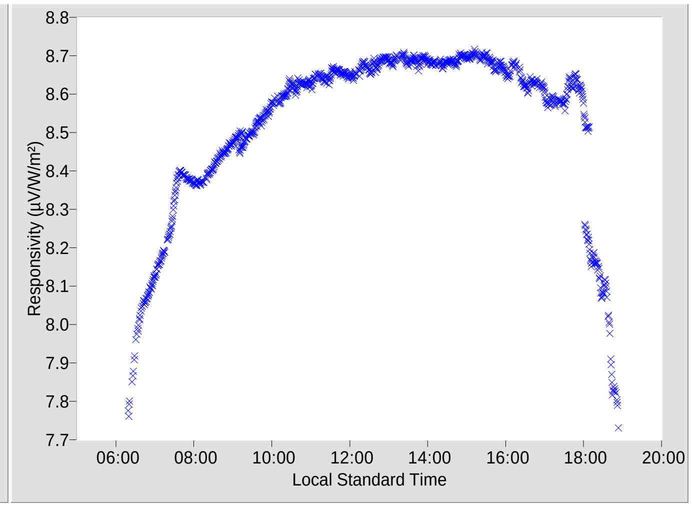


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5838	+2.08 / -2.77	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4802	0.57	97.12	8.6719	0.57	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4495	N/A	95.69	8.6457	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4967	0.61	101.85	8.6749	0.58	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4755	0.64	99.99	8.6365	0.65	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4561	0.66	98.25	8.6119	0.64	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4403	0.67	96.57	8.6301	0.61	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4156	0.69	94.98	8.6279	0.63	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3894	0.72	93.34	8.5753	0.70	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3693	0.75	91.83	8.5837	0.70	274.96
18	8.6477	0.53	155.43	8.6864	0.50	204.54	64	8.3669	0.79	90.30	8.5821	0.72	276.34
20	8.6564	0.47	142.74	8.6839	0.51	217.16	66	8.3780	0.84	88.84	8.5995	0.92	277.74
22	8.6465	0.54	134.46	8.6862	0.53	225.45	68	8.3951	0.90	87.36	8.6222	0.84	279.13
24	8.6433	0.49	128.32	8.6936	0.49	231.60	70	8.3390	1.21	85.91	8.6161	0.93	280.53
26	8.6403	0.52	123.44	8.6822	0.48	236.45	72	8.2279	1.09	84.46	8.5138	1.05	281.85
28	8.6243	0.49	119.30	8.6841	0.50	240.65	74	8.1804	1.20	83.06	8.2363	1.40	278.99
30	8.6301	0.52	115.80	8.6830	0.48	244.15	76	8.1275	1.41	81.58	8.1817	1.52	280.40
32	8.6238	0.54	112.65	8.6794	0.50	247.30	78	8.0850	1.61	80.19	8.1218	1.85	281.82
34	8.5973	0.50	109.78	8.6995	0.50	250.15	80	8.0489	1.97	78.71	8.0907	2.18	283.25
36	8.5832	0.51	107.36	8.6943	0.51	252.66	82	7.9396	2.71	77.19	7.8276	2.81	284.72
38	8.5759	0.57	104.98	8.7037	0.52	254.99	84	7.7826	3.46	75.77	N/A	N/A	N/A
40	8.5437	0.55	102.85	8.7010	0.53	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5299	0.53	100.77	8.6895	0.55	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5000	0.53	98.95	8.6614	0.56	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

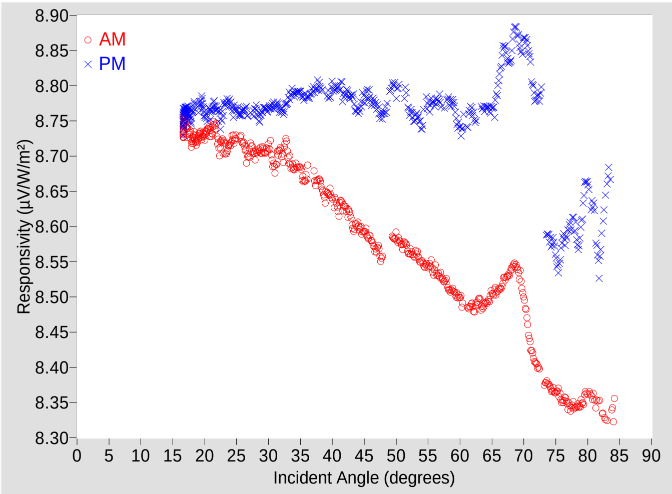


Figure 4. Responsivity vs Local Standard Time

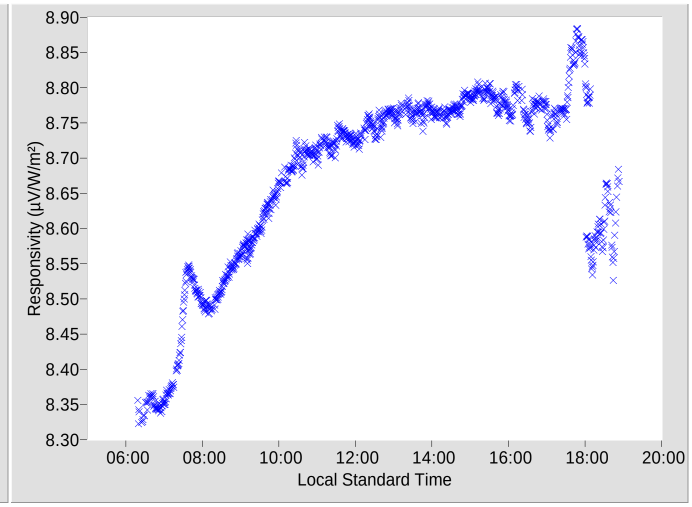


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6871	+1.96 / -2.73	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64270 µV/W/m², determination date: 07/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5825	0.60	97.12	8.7807	0.60	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5549	N/A	95.69	8.7595	0.63	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5829	0.63	101.85	8.7947	0.62	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5635	0.66	99.99	8.7645	0.68	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5499	0.68	98.25	8.7473	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5368	0.70	96.57	8.7758	0.67	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5183	0.71	94.98	8.7817	0.68	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4976	0.75	93.34	8.7397	0.75	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4851	0.78	91.83	8.7607	0.77	274.96
18	8.7248	0.55	155.43	8.7613	0.52	204.54	64	8.4914	0.83	90.30	8.7686	0.79	276.34
20	8.7308	0.49	142.74	8.7603	0.53	217.16	66	8.5093	0.88	88.84	8.8025	1.02	277.74
22	8.7238	0.56	134.46	8.7636	0.54	225.45	68	8.5382	0.94	87.36	8.8440	0.94	279.13
24	8.7192	0.51	128.32	8.7731	0.52	231.60	70	8.4962	1.18	85.91	8.8620	0.99	280.53
26	8.7185	0.54	123.44	8.7640	0.50	236.45	72	8.4035	1.12	84.46	8.7820	1.11	281.85
28	8.7032	0.51	119.30	8.7665	0.52	240.65	74	8.3741	1.23	83.06	8.5820	1.50	278.99
30	8.7112	0.54	115.80	8.7667	0.51	244.15	76	8.3520	1.44	81.58	8.5803	1.71	280.40
32	8.7066	0.57	112.65	8.7661	0.52	247.30	78	8.3444	1.66	80.19	8.5975	1.98	281.82
34	8.6849	0.52	109.78	8.7885	0.53	250.15	80	8.3634	2.03	78.71	8.6595	2.32	283.25
36	8.6732	0.54	107.36	8.7845	0.54	252.66	82	8.3437	2.69	77.19	8.5605	3.01	284.72
38	8.6645	0.58	104.98	8.7974	0.55	254.99	84	8.3402	3.57	75.77	N/A	N/A	N/A
40	8.6382	0.57	102.85	8.7981	0.56	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6268	0.56	100.77	8.7887	0.58	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6013	0.56	98.95	8.7647	0.59	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30951F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

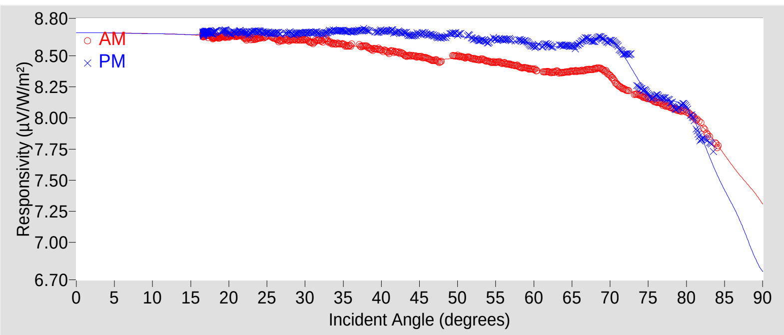
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

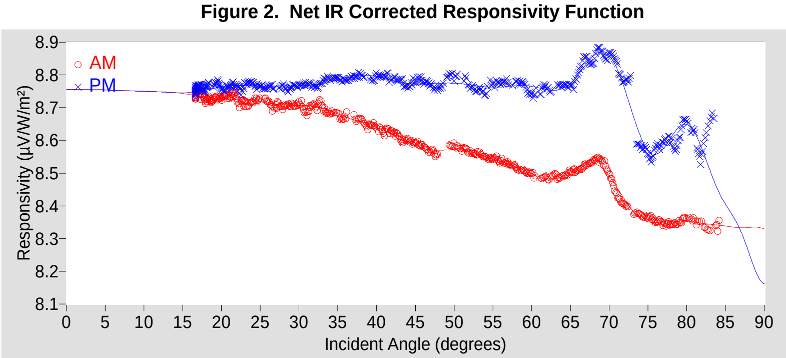


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.52	±1.52
R^2	0.9999993	0.9999977
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.57	±1.57
Net IR corrected R^2	0.9999996	0.9999985
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.6828	*	8.6827	*	8.6827	*	8.7540	*	8.7540	*	8.7540	*
9-18	8.6705	*	8.6736	*	8.6721	*	8.7451	*	8.7480	*	8.7466	*
18-27	8.6465	±1.52	8.6865	±1.52	8.6665	±1.59	8.7230	±1.57	8.7647	±1.57	8.7438	±1.63
27-36	8.6179	±1.54	8.6862	±1.52	8.6521	±1.78	8.7009	±1.58	8.7720	±1.58	8.7364	±1.82
36-45	8.5439	±1.61	8.6920	±1.53	8.6179	±2.37	8.6384	±1.64	8.7892	±1.58	8.7138	±2.32
45-54	8.4747	±1.52	8.6537	±1.53	8.5642	±2.25	8.5701	±1.58	8.7721	±1.57	8.6711	±2.39
54-63	8.4115	±1.62	8.6069	±1.55	8.5092	±2.68	8.5153	±1.62	8.7629	±1.57	8.6391	±2.83
63-72	8.3597	±1.69	8.5981	±1.67	8.4789	±3.50	8.5006	±1.66	8.8151	±1.71	8.6579	±3.88
72-81	8.1270	±2.06	8.2045	±3.11	8.1658	±4.50	8.3631	±1.63	8.6248	±1.95	8.4940	±3.87
81-90	7.6639	*	7.3639	*	7.5139	*	8.3386	*	8.3861	*	8.3623	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.5838	+2.08 / -2.77
45° - 55°	8.5608	±1.98
Composite	8.5972	+1.98 / -12.30
45° (Net IR Corr.)	8.6871	+1.96 / -2.73
45° - 55° (Net IR Corr.)	8.6688	±2.06
Composite (Net IR Corr.)	8.7066	+2.46 / -4.48

† Valid incident angle ranges:

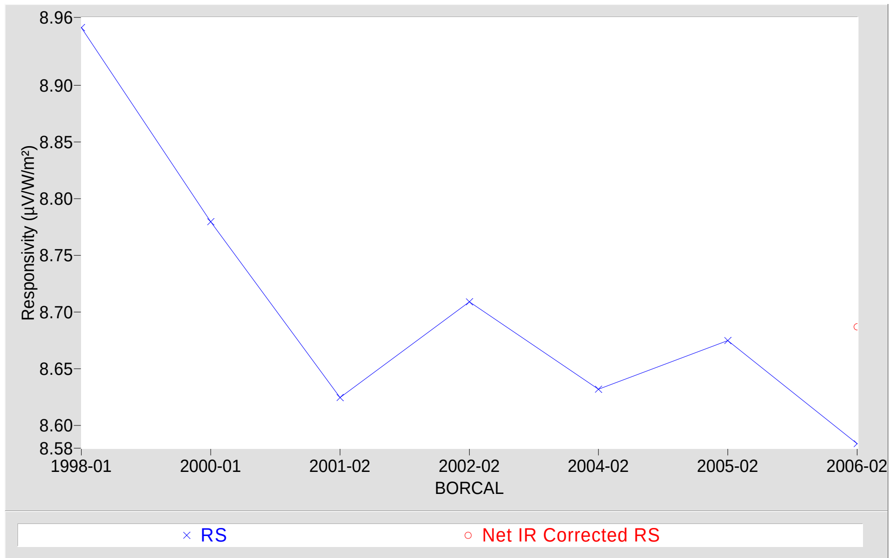
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



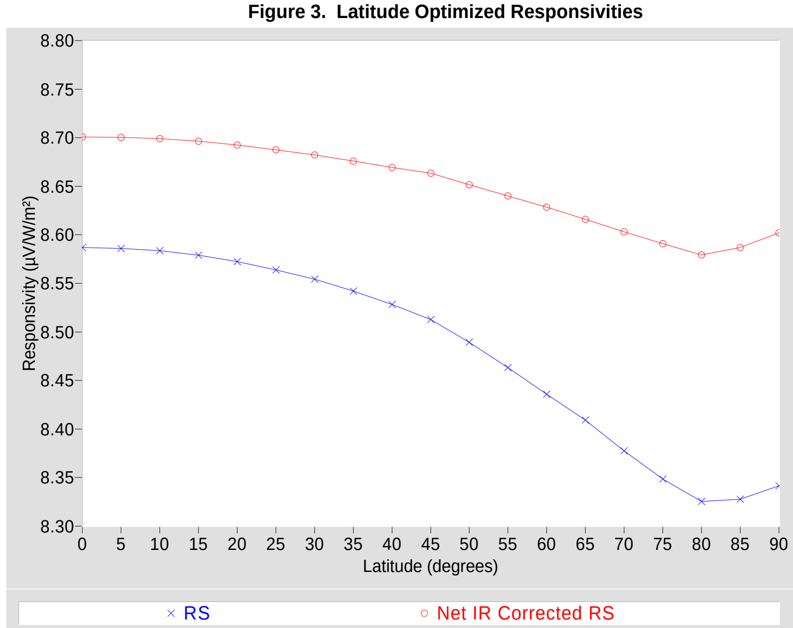
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5869	+2.06 / -19.97	8.7009	+2.51 / -6.03
5	8.5860	+2.07 / -19.96	8.7003	+2.52 / -6.02
10	8.5835	+2.09 / -19.94	8.6990	+2.53 / -6.01
15	8.5792	+2.12 / -19.90	8.6965	+2.55 / -5.98
20	8.5723	+2.18 / -19.84	8.6923	+2.59 / -5.94
25	8.5639	+2.25 / -19.76	8.6874	+2.64 / -5.89
30	8.5542	+2.34 / -19.67	8.6821	+2.69 / -5.83
35	8.5421	+2.45 / -19.55	8.6760	+2.75 / -5.77
40	8.5282	+2.58 / -19.42	8.6696	+2.81 / -5.70
45	8.5129	+2.73 / -19.28	8.6634	+2.87 / -5.64
50	8.4893	+2.97 / -19.05	8.6516	+2.99 / -5.51
55	8.4634	+3.25 / -18.81	8.6399	+3.11 / -5.39
60	8.4360	+3.55 / -18.54	8.6284	+3.23 / -5.27
65	8.4090	+3.68 / -18.28	8.6158	+3.36 / -5.14
70	8.3776	+3.75 / -17.98	8.6030	+3.50 / -5.00
75	8.3485	+3.90 / -17.69	8.5910	+3.62 / -4.88
80	8.3253	+4.11 / -17.46	8.5793	+3.75 / -4.75
85	8.3278	+4.08 / -17.49	8.5868	+3.67 / -4.83
90	8.3415	+3.92 / -17.62	8.6022	+3.50 / -4.99

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

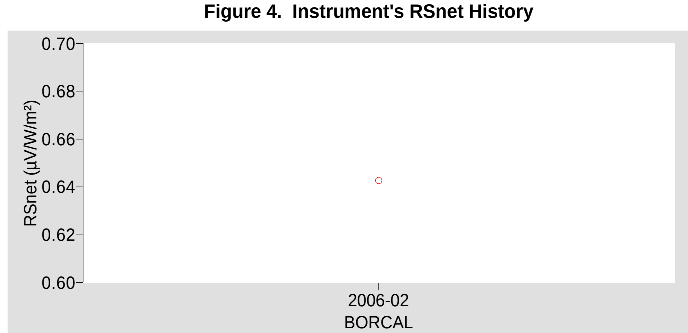
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30954F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data
Environmental Conditions:	Outdoors, under natural sunlight (see Ancillary Data)		
Data Acquisition Dates:	7/23, 8/6, 8/12		

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

30954F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

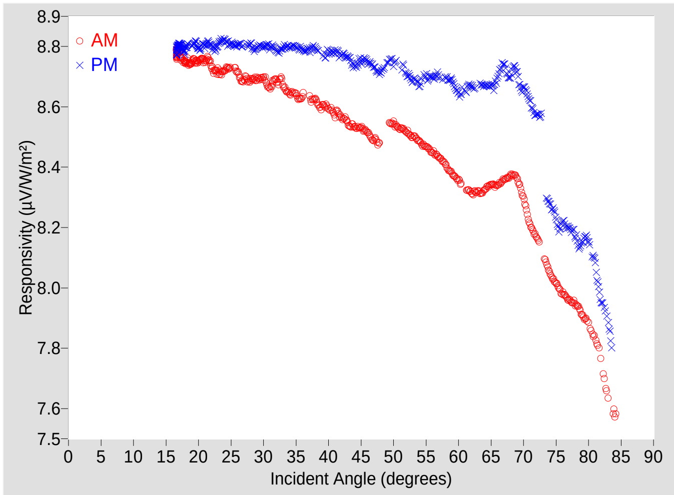


Figure 2. Responsivity vs Local Standard Time

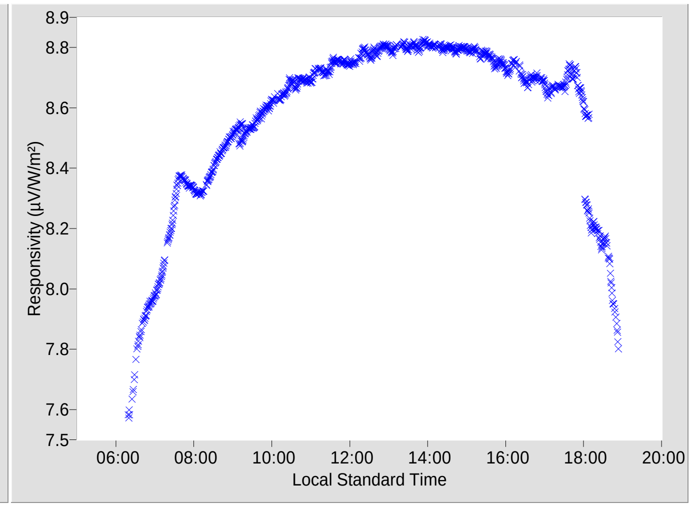


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6412	+2.47 / -3.77	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5150	0.60	97.12	8.7497	0.57	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4805	N/A	95.69	8.7135	0.60	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5439	0.62	101.85	8.7476	0.59	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5172	0.65	99.99	8.7063	0.68	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4857	0.67	98.25	8.6777	0.64	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4489	0.69	96.57	8.6980	0.63	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4104	0.73	94.98	8.6981	0.62	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3554	0.74	93.34	8.6447	0.71	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3146	0.75	91.83	8.6685	0.69	274.96
18	8.7497	0.56	155.43	8.7934	0.51	204.54	64	8.3250	0.81	90.30	8.6708	0.71	276.34
20	8.7522	0.47	142.74	8.7945	0.50	217.16	66	8.3407	0.85	88.84	8.6963	0.93	277.74
22	8.7324	0.58	134.46	8.8015	0.51	225.45	68	8.3719	0.90	87.36	8.7037	0.85	279.13
24	8.7220	0.49	128.32	8.8200	0.49	231.60	70	8.2954	1.33	85.91	8.6605	1.03	280.53
26	8.7149	0.54	123.44	8.8047	0.48	236.45	72	8.1676	1.10	84.46	8.5741	1.01	281.85
28	8.6881	0.49	119.30	8.8053	0.50	240.65	74	8.0540	1.27	83.06	8.2776	1.40	278.99
30	8.6943	0.52	115.80	8.7995	0.49	244.15	76	7.9805	1.42	81.58	8.2188	1.52	280.40
32	8.6880	0.53	112.65	8.7865	0.51	247.30	78	7.9472	1.63	80.19	8.1712	1.81	281.82
34	8.6460	0.51	109.78	8.7990	0.50	250.15	80	7.8808	2.01	78.71	8.1535	2.11	283.25
36	8.6340	0.51	107.36	8.7891	0.51	252.66	82	7.7405	2.81	77.19	7.9527	2.83	284.72
38	8.6234	0.56	104.98	8.7915	0.53	254.99	84	7.5839	3.47	75.77	N/A	N/A	N/A
40	8.5949	0.55	102.85	8.7831	0.54	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5652	0.56	100.77	8.7730	0.55	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5347	0.53	98.95	8.7342	0.57	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

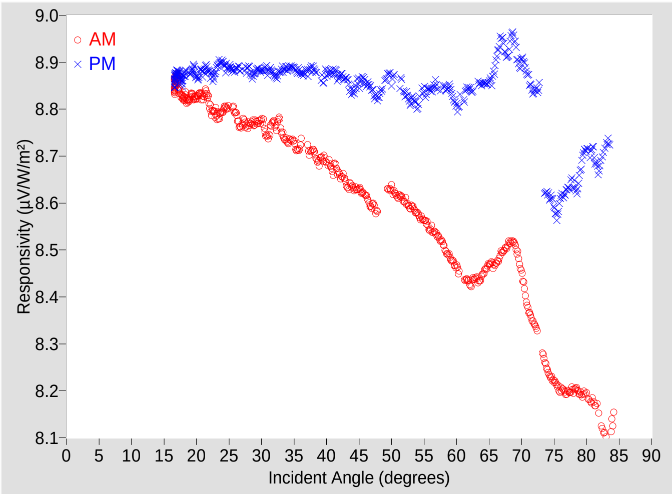

Figure 4. Responsivity vs Local Standard Time

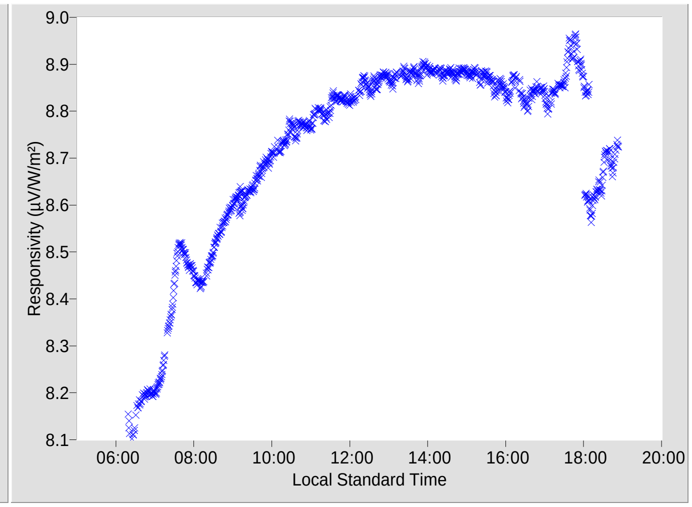

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7429	+2.28 / -3.72	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63330 µV/W/m², determination date: 06/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6158	0.62	97.12	8.8569	0.60	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5844	N/A	95.69	8.8256	0.64	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6288	0.64	101.85	8.8657	0.63	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6040	0.67	99.99	8.8324	0.71	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5781	0.69	98.25	8.8111	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5440	0.70	96.57	8.8416	0.69	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5117	0.75	94.98	8.8497	0.68	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4620	0.77	93.34	8.8067	0.76	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4287	0.78	91.83	8.8428	0.77	274.96
18	8.8257	0.58	155.43	8.8672	0.52	204.54	64	8.4478	0.85	90.30	8.8546	0.78	276.34
20	8.8255	0.48	142.74	8.8697	0.52	217.16	66	8.4701	0.90	88.84	8.8963	1.03	277.74
22	8.8085	0.60	134.46	8.8777	0.53	225.45	68	8.5130	0.94	87.36	8.9222	0.94	279.13
24	8.7968	0.52	128.32	8.8983	0.52	231.60	70	8.4503	1.28	85.91	8.9028	1.05	280.53
26	8.7920	0.55	123.44	8.8853	0.50	236.45	72	8.3407	1.14	84.46	8.8384	1.09	281.85
28	8.7659	0.51	119.30	8.8865	0.52	240.65	74	8.2449	1.28	83.06	8.6183	1.50	278.99
30	8.7742	0.54	115.80	8.8820	0.52	244.15	76	8.2017	1.45	81.58	8.6116	1.71	280.40
32	8.7697	0.57	112.65	8.8719	0.53	247.30	78	8.2028	1.67	80.19	8.6399	1.97	281.82
34	8.7323	0.52	109.78	8.8868	0.53	250.15	80	8.1907	2.05	78.71	8.7141	2.31	283.25
36	8.7227	0.54	107.36	8.8780	0.54	252.66	82	8.1387	2.74	77.19	8.6749	2.94	284.72
38	8.7107	0.58	104.98	8.8838	0.55	254.99	84	8.1333	3.62	75.77	N/A	N/A	N/A
40	8.6880	0.57	102.85	8.8788	0.57	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6607	0.58	100.77	8.8708	0.57	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6345	0.56	98.95	8.8361	0.60	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

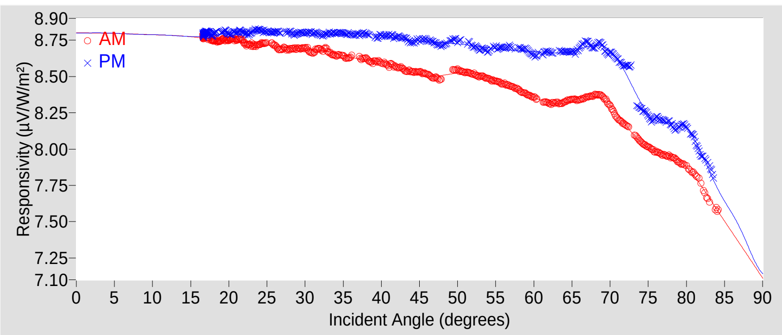
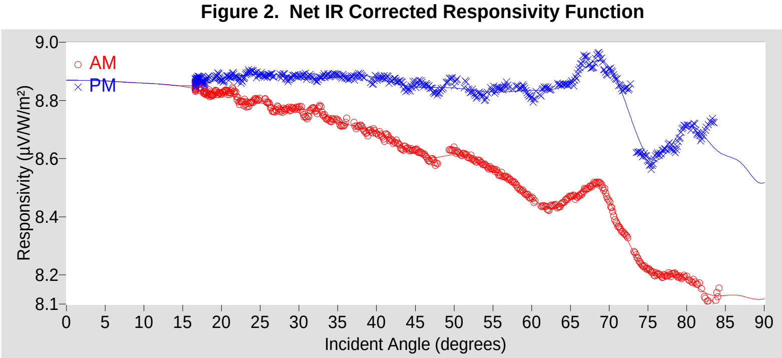


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.54	±1.54
R²	0.9999993	0.9999973
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.58	±1.58
Net IR corrected R²	0.9999995	0.9999981
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.7966	*	8.7965	*	8.7965	*	8.8668	*	8.8667	*	8.8667	*
9-18	8.7778	*	8.7812	*	8.7795	*	8.8513	*	8.8546	*	8.8530	*
18-27	8.7325	±1.57	8.8035	±1.55	8.7680	±1.77	8.8079	±1.61	8.8805	±1.59	8.8442	±1.81
27-36	8.6784	±1.58	8.7964	±1.54	8.7374	±2.08	8.7602	±1.61	8.8809	±1.58	8.8205	±2.07
36-45	8.5875	±1.67	8.7758	±1.57	8.6816	±2.75	8.6807	±1.68	8.8716	±1.60	8.7761	±2.68
45-54	8.5125	±1.55	8.7248	±1.56	8.6187	±2.52	8.6065	±1.59	8.8415	±1.59	8.7240	±2.62
54-63	8.3989	±1.86	8.6784	±1.55	8.5387	±3.57	8.5013	±1.81	8.8322	±1.58	8.6667	±3.72
63-72	8.3210	±1.81	8.6758	±1.74	8.4984	±4.56	8.4599	±1.77	8.8897	±1.68	8.6748	±4.88
72-81	7.9932	±2.54	8.2528	±2.95	8.1230	±6.21	8.2258	±1.88	8.6669	±1.99	8.4464	±5.51
81-90	7.4659	*	7.5987	*	7.5323	*	8.1308	*	8.6059	*	8.3684	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

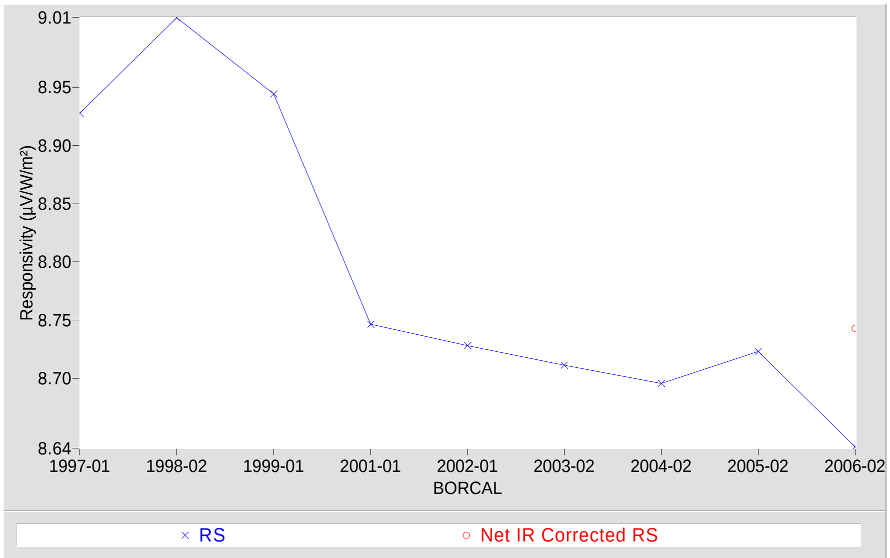
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6412	+2.47 / -3.77
45° - 55°	8.6142	±2.21
Composite	8.6726	+2.20 / -12.65
45° (Net IR Corr.)	8.7429	+2.28 / -3.72
45° - 55° (Net IR Corr.)	8.7207	±2.27
Composite (Net IR Corr.)	8.7805	+2.38 / -7.60

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



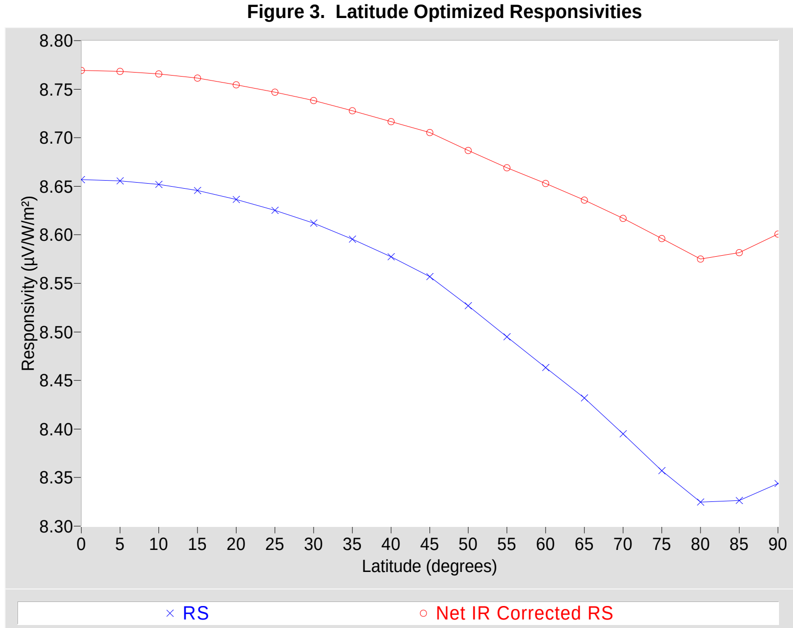
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6570	+2.34 / -17.00	8.7693	+2.47 / -7.61
5	8.6556	+2.35 / -16.99	8.7683	+2.48 / -7.60
10	8.6519	+2.38 / -16.95	8.7657	+2.50 / -7.58
15	8.6456	+2.44 / -16.89	8.7613	+2.54 / -7.53
20	8.6364	+2.53 / -16.81	8.7546	+2.60 / -7.46
25	8.6252	+2.63 / -16.70	8.7469	+2.67 / -7.38
30	8.6122	+2.76 / -16.57	8.7382	+2.76 / -7.29
35	8.5957	+2.92 / -16.41	8.7276	+2.86 / -7.18
40	8.5772	+3.11 / -16.23	8.7165	+2.97 / -7.07
45	8.5571	+3.33 / -16.04	8.7055	+3.08 / -6.95
50	8.5271	+3.64 / -15.74	8.6870	+3.27 / -6.76
55	8.4950	+3.87 / -15.43	8.6690	+3.46 / -6.57
60	8.4633	+4.23 / -15.11	8.6529	+3.63 / -6.40
65	8.4320	+4.32 / -14.80	8.6357	+3.81 / -6.22
70	8.3949	+4.38 / -14.42	8.6170	+4.02 / -6.02
75	8.3570	+4.58 / -14.04	8.5960	+4.25 / -5.80
80	8.3247	+4.94 / -13.71	8.5751	+4.49 / -5.58
85	8.3265	+4.92 / -13.72	8.5817	+4.41 / -5.65
90	8.3440	+4.71 / -13.90	8.6009	+4.20 / -5.85

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

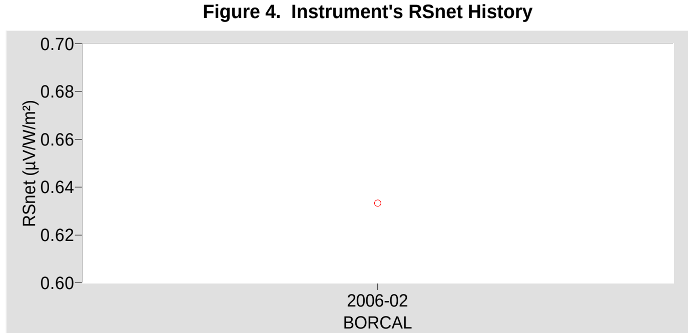
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30955F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30955F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

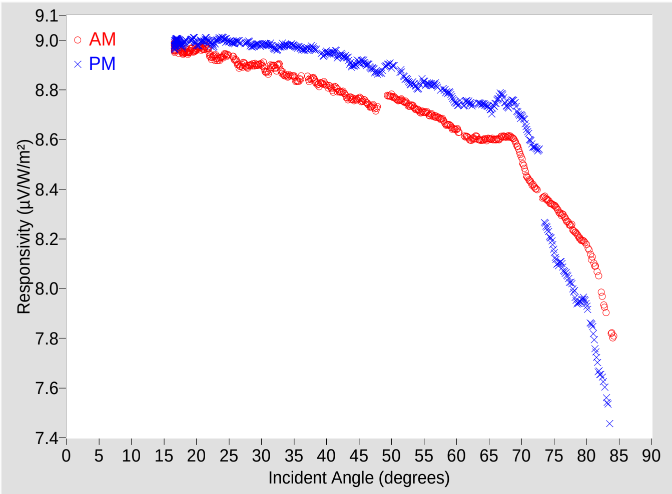


Figure 2. Responsivity vs Local Standard Time

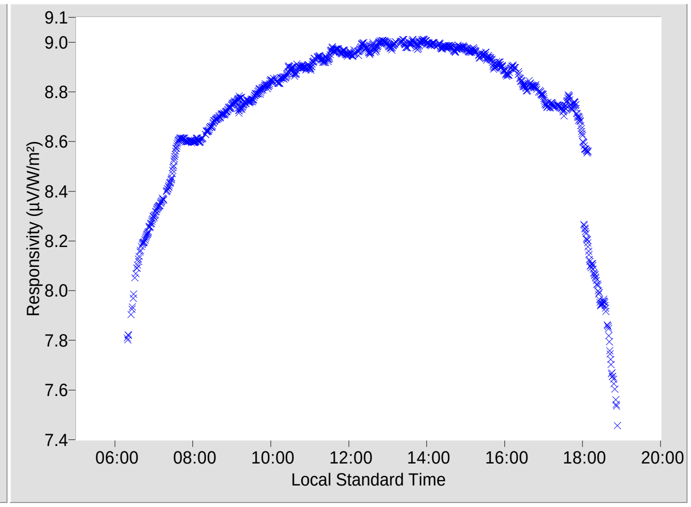


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8375	+2.23 / -2.75	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7532	0.58	97.12	8.9063	0.58	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7246	N/A	95.69	8.8678	0.58	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7748	0.62	101.85	8.8976	0.58	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7518	0.65	99.99	8.8484	0.67	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7203	0.66	98.25	8.8106	0.64	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6996	0.67	96.57	8.8210	0.61	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6767	0.70	94.98	8.8015	0.64	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6389	0.73	93.34	8.7442	0.70	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6023	0.75	91.83	8.7473	0.69	274.96
18	8.9522	0.53	155.43	8.9861	0.50	204.54	64	8.5986	0.79	90.30	8.7432	0.71	276.34
20	8.9634	0.47	142.74	8.9857	0.50	217.16	66	8.5997	0.84	88.84	8.7458	0.90	277.74
22	8.9442	0.58	134.46	8.9919	0.52	225.45	68	8.6127	0.90	87.36	8.7358	0.86	279.13
24	8.9339	0.49	128.32	9.0070	0.49	231.60	70	8.5237	1.29	85.91	8.6910	1.10	280.53
26	8.9194	0.54	123.44	8.9930	0.48	236.45	72	8.4084	1.09	84.46	8.5682	1.04	281.85
28	8.8943	0.49	119.30	8.9905	0.49	240.65	74	8.3575	1.19	83.06	8.2353	1.50	278.99
30	8.9007	0.53	115.80	8.9793	0.48	244.15	76	8.3014	1.42	81.58	8.1051	1.61	280.40
32	8.8937	0.53	112.65	8.9667	0.51	247.30	78	8.2379	1.63	80.19	7.9922	1.90	281.82
34	8.8580	0.50	109.78	8.9789	0.50	250.15	80	8.1750	2.00	78.71	7.9340	2.20	283.25
36	8.8449	0.51	107.36	8.9664	0.52	252.66	82	8.0189	2.80	77.19	7.6608	2.98	284.72
38	8.8438	0.55	104.98	8.9651	0.52	254.99	84	7.8137	3.47	75.77	N/A	N/A	N/A
40	8.8183	0.54	102.85	8.9509	0.53	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7944	0.55	100.77	8.9392	0.56	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7637	0.53	98.95	8.8963	0.58	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

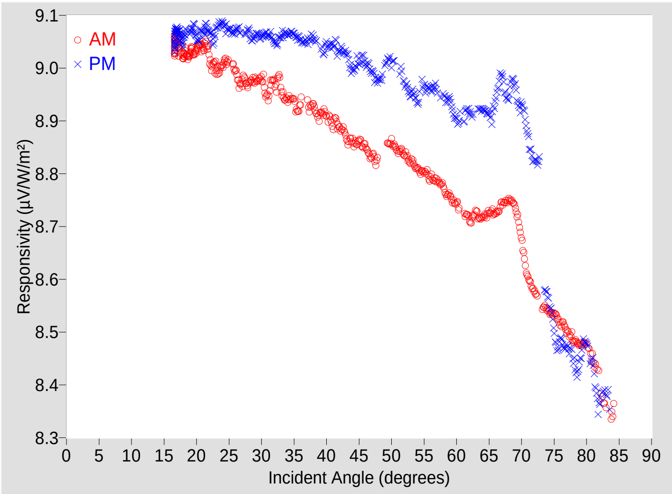


Figure 4. Responsivity vs Local Standard Time

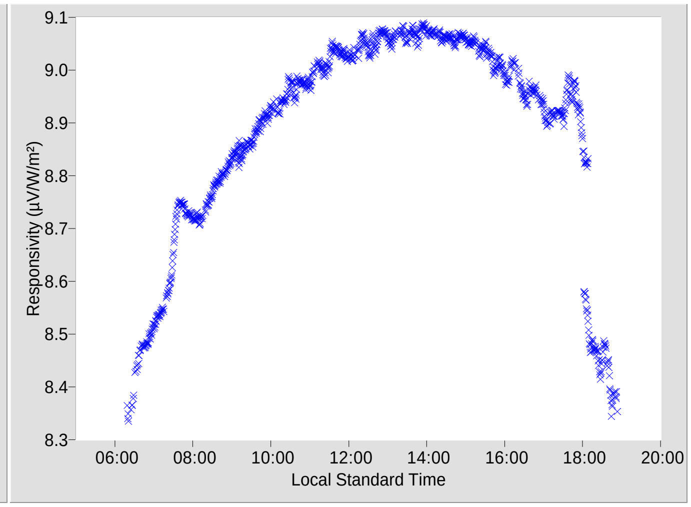


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9363	+2.07 / -2.71	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.61498 µV/W/m², determination date: 07/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8510	0.60	97.12	9.0103	0.61	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8255	N/A	95.69	8.9766	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8573	0.64	101.85	9.0123	0.61	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8361	0.66	99.99	8.9709	0.70	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8100	0.68	98.25	8.9401	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7919	0.69	96.57	8.9604	0.66	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7751	0.72	94.98	8.9487	0.68	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7424	0.75	93.34	8.9015	0.75	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7131	0.78	91.83	8.9166	0.76	274.96
18	9.0260	0.56	155.43	9.0578	0.52	204.54	64	8.7177	0.82	90.30	8.9217	0.78	276.34
20	9.0345	0.49	142.74	9.0588	0.52	217.16	66	8.7253	0.88	88.84	8.9400	1.00	277.74
22	9.0181	0.60	134.46	9.0660	0.54	225.45	68	8.7497	0.93	87.36	8.9480	0.93	279.13
24	9.0066	0.51	128.32	9.0831	0.51	231.60	70	8.6741	1.25	85.91	8.9262	1.11	280.53
26	8.9943	0.55	123.44	9.0712	0.50	236.45	72	8.5765	1.12	84.46	8.8248	1.11	281.85
28	8.9699	0.51	119.30	9.0694	0.51	240.65	74	8.5428	1.22	83.06	8.5661	1.55	278.99
30	8.9782	0.55	115.80	9.0594	0.51	244.15	76	8.5162	1.44	81.58	8.4866	1.69	280.40
32	8.9730	0.57	112.65	9.0496	0.53	247.30	78	8.4861	1.66	80.19	8.4474	2.00	281.82
34	8.9418	0.52	109.78	9.0641	0.52	250.15	80	8.4760	2.03	78.71	8.4784	2.33	283.25
36	8.9310	0.54	107.36	9.0527	0.54	252.66	82	8.4056	2.72	77.19	8.3621	3.01	284.72
38	8.9285	0.56	104.98	9.0548	0.55	254.99	84	8.3472	3.57	75.77	N/A	N/A	N/A
40	8.9087	0.57	102.85	9.0438	0.56	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8871	0.57	100.77	9.0342	0.58	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8606	0.56	98.95	8.9952	0.60	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30955F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

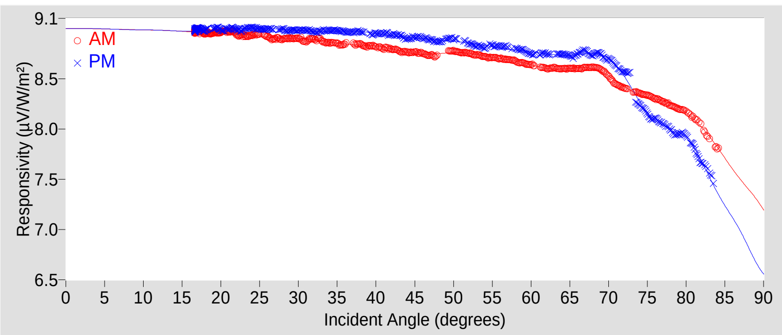
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

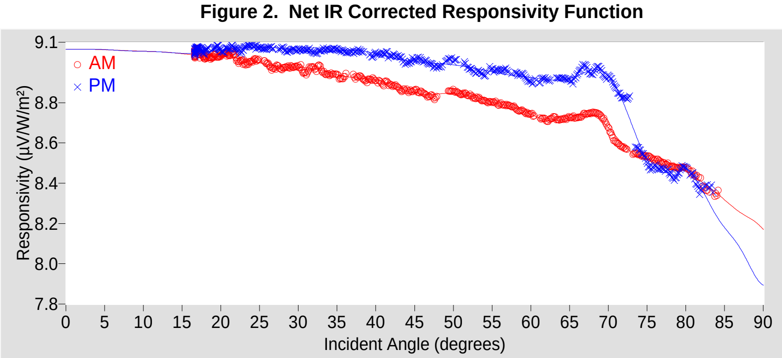


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.56	±1.56
R²	0.9999992	0.9999976
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.58	±1.58
Net IR corrected R²	0.9999995	0.9999983
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.9945	*	8.9945	*	8.9945	*	9.0627	*	9.0627	*	9.0627	*
9-18	8.9760	*	8.9786	*	8.9773	*	9.0473	*	9.0498	*	9.0485	*
18-27	8.9418	±1.58	8.9932	±1.56	8.9675	±1.72	9.0150	±1.60	9.0680	±1.58	9.0415	±1.74
27-36	8.8858	±1.59	8.9775	±1.57	8.9316	±1.94	8.9652	±1.60	9.0595	±1.58	9.0124	±1.92
36-45	8.8112	±1.64	8.9446	±1.60	8.8779	±2.36	8.9017	±1.64	9.0376	±1.61	8.9697	±2.29
45-54	8.7485	±1.57	8.8749	±1.60	8.8117	±2.08	8.8398	±1.59	8.9881	±1.59	8.9140	±2.16
54-63	8.6651	±1.72	8.7848	±1.64	8.7250	±2.46	8.7645	±1.68	8.9341	±1.60	8.8493	±2.56
63-72	8.5716	±1.82	8.7185	±1.83	8.6451	±3.01	8.7065	±1.75	8.9262	±1.73	8.8163	±3.27
72-81	8.2879	±2.35	8.1341	±4.32	8.2110	±5.86	8.5138	±1.78	8.5363	±2.55	8.5250	±3.64
81-90	7.6590	*	7.1795	*	7.4193	*	8.3046	*	8.1576	*	8.2311	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

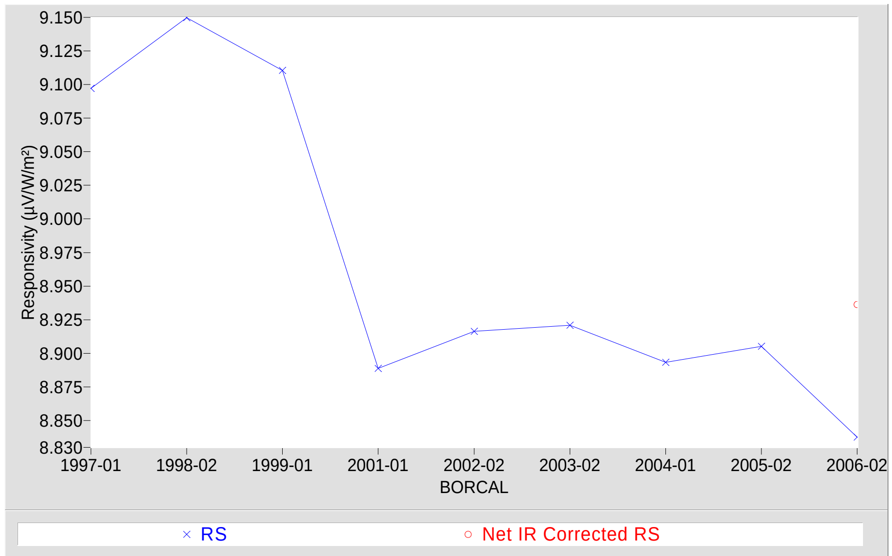
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.8375	+2.23 / -2.75
45° - 55°	8.8061	±1.90
Composite	8.8584	+2.22 / -16.84
45° (Net IR Corr.)	8.9363	+2.07 / -2.71
45° - 55° (Net IR Corr.)	8.9095	±1.94
Composite (Net IR Corr.)	8.9632	+2.01 / -8.27

† Valid incident angle ranges:
- 45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
- 45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
- Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



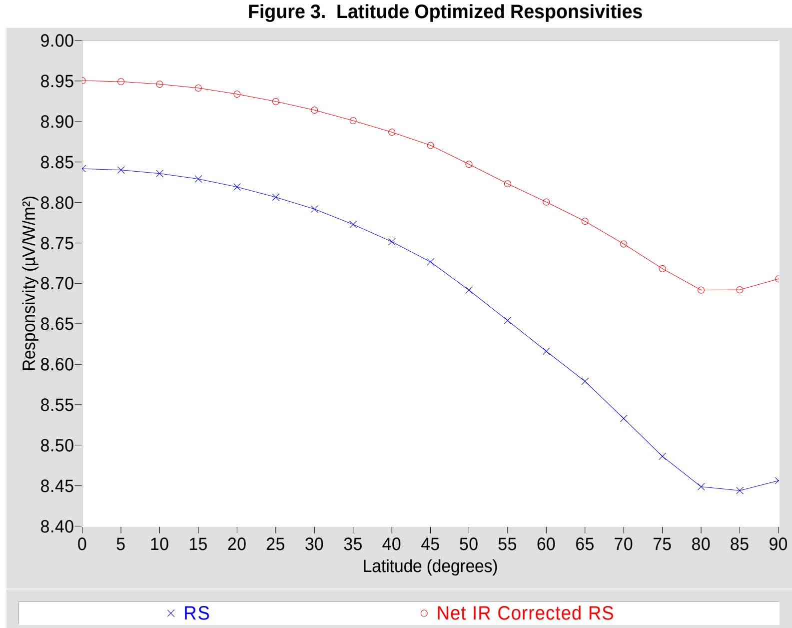
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.8416	+2.36 / -24.54	8.9507	+2.10 / -11.43
5	8.8400	+2.37 / -24.53	8.9494	+2.11 / -11.42
10	8.8359	+2.41 / -24.49	8.9464	+2.13 / -11.39
15	8.8291	+2.47 / -24.43	8.9414	+2.17 / -11.34
20	8.8191	+2.56 / -24.35	8.9339	+2.23 / -11.27
25	8.8066	+2.68 / -24.24	8.9248	+2.30 / -11.18
30	8.7917	+2.82 / -24.11	8.9141	+2.40 / -11.07
35	8.7730	+3.00 / -23.95	8.9011	+2.51 / -10.94
40	8.7515	+3.22 / -23.76	8.8867	+2.64 / -10.80
45	8.7267	+3.48 / -23.55	8.8708	+2.79 / -10.64
50	8.6918	+3.83 / -23.24	8.8472	+3.01 / -10.41
55	8.6542	+4.01 / -22.91	8.8231	+3.12 / -10.17
60	8.6163	+4.42 / -22.57	8.8004	+3.35 / -9.94
65	8.5789	+4.47 / -22.23	8.7767	+3.32 / -9.70
70	8.5331	+4.55 / -21.82	8.7488	+3.28 / -9.41
75	8.4862	+4.71 / -21.39	8.7183	+3.42 / -9.10
80	8.4487	+4.51 / -21.04	8.6917	+3.49 / -8.82
85	8.4441	+4.04 / -20.99	8.6919	+3.49 / -8.83
90	8.4560	+3.82 / -21.11	8.7056	+3.34 / -8.97

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

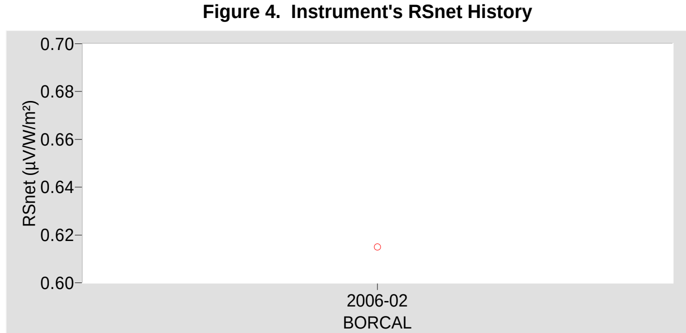
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30958F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

30958F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

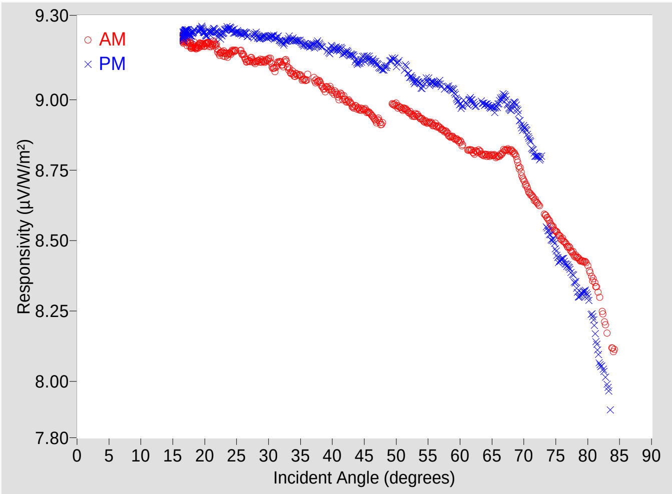


Figure 2. Responsivity vs Local Standard Time

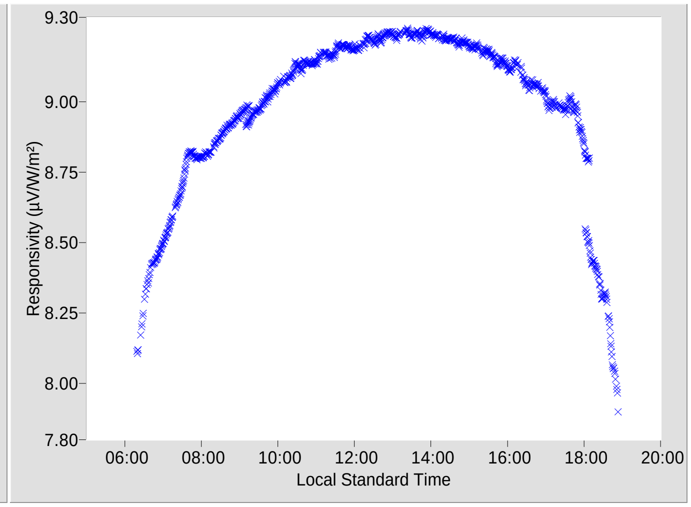


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.0553	+2.45 / -2.75	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9486	0.60	97.12	9.1412	0.57	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9130	N/A	95.69	9.1081	0.58	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9805	0.62	101.85	9.1321	0.59	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9560	0.64	99.99	9.0865	0.68	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9315	0.67	98.25	9.0501	0.63	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9097	0.67	96.57	9.0592	0.61	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8828	0.69	94.98	9.0461	0.62	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8489	0.73	93.34	8.9816	0.72	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8149	0.75	91.83	8.9922	0.70	274.96
18	9.1910	0.54	155.43	9.2346	0.49	204.54	64	8.8041	0.79	90.30	8.9842	0.72	276.34
20	9.1961	0.46	142.74	9.2353	0.50	217.16	66	8.7995	0.85	88.84	8.9855	0.84	277.74
22	9.1771	0.55	134.46	9.2370	0.51	225.45	68	8.8193	0.91	87.36	8.9699	0.85	279.13
24	9.1674	0.49	128.32	9.2523	0.49	231.60	70	8.7111	1.15	85.91	8.8989	1.06	280.53
26	9.1605	0.52	123.44	9.2355	0.49	236.45	72	8.6362	1.08	84.46	8.7988	1.02	281.85
28	9.1346	0.49	119.30	9.2316	0.49	240.65	74	8.5690	1.21	83.06	8.5225	1.42	278.99
30	9.1414	0.52	115.80	9.2214	0.48	244.15	76	8.5027	1.40	81.58	8.4355	1.54	280.40
32	9.1300	0.53	112.65	9.2067	0.52	247.30	78	8.4483	1.60	80.19	8.3528	1.86	281.82
34	9.0906	0.51	109.78	9.2122	0.50	250.15	80	8.4088	1.97	78.71	8.3018	2.15	283.25
36	9.0751	0.51	107.36	9.1936	0.51	252.66	82	8.2736	2.71	77.19	8.0582	2.84	284.72
38	9.0629	0.57	104.98	9.1932	0.53	254.99	84	8.1141	3.40	75.77	N/A	N/A	N/A
40	9.0295	0.55	102.85	9.1850	0.54	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0009	0.55	100.77	9.1684	0.55	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9704	0.53	98.95	9.1298	0.56	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

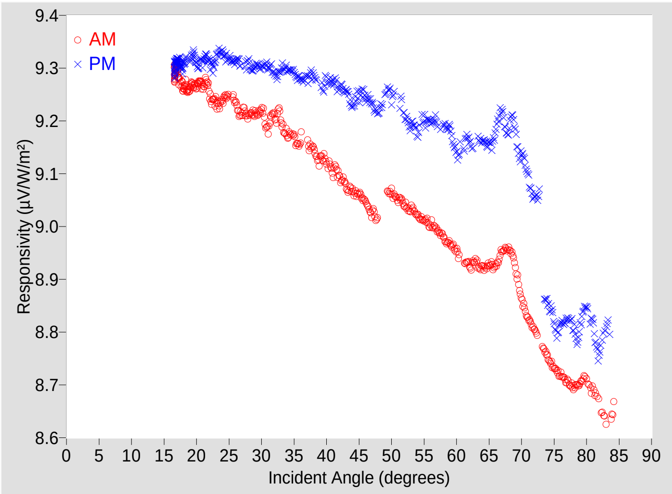


Figure 4. Responsivity vs Local Standard Time

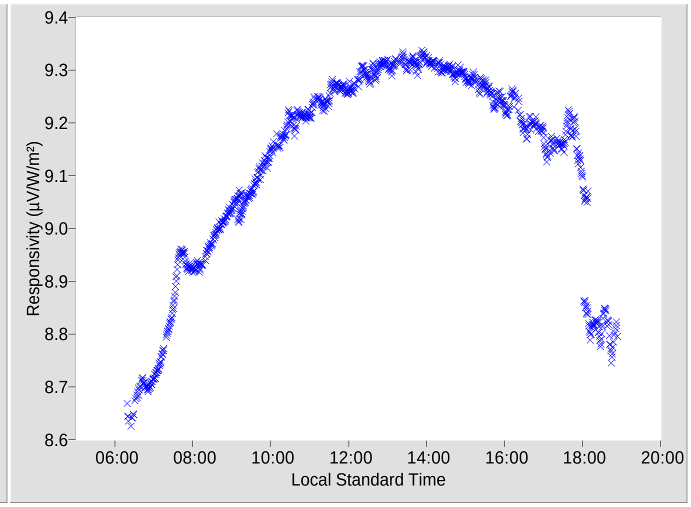


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.1542	+2.28 / -2.73	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.61540 µV/W/m², determination date: 06/06/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0465	0.62	97.12	9.2453	0.59	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0139	N/A	95.69	9.2170	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0630	0.63	101.85	9.2468	0.63	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0403	0.66	99.99	9.2091	0.71	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0213	0.68	98.25	9.1797	0.68	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0021	0.69	96.57	9.1987	0.66	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9812	0.71	94.98	9.1933	0.67	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9525	0.75	93.34	9.1390	0.76	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9258	0.78	91.83	9.1616	0.76	274.96
18	9.2648	0.56	155.43	9.3064	0.51	204.54	64	8.9233	0.82	90.30	9.1627	0.78	276.34
20	9.2673	0.48	142.74	9.3084	0.52	217.16	66	8.9252	0.89	88.84	9.1799	0.94	277.74
22	9.2511	0.57	134.46	9.3111	0.53	225.45	68	8.9564	0.94	87.36	9.1823	0.92	279.13
24	9.2401	0.51	128.32	9.3284	0.51	231.60	70	8.8616	1.14	85.91	9.1343	1.07	280.53
26	9.2354	0.53	123.44	9.3138	0.50	236.45	72	8.8043	1.11	84.46	9.0556	1.09	281.85
28	9.2102	0.50	119.30	9.3106	0.51	240.65	74	8.7545	1.24	83.06	8.8535	1.49	278.99
30	9.2190	0.54	115.80	9.3016	0.51	244.15	76	8.7176	1.42	81.58	8.8172	1.67	280.40
32	9.2094	0.57	112.65	9.2897	0.53	247.30	78	8.6967	1.64	80.19	8.8082	1.96	281.82
34	9.1745	0.53	109.78	9.2974	0.52	250.15	80	8.7100	2.02	78.71	8.8465	2.29	283.25
36	9.1613	0.54	107.36	9.2800	0.53	252.66	82	8.6606	2.67	77.19	8.7600	2.93	284.72
38	9.1477	0.58	104.98	9.2829	0.55	254.99	84	8.6480	3.53	75.77	N/A	N/A	N/A
40	9.1201	0.57	102.85	9.2780	0.57	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0937	0.57	100.77	9.2634	0.57	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0674	0.56	98.95	9.2288	0.59	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30958F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

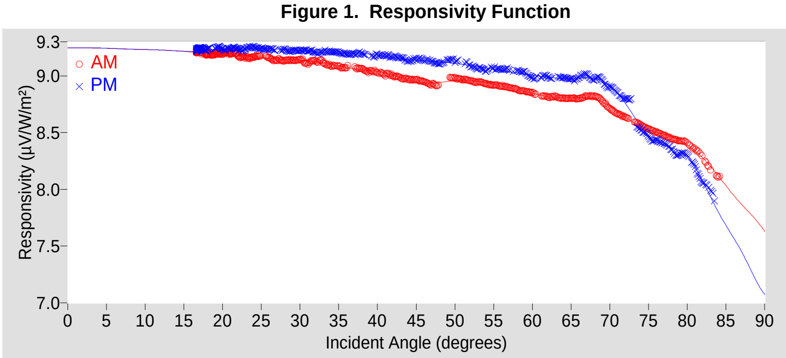
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

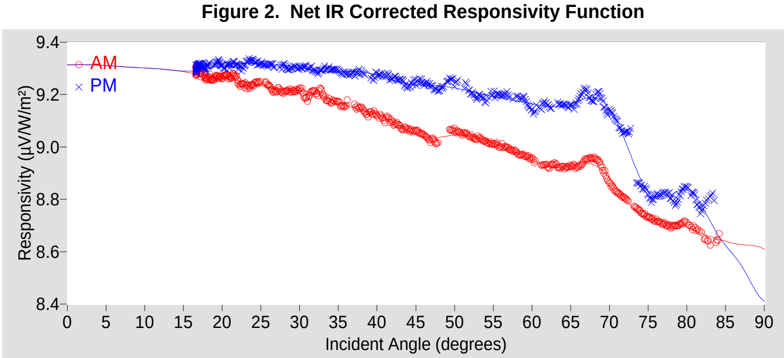


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.51	±1.51
R^2	0.9999989	0.9999980
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.55	±1.55
Net IR corrected R^2	0.9999992	0.9999986
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	9.2425	*	9.2424	*	9.2425	*	9.3107	*	9.3107	*	9.3107	*
9-18	9.2206	*	9.2241	*	9.2223	*	9.2920	*	9.2953	*	9.2937	*
18-27	9.1770	±1.53	9.2391	±1.51	9.2080	±1.68	9.2502	±1.57	9.3139	±1.55	9.2821	±1.71
27-36	9.1230	±1.56	9.2159	±1.52	9.1695	±1.94	9.2025	±1.58	9.2980	±1.56	9.2502	±1.93
36-45	9.0243	±1.65	9.1753	±1.55	9.0998	±2.46	9.1149	±1.65	9.2684	±1.57	9.1916	±2.40
45-54	8.9486	±1.52	9.1117	±1.55	9.0302	±2.18	9.0400	±1.55	9.2251	±1.56	9.1325	±2.23
54-63	8.8746	±1.67	9.0254	±1.58	8.9500	±2.54	8.9741	±1.65	9.1749	±1.57	9.0745	±2.65
63-72	8.7753	±1.72	8.9498	±1.80	8.8625	±3.03	8.9103	±1.68	9.1576	±1.70	9.0339	±3.28
72-81	8.5020	±2.19	8.4555	±3.39	8.4787	±4.56	8.7281	±1.69	8.8579	±2.01	8.7930	±3.30
81-90	7.9947	*	7.6292	*	7.8120	*	8.6408	*	8.6080	*	8.6244	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

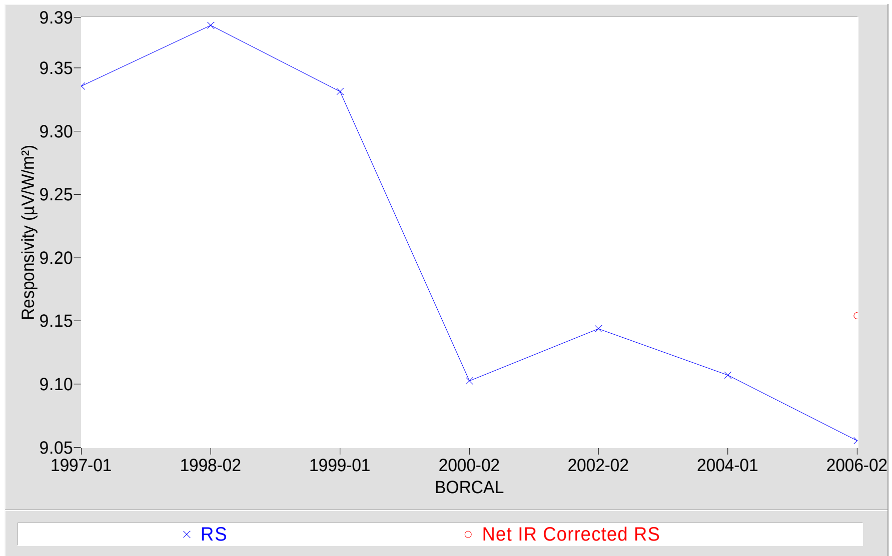
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.0553	+2.45 / -2.75
45° - 55°	9.0256	±1.92
Composite	9.0958	+2.23 / -14.30
45° (Net IR Corr.)	9.1542	+2.28 / -2.73
45° - 55° (Net IR Corr.)	9.1290	±1.97
Composite (Net IR Corr.)	9.2006	+2.02 / -6.20

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



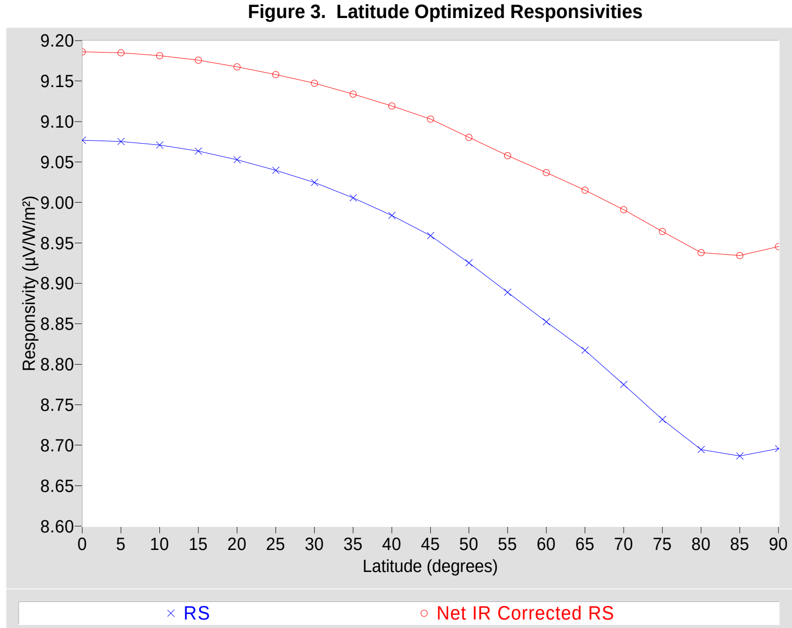
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.0771	+2.40 / -20.92	9.1862	+2.12 / -8.22
5	9.0755	+2.42 / -20.91	9.1850	+2.13 / -8.21
10	9.0710	+2.46 / -20.87	9.1815	+2.16 / -8.17
15	9.0635	+2.52 / -20.81	9.1759	+2.20 / -8.12
20	9.0528	+2.62 / -20.71	9.1677	+2.27 / -8.04
25	9.0398	+2.74 / -20.60	9.1581	+2.35 / -7.94
30	9.0247	+2.87 / -20.47	9.1472	+2.44 / -7.84
35	9.0058	+3.06 / -20.30	9.1340	+2.55 / -7.71
40	8.9841	+3.27 / -20.11	9.1194	+2.69 / -7.56
45	8.9590	+3.53 / -19.88	9.1032	+2.84 / -7.40
50	8.9252	+3.81 / -19.58	9.0806	+3.02 / -7.17
55	8.8889	+3.98 / -19.25	9.0580	+3.06 / -6.95
60	8.8526	+4.22 / -18.92	9.0369	+3.19 / -6.74
65	8.8172	+4.28 / -18.60	9.0152	+3.17 / -6.52
70	8.7751	+4.35 / -18.21	8.9909	+3.13 / -6.27
75	8.7317	+4.49 / -17.80	8.9640	+3.25 / -6.00
80	8.6946	+4.33 / -17.45	8.9379	+3.21 / -5.73
85	8.6865	+3.89 / -17.38	8.9345	+3.24 / -5.70
90	8.6958	+3.62 / -17.47	8.9455	+3.13 / -5.81

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

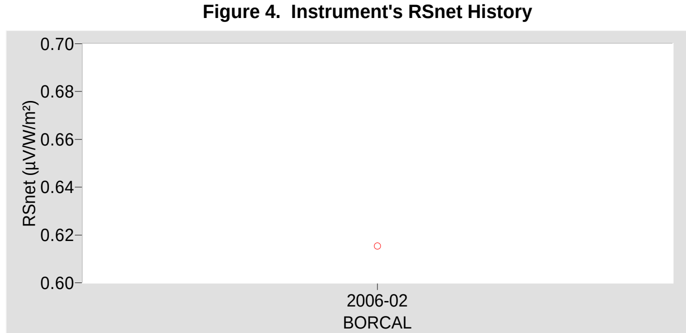
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30961F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

30961F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

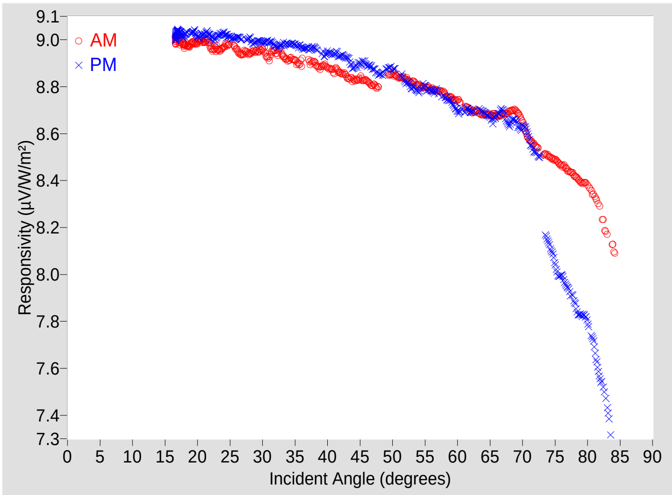


Figure 2. Responsivity vs Local Standard Time

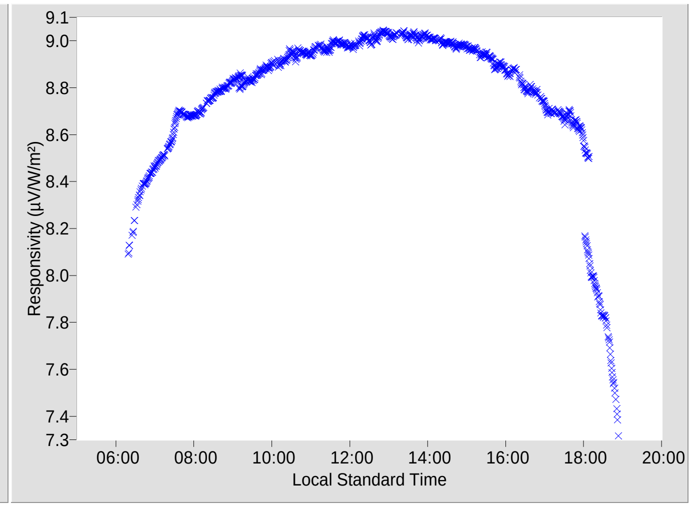


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8662	+2.01 / -2.35	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8261	0.58	97.12	8.8946	0.58	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8013	N/A	95.69	8.8520	0.58	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8528	0.62	101.85	8.8758	0.58	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8347	0.64	99.99	8.8187	0.68	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8069	0.66	98.25	8.7824	0.63	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7878	0.67	96.57	8.7827	0.63	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7721	0.70	94.98	8.7564	0.64	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7416	0.72	93.34	8.6948	0.71	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6978	0.76	91.83	8.6968	0.69	274.96
18	8.9783	0.55	155.43	9.0205	0.50	204.54	64	8.6824	0.79	90.30	8.6929	0.73	276.34
20	8.9903	0.47	142.74	9.0163	0.51	217.16	66	8.6754	0.84	88.84	8.6766	0.85	277.74
22	8.9705	0.56	134.46	9.0162	0.54	225.45	68	8.6947	0.90	87.36	8.6397	0.89	279.13
24	8.9698	0.50	128.32	9.0259	0.49	231.60	70	8.6485	1.19	85.91	8.6290	0.96	280.53
26	8.9607	0.52	123.44	9.0084	0.48	236.45	72	8.5479	1.07	84.46	8.5206	1.05	281.85
28	8.9411	0.48	119.30	9.0046	0.51	240.65	74	8.5051	1.18	83.06	8.1326	1.53	278.99
30	8.9567	0.53	115.80	8.9902	0.48	244.15	76	8.4641	1.39	81.58	7.9957	1.63	280.40
32	8.9497	0.57	112.65	8.9748	0.52	247.30	78	8.4224	1.60	80.19	7.8811	1.90	281.82
34	8.9153	0.50	109.78	8.9820	0.50	250.15	80	8.3814	1.95	78.71	7.7980	2.20	283.25
36	8.9050	0.53	107.36	8.9677	0.52	252.66	82	8.2629	2.70	77.19	7.5513	3.01	284.72
38	8.9036	0.55	104.98	8.9638	0.52	254.99	84	8.1110	3.41	75.77	N/A	N/A	N/A
40	8.8816	0.54	102.85	8.9457	0.54	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8594	0.56	100.77	8.9317	0.55	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8293	0.53	98.95	8.8814	0.59	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

30961F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

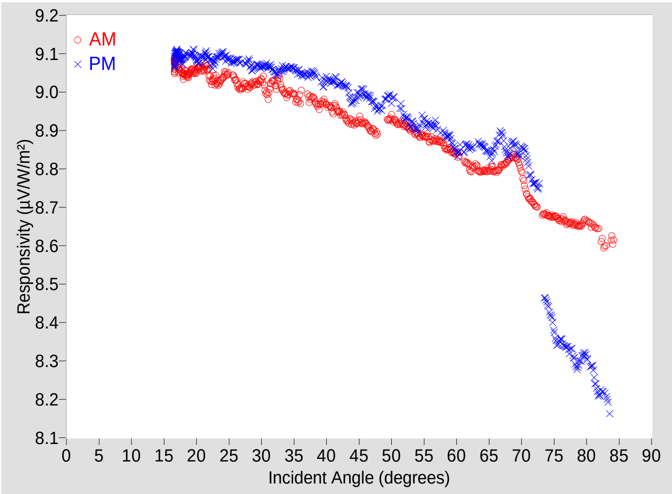


Figure 4. Responsivity vs Local Standard Time

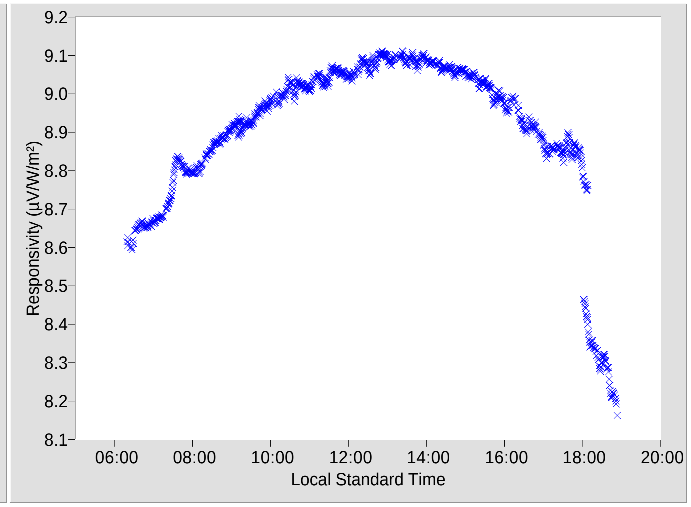


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9594	+1.85 / -1.91	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.58065 µV/W/m², determination date: 07/10/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9184	0.60	97.12	8.9928	0.60	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8966	N/A	95.69	8.9548	0.61	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9306	0.64	101.85	8.9841	0.62	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9142	0.66	99.99	8.9343	0.71	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8917	0.67	98.25	8.9047	0.68	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8749	0.69	96.57	8.9144	0.67	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8650	0.72	94.98	8.8954	0.69	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8394	0.74	93.34	8.8433	0.76	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8024	0.78	91.83	8.8567	0.75	274.96
18	9.0480	0.57	155.43	9.0883	0.51	204.54	64	8.7949	0.82	90.30	8.8614	0.80	276.34
20	9.0575	0.49	142.74	9.0853	0.52	217.16	66	8.7940	0.87	88.84	8.8600	0.95	277.74
22	9.0402	0.57	134.46	9.0861	0.55	225.45	68	8.8240	0.94	87.36	8.8400	0.95	279.13
24	9.0384	0.52	128.32	9.0978	0.51	231.60	70	8.7906	1.17	85.91	8.8511	1.01	280.53
26	9.0314	0.53	123.44	9.0823	0.50	236.45	72	8.7066	1.11	84.46	8.7629	1.12	281.85
28	9.0125	0.50	119.30	9.0791	0.53	240.65	74	8.6801	1.22	83.06	8.4449	1.57	278.99
30	9.0299	0.56	115.80	9.0658	0.51	244.15	76	8.6669	1.42	81.58	8.3559	1.70	280.40
32	9.0245	0.61	112.65	9.0531	0.53	247.30	78	8.6567	1.64	80.19	8.3108	2.01	281.82
34	8.9944	0.52	109.78	9.0625	0.53	250.15	80	8.6656	2.01	78.71	8.3119	2.34	283.25
36	8.9863	0.55	107.36	9.0492	0.54	252.66	82	8.6280	2.68	77.19	8.2135	3.00	284.72
38	8.9836	0.56	104.98	9.0485	0.54	254.99	84	8.6147	3.52	75.77	N/A	N/A	N/A
40	8.9670	0.57	102.85	9.0334	0.56	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9470	0.58	100.77	9.0213	0.58	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9208	0.56	98.95	8.9747	0.62	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30961F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

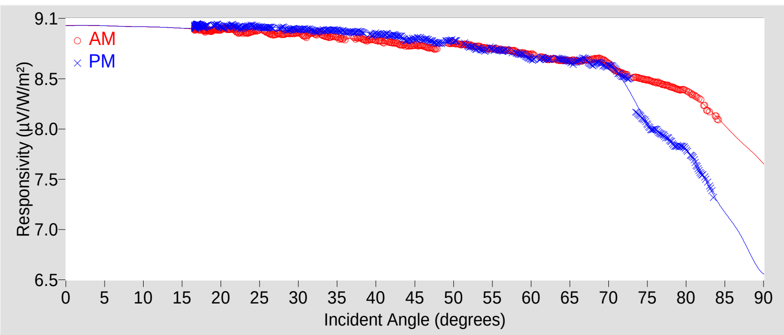
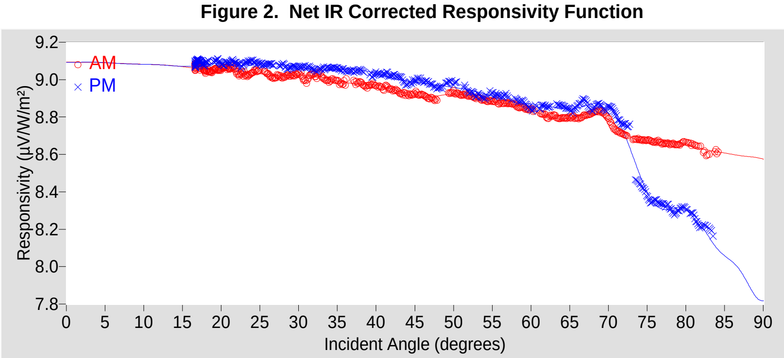


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.57	±1.57
R²	0.9999994	0.9999962
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.59	±1.59
Net IR corrected R²	0.9999995	0.9999971
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	Responsivity AM U95 (%)	Responsivity PM RS (µV/W/m²)	Responsivity PM U95 (%)	Responsivity Combined RS (µV/W/m²)	Responsivity Combined U95 (%)	Net IR Corr. AM RSc (µV/W/m²)	Net IR Corr. AM U95 (%)	Net IR Corr. PM RSc (µV/W/m²)	Net IR Corr. PM U95 (%)	Net IR Corr. Combined RSc (µV/W/m²)	Net IR Corr. Combined U95 (%)
0-9	9.0257	*	9.0256	*	9.0257	*	9.0901	*	9.0900	*	9.0901	*
9-18	9.0062	*	9.0095	*	9.0078	*	9.0736	*	9.0768	*	9.0752	*
18-27	8.9731	±1.58	9.0173	±1.57	8.9952	±1.66	9.0422	±1.60	9.0879	±1.59	9.0651	±1.68
27-36	8.9401	±1.59	8.9862	±1.58	8.9631	±1.76	9.0151	±1.60	9.0636	±1.60	9.0394	±1.75
36-45	8.8743	±1.63	8.9391	±1.63	8.9067	±1.99	8.9598	±1.63	9.0269	±1.63	8.9934	±1.94
45-54	8.8262	±1.58	8.8548	±1.63	8.8405	±1.71	8.9125	±1.59	8.9617	±1.62	8.9371	±1.74
54-63	8.7595	±1.71	8.7420	±1.68	8.7507	±1.84	8.8533	±1.68	8.8830	±1.63	8.8681	±1.88
63-72	8.6663	±1.68	8.6499	±1.84	8.6581	±2.26	8.7936	±1.65	8.8460	±1.71	8.8198	±1.94
72-81	8.4582	±2.01	8.0303	±4.71	8.2443	±7.29	8.6715	±1.64	8.4100	±2.93	8.5408	±3.85
81-90	7.9965	*	7.1155	*	7.5560	*	8.6061	*	8.0390	*	8.3225	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

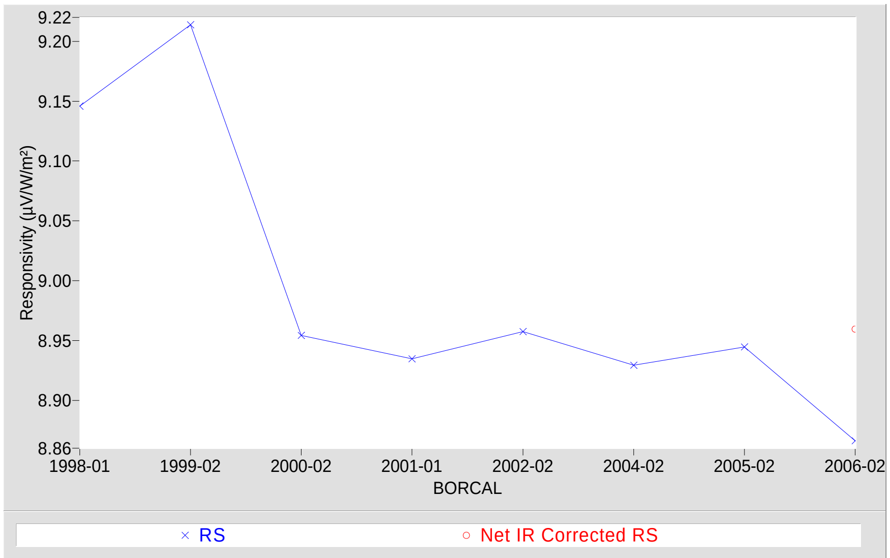
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.8662	+2.01 / -2.35
45° - 55°	8.8346	±1.68
Composite	8.8880	+2.19 / -18.11
45° (Net IR Corr.)	8.9594	+1.85 / -1.91
45° - 55° (Net IR Corr.)	8.9322	±1.69
Composite (Net IR Corr.)	8.9869	+1.98 / -10.01

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



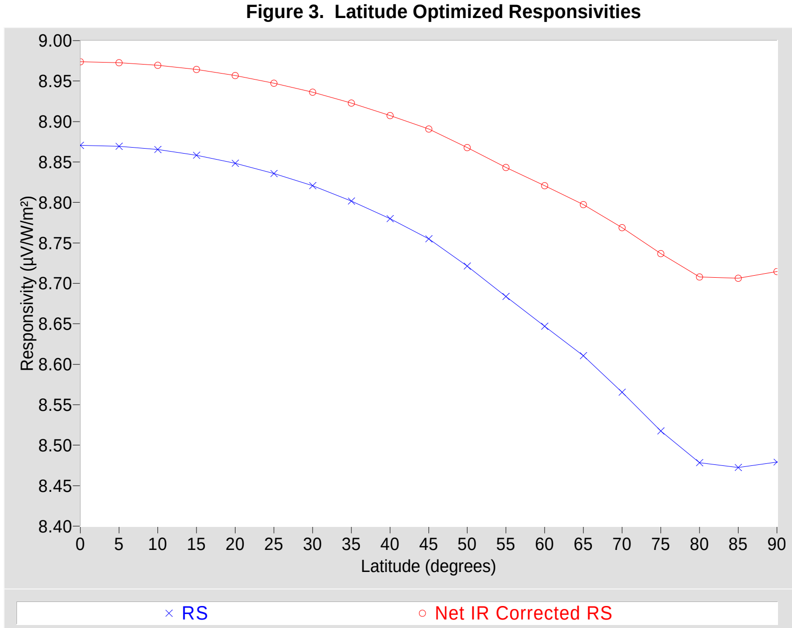
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.8707	+2.38 / -25.07	8.9737	+2.07 / -12.71
5	8.8693	+2.39 / -25.06	8.9726	+2.08 / -12.70
10	8.8652	+2.43 / -25.02	8.9696	+2.10 / -12.67
15	8.8584	+2.49 / -24.96	8.9644	+2.14 / -12.62
20	8.8482	+2.58 / -24.88	8.9567	+2.20 / -12.55
25	8.8357	+2.70 / -24.77	8.9473	+2.28 / -12.46
30	8.8206	+2.79 / -24.64	8.9362	+2.36 / -12.35
35	8.8016	+2.97 / -24.48	8.9226	+2.48 / -12.22
40	8.7798	+3.19 / -24.29	8.9075	+2.61 / -12.07
45	8.7549	+3.45 / -24.08	8.8909	+2.77 / -11.91
50	8.7212	+3.68 / -23.79	8.8678	+2.92 / -11.68
55	8.6839	+3.79 / -23.46	8.8434	+2.92 / -11.44
60	8.6470	+4.11 / -23.13	8.8209	+3.11 / -11.21
65	8.6105	+4.03 / -22.81	8.7973	+2.98 / -10.98
70	8.5654	+4.04 / -22.40	8.7691	+2.90 / -10.69
75	8.5176	+4.10 / -21.97	8.7368	+2.93 / -10.37
80	8.4785	+3.98 / -21.61	8.7080	+2.70 / -10.07
85	8.4724	+3.32 / -21.55	8.7064	+2.48 / -10.06
90	8.4791	+2.93 / -21.61	8.7147	+2.41 / -10.14

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

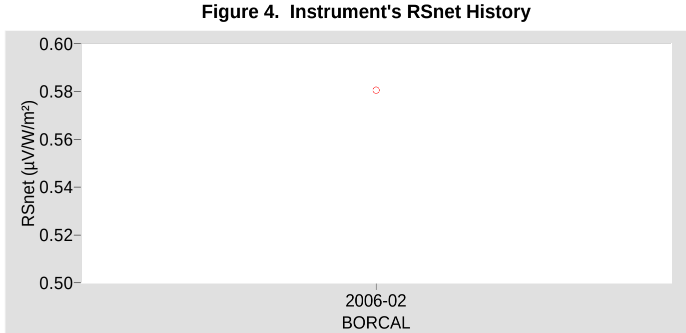
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 31099F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: Calibration System

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

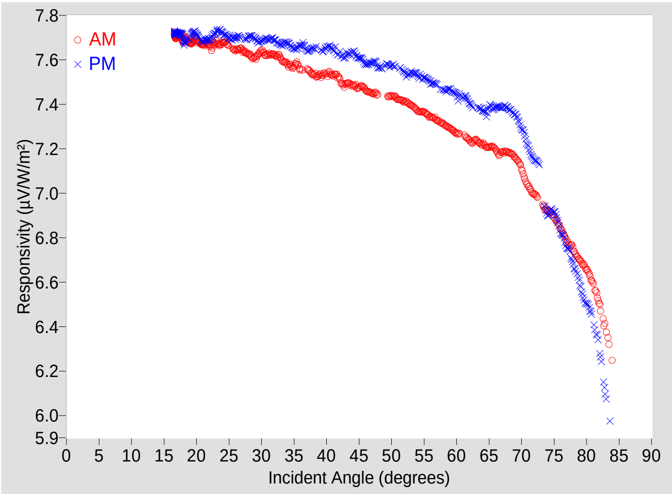

Figure 2. Responsivity vs Local Standard Time

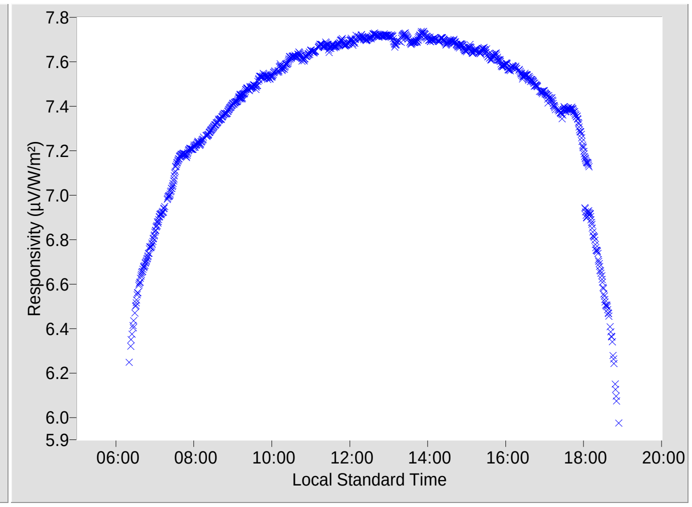

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.5423	+2.63 / -4.12	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4651	0.58	97.14	7.5797	0.59	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4420	N/A	95.65	7.5669	0.60	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4371	0.62	101.81	7.5737	0.58	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4127	0.65	100.01	7.5404	0.65	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3720	0.67	98.27	7.5300	0.65	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3429	0.71	96.59	7.4971	0.65	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3113	0.72	94.95	7.4638	0.66	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2691	0.75	93.36	7.4388	0.76	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2364	0.80	91.79	7.4044	0.77	274.98
18	7.6915	0.56	155.29	7.6914	0.60	204.62	64	7.2209	0.83	90.32	7.3719	0.78	276.40
20	7.6899	0.52	142.61	7.7144	0.58	217.23	66	7.1955	0.90	88.81	7.3862	0.79	277.76
22	7.6675	0.53	134.68	7.6929	0.54	225.35	68	7.1826	0.93	87.33	7.3810	0.87	279.10
24	7.6754	0.50	128.37	7.7197	0.54	231.51	70	7.1106	1.30	85.92	7.2906	1.31	280.50
26	7.6457	0.48	123.49	7.6995	0.50	236.49	72	6.9952	1.15	84.48	7.1485	1.15	281.91
28	7.6264	0.55	119.23	7.7023	0.49	240.58	74	6.9209	1.26	83.03	6.9072	1.42	278.96
30	7.6377	0.56	115.74	7.6856	0.51	244.18	76	6.8437	1.63	81.60	6.8258	1.97	280.42
32	7.6218	0.51	112.60	7.6909	0.54	247.24	78	6.7466	1.77	80.16	6.6782	2.20	281.79
34	7.5782	0.55	109.73	7.6757	0.54	250.10	80	6.6555	2.16	78.68	6.5027	2.36	283.27
36	7.5568	0.56	107.28	7.6643	0.56	252.62	82	6.4976	3.03	77.25	6.2814	3.73	284.76
38	7.5351	0.56	104.94	7.6509	0.53	254.94	84	6.2483	N/A	75.79	N/A	N/A	N/A
40	7.5358	0.55	102.74	7.6558	0.55	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5135	0.65	100.86	7.6262	0.63	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4855	0.56	98.92	7.6370	0.57	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

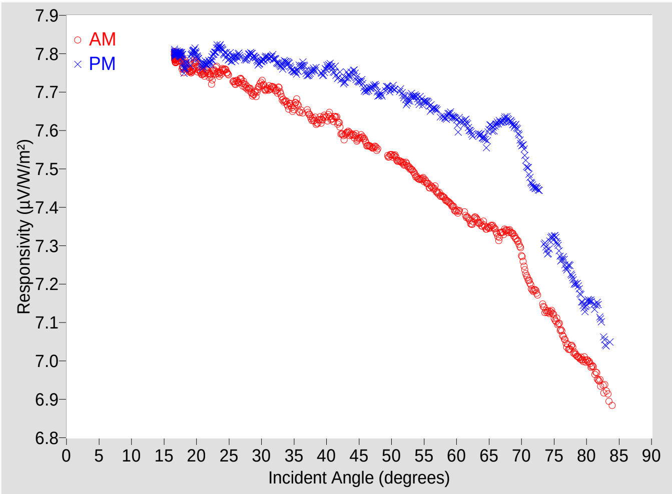

Figure 4. Responsivity vs Local Standard Time

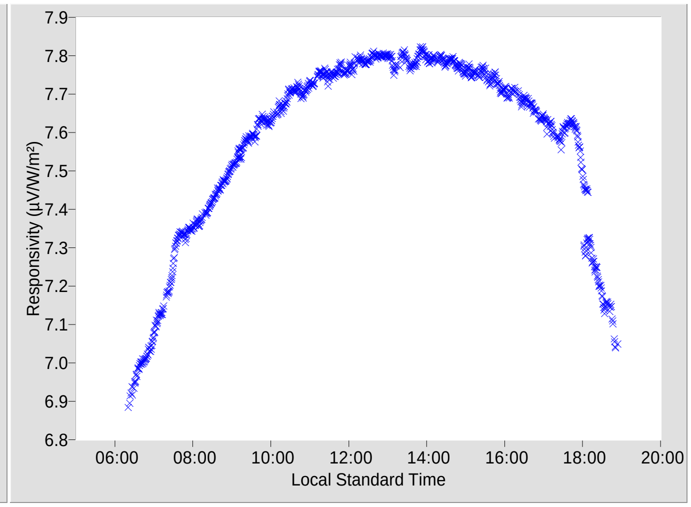

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.6543	+2.47 / -4.03	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.57866 µV/W/m², determination date: 05/08/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5701	0.63	97.14	7.7031	0.65	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5482	N/A	95.65	7.6939	0.66	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5357	0.66	101.81	7.7088	0.66	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5139	0.69	100.01	7.6828	0.72	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4770	0.71	98.27	7.6805	0.72	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4529	0.75	96.59	7.6587	0.73	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4263	0.76	94.95	7.6342	0.76	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3901	0.79	93.36	7.6204	0.85	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3642	0.84	91.79	7.6009	0.87	274.98
18	7.7689	0.59	155.29	7.7746	0.62	204.62	64	7.3564	0.88	90.32	7.5828	0.93	276.40
20	7.7692	0.55	142.61	7.7983	0.61	217.23	66	7.3388	0.96	88.81	7.6134	0.95	277.76
22	7.7460	0.56	134.68	7.7780	0.57	225.35	68	7.3383	0.99	87.33	7.6281	1.01	279.10
24	7.7563	0.53	128.37	7.8077	0.57	231.51	70	7.2797	1.28	85.92	7.5651	1.32	280.50
26	7.7265	0.51	123.49	7.7905	0.54	236.49	72	7.1836	1.21	84.48	7.4512	1.27	281.91
28	7.7100	0.57	119.23	7.7951	0.54	240.58	74	7.1278	1.32	83.03	7.2869	1.68	278.96
30	7.7226	0.59	115.74	7.7808	0.55	244.18	76	7.0844	1.62	81.60	7.2691	1.97	280.42
32	7.7085	0.54	112.60	7.7885	0.57	247.24	78	7.0278	1.81	80.16	7.2104	2.28	281.79
34	7.6669	0.58	109.73	7.7763	0.58	250.10	80	7.0004	2.22	78.68	7.1465	2.68	283.27
36	7.6488	0.59	107.28	7.7681	0.60	252.62	82	6.9459	2.92	77.25	7.1180	3.53	284.76
38	7.6291	0.60	104.94	7.7572	0.58	254.94	84	6.8841	N/A	75.79	N/A	N/A	N/A
40	7.6344	0.59	102.74	7.7654	0.61	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6116	0.69	100.86	7.7407	0.66	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5876	0.60	98.92	7.7541	0.63	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

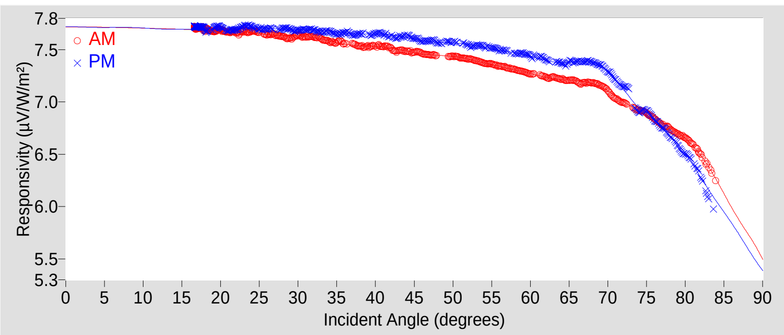
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (μV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (μV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (μV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

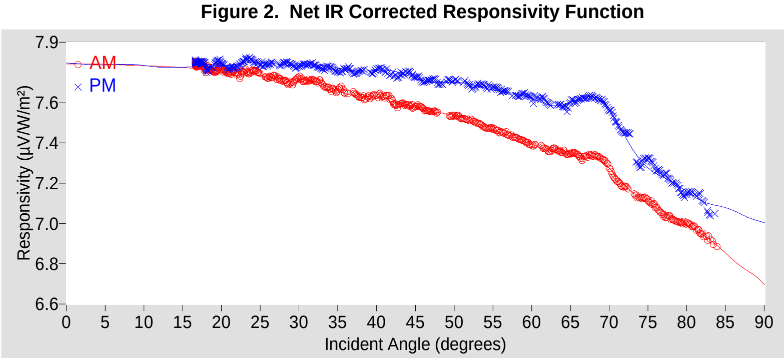


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.58	±1.58
R²	0.9999994	0.9999984
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.58	±1.58
Net IR corrected R²	0.9999995	0.9999987
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (μV/W/m²)	AM U95 (%)	PM RS (μV/W/m²)	PM U95 (%)	Combined RS (μV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (μV/W/m²)	AM U95 (%)	PM RSc (μV/W/m²)	PM U95 (%)	Combined RSc (μV/W/m²)	Combined U95 (%)
0-9	7.7153	*	7.7153	*	7.7153	*	7.7902	*	7.7903	*	7.7903	*
9-18	7.6991	*	7.6995	*	7.6993	*	7.7775	*	7.7784	*	7.7779	*
18-27	7.6723	±1.61	7.7048	±1.58	7.6885	±1.72	7.7519	±1.61	7.7911	±1.59	7.7715	±1.74
27-36	7.6136	±1.66	7.6868	±1.59	7.6502	±2.07	7.6998	±1.65	7.7838	±1.59	7.7418	±2.07
36-45	7.5236	±1.65	7.6440	±1.61	7.5838	±2.33	7.6210	±1.64	7.7546	±1.60	7.6878	±2.32
45-54	7.4349	±1.68	7.5664	±1.65	7.5007	±2.58	7.5377	±1.69	7.6992	±1.61	7.6185	±2.70
54-63	7.3027	±1.87	7.4616	±1.81	7.3822	±3.22	7.4191	±1.78	7.6348	±1.68	7.5269	±3.36
63-72	7.1650	±2.06	7.3447	±2.16	7.2548	±3.91	7.3179	±1.85	7.5877	±1.90	7.4528	±4.30
72-81	6.8229	±3.27	6.7914	±5.18	6.8071	±7.15	7.0778	±2.18	7.2612	±2.56	7.1695	±4.82
81-90	6.0588	*	5.8903	*	5.9746	*	6.8379	*	7.0664	*	6.9521	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

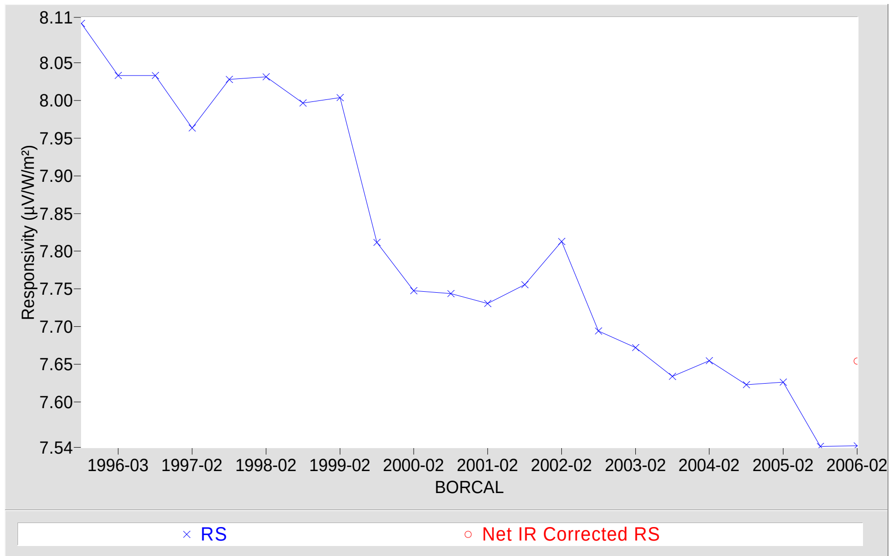
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.5423	+2.63 / -4.12
45° - 55°	7.4922	±2.26
Composite	7.5557	+2.60 / -19.22
45° (Net IR Corr.)	7.6543	+2.47 / -4.03
45° - 55° (Net IR Corr.)	7.6115	±2.31
Composite (Net IR Corr.)	7.6751	+2.28 / -10.17

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



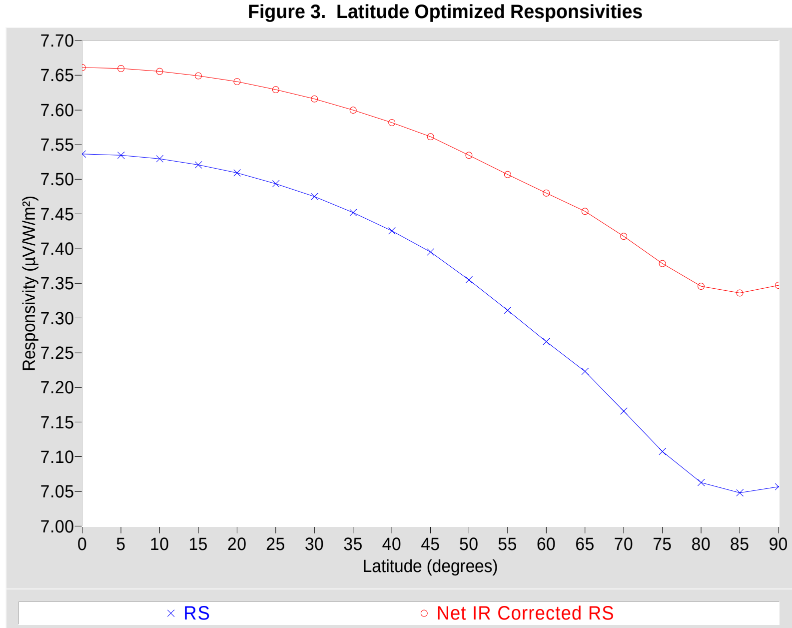
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.5364	+2.92 / -27.16	7.6612	+2.41 / -12.19
5	7.5345	+2.94 / -27.14	7.6597	+2.43 / -12.18
10	7.5294	+3.00 / -27.09	7.6559	+2.47 / -12.13
15	7.5208	+3.10 / -27.01	7.6494	+2.53 / -12.06
20	7.5093	+3.23 / -26.89	7.6409	+2.62 / -11.96
25	7.4938	+3.41 / -26.74	7.6294	+2.75 / -11.83
30	7.4751	+3.56 / -26.56	7.6160	+2.90 / -11.68
35	7.4521	+3.83 / -26.33	7.5998	+3.08 / -11.49
40	7.4256	+4.17 / -26.07	7.5817	+3.29 / -11.28
45	7.3951	+4.57 / -25.77	7.5617	+3.54 / -11.05
50	7.3549	+5.03 / -25.36	7.5347	+3.83 / -10.73
55	7.3111	+5.41 / -24.91	7.5071	+4.05 / -10.41
60	7.2662	+5.67 / -24.45	7.4804	+4.12 / -10.09
65	7.2231	+6.11 / -24.00	7.4537	+4.43 / -9.77
70	7.1659	+6.09 / -23.39	7.4179	+4.23 / -9.34
75	7.1075	+6.56 / -22.77	7.3787	+4.62 / -8.87
80	7.0629	+6.32 / -22.28	7.3460	+4.51 / -8.47
85	7.0480	+5.47 / -22.11	7.3363	+4.29 / -8.35
90	7.0569	+4.98 / -22.21	7.3470	+4.15 / -8.48

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

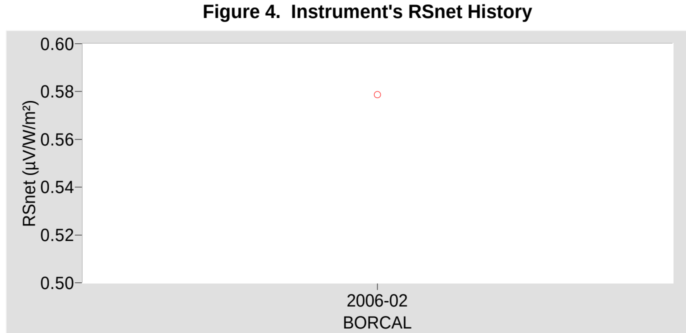
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31100F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	Calibration System	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

31100F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

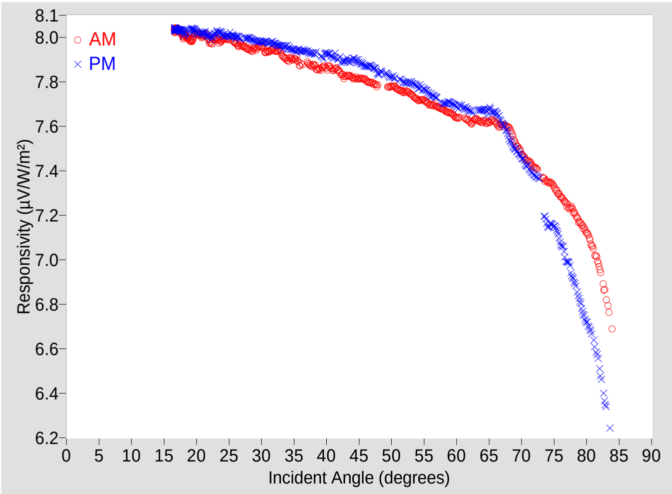


Figure 2. Responsivity vs Local Standard Time

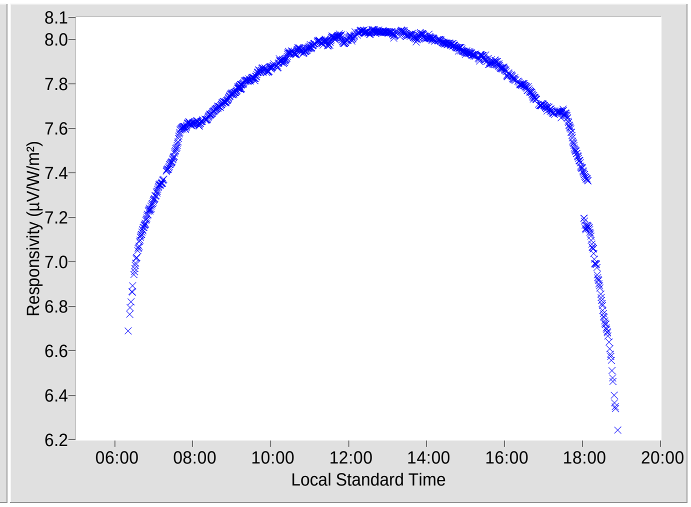


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8519	+2.22 / -3.22	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8097	0.56	97.14	7.8705	0.57	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7784	N/A	95.65	7.8382	0.60	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7805	0.62	101.81	7.8228	0.60	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7558	0.64	100.01	7.7974	0.60	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7214	0.67	98.27	7.7784	0.64	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6974	0.69	96.59	7.7406	0.65	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6755	0.71	94.95	7.7034	0.66	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6394	0.74	93.36	7.6890	0.69	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6211	0.77	91.79	7.6701	0.71	274.98
18	8.0091	0.58	155.29	8.0235	0.51	204.62	64	7.6225	0.81	90.32	7.6750	0.75	276.40
20	8.0166	0.53	142.61	8.0257	0.50	217.23	66	7.6184	0.88	88.81	7.6623	0.90	277.76
22	7.9846	0.55	134.51	8.0049	0.53	225.35	68	7.5943	1.03	87.33	7.5577	1.11	279.10
24	7.9883	0.50	128.37	8.0132	0.51	231.51	70	7.4810	1.11	85.92	7.4605	1.03	280.50
26	7.9764	0.49	123.49	8.0024	0.51	236.49	72	7.4164	1.11	84.48	7.3786	1.06	281.91
28	7.9485	0.51	119.23	7.9973	0.49	240.58	74	7.3516	1.22	83.03	7.1579	1.42	278.96
30	7.9601	0.52	115.74	7.9808	0.49	244.18	76	7.2865	1.51	81.60	7.0728	1.93	280.42
32	7.9431	0.49	112.60	7.9750	0.51	247.24	78	7.2195	1.73	80.16	6.9115	2.23	281.79
34	7.9008	0.52	109.73	7.9573	0.51	250.10	80	7.1217	2.14	78.68	6.7193	2.38	283.27
36	7.8778	0.56	107.28	7.9412	0.51	252.62	82	6.9635	2.92	77.25	6.5020	3.55	284.76
38	7.8749	0.55	104.94	7.9275	0.52	254.94	84	6.6896	N/A	75.79	N/A	N/A	N/A
40	7.8633	0.53	102.74	7.9283	0.55	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8466	0.60	100.86	7.9016	0.60	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8198	0.54	98.92	7.9029	0.56	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

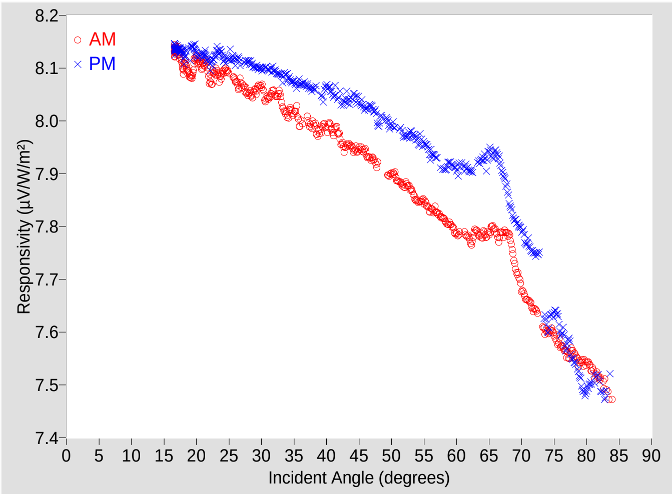

Figure 4. Responsivity vs Local Standard Time

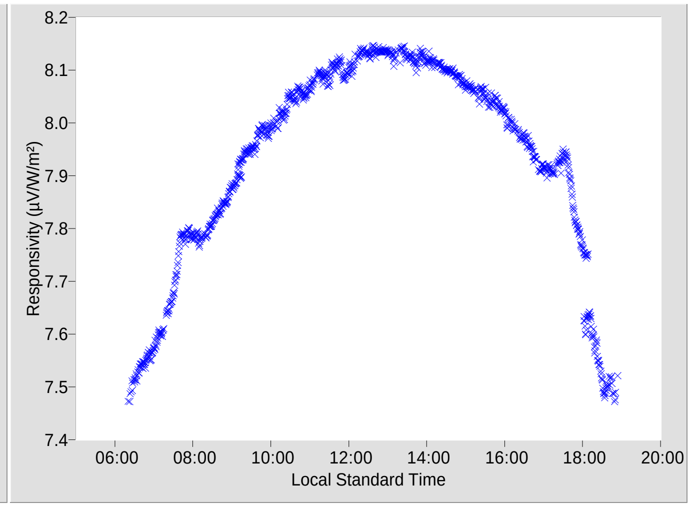

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9911	+2.01 / -3.16	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64729 µV/W/m², determination date: 05/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9417	0.61	97.14	8.0227	0.63	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9113	N/A	95.65	7.9965	0.67	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9003	0.66	101.81	7.9905	0.67	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8782	0.68	100.01	7.9713	0.68	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8485	0.71	98.27	7.9614	0.72	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8310	0.73	96.59	7.9360	0.74	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8149	0.75	94.95	7.9085	0.76	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7855	0.79	93.36	7.9062	0.80	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7744	0.83	91.79	7.9049	0.83	274.98
18	8.1047	0.61	155.29	8.1251	0.55	204.62	64	7.7851	0.86	90.32	7.9292	0.91	276.40
20	8.1160	0.57	142.61	8.1296	0.54	217.23	66	7.7911	0.94	88.81	7.9386	0.98	277.76
22	8.0818	0.58	134.51	8.1115	0.57	225.35	68	7.7829	1.06	87.33	7.8576	1.16	279.10
24	8.0894	0.54	128.37	8.1221	0.55	231.51	70	7.6850	1.13	85.92	7.7944	1.15	280.50
26	8.0775	0.53	123.49	8.1150	0.56	236.49	72	7.6425	1.18	84.48	7.7489	1.25	281.91
28	8.0529	0.54	119.23	8.1122	0.53	240.58	74	7.6004	1.30	83.03	7.6093	1.67	278.96
30	8.0653	0.56	115.74	8.0990	0.54	244.18	76	7.5769	1.54	81.60	7.6006	1.95	280.42
32	8.0521	0.54	112.60	8.0966	0.55	247.24	78	7.5605	1.79	80.16	7.5468	2.28	281.79
34	8.0125	0.56	109.73	8.0832	0.57	250.10	80	7.5422	2.19	78.68	7.4886	2.68	283.27
36	7.9939	0.60	107.28	8.0710	0.57	252.62	82	7.5137	2.84	77.25	7.5003	3.45	284.76
38	7.9933	0.60	104.94	8.0598	0.58	254.94	84	7.4725	N/A	75.79	N/A	N/A	N/A
40	7.9870	0.58	102.74	8.0649	0.62	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9700	0.64	100.86	8.0434	0.64	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9481	0.59	98.92	8.0472	0.62	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

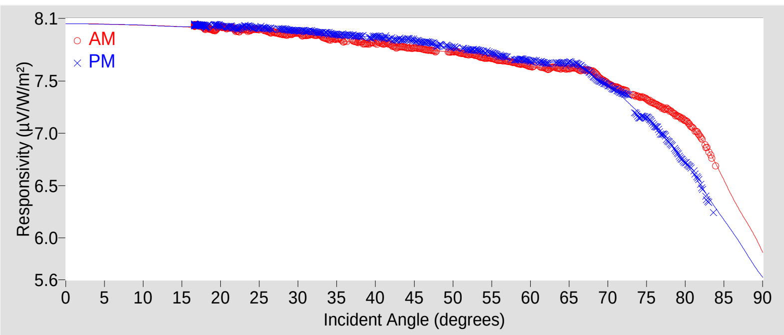
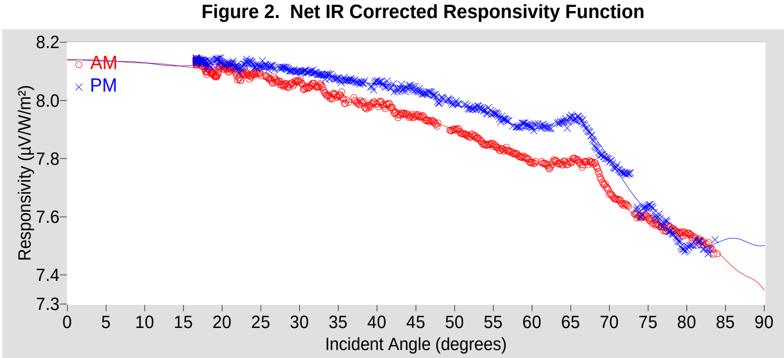


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.54	±1.54
R^2	0.9999993	0.9999983
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.56	±1.56
Net IR corrected R^2	0.9999995	0.9999987
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

	Responsivity						Net IR Corr. Responsivity					
Inc.	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.0446	*	8.0446	*	8.0446	*	8.1363	*	8.1364	*	8.1364	*
9-18	8.0249	*	8.0263	*	8.0256	*	8.1211	*	8.1230	*	8.1221	*
18-27	7.9926	±1.57	8.0129	±1.55	8.0028	±1.63	8.0918	±1.58	8.1199	±1.56	8.1059	±1.65
27-36	7.9362	±1.62	7.9754	±1.58	7.9558	±1.86	8.0442	±1.62	8.0961	±1.58	8.0702	±1.86
36-45	7.8558	±1.60	7.9188	±1.58	7.8873	±1.92	7.9783	±1.59	8.0562	±1.58	8.0173	±1.92
45-54	7.7767	±1.62	7.8305	±1.67	7.8036	±2.07	7.9033	±1.65	7.9945	±1.62	7.9489	±2.21
54-63	7.6682	±1.69	7.7125	±1.67	7.6903	±2.11	7.8088	±1.64	7.9208	±1.61	7.8648	±2.28
63-72	7.5693	±2.00	7.5753	±2.54	7.5723	±3.35	7.7536	±1.82	7.8703	±1.99	7.8120	±3.01
72-81	7.2702	±2.72	7.0279	±4.99	7.1491	±7.76	7.5787	±1.71	7.5893	±2.13	7.5840	±2.61
81-90	6.4811	*	6.1180	*	6.2995	*	7.4419	*	7.5087	*	7.4753	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

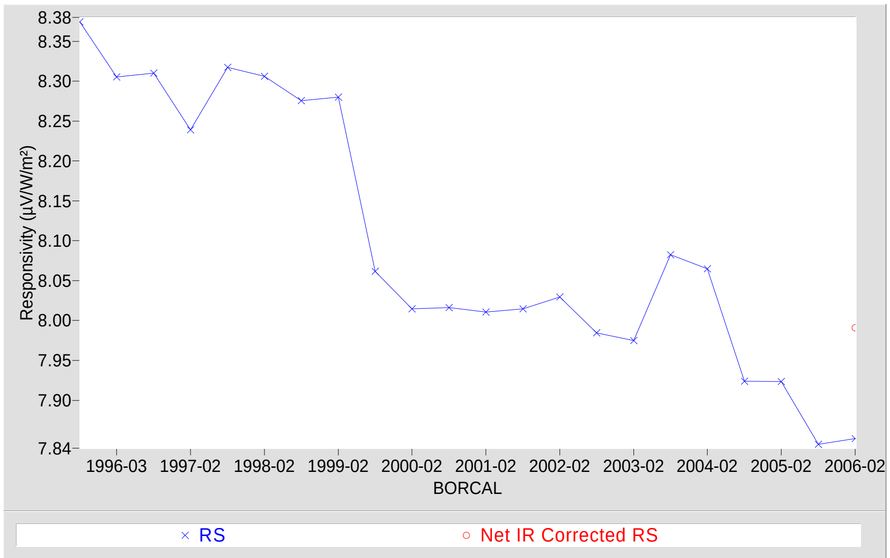
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.8519	+2.22 / -3.22
45° - 55°	7.7952	±1.90
Composite	7.8716	+2.45 / -19.62
45° (Net IR Corr.)	7.9911	+2.01 / -3.16
45° - 55° (Net IR Corr.)	7.9421	±1.97
Composite (Net IR Corr.)	8.0179	+2.05 / -6.79

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.6°, 16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



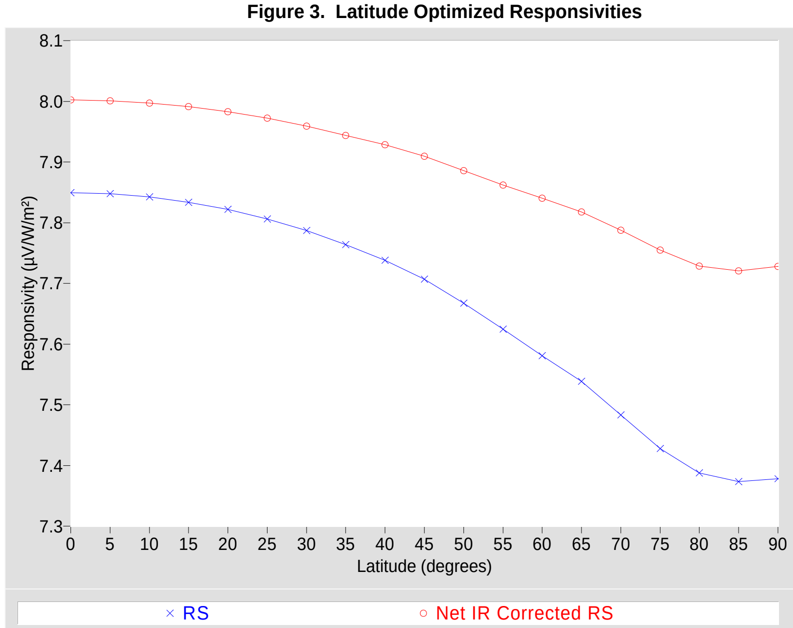
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.8491	+2.98 / -27.09	8.0022	+2.33 / -7.97
5	7.8476	+3.00 / -27.07	8.0011	+2.34 / -7.96
10	7.8422	+3.06 / -27.02	7.9972	+2.38 / -7.92
15	7.8336	+3.16 / -26.94	7.9911	+2.44 / -7.85
20	7.8218	+3.29 / -26.83	7.9830	+2.52 / -7.75
25	7.8061	+3.47 / -26.69	7.9721	+2.62 / -7.63
30	7.7869	+3.63 / -26.51	7.9590	+2.71 / -7.48
35	7.7638	+3.79 / -26.29	7.9440	+2.79 / -7.31
40	7.7380	+3.98 / -26.04	7.9283	+2.92 / -7.13
45	7.7066	+4.32 / -25.74	7.9095	+3.11 / -6.92
50	7.6672	+4.64 / -25.36	7.8859	+3.30 / -6.64
55	7.6243	+4.89 / -24.94	7.8622	+3.39 / -6.37
60	7.5805	+5.03 / -24.51	7.8403	+3.34 / -6.12
65	7.5385	+5.24 / -24.09	7.8176	+3.41 / -5.85
70	7.4830	+5.42 / -23.53	7.7874	+3.40 / -5.50
75	7.4278	+5.36 / -22.96	7.7547	+3.30 / -5.12
80	7.3875	+5.03 / -22.54	7.7283	+3.11 / -4.81
85	7.3733	+4.44 / -22.39	7.7208	+3.13 / -4.72
90	7.3779	+3.92 / -22.44	7.7280	+2.96 / -4.81

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

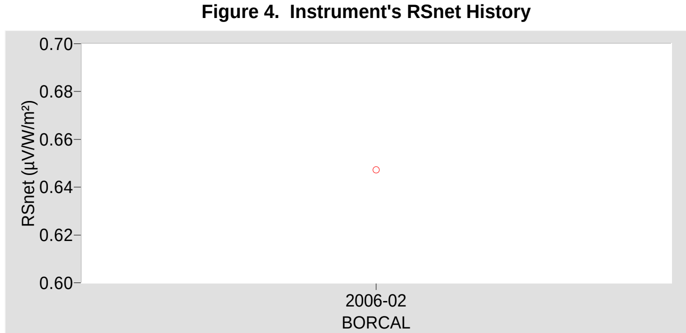
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31101F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	Calibration System	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

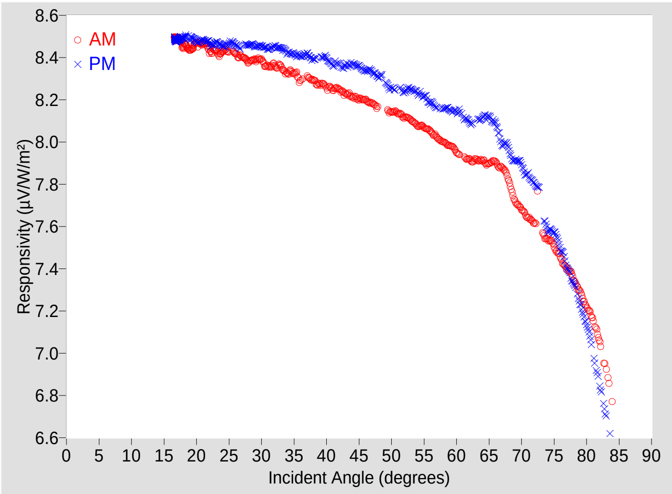

Figure 2. Responsivity vs Local Standard Time

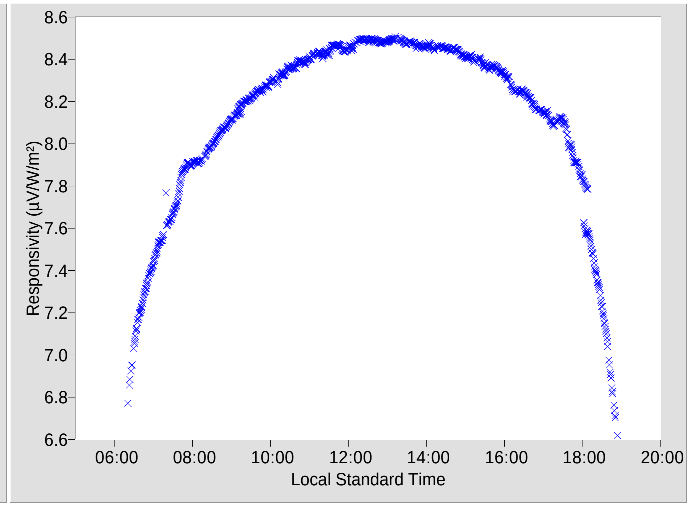

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2812	+2.67 / -4.39	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1997	0.55	97.14	8.3381	0.57	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1589	N/A	95.65	8.3100	0.58	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1429	0.62	101.81	8.2540	0.61	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1176	0.65	100.01	8.2385	0.60	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0788	0.66	98.27	8.2322	0.64	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0515	0.72	96.59	8.1862	0.70	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0006	0.72	94.95	8.1582	0.63	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9520	0.76	93.36	8.1439	0.67	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9165	0.77	91.79	8.0921	0.72	274.98
18	8.4589	0.59	155.29	8.4949	0.49	204.62	64	7.9140	0.81	90.32	8.1183	0.74	276.40
20	8.4664	0.52	142.61	8.4766	0.50	217.23	66	7.9047	0.87	88.81	8.0831	1.16	277.76
22	8.4354	0.55	134.51	8.4693	0.51	225.35	68	7.8161	1.34	87.33	7.9717	0.99	279.10
24	8.4276	0.51	128.37	8.4561	0.50	231.51	70	7.6832	1.09	85.92	7.8919	1.00	280.50
26	8.4201	0.50	123.49	8.4597	0.52	236.49	72	7.6166	1.47	84.52	7.7996	1.07	281.91
28	8.3807	0.50	119.23	8.4596	0.48	240.58	74	7.5385	1.24	83.03	7.5873	1.41	278.96
30	8.3886	0.54	115.74	8.4536	0.49	244.18	76	7.4547	1.56	81.60	7.4926	1.90	280.42
32	8.3640	0.50	112.60	8.4538	0.50	247.24	78	7.3527	1.77	80.16	7.3319	2.13	281.79
34	8.3279	0.52	109.73	8.4233	0.53	250.10	80	7.2179	2.19	78.68	7.1345	2.49	283.27
36	8.2916	0.58	107.28	8.4073	0.52	252.62	82	7.0558	2.96	77.25	6.8442	3.33	284.76
38	8.2932	0.57	104.94	8.3915	0.55	254.94	84	6.7714	N/A	75.79	N/A	N/A	N/A
40	8.2568	0.55	102.74	8.3953	0.59	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2483	0.56	100.86	8.3657	0.57	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2133	0.57	98.92	8.3712	0.55	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

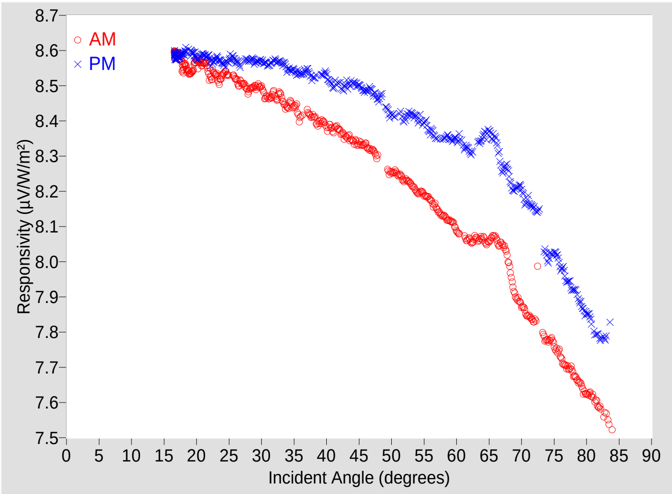

Figure 4. Responsivity vs Local Standard Time

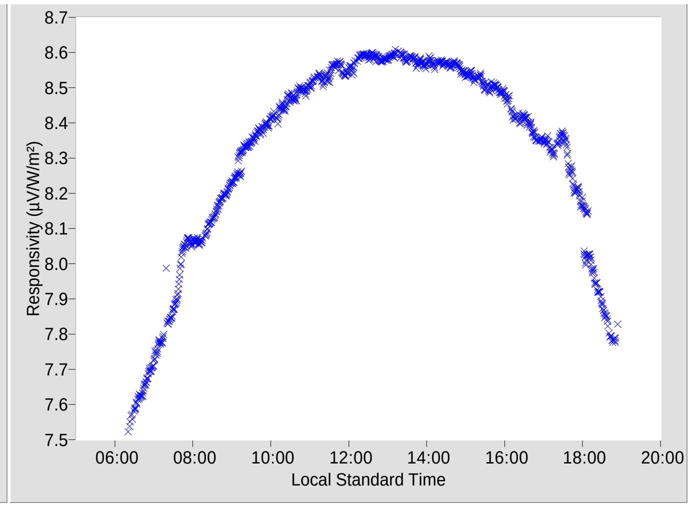

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.4181	+2.47 / -4.40	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64834 µV/W/m², determination date: 05/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3329	0.61	97.14	8.4851	0.62	262.77
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2924	N/A	95.65	8.4636	0.64	264.48
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2541	0.65	101.81	8.4162	0.67	266.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2316	0.68	100.01	8.4043	0.68	267.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1971	0.70	98.27	8.4055	0.71	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1759	0.74	96.59	8.3703	0.76	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1307	0.75	94.95	8.3504	0.72	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0887	0.79	93.36	8.3471	0.77	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0611	0.81	91.79	8.3121	0.81	274.98
18	8.5544	0.61	155.29	8.5933	0.53	204.62	64	8.0681	0.86	90.32	8.3573	0.87	276.40
20	8.5670	0.55	142.61	8.5795	0.53	217.23	66	8.0685	0.92	88.81	8.3439	1.14	277.76
22	8.5321	0.58	134.51	8.5763	0.54	225.35	68	7.9943	1.30	87.33	8.2534	1.07	279.10
24	8.5294	0.55	128.37	8.5639	0.54	231.51	70	7.8768	1.10	85.92	8.2055	1.12	280.50
26	8.5221	0.53	123.49	8.5709	0.56	236.49	72	7.8315	1.53	84.52	8.1480	1.21	281.91
28	8.4862	0.54	119.23	8.5722	0.53	240.58	74	7.7767	1.29	83.03	8.0101	1.60	278.96
30	8.4942	0.57	115.74	8.5699	0.54	244.18	76	7.7336	1.55	81.60	7.9837	1.88	280.42
32	8.4748	0.54	112.60	8.5725	0.54	247.24	78	7.6811	1.78	80.16	7.9199	2.15	281.79
34	8.4414	0.56	109.73	8.5472	0.57	250.10	80	7.6236	2.18	78.68	7.8521	2.58	283.27
36	8.4094	0.62	107.28	8.5347	0.57	252.62	82	7.5861	2.83	77.25	7.7839	3.30	284.76
38	8.4126	0.61	104.94	8.5213	0.60	254.94	84	7.5229	N/A	75.79	N/A	N/A	N/A
40	8.3807	0.59	102.74	8.5290	0.64	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3734	0.60	100.86	8.5026	0.61	259.13	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3428	0.60	98.92	8.5097	0.61	261.01	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

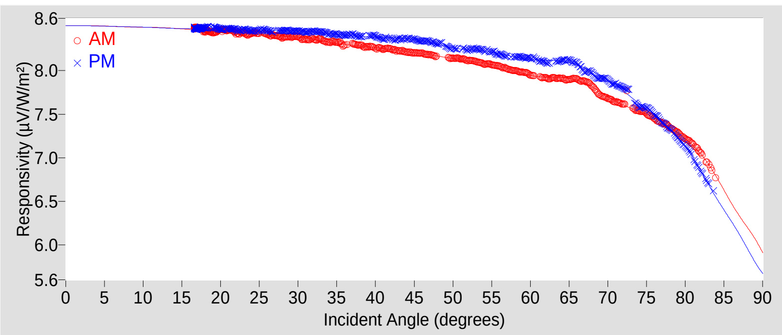
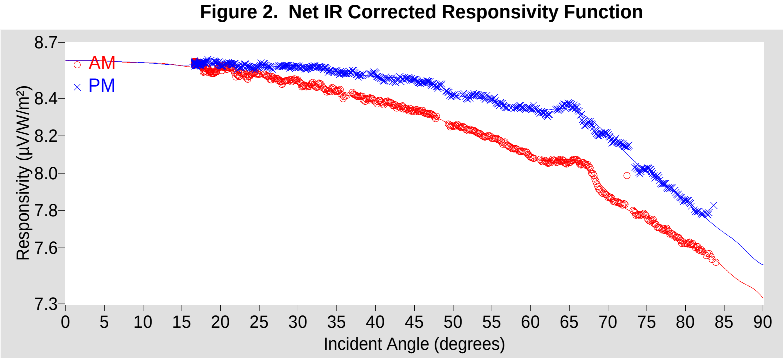


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.54	±1.54
R²	0.9999992	0.9999983
Valid incidence angle range	16.6° to 83.9°	16.6° to 83.6°
Net IR corr. uncert. U95 (%)	±1.53	±1.53
Net IR corrected R²	0.9999994	0.9999987
Corr. valid inc. angle range	16.6° to 83.9°	16.6° to 83.6°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.5106	*	8.5106	*	8.5106	*	8.6007	*	8.6007	*	8.6007	*
9-18	8.4863	*	8.4893	*	8.4878	*	8.5809	*	8.5842	*	8.5826	*
18-27	8.4391	±1.58	8.4689	±1.55	8.4540	±1.69	8.5387	±1.56	8.5749	±1.54	8.5568	±1.67
27-36	8.3629	±1.64	8.4453	±1.56	8.4041	±2.05	8.4722	±1.60	8.5636	±1.55	8.5179	±2.01
36-45	8.2593	±1.63	8.3847	±1.56	8.3220	±2.28	8.3830	±1.59	8.5184	±1.54	8.4507	±2.22
45-54	8.1497	±1.68	8.2835	±1.72	8.2166	±2.74	8.2721	±1.72	8.4413	±1.64	8.3567	±2.90
54-63	7.9958	±1.85	8.1607	±1.67	8.0783	±3.06	8.1273	±1.75	8.3561	±1.58	8.2417	±3.23
63-72	7.8167	±2.44	8.0003	±2.49	7.9085	±4.68	7.9914	±2.14	8.2778	±1.96	8.1346	±4.77
72-81	7.4255	±3.24	7.4489	±4.93	7.4372	±6.82	7.7219	±2.03	7.9720	±2.33	7.8469	±4.85
81-90	6.5546	*	6.3319	*	6.4433	*	7.4753	*	7.6630	*	7.5691	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

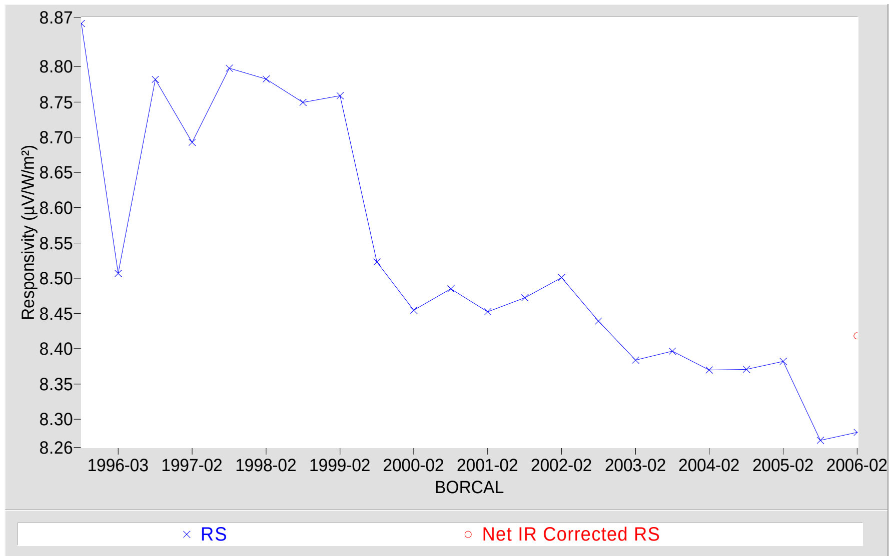
Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.2812	+2.67 / -4.39
45° - 55°	8.2070	±2.32
Composite	8.2993	+2.72 / -20.31
45° (Net IR Corr.)	8.4181	+2.47 / -4.40
45° - 55° (Net IR Corr.)	8.3480	±2.40
Composite (Net IR Corr.)	8.4410	+2.30 / -10.71

† Valid incident angle ranges:

45°:	30.0° to 60.0°,	30.0° to 60.0° (Net IR corr.)
45° - 55°:	45.0° to 55.0°,	45.0° to 55.0° (Net IR corr.)
Composite:	16.6° to 83.6°,	16.6° to 83.6° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



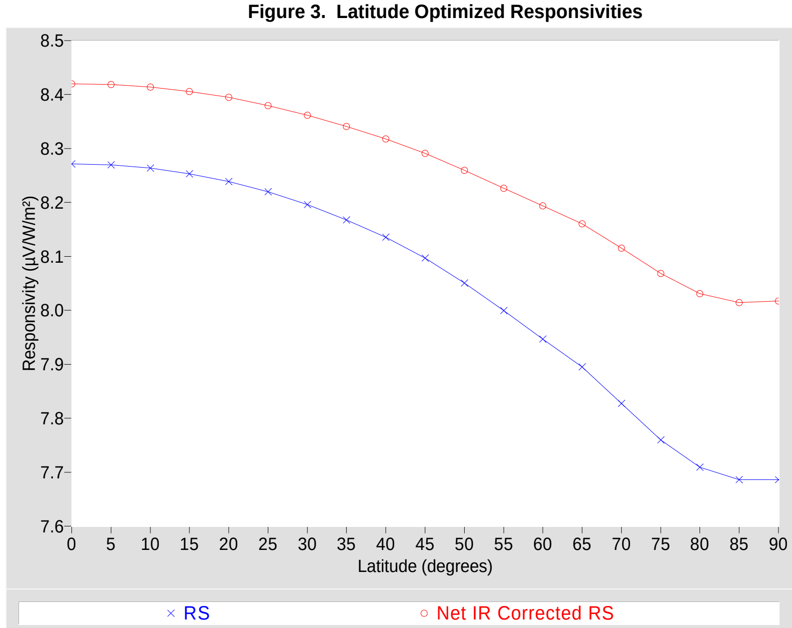
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.2714	+3.32 / -29.84	8.4197	+2.68 / -12.52
5	8.2698	+3.34 / -29.83	8.4186	+2.69 / -12.50
10	8.2636	+3.41 / -29.78	8.4138	+2.74 / -12.45
15	8.2532	+3.53 / -29.69	8.4057	+2.82 / -12.37
20	8.2389	+3.69 / -29.56	8.3947	+2.93 / -12.26
25	8.2196	+3.91 / -29.40	8.3797	+3.09 / -12.10
30	8.1958	+4.11 / -29.19	8.3615	+3.22 / -11.91
35	8.1676	+4.32 / -28.95	8.3407	+3.36 / -11.69
40	8.1355	+4.57 / -28.67	8.3180	+3.57 / -11.45
45	8.0969	+4.94 / -28.33	8.2912	+3.82 / -11.17
50	8.0505	+5.35 / -27.92	8.2594	+4.14 / -10.83
55	7.9995	+5.88 / -27.46	8.2264	+4.46 / -10.48
60	7.9464	+6.03 / -26.97	8.1936	+4.46 / -10.12
65	7.8951	+6.31 / -26.50	8.1602	+4.60 / -9.76
70	7.8271	+6.77 / -25.86	8.1154	+4.85 / -9.27
75	7.7598	+6.47 / -25.22	8.0686	+4.52 / -8.75
80	7.7094	+6.50 / -24.73	8.0311	+4.59 / -8.33
85	7.6859	+5.88 / -24.50	8.0142	+4.41 / -8.14
90	7.6863	+5.18 / -24.51	8.0173	+4.18 / -8.17

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

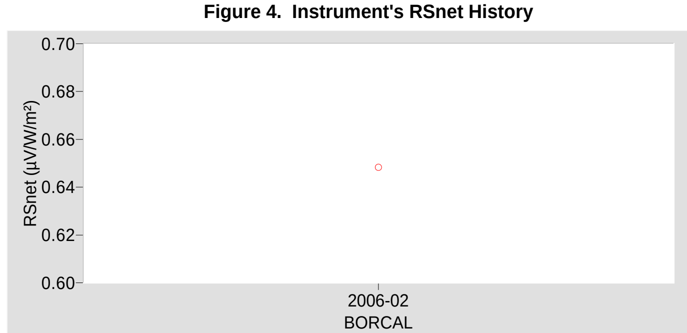
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 31120E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: Calibration System

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31120E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

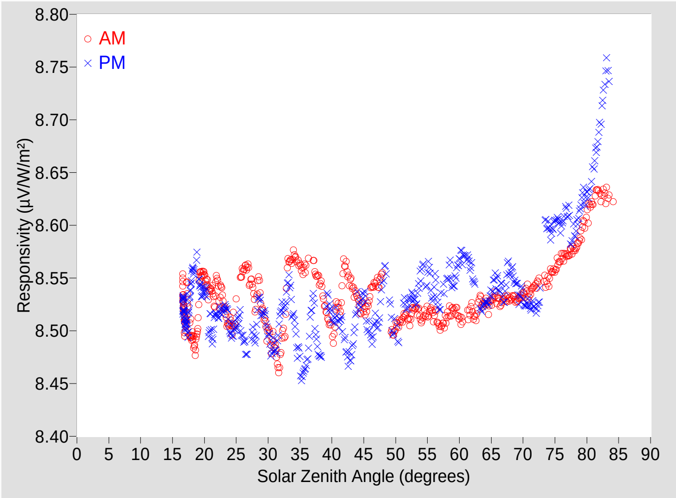


Figure 2. Responsivity vs Local Standard Time

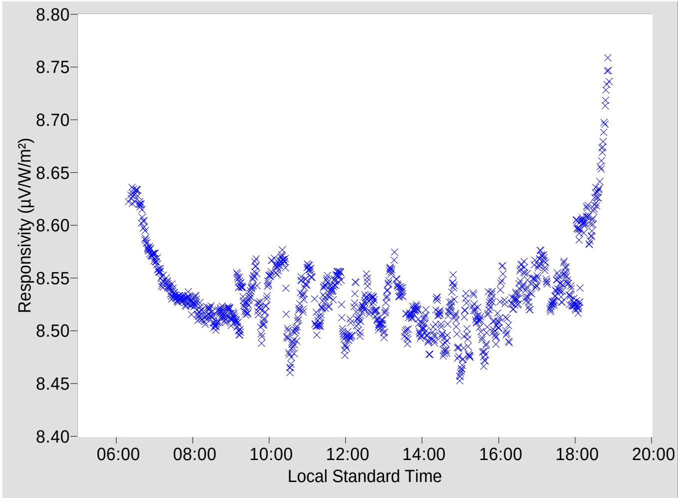


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5268	+0.96 / -1.24	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Zen. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5334	0.41	97.17	8.4973	0.47	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5536	N/A	95.63	8.5482	0.51	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5029	0.38	101.85	8.5083	0.44	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5112	0.39	100.04	8.5266	0.38	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5109	0.39	98.24	8.5562	0.43	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5151	0.39	96.56	8.5390	0.46	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5131	0.39	94.92	8.5494	0.42	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5118	0.39	93.39	8.5686	0.42	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5197	0.39	91.82	8.5534	0.41	275.00
18	8.4961	0.55	155.18	8.5486	0.60	204.51	64	8.5267	0.39	90.30	8.5266	0.39	276.38
20	8.5515	0.45	142.71	8.5375	0.49	217.33	66	8.5303	0.39	88.84	8.5438	0.41	277.74
22	8.5428	0.41	134.61	8.5143	0.42	225.43	68	8.5300	0.39	87.36	8.5554	0.44	279.12
24	8.5074	0.42	128.44	8.5009	0.41	231.45	70	8.5337	0.40	85.90	8.5320	0.40	280.48
26	8.5555	0.37	123.43	8.4944	0.45	236.43	72	8.5434	0.40	84.50	8.5212	0.41	281.89
28	8.5284	0.42	119.29	8.4994	0.45	240.64	74	8.5493	0.41	83.01	8.5987	0.43	278.99
30	8.4986	0.45	115.69	8.4959	0.45	244.24	76	8.5692	0.41	81.62	8.6003	0.44	280.40
32	8.4831	0.60	112.56	8.5201	0.50	247.38	78	8.5774	0.43	80.15	8.5939	0.49	281.91
34	8.5700	0.38	109.85	8.5116	0.59	250.07	80	8.6081	0.49	78.66	8.6268	0.51	283.25
36	8.5602	0.38	107.50	8.4682	0.59	252.58	82	8.6298	0.48	77.27	8.6902	0.72	284.70
38	8.5483	0.45	104.97	8.4783	0.51	254.91	84	8.6225	N/A	75.67	N/A	N/A	N/A
40	8.4961	0.44	102.79	8.5145	0.40	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5622	0.48	100.83	8.4863	0.46	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5321	0.42	98.95	8.5227	0.51	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
31120E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

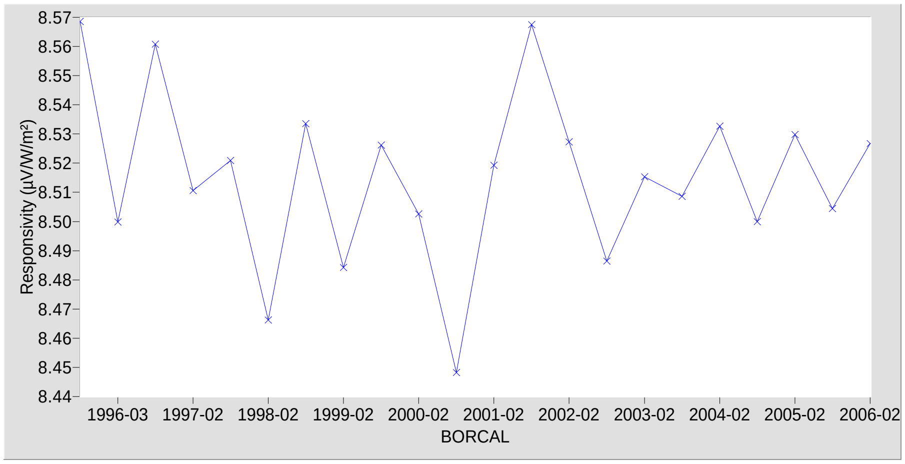
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5268	+0.96 / -1.24 †
Average	8.5368	+2.53 / -1.39 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 31122E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: Calibration System

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31122E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

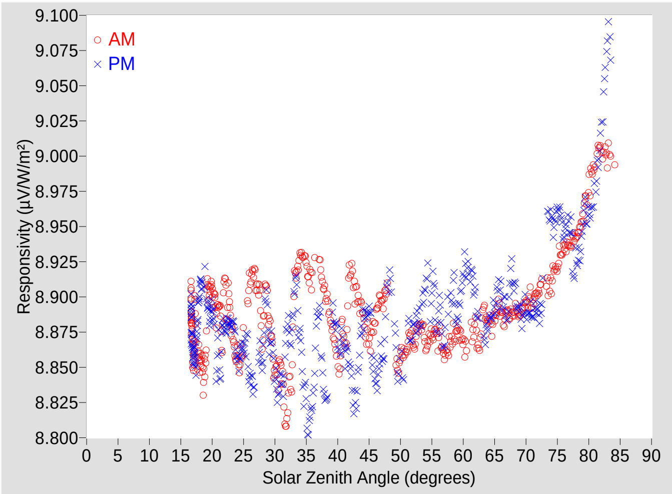


Figure 2. Responsivity vs Local Standard Time

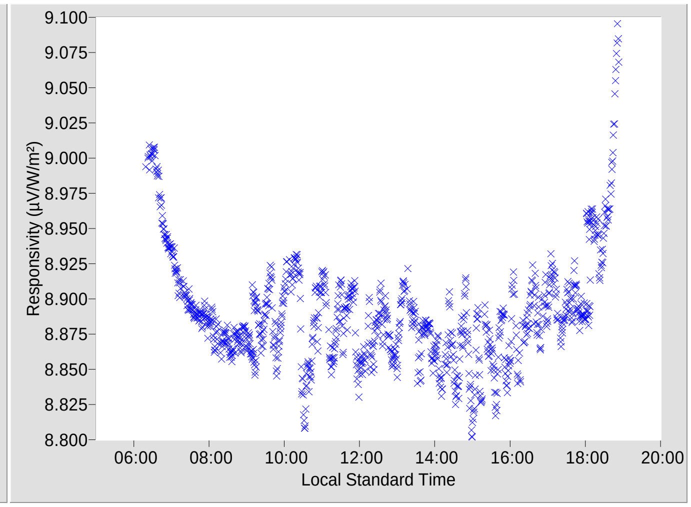


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8798	+0.95 / -1.25	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8842	0.43	97.17	8.8418	0.50	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9020	N/A	95.63	8.9097	0.52	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8584	0.39	101.85	8.8589	0.44	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8674	0.39	100.04	8.8780	0.39	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8659	0.39	98.24	8.9090	0.45	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8717	0.40	96.56	8.8868	0.48	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8687	0.40	94.92	8.8985	0.43	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8666	0.39	93.39	8.9183	0.46	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8765	0.40	91.82	8.8943	0.42	275.00
18	8.8565	0.54	155.18	8.9021	0.57	204.51	64	8.8836	0.40	90.30	8.8817	0.41	276.38
20	8.9041	0.46	142.71	8.8889	0.49	217.33	66	8.8899	0.39	88.84	8.8991	0.41	277.74
22	8.9019	0.47	134.61	8.8783	0.44	225.43	68	8.8879	0.39	87.36	8.9084	0.45	279.12
24	8.8572	0.41	128.44	8.8563	0.42	231.45	70	8.8948	0.40	85.90	8.8916	0.40	280.48
26	8.9088	0.39	123.43	8.8435	0.44	236.43	72	8.9040	0.40	84.50	8.8893	0.42	281.89
28	8.8792	0.45	119.29	8.8586	0.49	240.64	74	8.9107	0.41	83.01	8.9571	0.42	278.99
30	8.8473	0.47	115.69	8.8445	0.47	244.24	76	8.9337	0.41	81.62	8.9461	0.43	280.40
32	8.8229	0.44	112.56	8.8790	0.49	247.38	78	8.9436	0.42	80.15	8.9267	0.50	281.91
34	8.9275	0.41	109.85	8.8707	0.64	250.07	80	8.9776	0.49	78.66	8.9577	0.49	283.25
36	8.9133	0.39	107.50	8.8261	0.62	252.58	82	9.0037	0.48	77.27	9.0171	0.79	284.70
38	8.9023	0.45	104.97	8.8294	0.53	254.91	84	8.9938	N/A	75.67	N/A	N/A	N/A
40	8.8512	0.43	102.79	8.8717	0.42	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9182	0.50	100.83	8.8447	0.46	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8897	0.43	98.95	8.8812	0.49	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31122E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

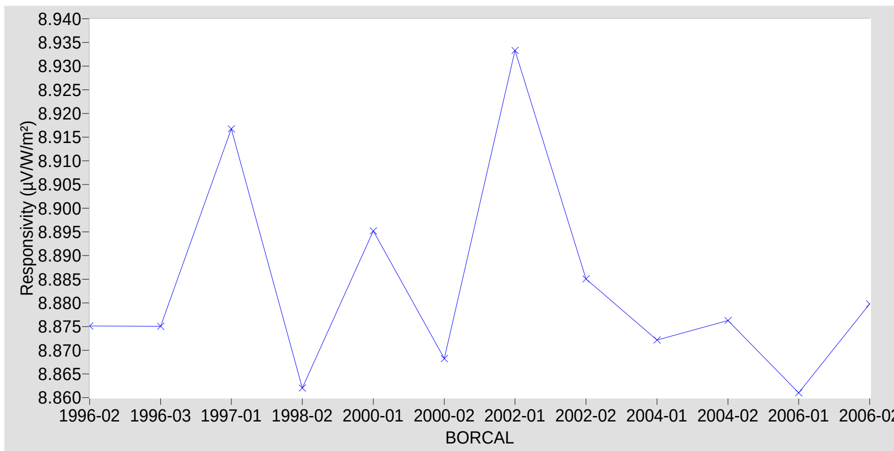
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.8798	+0.95 / -1.25 †
Average	8.8911	+2.22 / -1.34 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 31149F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: Calibration System
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31149F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

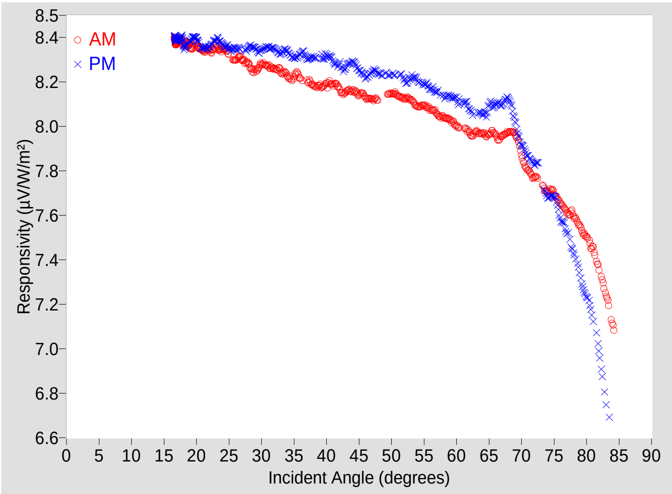


Figure 2. Responsivity vs Local Standard Time

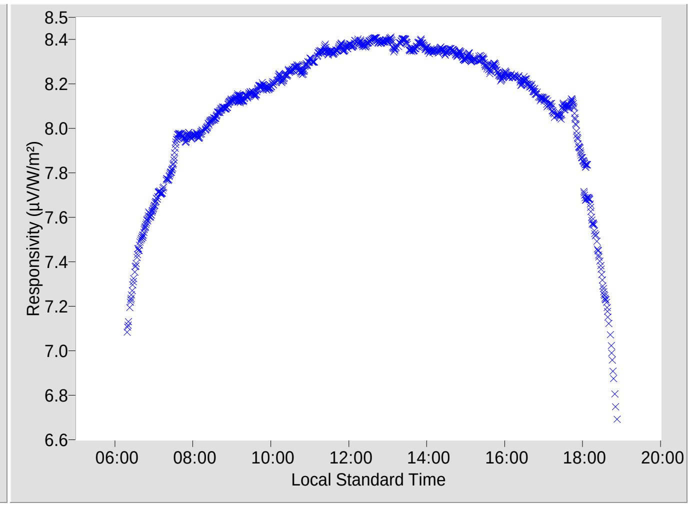


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1974	+2.52 / -2.88	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1301	0.56	97.15	8.2247	0.59	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1191	N/A	95.66	8.2378	0.59	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1482	0.62	101.83	8.2344	0.58	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1260	0.64	100.02	8.2063	0.63	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0917	0.67	98.28	8.2065	0.66	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0761	0.70	96.55	8.1705	0.67	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0424	0.70	94.96	8.1348	0.67	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0020	0.75	93.37	8.1192	0.70	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9716	0.78	91.80	8.0754	0.79	274.99
18	8.3740	0.53	155.33	8.3719	0.61	204.67	64	7.9693	0.81	90.33	8.0550	0.79	276.37
20	8.3685	0.52	142.65	8.3955	0.57	217.08	66	7.9629	0.89	88.82	8.0987	0.79	277.77
22	8.3433	0.51	134.55	8.3610	0.53	225.38	68	7.9747	0.91	87.34	8.1239	1.07	279.11
24	8.3462	0.55	128.25	8.3690	0.57	231.54	70	7.8750	1.40	85.93	7.9177	1.29	280.51
26	8.2996	0.48	123.51	8.3502	0.49	236.51	72	7.7707	1.10	84.49	7.8320	1.00	281.88
28	8.2809	0.60	119.25	8.3569	0.50	240.61	74	7.7074	1.21	83.04	7.6844	1.38	278.97
30	8.2803	0.54	115.76	8.3449	0.51	244.21	76	7.6561	1.48	81.61	7.5798	1.89	280.43
32	8.2592	0.52	112.61	8.3507	0.54	247.26	78	7.6010	1.67	80.17	7.4385	2.14	281.76
34	8.2250	0.55	109.74	8.3367	0.55	250.12	80	7.5049	2.08	78.74	7.2357	2.40	283.23
36	8.2154	0.55	107.29	8.3288	0.55	252.63	82	7.3531	2.94	77.25	6.9696	3.52	284.72
38	8.1848	0.54	104.95	8.3104	0.52	254.96	84	7.1092	3.69	75.75	N/A	N/A	N/A
40	8.1904	0.55	102.78	8.3185	0.56	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1686	0.60	100.81	8.2761	0.60	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1588	0.56	98.93	8.2904	0.59	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31149F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

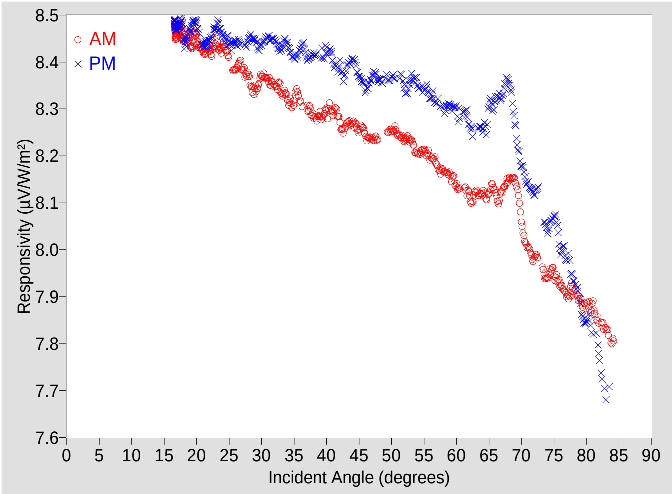


Figure 4. Responsivity vs Local Standard Time

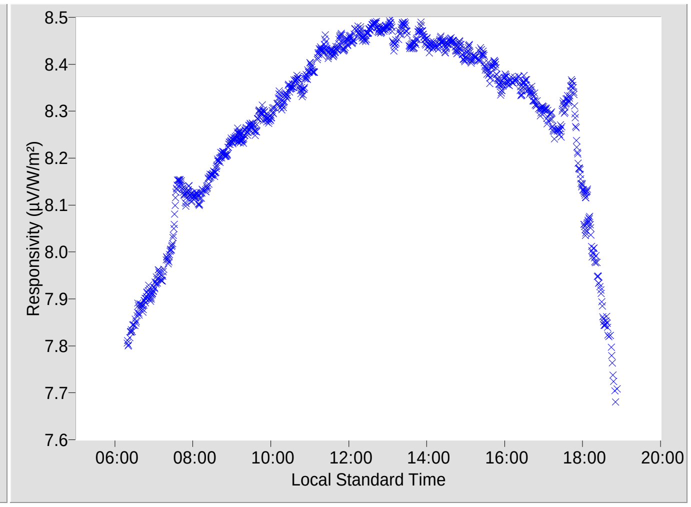


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3121	+2.33 / -2.69	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.54900 µV/W/m², determination date: 03/30/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2428	0.62	97.15	8.3454	0.64	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2336	N/A	95.66	8.3620	0.64	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2545	0.66	101.83	8.3666	0.64	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2352	0.68	100.02	8.3450	0.70	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2061	0.72	98.28	8.3522	0.72	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1961	0.74	96.55	8.3263	0.74	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1683	0.75	94.96	8.3001	0.75	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1354	0.80	93.37	8.2940	0.79	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1135	0.84	91.80	8.2637	0.87	274.99
18	8.4534	0.55	155.33	8.4562	0.64	204.67	64	8.1207	0.87	90.33	8.2571	0.92	276.37
20	8.4505	0.55	142.65	8.4798	0.60	217.08	66	8.1233	0.96	88.82	8.3166	0.93	277.77
22	8.4251	0.54	134.55	8.4461	0.56	225.38	68	8.1491	0.99	87.34	8.3597	1.13	279.11
24	8.4306	0.57	128.25	8.4564	0.60	231.54	70	8.0648	1.37	85.93	8.1797	1.31	280.51
26	8.3843	0.52	123.51	8.4408	0.53	236.51	72	7.9828	1.19	84.49	8.1200	1.18	281.88
28	8.3684	0.61	119.25	8.4492	0.54	240.61	74	7.9412	1.31	83.04	8.0445	1.60	278.97
30	8.3696	0.57	115.76	8.4391	0.55	244.21	76	7.9266	1.54	81.61	7.9997	1.90	280.43
32	8.3500	0.55	112.61	8.4472	0.57	247.26	78	7.9149	1.78	80.17	7.9408	2.20	281.76
34	8.3187	0.57	109.74	8.4358	0.59	250.12	80	7.8853	2.16	78.74	7.8467	2.57	283.23
36	8.3130	0.59	107.29	8.4307	0.59	252.63	82	7.8485	2.85	77.25	7.7695	3.37	284.72
38	8.2848	0.58	104.95	8.4154	0.57	254.96	84	7.8047	3.89	75.75	N/A	N/A	N/A
40	8.2955	0.60	102.78	8.4258	0.60	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2739	0.65	100.81	8.3875	0.64	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2684	0.60	98.93	8.4051	0.63	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31149F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

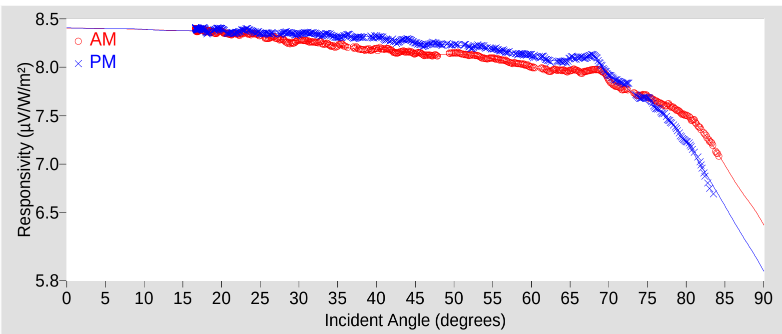
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

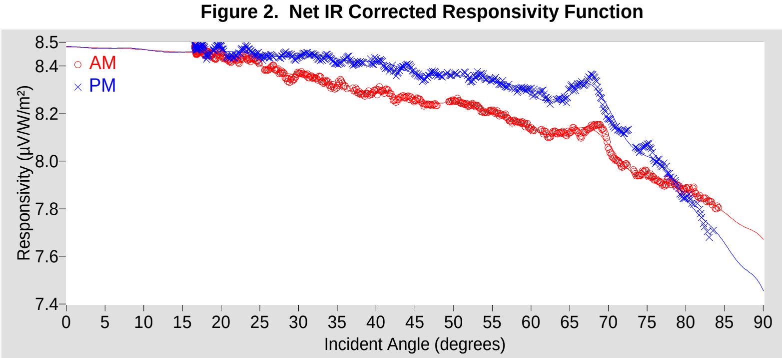


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.70	±1.70
R²	0.9999993	0.9999973
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.73	±1.73
Net IR corrected R²	0.9999995	0.9999977
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	Responsivity AM U95 (%)	Responsivity PM RS (µV/W/m²)	Responsivity PM U95 (%)	Responsivity Combined RS (µV/W/m²)	Responsivity Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	Net IR Corr. Responsivity AM U95 (%)	Net IR Corr. Responsivity PM RSc (µV/W/m²)	Net IR Corr. Responsivity PM U95 (%)	Net IR Corr. Responsivity Combined RSc (µV/W/m²)	Net IR Corr. Responsivity Combined U95 (%)
0-9	8.4001	*	8.4001	*	8.4001	*	8.4765	*	8.4765	*	8.4765	*
9-18	8.3819	*	8.3820	*	8.3820	*	8.4618	*	8.4624	*	8.4621	*
18-27	8.3450	±1.76	8.3699	±1.71	8.3574	±1.86	8.4278	±1.77	8.4562	±1.73	8.4420	±1.87
27-36	8.2594	±1.77	8.3454	±1.71	8.3024	±2.11	8.3501	±1.78	8.4413	±1.73	8.3957	±2.12
36-45	8.1802	±1.74	8.3010	±1.75	8.2406	±2.30	8.2843	±1.75	8.4094	±1.76	8.3469	±2.25
45-54	8.1293	±1.71	8.2285	±1.73	8.1789	±2.11	8.2401	±1.74	8.3582	±1.74	8.2991	±2.15
54-63	8.0339	±1.89	8.1350	±1.88	8.0845	±2.62	8.1617	±1.84	8.3020	±1.80	8.2319	±2.63
63-72	7.9336	±2.02	8.0390	±2.33	7.9863	±3.22	8.1049	±1.92	8.2712	±2.10	8.1881	±3.31
72-81	7.6405	±2.63	7.5349	±4.60	7.5877	±6.51	7.9257	±1.87	7.9800	±2.48	7.9528	±3.07
81-90	6.9236	*	6.5013	*	6.7125	*	7.7719	*	7.6341	*	7.7030	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.1974	+2.52 / -2.88
45° - 55°	8.1735	±1.98
Composite	8.2381	+2.41 / -18.68
45° (Net IR Corr.)	8.3121	+2.33 / -2.69
45° - 55° (Net IR Corr.)	8.2953	±2.00
Composite (Net IR Corr.)	8.3595	+2.12 / -8.08

† Valid incident angle ranges:

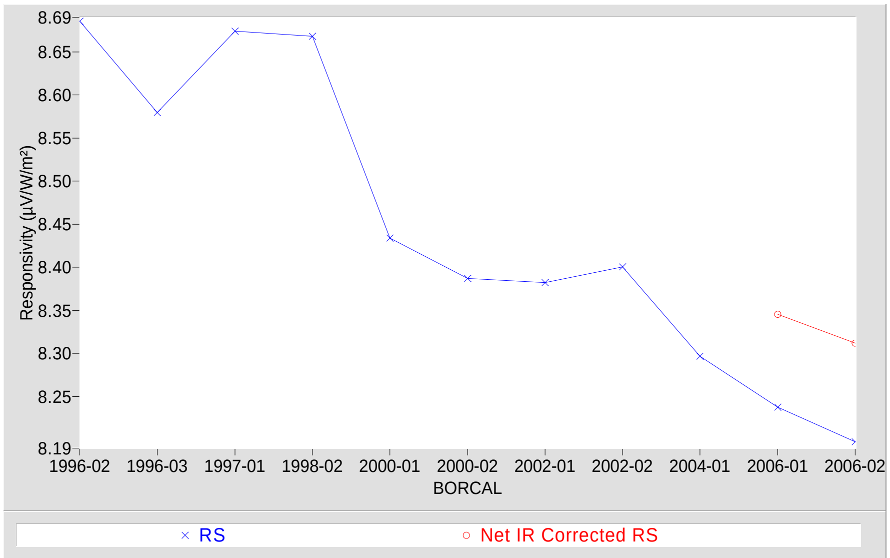
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



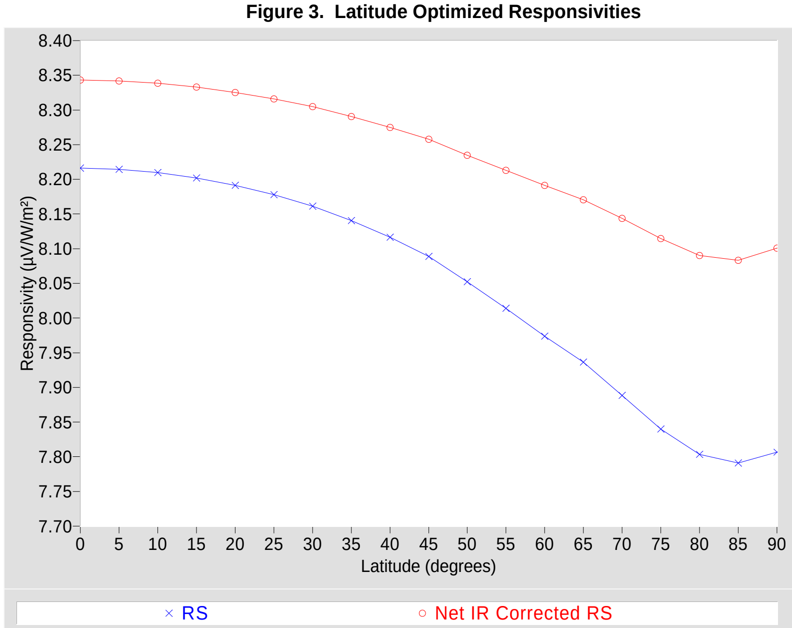
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.2163	+2.87 / -26.56	8.3432	+2.40 / -10.13
5	8.2146	+2.89 / -26.55	8.3419	+2.41 / -10.11
10	8.2099	+2.93 / -26.50	8.3385	+2.44 / -10.08
15	8.2021	+3.01 / -26.43	8.3329	+2.49 / -10.02
20	8.1914	+3.12 / -26.34	8.3254	+2.56 / -9.94
25	8.1778	+3.26 / -26.22	8.3158	+2.64 / -9.84
30	8.1614	+3.36 / -26.07	8.3047	+2.69 / -9.72
35	8.1406	+3.47 / -25.88	8.2907	+2.73 / -9.57
40	8.1164	+3.65 / -25.66	8.2750	+2.85 / -9.40
45	8.0887	+3.95 / -25.40	8.2580	+3.01 / -9.21
50	8.0522	+4.11 / -25.07	8.2348	+3.11 / -8.96
55	8.0141	+4.55 / -24.71	8.2130	+3.34 / -8.72
60	7.9738	+4.70 / -24.33	8.1912	+3.33 / -8.49
65	7.9363	+4.95 / -23.98	8.1703	+3.46 / -8.26
70	7.8883	+4.80 / -23.51	8.1439	+3.19 / -7.97
75	7.8400	+5.18 / -23.04	8.1147	+3.47 / -7.64
80	7.8035	+5.06 / -22.68	8.0902	+3.45 / -7.37
85	7.7911	+4.35 / -22.56	8.0833	+3.52 / -7.29
90	7.8066	+4.16 / -22.71	8.1008	+3.32 / -7.49

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

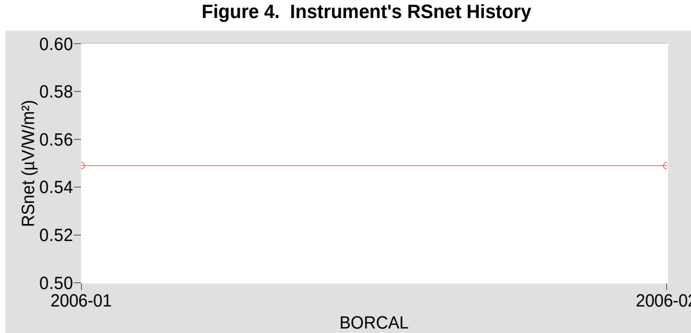
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 31150F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: Calibration System
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

31150F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

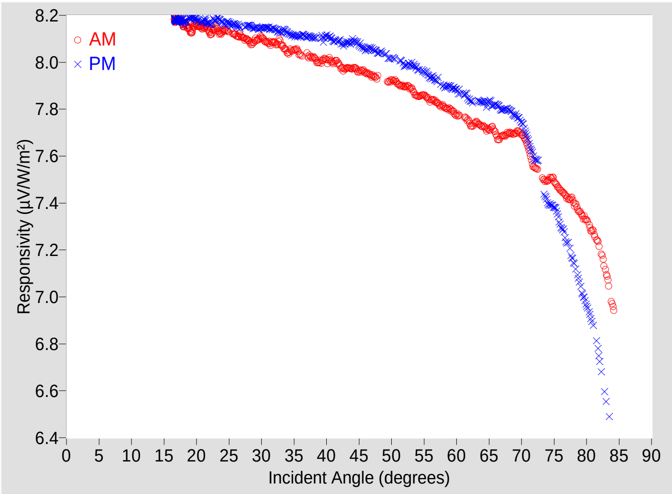


Figure 2. Responsivity vs Local Standard Time

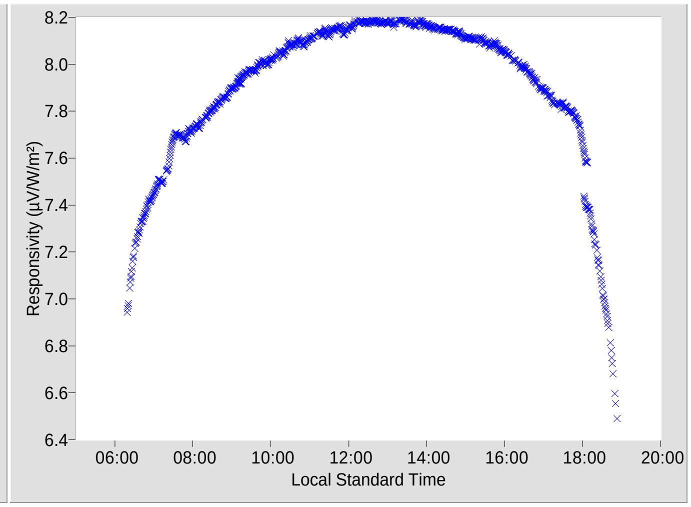


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0183	+2.18 / -3.55	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡		RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9556	0.57	97.15	8.0563	0.58	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9293	N/A	95.66	8.0403	0.58	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9222	0.62	101.83	8.0174	0.59	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8971	0.64	100.02	7.9863	0.61	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8568	0.69	98.28	7.9714	0.65	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8382	0.69	96.55	7.9353	0.66	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8122	0.71	94.96	7.8969	0.69	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7755	0.74	93.37	7.8798	0.69	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7405	0.79	91.80	7.8373	0.74	274.99
18	8.1624	0.55	155.33	8.1755	0.50	204.67	64	7.7277	0.84	90.33	7.8297	0.75	276.37
20	8.1575	0.52	142.65	8.1817	0.48	217.08	66	7.6973	0.92	88.82	7.8193	0.82	277.77
22	8.1275	0.53	134.55	8.1639	0.50	225.38	68	7.6983	0.91	87.34	7.7989	0.85	279.11
24	8.1320	0.51	128.25	8.1687	0.52	231.54	70	7.6938	1.06	85.93	7.7432	1.12	280.51
26	8.1177	0.48	123.51	8.1582	0.49	236.51	72	7.5519	1.24	84.49	7.5890	1.14	281.88
28	8.0915	0.51	119.25	8.1572	0.49	240.61	74	7.4964	1.20	83.04	7.4055	1.42	278.97
30	8.1062	0.51	115.76	8.1459	0.49	244.21	76	7.4559	1.46	81.61	7.3004	1.86	280.43
32	8.0832	0.51	112.61	8.1424	0.51	247.26	78	7.4050	1.68	80.17	7.1543	2.14	281.76
34	8.0423	0.54	109.74	8.1252	0.53	250.12	80	7.3280	2.06	78.74	6.9656	2.37	283.23
36	8.0314	0.54	107.29	8.1124	0.51	252.63	82	7.2108	2.84	77.25	6.7336	3.42	284.72
38	8.0196	0.56	104.95	8.1041	0.52	254.96	84	6.9631	3.72	75.75	N/A	N/A	N/A
40	8.0086	0.54	102.78	8.1106	0.55	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9871	0.59	100.81	8.0884	0.56	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9736	0.54	98.93	8.0912	0.56	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31150F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

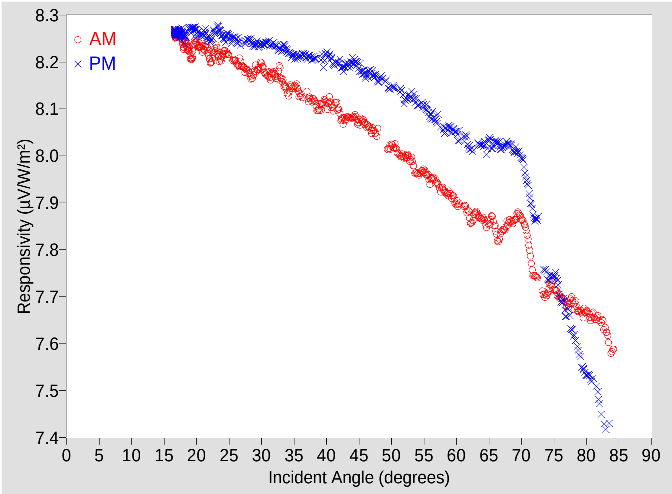


Figure 4. Responsivity vs Local Standard Time

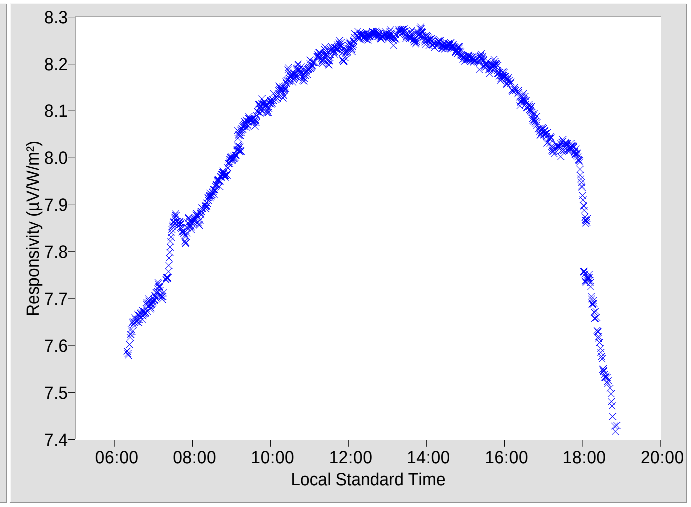


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1302	+2.01 / -3.45	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.55100 µV/W/m², determination date: 03/30/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡		RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0668	0.62	97.15	8.1731	0.64	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0419	N/A	95.66	8.1610	0.64	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0208	0.66	101.83	8.1460	0.65	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9978	0.68	100.02	8.1199	0.68	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9622	0.73	98.28	8.1115	0.71	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9492	0.73	96.55	8.0847	0.73	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9283	0.75	94.96	8.0549	0.76	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8979	0.79	93.37	8.0461	0.78	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8696	0.84	91.80	8.0164	0.83	274.99
18	8.2401	0.57	155.33	8.2574	0.54	204.67	64	7.8658	0.88	90.33	8.0232	0.86	276.37
20	8.2393	0.57	142.65	8.2650	0.52	217.08	66	7.8440	0.98	88.82	8.0291	0.92	277.77
22	8.2076	0.56	134.55	8.2485	0.54	225.38	68	7.8588	0.99	87.34	8.0261	0.97	279.11
24	8.2159	0.54	128.25	8.2550	0.56	231.54	70	7.8674	1.10	85.93	7.9956	1.17	280.51
26	8.2017	0.52	123.51	8.2474	0.53	236.51	72	7.7445	1.28	84.49	7.8673	1.26	281.88
28	8.1779	0.54	119.25	8.2479	0.53	240.61	74	7.7079	1.31	83.04	7.7438	1.59	278.97
30	8.1936	0.54	115.76	8.2385	0.53	244.21	76	7.6999	1.52	81.61	7.6939	1.89	280.43
32	8.1735	0.55	112.61	8.2371	0.55	247.26	78	7.6872	1.76	80.17	7.6233	2.20	281.76
34	8.1352	0.57	109.74	8.2226	0.57	250.12	80	7.6681	2.14	78.74	7.5340	2.55	283.23
36	8.1280	0.57	107.29	8.2126	0.56	252.63	82	7.6513	2.81	77.25	7.4747	3.32	284.72
38	8.1185	0.60	104.95	8.2070	0.56	254.96	84	7.5844	3.87	75.75	N/A	N/A	N/A
40	8.1121	0.59	102.78	8.2155	0.60	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0912	0.63	100.81	8.1968	0.61	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0818	0.59	98.93	8.2021	0.61	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31150F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

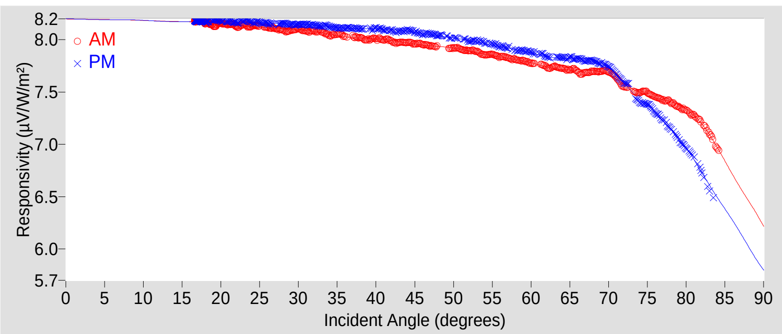
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

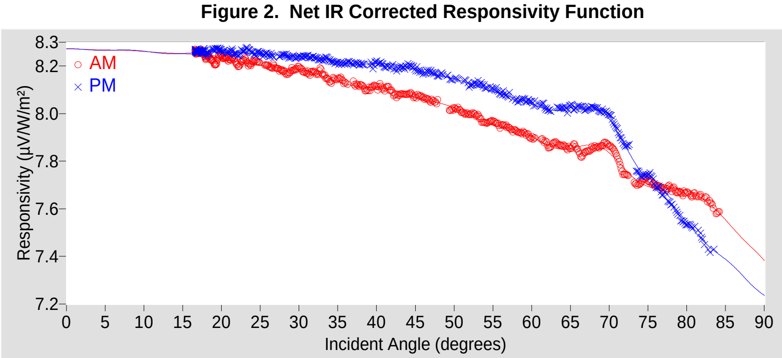


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.66	±1.66
R²	0.9999987	0.9999995
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.70	±1.70
Net IR corrected R²	0.9999989	0.9999995
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

	Responsivity						Net IR Corr. Responsivity					
Inc.	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.1940	*	8.1940	*	8.1940	*	8.2683	*	8.2684	*	8.2684	*
9-18	8.1767	*	8.1779	*	8.1773	*	8.2546	*	8.2561	*	8.2554	*
18-27	8.1366	±1.69	8.1692	±1.66	8.1529	±1.76	8.2184	±1.72	8.2543	±1.70	8.2364	±1.78
27-36	8.0800	±1.73	8.1406	±1.68	8.1103	±2.00	8.1696	±1.74	8.2349	±1.71	8.2022	±1.99
36-45	8.0019	±1.71	8.1001	±1.67	8.0510	±2.12	8.1047	±1.73	8.2060	±1.70	8.1553	±2.08
45-54	7.9216	±1.76	8.0237	±1.78	7.9727	±2.45	8.0272	±1.81	8.1493	±1.76	8.0883	±2.53
54-63	7.8025	±1.86	7.8998	±1.85	7.8512	±2.67	7.9199	±1.82	8.0594	±1.78	7.9897	±2.73
63-72	7.6913	±1.84	7.7826	±2.11	7.7370	±2.70	7.8480	±1.78	8.0061	±1.91	7.9271	±2.85
72-81	7.4442	±2.44	7.2656	±4.91	7.3549	±6.95	7.7008	±1.81	7.6829	±2.81	7.6918	±3.59
81-90	6.7724	*	6.3235	*	6.5480	*	7.5320	*	7.3691	*	7.4505	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

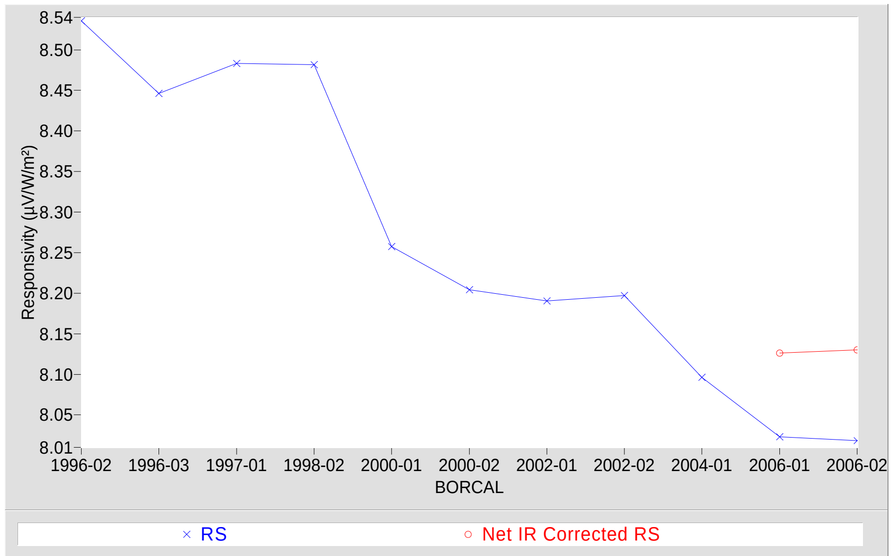
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.0183	+2.18 / -3.55
45° - 55°	7.9629	±2.18
Composite	8.0307	+2.45 / -19.20
45° (Net IR Corr.)	8.1302	+2.01 / -3.45
45° - 55° (Net IR Corr.)	8.0797	±2.22
Composite (Net IR Corr.)	8.1472	+2.17 / -9.17

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



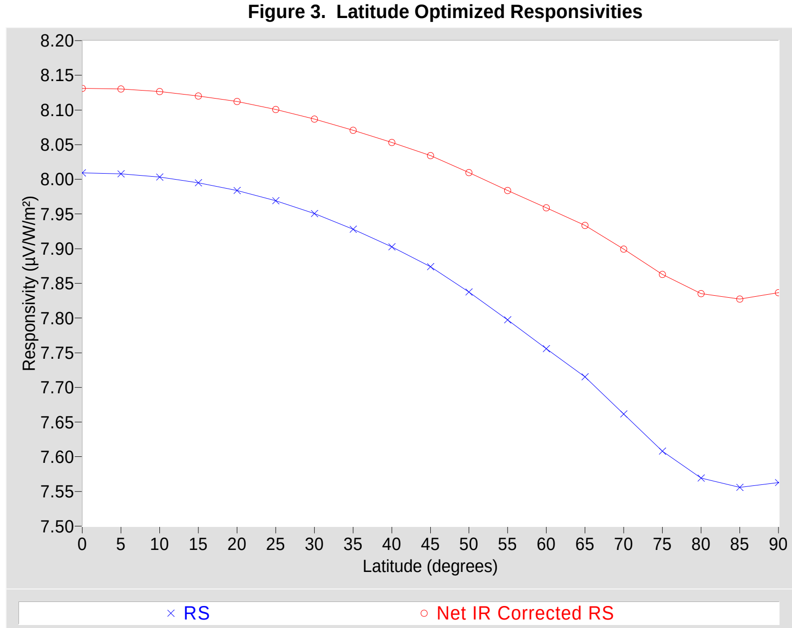
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.0094	+2.90 / -26.31	8.1311	+2.44 / -10.83
5	8.0080	+2.91 / -26.30	8.1301	+2.45 / -10.82
10	8.0031	+2.96 / -26.26	8.1264	+2.48 / -10.78
15	7.9951	+3.05 / -26.18	8.1203	+2.54 / -10.71
20	7.9841	+3.17 / -26.08	8.1121	+2.61 / -10.62
25	7.9692	+3.32 / -25.94	8.1009	+2.71 / -10.50
30	7.9505	+3.46 / -25.77	8.0869	+2.80 / -10.35
35	7.9282	+3.61 / -25.56	8.0709	+2.88 / -10.17
40	7.9027	+3.83 / -25.32	8.0531	+3.06 / -9.97
45	7.8739	+4.14 / -25.05	8.0340	+3.24 / -9.76
50	7.8375	+4.44 / -24.70	8.0096	+3.44 / -9.49
55	7.7972	+4.76 / -24.31	7.9840	+3.62 / -9.21
60	7.7558	+4.89 / -23.91	7.9592	+3.60 / -8.93
65	7.7154	+5.29 / -23.51	7.9337	+3.88 / -8.64
70	7.6618	+5.45 / -22.98	7.8994	+3.88 / -8.25
75	7.6081	+5.49 / -22.43	7.8629	+3.88 / -7.83
80	7.5692	+5.10 / -22.04	7.8351	+3.59 / -7.51
85	7.5559	+4.31 / -21.90	7.8273	+3.21 / -7.42
90	7.5629	+3.82 / -21.97	7.8367	+3.11 / -7.53

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

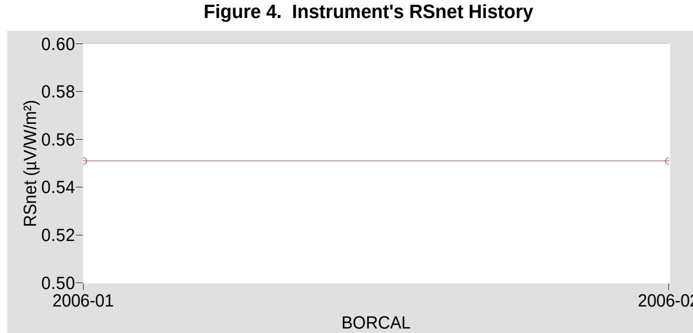
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31151F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	Calibration System	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

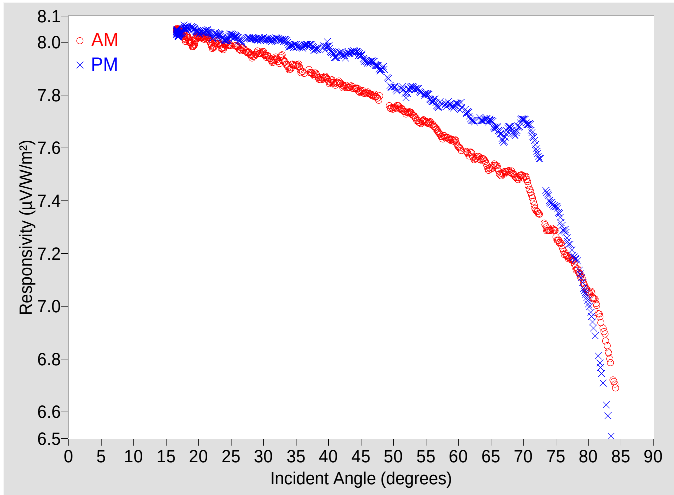

Figure 2. Responsivity vs Local Standard Time

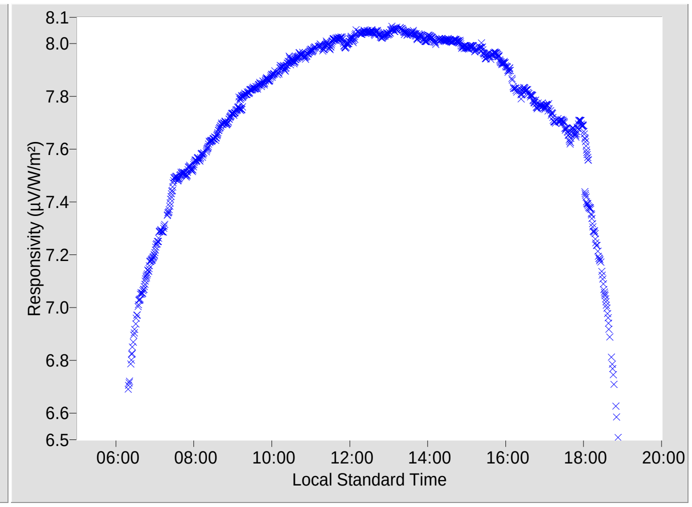

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8830	+2.24 / -3.99	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8092	0.55	97.15	7.9265	0.59	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7811	N/A	95.66	7.8981	0.60	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7520	0.62	101.83	7.8313	0.66	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7345	0.65	100.02	7.8070	0.64	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6980	0.67	98.28	7.8170	0.63	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6876	0.72	96.55	7.7797	0.70	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6427	0.71	94.96	7.7626	0.64	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6059	0.77	93.37	7.7631	0.68	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5770	0.78	91.80	7.7057	0.75	274.99
18	8.0205	0.58	155.33	8.0546	0.52	204.67	64	7.5533	0.87	90.33	7.7080	0.73	276.37
20	8.0198	0.53	142.65	8.0402	0.50	217.08	66	7.5251	0.90	88.82	7.6732	0.95	277.77
22	7.9893	0.54	134.55	8.0261	0.52	225.38	68	7.5096	0.92	87.34	7.6773	0.90	279.11
24	7.9877	0.50	128.25	8.0103	0.50	231.54	70	7.4934	1.05	85.93	7.7095	0.91	280.51
26	7.9833	0.48	123.51	8.0161	0.52	236.51	72	7.3639	1.25	84.49	7.5940	1.30	281.88
28	7.9523	0.52	119.25	8.0152	0.48	240.61	74	7.2885	1.21	83.04	7.4061	1.43	278.97
30	7.9603	0.51	115.76	8.0145	0.49	244.21	76	7.2243	1.50	81.61	7.2978	1.82	280.43
32	7.9374	0.52	112.61	8.0140	0.50	247.26	78	7.1523	1.71	80.17	7.1832	1.99	281.76
34	7.9013	0.54	109.74	7.9877	0.54	250.12	80	7.0566	2.07	78.74	7.0156	2.45	283.23
36	7.8875	0.54	107.29	7.9840	0.51	252.63	82	6.9390	2.92	77.25	6.7530	3.33	284.72
38	7.8791	0.56	104.95	7.9736	0.54	254.96	84	6.7086	3.74	75.75	N/A	N/A	N/A
40	7.8533	0.54	102.78	7.9838	0.64	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8390	0.54	100.81	7.9582	0.55	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8269	0.55	98.93	7.9652	0.55	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

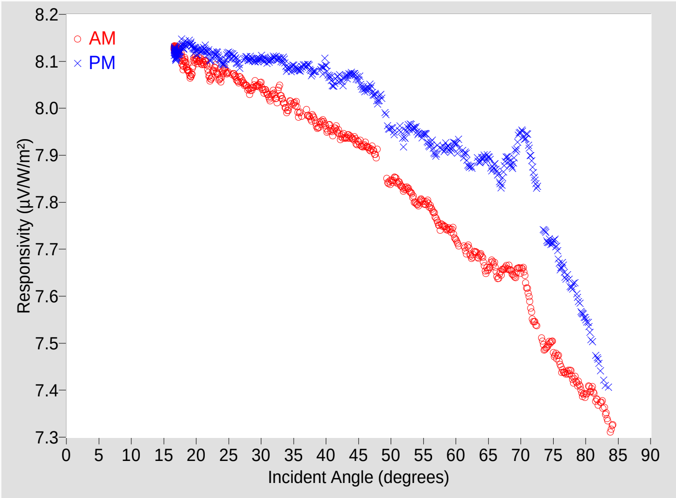


Figure 4. Responsivity vs Local Standard Time

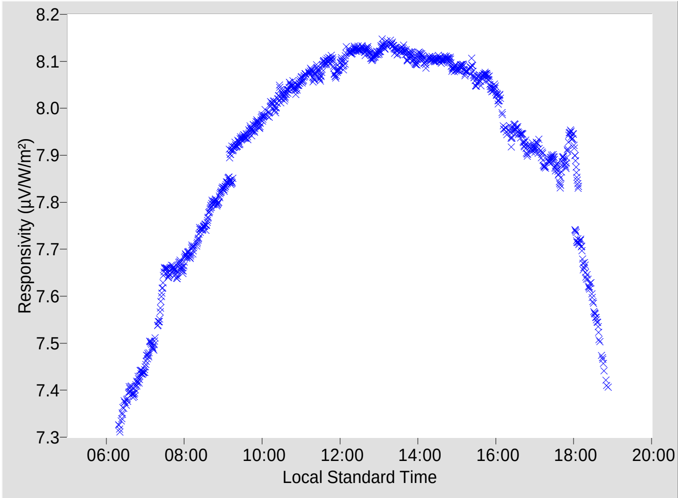


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9944	+2.06 / -3.98	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.53300 µV/W/m², determination date: 03/30/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9222	0.61	97.15	8.0409	0.64	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8946	N/A	95.66	8.0170	0.67	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8436	0.66	101.83	7.9575	0.71	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8283	0.68	100.02	7.9364	0.73	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7962	0.71	98.28	7.9517	0.70	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7909	0.75	96.55	7.9227	0.76	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7510	0.75	94.96	7.9132	0.74	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7203	0.81	93.37	7.9214	0.78	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6986	0.83	91.80	7.8765	0.83	274.99
18	8.0990	0.60	155.33	8.1343	0.55	204.67	64	7.6839	0.91	90.33	7.8925	0.85	276.37
20	8.1030	0.58	142.65	8.1230	0.53	217.08	66	7.6638	0.95	88.82	7.8740	1.00	277.77
22	8.0696	0.57	134.55	8.1111	0.55	225.38	68	7.6607	0.99	87.34	7.8938	1.04	279.11
24	8.0730	0.54	128.25	8.0960	0.54	231.54	70	7.6577	1.10	85.93	7.9500	1.09	280.51
26	8.0689	0.52	123.51	8.1046	0.55	236.51	72	7.5475	1.29	84.49	7.8593	1.37	281.88
28	8.0404	0.56	119.25	8.1047	0.52	240.61	74	7.4915	1.31	83.04	7.7242	1.58	278.97
30	8.0489	0.55	115.76	8.1062	0.54	244.21	76	7.4601	1.54	81.61	7.6652	1.86	280.43
32	8.0301	0.58	112.61	8.1075	0.54	247.26	78	7.4271	1.79	80.17	7.6203	2.12	281.76
34	7.9968	0.58	109.74	8.0846	0.58	250.12	80	7.3905	2.17	78.74	7.5509	2.55	283.23
36	7.9866	0.59	107.29	8.0833	0.56	252.63	82	7.3740	2.87	77.25	7.4581	3.29	284.72
38	7.9796	0.60	104.95	8.0754	0.59	254.96	84	7.3197	3.94	75.75	N/A	N/A	N/A
40	7.9576	0.59	102.78	8.0878	0.68	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9454	0.60	100.81	8.0646	0.61	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9368	0.60	98.93	8.0734	0.60	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31151F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

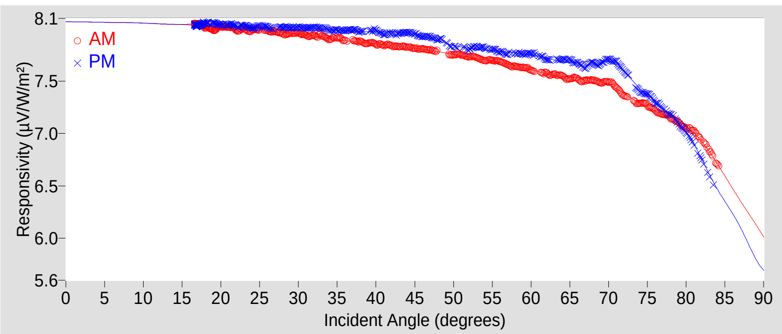
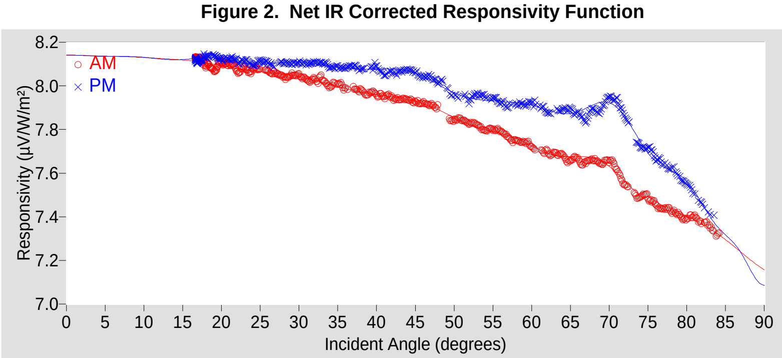


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.66	±1.66
R²	0.9999990	0.9999985
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.71	±1.71
Net IR corrected R²	0.9999991	0.9999986
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.0634	*	8.0633	*	8.0634	*	8.1370	*	8.1370	*	8.1370	*
9-18	8.0447	*	8.0475	*	8.0461	*	8.1220	*	8.1249	*	8.1235	*
18-27	7.9974	±1.69	8.0270	±1.68	8.0122	±1.79	8.0802	±1.73	8.1116	±1.72	8.0959	±1.81
27-36	7.9372	±1.73	8.0069	±1.67	7.9721	±2.02	8.0288	±1.76	8.1002	±1.71	8.0645	±2.01
36-45	7.8547	±1.71	7.9720	±1.67	7.9134	±2.22	7.9593	±1.74	8.0763	±1.71	8.0178	±2.16
45-54	7.7649	±1.79	7.8652	±1.90	7.8150	±2.73	7.8675	±1.88	7.9879	±1.87	7.9277	±2.84
54-63	7.6391	±1.90	7.7639	±1.75	7.7015	±2.75	7.7489	±1.86	7.9162	±1.73	7.8325	±2.84
63-72	7.5086	±1.94	7.6829	±1.74	7.5958	±3.31	7.6568	±1.82	7.8962	±1.74	7.7765	±3.58
72-81	7.2111	±2.90	7.2826	±4.60	7.2469	±6.35	7.4600	±2.05	7.6741	±2.69	7.5670	±4.82
81-90	6.5311	*	6.2883	*	6.4097	*	7.2768	*	7.2927	*	7.2847	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

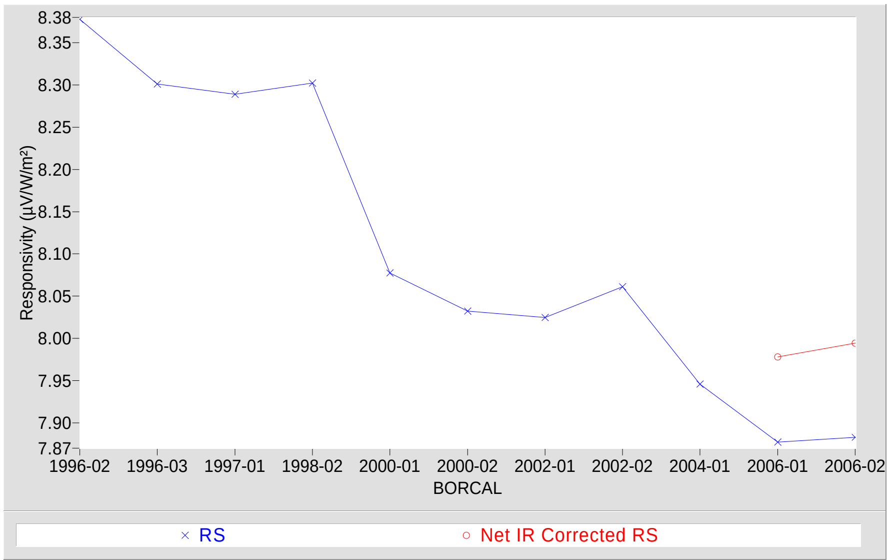
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.8830	+2.24 / -3.99
45° - 55°	7.8052	±2.34
Composite	7.8926	+2.58 / -18.05
45° (Net IR Corr.)	7.9944	+2.06 / -3.98
45° - 55° (Net IR Corr.)	7.9185	±2.40
Composite (Net IR Corr.)	8.0066	+2.29 / -8.73

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



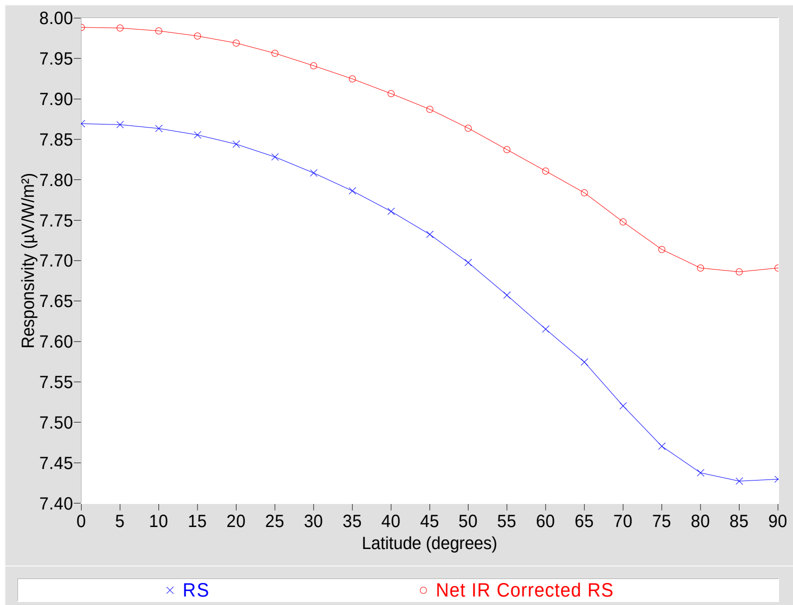
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.8693	+3.02 / -26.32	7.9885	+2.56 / -11.11
5	7.8683	+3.03 / -26.31	7.9878	+2.57 / -11.10
10	7.8635	+3.09 / -26.26	7.9841	+2.60 / -11.06
15	7.8554	+3.18 / -26.19	7.9778	+2.67 / -10.99
20	7.8440	+3.30 / -26.08	7.9690	+2.75 / -10.89
25	7.8281	+3.48 / -25.93	7.9564	+2.88 / -10.75
30	7.8086	+3.64 / -25.74	7.9412	+2.98 / -10.58
35	7.7865	+3.79 / -25.53	7.9248	+3.09 / -10.40
40	7.7609	+4.06 / -25.29	7.9066	+3.29 / -10.20
45	7.7323	+4.25 / -25.01	7.8872	+3.39 / -9.98
50	7.6977	+4.49 / -24.68	7.8639	+3.55 / -9.72
55	7.6573	+4.93 / -24.28	7.8373	+3.82 / -9.41
60	7.6153	+5.11 / -23.86	7.8110	+3.87 / -9.11
65	7.5744	+5.50 / -23.45	7.7840	+4.14 / -8.80
70	7.5204	+5.70 / -22.90	7.7478	+4.18 / -8.39
75	7.4705	+5.05 / -22.39	7.7137	+3.56 / -7.99
80	7.4375	+4.97 / -22.05	7.6910	+3.52 / -7.72
85	7.4273	+4.49 / -21.94	7.6862	+3.55 / -7.67
90	7.4297	+3.99 / -21.96	7.6908	+3.49 / -7.72

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

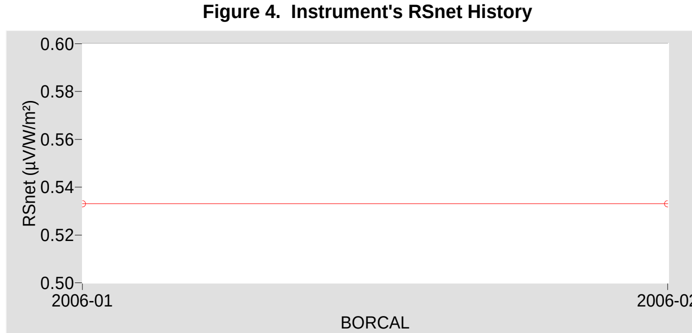
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley

Model: PSP
Serial Number: 31152F3

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: Calibration System
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ________________

Calibration Results

31152F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

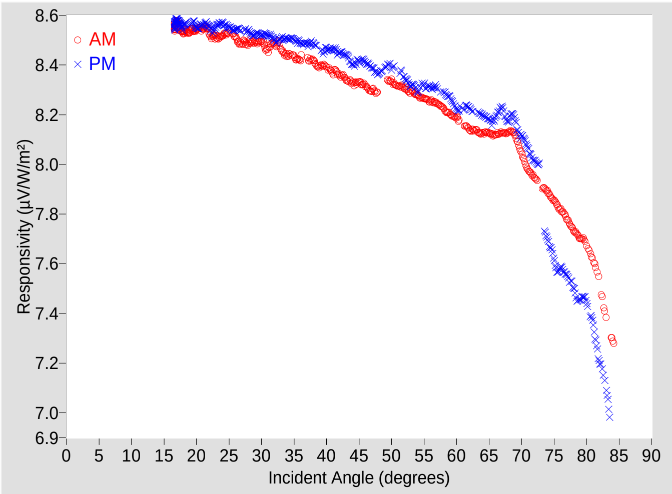


Figure 2. Responsivity vs Local Standard Time

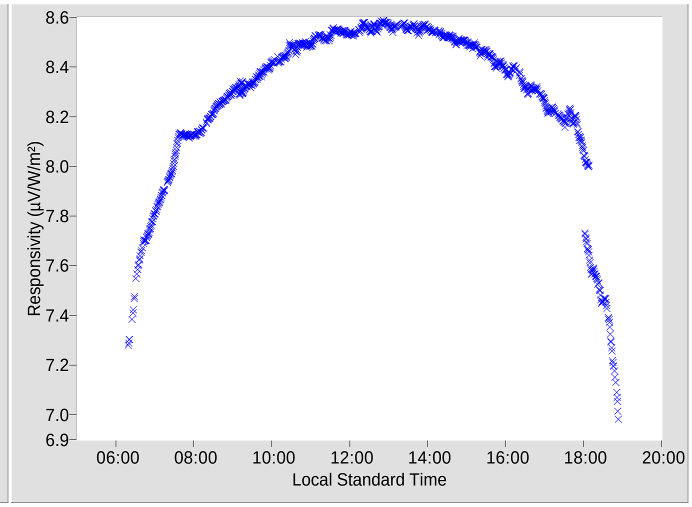


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3730	+2.40 / -2.71	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3167	0.58	97.12	8.4105	0.58	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2904	N/A	95.69	8.3647	0.58	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3339	0.63	101.85	8.3932	0.59	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3074	0.65	99.99	8.3466	0.71	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2791	0.67	98.25	8.3004	0.64	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2537	0.67	96.57	8.3104	0.62	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2267	0.72	94.98	8.2909	0.65	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1868	0.73	93.34	8.2230	0.72	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1402	0.76	91.83	8.2266	0.70	274.96
18	8.5341	0.54	155.43	8.5594	0.52	204.54	64	8.1256	0.80	90.30	8.1990	0.74	276.34
20	8.5422	0.47	142.74	8.5529	0.50	217.16	66	8.1191	0.85	88.84	8.1889	0.90	277.74
22	8.5274	0.56	134.46	8.5519	0.54	225.45	68	8.1304	0.90	87.36	8.1773	0.89	279.13
24	8.5199	0.49	128.32	8.5662	0.50	231.60	70	8.0436	1.30	85.91	8.1122	1.10	280.53
26	8.5125	0.53	123.44	8.5429	0.48	236.45	72	7.9470	1.09	84.46	8.0142	1.04	281.85
28	8.4895	0.49	119.30	8.5355	0.50	240.65	74	7.8905	1.23	83.06	7.6950	1.53	278.99
30	8.4938	0.53	115.80	8.5208	0.49	244.15	76	7.8162	1.46	81.58	7.5848	1.57	280.40
32	8.4848	0.55	112.65	8.5013	0.53	247.30	78	7.7366	1.67	80.19	7.5038	1.90	281.82
34	8.4403	0.51	109.78	8.5059	0.51	250.15	80	7.6747	2.04	78.71	7.4472	2.19	283.25
36	8.4255	0.52	107.36	8.4891	0.52	252.66	82	7.5122	2.92	77.19	7.2055	3.08	284.72
38	8.4174	0.55	104.98	8.4832	0.53	254.99	84	7.2936	3.56	75.77	N/A	N/A	N/A
40	8.3914	0.55	102.85	8.4650	0.54	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3604	0.56	100.77	8.4514	0.56	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3281	0.55	98.95	8.4009	0.60	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

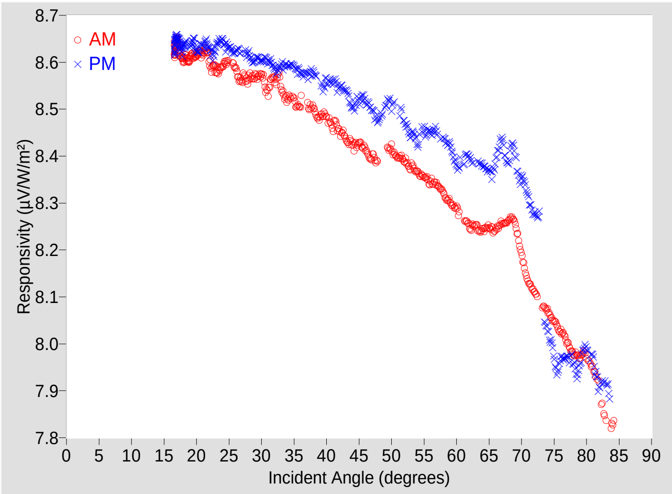


Figure 4. Responsivity vs Local Standard Time

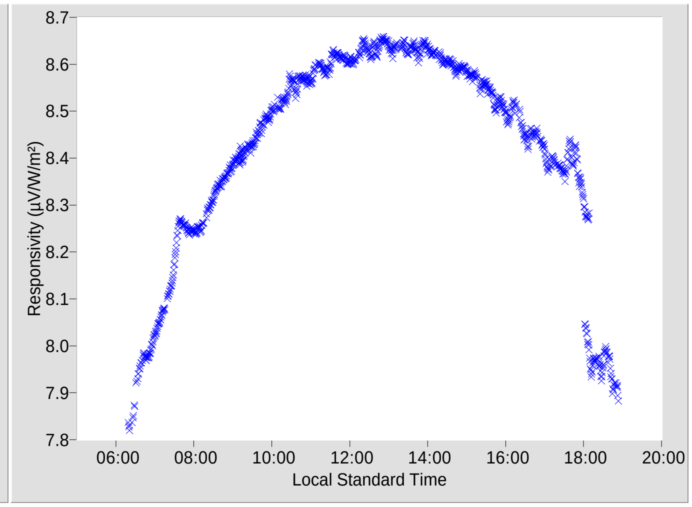


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.4729	+2.20 / -2.73	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63390 µV/W/m², determination date: 05/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4143	0.61	97.12	8.5174	0.61	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3910	N/A	95.69	8.4761	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4138	0.65	101.85	8.5102	0.63	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3896	0.67	99.99	8.4702	0.73	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3668	0.69	98.25	8.4311	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3439	0.69	96.57	8.4508	0.67	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3222	0.73	94.98	8.4381	0.70	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2872	0.76	93.34	8.3802	0.77	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2492	0.78	91.83	8.3963	0.76	274.96
18	8.6076	0.56	155.43	8.6325	0.54	204.54	64	8.2429	0.83	90.30	8.3809	0.81	276.34
20	8.6142	0.49	142.74	8.6274	0.52	217.16	66	8.2428	0.89	88.84	8.3871	1.01	277.74
22	8.6011	0.58	134.46	8.6274	0.56	225.45	68	8.2636	0.94	87.36	8.3914	0.96	279.13
24	8.5933	0.51	128.32	8.6438	0.52	231.60	70	8.1895	1.25	85.91	8.3517	1.10	280.53
26	8.5873	0.54	123.44	8.6233	0.50	236.45	72	8.1103	1.13	84.46	8.2767	1.12	281.85
28	8.5653	0.51	119.30	8.6166	0.52	240.65	74	8.0710	1.25	83.06	8.0275	1.58	278.99
30	8.5723	0.55	115.80	8.6030	0.51	244.15	76	8.0257	1.47	81.58	7.9675	1.72	280.40
32	8.5646	0.59	112.65	8.5861	0.55	247.30	78	7.9791	1.68	80.19	7.9596	2.02	281.82
34	8.5230	0.53	109.78	8.5930	0.53	250.15	80	7.9712	2.06	78.71	7.9912	2.37	283.25
36	8.5112	0.54	107.36	8.5775	0.55	252.66	82	7.8961	2.79	77.19	7.9077	3.04	284.72
38	8.5023	0.57	104.98	8.5751	0.56	254.99	84	7.8286	3.65	75.77	N/A	N/A	N/A
40	8.4822	0.57	102.85	8.5601	0.57	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4525	0.59	100.77	8.5482	0.58	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4245	0.58	98.95	8.5018	0.62	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31152F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

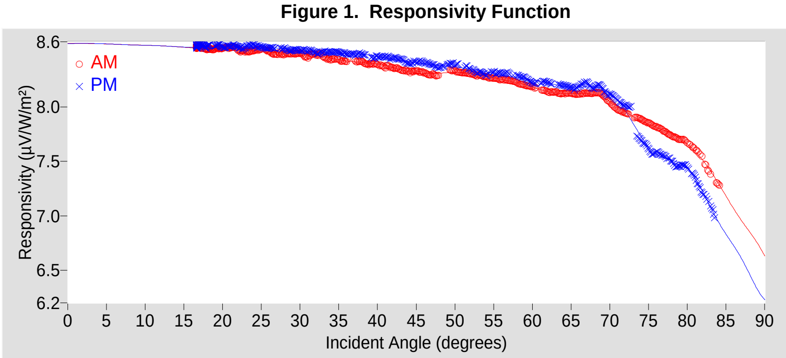
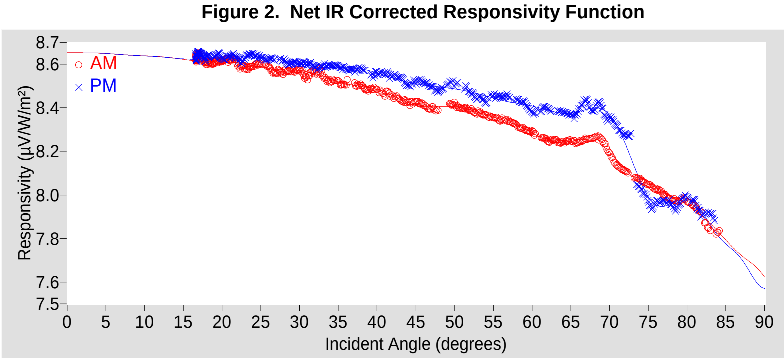


Figure 2. Net IR Corrected Responsivity Function



$$RS\,(am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\,(pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.60	±1.60
R^2	0.9999992	0.9999971
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.61	±1.61
Net IR corrected R^2	0.9999994	0.9999979
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.5801	*	8.5800	*	8.5800	*	8.6486	*	8.6487	*	8.6487	*
9-18	8.5565	*	8.5584	*	8.5574	*	8.6282	*	8.6302	*	8.6292	*
18-27	8.5262	±1.61	8.5545	±1.60	8.5403	±1.67	8.5996	±1.62	8.6308	±1.61	8.6152	±1.68
27-36	8.4756	±1.65	8.5139	±1.62	8.4947	±1.86	8.5552	±1.65	8.5979	±1.63	8.5766	±1.85
36-45	8.3822	±1.72	8.4586	±1.68	8.4204	±2.19	8.4725	±1.70	8.5537	±1.66	8.5131	±2.14
45-54	8.3095	±1.61	8.3726	±1.66	8.3411	±1.89	8.3995	±1.63	8.4881	±1.64	8.4438	±1.98
54-63	8.2143	±1.83	8.2696	±1.73	8.2419	±2.28	8.3112	±1.77	8.4194	±1.66	8.3653	±2.40
63-72	8.0948	±1.84	8.1611	±1.97	8.1280	±2.58	8.2266	±1.76	8.3722	±1.77	8.2994	±2.79
72-81	7.8032	±2.65	7.6183	±4.08	7.7107	±5.51	8.0240	±1.96	8.0220	±2.43	8.0230	±3.29
81-90	7.1289	*	6.7795	*	6.9542	*	7.7792	*	7.7604	*	7.7698	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

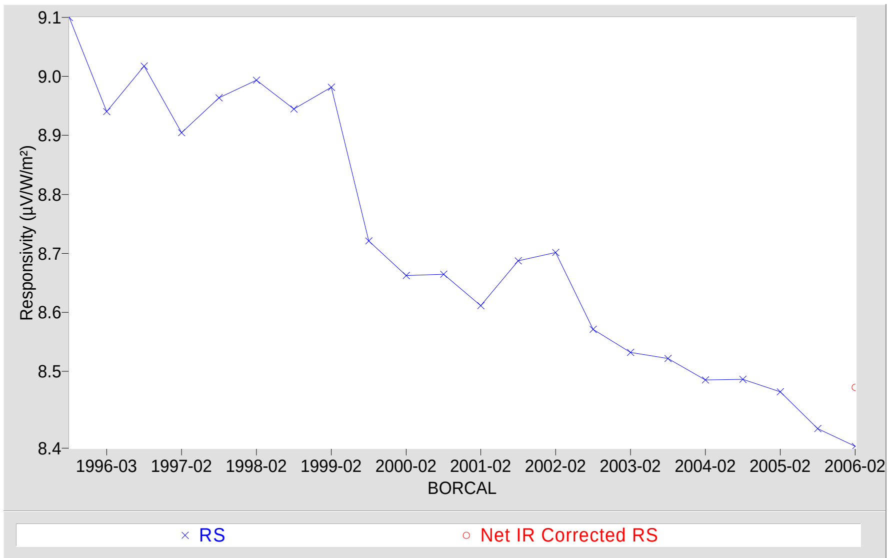
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.3730	+2.40 / -2.71
45° - 55°	8.3347	±1.80
Composite	8.4118	+2.37 / -17.47
45° (Net IR Corr.)	8.4729	+2.20 / -2.73
45° - 55° (Net IR Corr.)	8.4384	±1.85
Composite (Net IR Corr.)	8.5170	+2.12 / -8.42

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



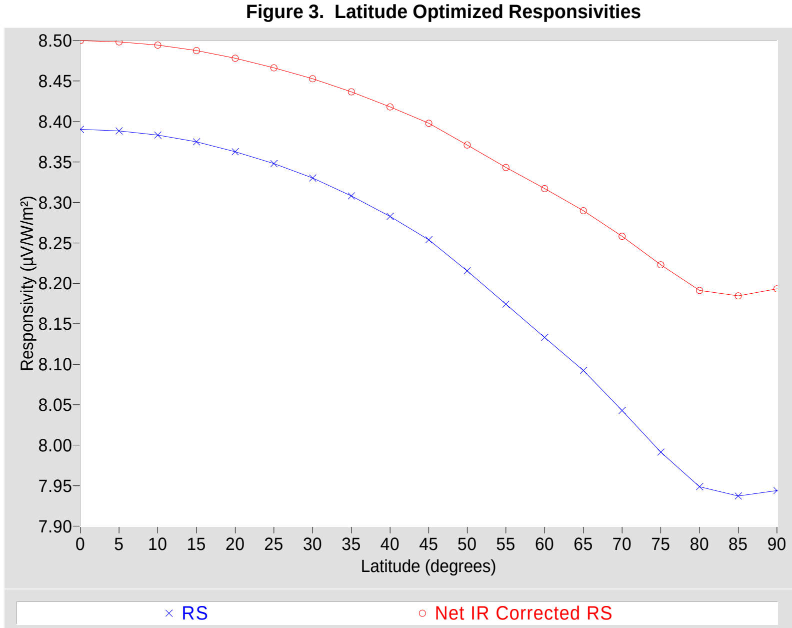
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.3903	+2.81 / -24.58	8.4999	+2.41 / -10.74
5	8.3885	+2.83 / -24.57	8.4984	+2.42 / -10.72
10	8.3833	+2.89 / -24.52	8.4943	+2.46 / -10.68
15	8.3749	+2.97 / -24.44	8.4877	+2.52 / -10.61
20	8.3628	+3.10 / -24.33	8.4781	+2.61 / -10.51
25	8.3479	+3.25 / -24.20	8.4665	+2.72 / -10.39
30	8.3301	+3.38 / -24.04	8.4528	+2.80 / -10.25
35	8.3081	+3.49 / -23.84	8.4365	+2.87 / -10.08
40	8.2827	+3.70 / -23.60	8.4181	+3.03 / -9.88
45	8.2537	+4.03 / -23.34	8.3981	+3.24 / -9.67
50	8.2156	+4.34 / -22.98	8.3711	+3.46 / -9.38
55	8.1743	+4.43 / -22.59	8.3433	+3.42 / -9.08
60	8.1330	+4.73 / -22.20	8.3171	+3.59 / -8.80
65	8.0922	+4.73 / -21.81	8.2899	+3.51 / -8.51
70	8.0428	+4.71 / -21.33	8.2581	+3.39 / -8.16
75	7.9916	+4.88 / -20.83	8.2231	+3.52 / -7.78
80	7.9488	+4.64 / -20.40	8.1912	+3.39 / -7.43
85	7.9371	+4.11 / -20.28	8.1846	+3.08 / -7.35
90	7.9440	+3.43 / -20.35	8.1933	+2.99 / -7.45

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

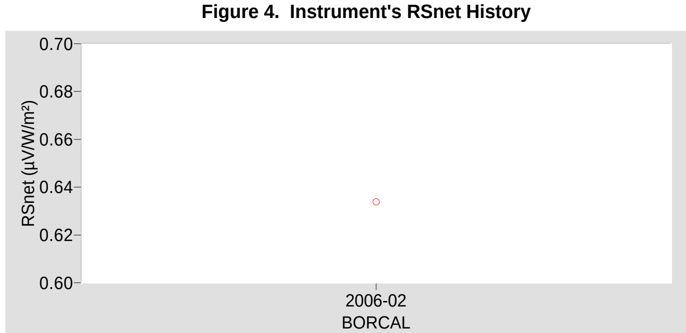
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 31153F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: Calibration System

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31153F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

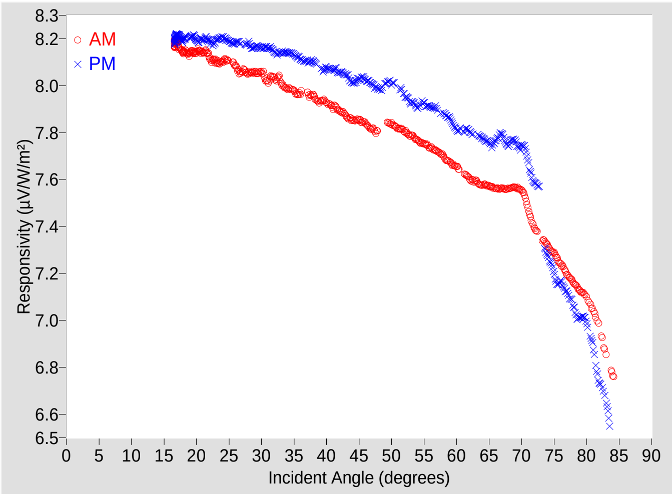


Figure 2. Responsivity vs Local Standard Time

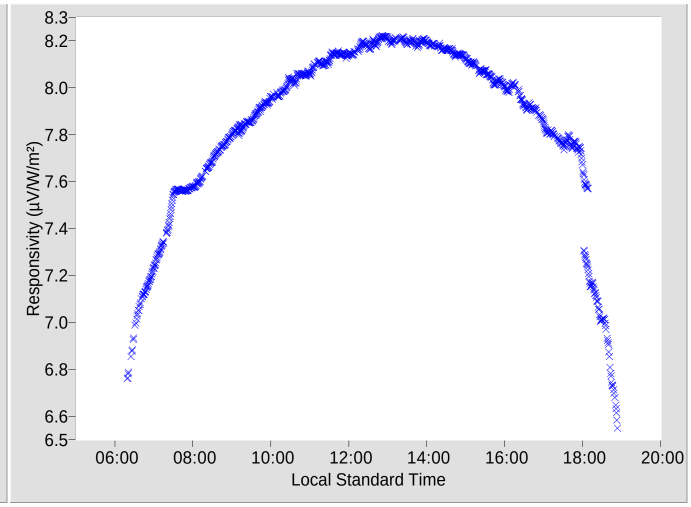


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9410	+3.39 / -4.08	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc.	AM			PM			Inc.	AM			PM		
Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8396	0.60	97.12	8.0256	0.58	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8095	N/A	95.69	7.9858	0.59	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8364	0.63	101.85	8.0124	0.59	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8057	0.66	99.99	7.9580	0.73	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7687	0.69	98.25	7.9106	0.63	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7355	0.69	96.57	7.9105	0.63	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7006	0.74	94.98	7.8819	0.66	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6546	0.74	93.34	7.8132	0.73	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6039	0.78	91.83	7.8057	0.71	274.96
18	8.1457	0.62	155.43	8.1985	0.51	204.54	64	7.5771	0.81	90.30	7.7769	0.75	276.34
20	8.1448	0.48	142.74	8.1951	0.51	217.16	66	7.5625	0.86	88.84	7.7652	0.88	277.74
22	8.1204	0.58	134.46	8.1910	0.53	225.45	68	7.5618	0.91	87.36	7.7491	0.88	279.13
24	8.1044	0.49	128.32	8.2043	0.49	231.60	70	7.5537	1.14	85.91	7.7414	1.04	280.53
26	8.0848	0.57	123.44	8.1841	0.48	236.45	72	7.3931	1.22	84.46	7.5882	1.18	281.85
28	8.0545	0.49	119.30	8.1784	0.51	240.65	74	7.3213	1.25	83.06	7.2735	1.53	278.99
30	8.0561	0.54	115.80	8.1614	0.49	244.15	76	7.2396	1.54	81.58	7.1666	1.62	280.40
32	8.0335	0.52	112.65	8.1434	0.54	247.30	78	7.1622	1.69	80.19	7.0598	1.97	281.82
34	7.9878	0.51	109.78	8.1410	0.50	250.15	80	7.0981	2.06	78.71	6.9913	2.27	283.25
36	7.9687	0.51	107.36	8.1138	0.54	252.66	82	6.9612	2.91	77.19	6.7340	3.07	284.72
38	7.9569	0.58	104.98	8.1009	0.53	254.99	84	6.7732	3.64	75.77	N/A	N/A	N/A
40	7.9285	0.56	102.85	8.0755	0.54	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8938	0.58	100.77	8.0573	0.56	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8558	0.54	98.95	8.0129	0.58	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

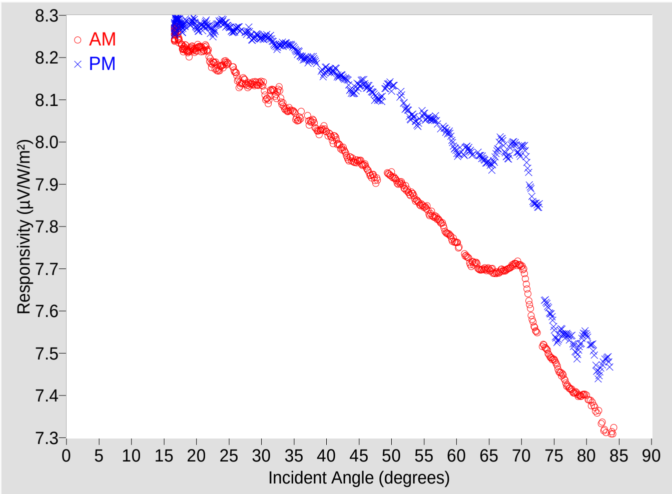


Figure 4. Responsivity vs Local Standard Time

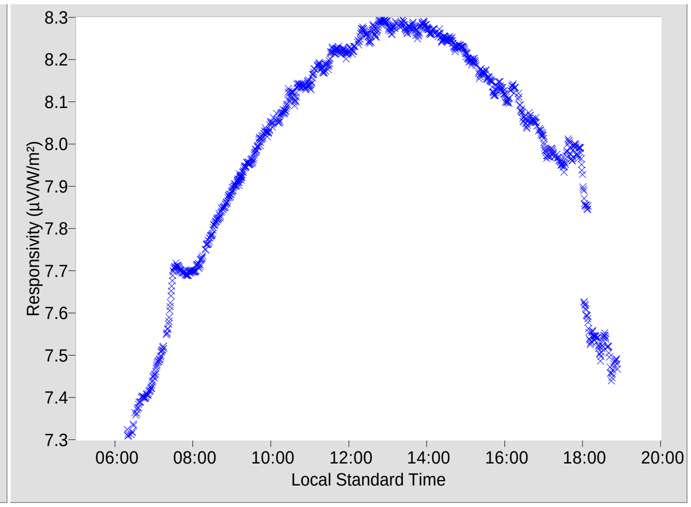


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0445	+3.18 / -4.08	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64286 µV/W/m², determination date: 05/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9421	0.63	97.12	8.1349	0.61	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9148	N/A	95.69	8.1001	0.63	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9209	0.65	101.85	8.1325	0.63	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8921	0.68	99.99	8.0853	0.75	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8604	0.71	98.25	8.0452	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8297	0.71	96.57	8.0549	0.68	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8010	0.75	94.98	8.0339	0.71	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7601	0.77	93.34	7.9754	0.79	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7164	0.81	91.83	7.9806	0.78	274.96
18	8.2236	0.65	155.43	8.2743	0.53	204.54	64	7.6983	0.84	90.30	7.9630	0.82	276.34
20	8.2209	0.50	142.74	8.2726	0.53	217.16	66	7.6900	0.89	88.84	7.9675	1.00	277.74
22	8.1982	0.60	134.46	8.2697	0.55	225.45	68	7.7005	0.95	87.36	7.9684	0.96	279.13
24	8.1818	0.51	128.32	8.2845	0.51	231.60	70	7.7049	1.15	85.91	7.9859	1.08	280.53
26	8.1643	0.58	123.44	8.2668	0.51	236.45	72	7.5608	1.24	84.46	7.8556	1.23	281.85
28	8.1349	0.52	119.30	8.2618	0.53	240.65	74	7.5052	1.28	83.06	7.6103	1.59	278.99
30	8.1382	0.57	115.80	8.2461	0.51	244.15	76	7.4524	1.53	81.58	7.5534	1.74	280.40
32	8.1177	0.56	112.65	8.2309	0.55	247.30	78	7.4087	1.72	80.19	7.5213	2.07	281.82
34	8.0763	0.53	109.78	8.2309	0.53	250.15	80	7.3979	2.11	78.71	7.5450	2.42	283.25
36	8.0597	0.55	107.36	8.2048	0.56	252.66	82	7.3488	2.83	77.19	7.4519	3.13	284.72
38	8.0467	0.60	104.98	8.1953	0.55	254.99	84	7.3142	3.75	75.77	N/A	N/A	N/A
40	8.0239	0.58	102.85	8.1732	0.57	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9912	0.60	100.77	8.1568	0.59	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9574	0.57	98.95	8.1162	0.61	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31153F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

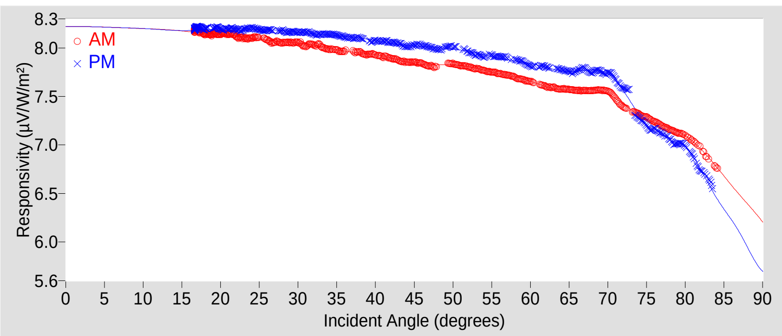
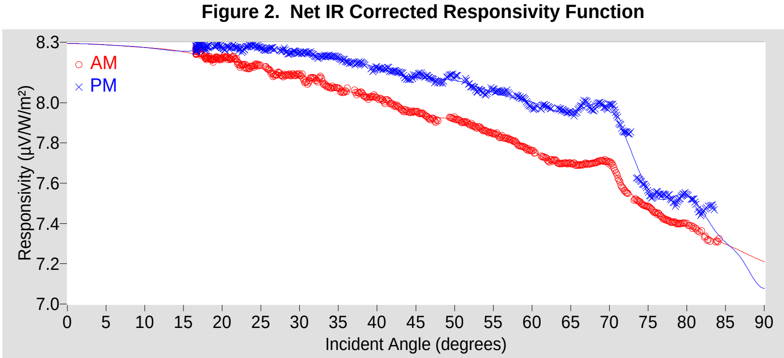


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.62	±1.62
R^2	0.9999989	0.9999971
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.65	±1.65
Net IR corrected R^2	0.9999990	0.9999977
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.2155	*	8.2155	*	8.2155	*	8.2876	*	8.2877	*	8.2876	*
9-18	8.1839	*	8.1883	*	8.1861	*	8.2593	*	8.2636	*	8.2614	*
18-27	8.1181	±1.69	8.1942	±1.63	8.1562	±1.97	8.1958	±1.71	8.2734	±1.65	8.2346	±1.98
27-36	8.0309	±1.73	8.1530	±1.66	8.0919	±2.46	8.1151	±1.74	8.2396	±1.68	8.1773	±2.41
36-45	7.9181	±1.80	8.0718	±1.73	7.9949	±2.93	8.0135	±1.78	8.1694	±1.73	8.0915	±2.83
45-54	7.8191	±1.67	7.9891	±1.70	7.9041	±2.69	7.9136	±1.72	8.1075	±1.68	8.0106	±2.82
54-63	7.6887	±1.99	7.8627	±1.85	7.7757	±3.48	7.7900	±1.92	8.0171	±1.76	7.9036	±3.62
63-72	7.5506	±1.84	7.7464	±1.94	7.6485	±3.50	7.6870	±1.77	7.9621	±1.81	7.8246	±3.86
72-81	7.2343	±2.96	7.1873	±4.63	7.2108	±6.37	7.4587	±2.15	7.5967	±2.67	7.5277	±4.83
81-90	6.6304	*	6.2800	*	6.4552	*	7.2885	*	7.2872	*	7.2879	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.9410	+3.39 / -4.08
45° - 55°	7.8950	±2.35
Composite	8.0016	+2.96 / -19.33
45° (Net IR Corr.)	8.0445	+3.18 / -4.08
45° - 55° (Net IR Corr.)	8.0025	±2.41
Composite (Net IR Corr.)	8.1107	+2.64 / -9.97

† Valid incident angle ranges:

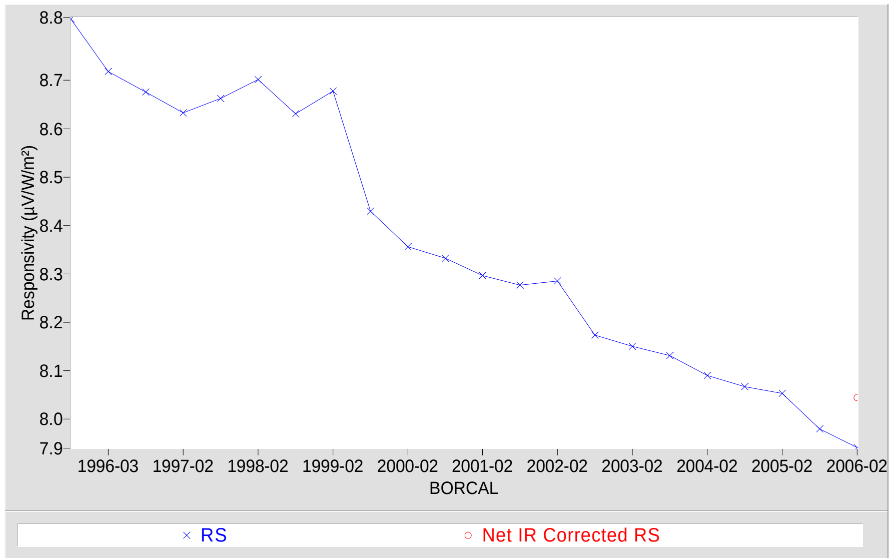
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



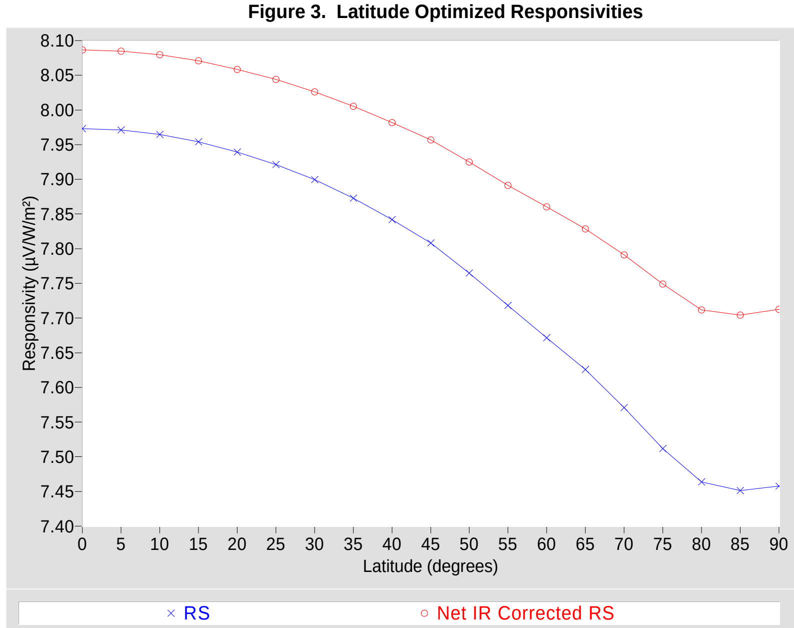
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.9731	+3.52 / -27.26	8.0866	+3.05 / -12.24
5	7.9709	+3.54 / -27.24	8.0848	+3.07 / -12.22
10	7.9645	+3.62 / -27.19	8.0795	+3.12 / -12.17
15	7.9541	+3.74 / -27.09	8.0708	+3.22 / -12.07
20	7.9393	+3.91 / -26.95	8.0586	+3.35 / -11.94
25	7.9213	+4.12 / -26.79	8.0439	+3.51 / -11.78
30	7.8994	+4.28 / -26.59	8.0263	+3.62 / -11.59
35	7.8726	+4.46 / -26.34	8.0052	+3.79 / -11.36
40	7.8420	+4.84 / -26.05	7.9817	+4.06 / -11.10
45	7.8082	+5.27 / -25.73	7.9569	+4.36 / -10.83
50	7.7650	+5.68 / -25.32	7.9249	+4.66 / -10.47
55	7.7179	+5.88 / -24.86	7.8915	+4.72 / -10.10
60	7.6714	+6.08 / -24.41	7.8603	+4.77 / -9.74
65	7.6259	+5.93 / -23.96	7.8287	+4.54 / -9.38
70	7.5707	+6.07 / -23.40	7.7913	+4.55 / -8.95
75	7.5120	+6.42 / -22.80	7.7489	+4.85 / -8.46
80	7.4638	+5.99 / -22.31	7.7116	+4.55 / -8.03
85	7.4512	+5.24 / -22.18	7.7041	+4.12 / -7.94
90	7.4578	+4.56 / -22.25	7.7125	+4.02 / -8.04

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

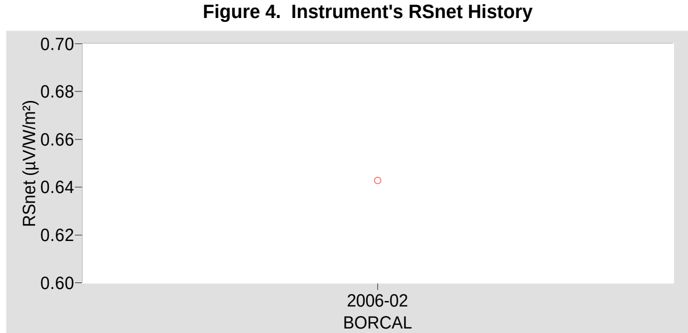
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31154F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	Calibration System	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

31154F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

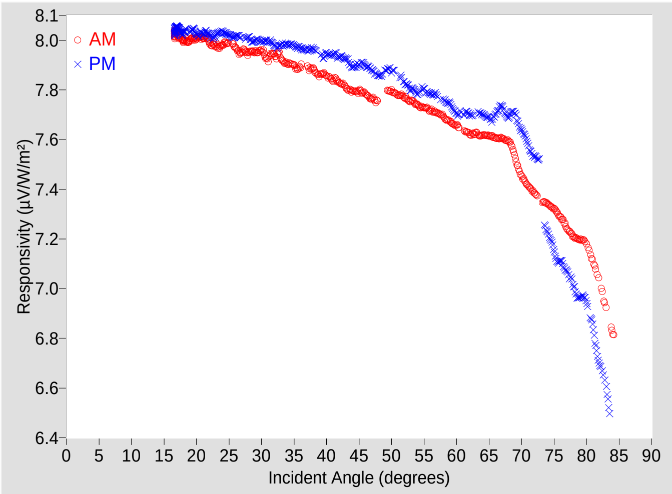


Figure 2. Responsivity vs Local Standard Time

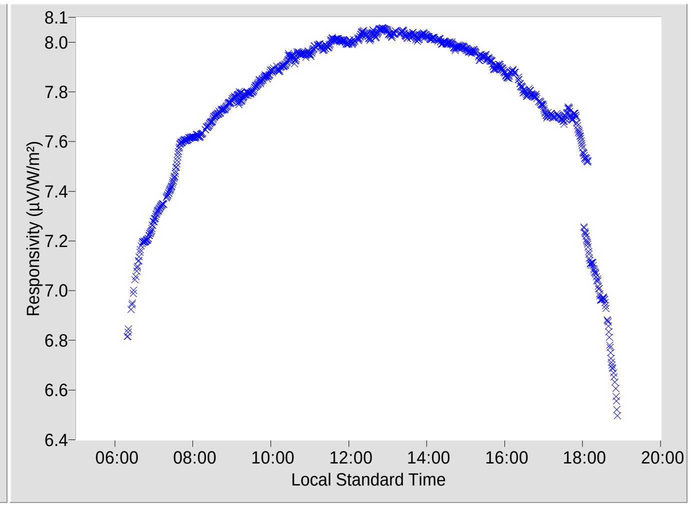


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8472	+2.50 / -2.96	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7844	0.59	97.12	7.8968	0.58	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7590	N/A	95.69	7.8568	0.58	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7938	0.63	101.85	7.8791	0.59	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7703	0.66	99.99	7.8271	0.71	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7397	0.67	98.25	7.7868	0.63	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7170	0.68	96.57	7.7844	0.63	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6934	0.71	94.98	7.7598	0.65	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6563	0.74	93.34	7.7042	0.72	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6227	0.76	91.83	7.7020	0.70	274.96
18	8.0006	0.55	155.43	8.0322	0.51	204.54	64	7.6171	0.80	90.30	7.7020	0.74	276.34
20	8.0083	0.47	142.74	8.0263	0.51	217.16	66	7.6069	0.85	88.84	7.7014	0.90	277.74
22	7.9910	0.55	134.46	8.0218	0.52	225.45	68	7.5936	1.00	87.36	7.6914	0.87	279.13
24	7.9821	0.50	128.32	8.0322	0.48	231.60	70	7.4527	1.23	85.91	7.6346	1.19	280.53
26	7.9703	0.54	123.44	8.0159	0.48	236.45	72	7.3842	1.11	84.46	7.5324	1.04	281.85
28	7.9493	0.50	119.30	8.0102	0.50	240.65	74	7.3420	1.21	83.06	7.2246	1.53	278.99
30	7.9565	0.53	115.80	7.9945	0.49	244.15	76	7.2853	1.50	81.58	7.1120	1.63	280.40
32	7.9412	0.55	112.65	7.9793	0.54	247.30	78	7.2105	1.65	80.19	7.0116	1.96	281.82
34	7.9064	0.50	109.78	7.9829	0.50	250.15	80	7.1779	2.08	78.71	6.9459	2.28	283.25
36	7.8935	0.52	107.36	7.9675	0.52	252.66	82	7.0229	2.88	77.19	6.6966	3.10	284.72
38	7.8823	0.57	104.98	7.9624	0.53	254.99	84	6.8273	3.65	75.77	N/A	N/A	N/A
40	7.8564	0.55	102.85	7.9460	0.54	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8291	0.57	100.77	7.9332	0.56	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7955	0.54	98.95	7.8910	0.58	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

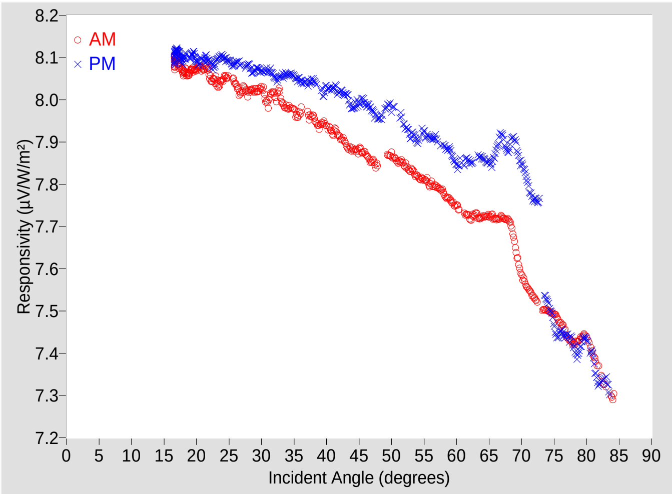

Figure 4. Responsivity vs Local Standard Time

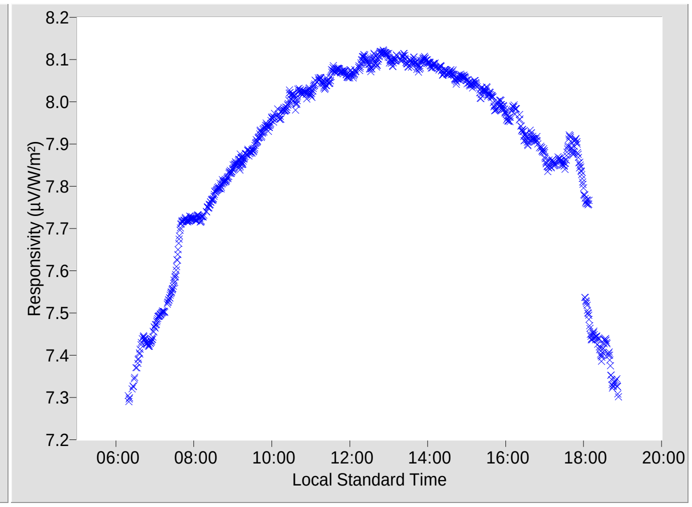

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9359	+2.33 / -2.93	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.56158 µV/W/m², determination date: 05/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8722	0.61	97.12	7.9905	0.62	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8498	N/A	95.69	7.9548	0.62	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8672	0.65	101.85	7.9824	0.63	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8453	0.67	99.99	7.9373	0.74	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8196	0.69	98.25	7.9032	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7991	0.71	96.57	7.9097	0.68	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7807	0.73	94.98	7.8921	0.71	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7482	0.76	93.34	7.8454	0.79	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7210	0.79	91.83	7.8542	0.78	274.96
18	8.0672	0.58	155.43	8.0972	0.53	204.54	64	7.7229	0.84	90.30	7.8627	0.82	276.34
20	8.0729	0.49	142.74	8.0926	0.53	217.16	66	7.7182	0.89	88.84	7.8762	1.01	277.74
22	8.0576	0.57	134.46	8.0891	0.54	225.45	68	7.7144	1.01	87.36	7.8820	0.96	279.13
24	8.0479	0.52	128.32	8.1011	0.51	231.60	70	7.5844	1.21	85.91	7.8463	1.20	280.53
26	8.0379	0.55	123.44	8.0868	0.51	236.45	72	7.5302	1.15	84.46	7.7635	1.14	281.85
28	8.0177	0.53	119.30	8.0817	0.52	240.65	74	7.5018	1.26	83.06	7.5204	1.60	278.99
30	8.0264	0.55	115.80	8.0671	0.51	244.15	76	7.4699	1.51	81.58	7.4524	1.75	280.40
32	8.0128	0.59	112.65	8.0542	0.56	247.30	78	7.4240	1.71	80.19	7.4182	2.09	281.82
34	7.9820	0.52	109.78	8.0599	0.53	250.15	80	7.4375	2.11	78.71	7.4334	2.44	283.25
36	7.9713	0.55	107.36	8.0456	0.55	252.66	82	7.3590	2.82	77.19	7.3269	3.15	284.72
38	7.9586	0.59	104.98	8.0435	0.56	254.99	84	7.2975	3.75	75.77	N/A	N/A	N/A
40	7.9376	0.58	102.85	8.0298	0.58	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9122	0.59	100.77	8.0188	0.59	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8823	0.58	98.95	7.9799	0.61	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

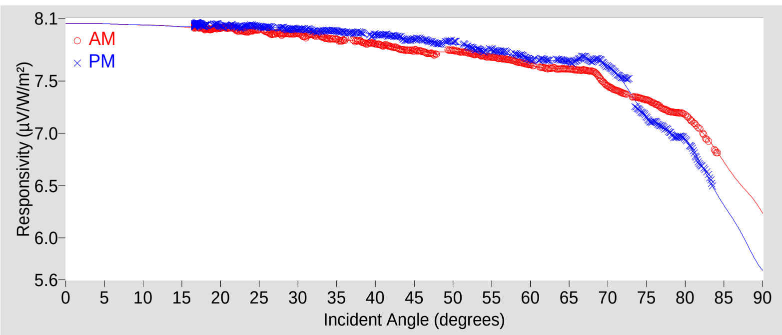
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

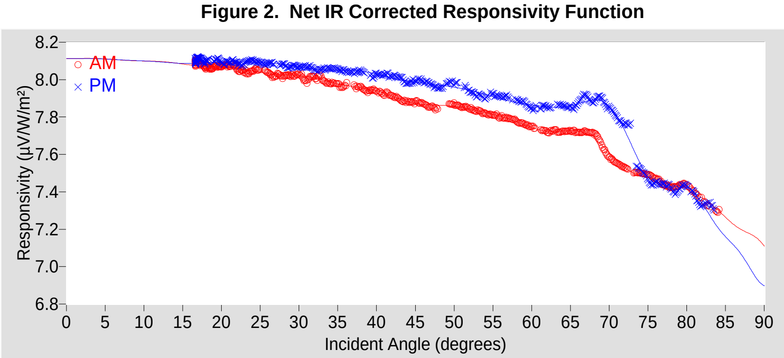


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.63	±1.63
R²	0.9999985	0.9999973
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.65	±1.65
Net IR corrected R²	0.9999987	0.9999981
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.0479	*	8.0480	*	8.0480	*	8.1097	*	8.1098	*	8.1098	*
9-18	8.0252	*	8.0279	*	8.0265	*	8.0898	*	8.0923	*	8.0911	*
18-27	7.9895	±1.65	8.0251	±1.63	8.0073	±1.74	8.0556	±1.67	8.0930	±1.66	8.0743	±1.76
27-36	7.9370	±1.68	7.9899	±1.65	7.9634	±1.95	8.0087	±1.69	8.0641	±1.67	8.0364	±1.94
36-45	7.8489	±1.76	7.9405	±1.69	7.8947	±2.34	7.9302	±1.75	8.0244	±1.70	7.9773	±2.28
45-54	7.7740	±1.64	7.8594	±1.71	7.8167	±2.08	7.8556	±1.68	7.9614	±1.70	7.9085	±2.17
54-63	7.6831	±1.81	7.7463	±1.76	7.7147	±2.32	7.7714	±1.78	7.8805	±1.71	7.8260	±2.44
63-72	7.5572	±2.16	7.6728	±1.94	7.6150	±3.37	7.6761	±2.03	7.8596	±1.83	7.7678	±3.64
72-81	7.2701	±2.41	7.1353	±4.50	7.2027	±6.11	7.4648	±1.87	7.4950	±2.69	7.4799	±3.87
81-90	6.6812	*	6.2574	*	6.4693	*	7.2537	*	7.1395	*	7.1966	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

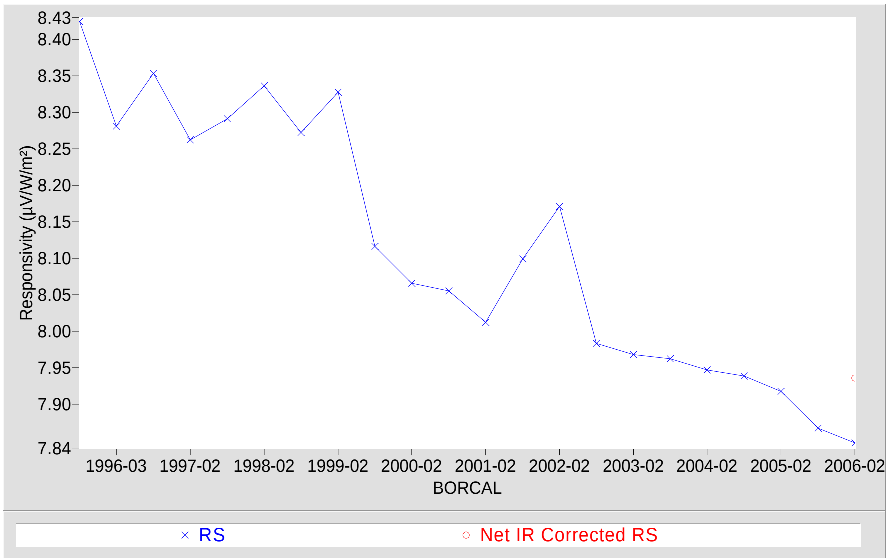
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.8472	+2.50 / -2.96
45° - 55°	7.8098	±1.93
Composite	7.8844	+2.46 / -18.47
45° (Net IR Corr.)	7.9359	+2.33 / -2.93
45° - 55° (Net IR Corr.)	7.9026	±1.98
Composite (Net IR Corr.)	7.9785	+2.22 / -9.76

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



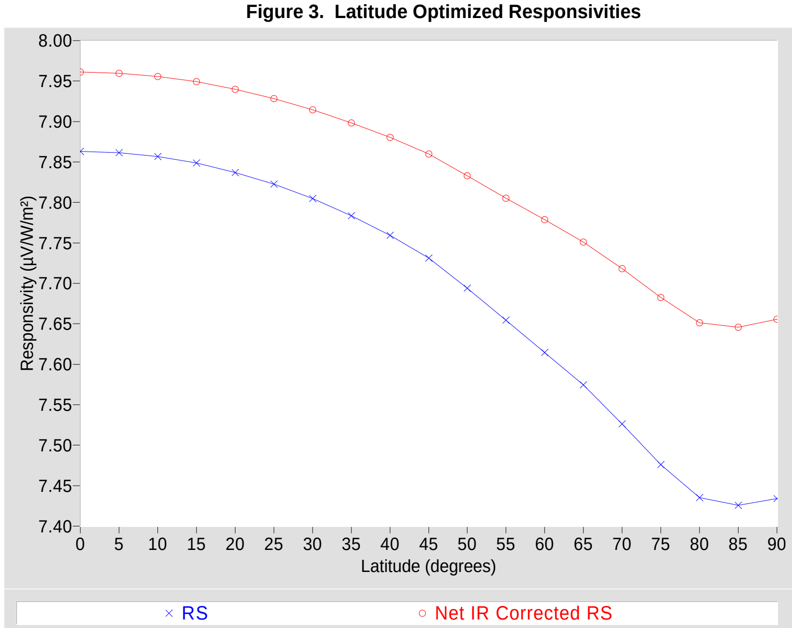
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.8632	+2.90 / -26.31	7.9611	+2.53 / -12.96
5	7.8616	+2.92 / -26.30	7.9598	+2.54 / -12.95
10	7.8567	+2.97 / -26.25	7.9559	+2.58 / -12.91
15	7.8487	+3.06 / -26.17	7.9494	+2.65 / -12.84
20	7.8370	+3.19 / -26.06	7.9400	+2.74 / -12.73
25	7.8225	+3.35 / -25.93	7.9285	+2.86 / -12.61
30	7.8050	+3.49 / -25.76	7.9147	+2.95 / -12.46
35	7.7836	+3.62 / -25.56	7.8983	+3.03 / -12.28
40	7.7593	+3.85 / -25.33	7.8803	+3.20 / -12.08
45	7.7312	+4.19 / -25.05	7.8600	+3.43 / -11.85
50	7.6941	+4.51 / -24.69	7.8328	+3.66 / -11.55
55	7.6544	+4.65 / -24.30	7.8051	+3.68 / -11.24
60	7.6144	+4.99 / -23.91	7.7786	+3.88 / -10.94
65	7.5746	+5.01 / -23.51	7.7510	+3.83 / -10.62
70	7.5262	+5.08 / -23.02	7.7184	+3.78 / -10.25
75	7.4761	+5.20 / -22.50	7.6827	+3.88 / -9.84
80	7.4354	+4.81 / -22.08	7.6515	+3.61 / -9.48
85	7.4256	+4.22 / -21.97	7.6460	+3.61 / -9.41
90	7.4339	+3.95 / -22.06	7.6558	+3.50 / -9.53

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

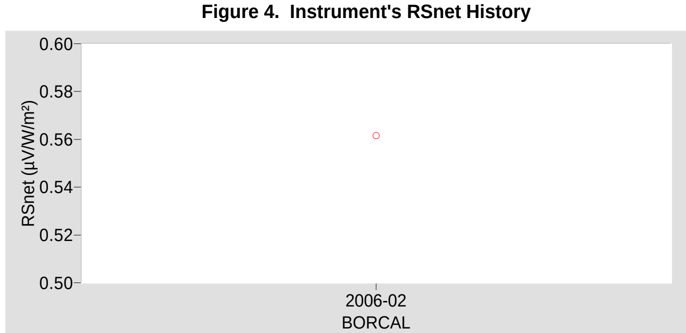
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 31158F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: Calibration System

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ____________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ____________________

Calibration Results

31158F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

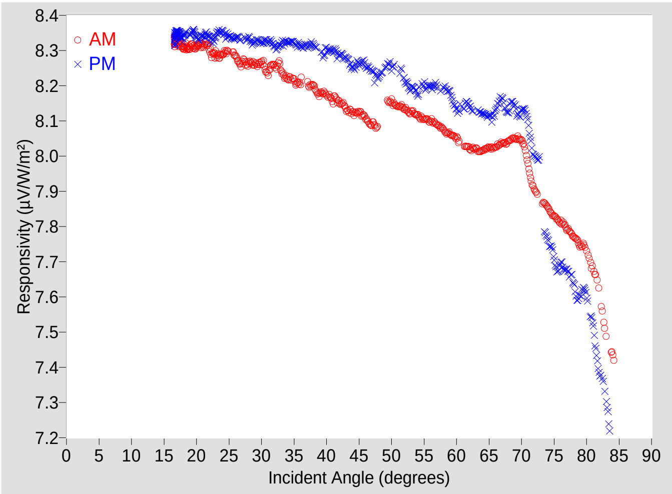


Figure 2. Responsivity vs Local Standard Time

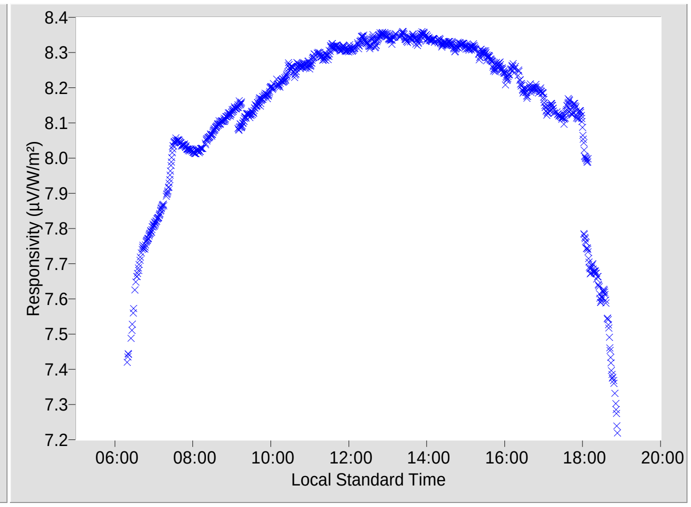


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1939	+2.21 / -2.25	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1082	0.59	97.12	8.2586	0.58	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0821	N/A	95.69	8.2254	0.61	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1530	0.62	101.85	8.2545	0.59	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1346	0.65	99.99	8.2144	0.70	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1165	0.66	98.25	8.1807	0.64	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0995	0.67	96.57	8.1974	0.62	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0764	0.70	94.98	8.1961	0.63	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0496	0.73	93.34	8.1327	0.73	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0215	0.75	91.83	8.1430	0.70	274.96
18	8.3100	0.53	155.43	8.3409	0.50	204.54	64	8.0163	0.79	90.30	8.1219	0.73	276.34
20	8.3105	0.47	142.74	8.3387	0.50	217.16	66	8.0255	0.85	88.84	8.1286	0.89	277.74
22	8.3015	0.55	134.46	8.3368	0.51	225.45	68	8.0427	0.90	87.36	8.1299	0.85	279.13
24	8.2907	0.49	128.32	8.3518	0.50	231.60	70	8.0434	1.09	85.91	8.1283	0.92	280.53
26	8.2842	0.53	123.44	8.3351	0.48	236.45	72	7.9047	1.16	84.46	8.0014	1.14	281.85
28	8.2633	0.49	119.30	8.3337	0.50	240.65	74	7.8565	1.21	83.06	7.7623	1.43	278.99
30	8.2645	0.52	115.80	8.3233	0.49	244.15	76	7.8115	1.40	81.58	7.6949	1.53	280.40
32	8.2579	0.54	112.65	8.3119	0.52	247.30	78	7.7720	1.63	80.19	7.6384	1.86	281.82
34	8.2216	0.50	109.78	8.3237	0.51	250.15	80	7.7303	2.02	78.71	7.6039	2.19	283.25
36	8.2106	0.52	107.36	8.3131	0.51	252.66	82	7.5992	2.82	77.19	7.3834	2.93	284.72
38	8.1998	0.56	104.98	8.3130	0.52	254.99	84	7.4357	3.49	75.77	N/A	N/A	N/A
40	8.1739	0.54	102.85	8.3031	0.55	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1521	0.56	100.77	8.2883	0.56	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1239	0.54	98.95	8.2499	0.57	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31158F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

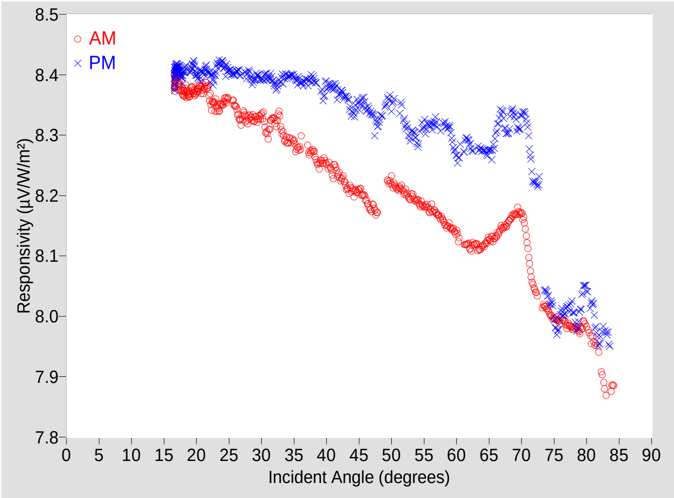


Figure 4. Responsivity vs Local Standard Time

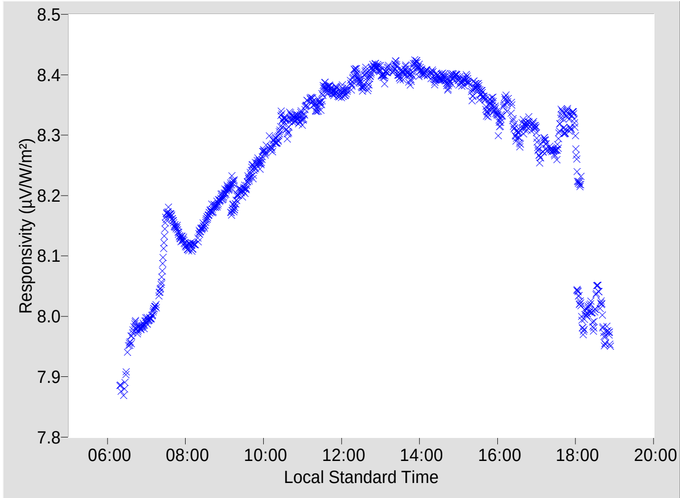


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2797	+2.05 / -2.26	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.52400 µV/W/m², determination date: 03/30/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1942	0.62	97.12	8.3488	0.61	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1717	N/A	95.69	8.3191	0.66	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2218	0.64	101.85	8.3533	0.63	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2052	0.66	99.99	8.3189	0.74	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1914	0.68	98.25	8.2912	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1765	0.69	96.57	8.3159	0.68	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1585	0.72	94.98	8.3203	0.69	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1358	0.75	93.34	8.2654	0.78	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1146	0.78	91.83	8.2865	0.77	274.96
18	8.3716	0.56	155.43	8.4024	0.52	204.54	64	8.1161	0.84	90.30	8.2757	0.80	276.34
20	8.3714	0.49	142.74	8.4012	0.52	217.16	66	8.1305	0.89	88.84	8.2958	0.99	277.74
22	8.3635	0.57	134.46	8.4001	0.53	225.45	68	8.1563	0.95	87.36	8.3103	0.95	279.13
24	8.3530	0.51	128.32	8.4171	0.52	231.60	70	8.1684	1.10	85.91	8.3304	1.01	280.53
26	8.3474	0.55	123.44	8.4029	0.50	236.45	72	8.0449	1.19	84.46	8.2225	1.21	281.85
28	8.3272	0.51	119.30	8.4022	0.52	240.65	74	8.0119	1.25	83.06	8.0341	1.53	278.99
30	8.3313	0.54	115.80	8.3928	0.51	244.15	76	7.9917	1.45	81.58	8.0052	1.71	280.40
32	8.3257	0.57	112.65	8.3836	0.54	247.30	78	7.9801	1.68	80.19	8.0068	2.00	281.82
34	8.2909	0.52	109.78	8.3973	0.53	250.15	80	7.9828	2.07	78.71	8.0460	2.35	283.25
36	8.2828	0.55	107.36	8.3880	0.54	252.66	82	7.9243	2.77	77.19	7.9567	3.01	284.72
38	8.2722	0.57	104.98	8.3908	0.55	254.99	84	7.8835	3.63	75.77	N/A	N/A	N/A
40	8.2520	0.57	102.85	8.3833	0.58	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2310	0.58	100.77	8.3703	0.59	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2076	0.57	98.95	8.3350	0.60	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31158F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (μV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (μV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (μV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

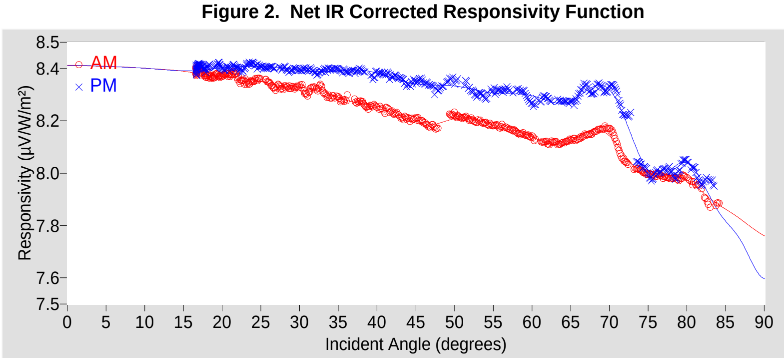


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.54	±1.54
R²	0.9999989	0.9999980
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.59	±1.59
Net IR corrected R²	0.9999991	0.9999983
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (μV/W/m²)	U95 (%)	RS (μV/W/m²)	U95 (%)	RS (μV/W/m²)	U95 (%)	RSc (μV/W/m²)	U95 (%)	RSc (μV/W/m²)	U95 (%)	RSc (μV/W/m²)	U95 (%)
0-9	8.3508	*	8.3507	*	8.3508	*	8.4081	*	8.4081	*	8.4081	*
9-18	8.3324	*	8.3349	*	8.3336	*	8.3925	*	8.3951	*	8.3938	*
18-27	8.2984	±1.56	8.3407	±1.54	8.3196	±1.65	8.3604	±1.61	8.4048	±1.60	8.3826	±1.70
27-36	8.2508	±1.59	8.3219	±1.55	8.2864	±1.88	8.3182	±1.63	8.3930	±1.60	8.3556	±1.90
36-45	8.1693	±1.65	8.2946	±1.59	8.2319	±2.38	8.2467	±1.67	8.3750	±1.62	8.3108	±2.33
45-54	8.1195	±1.57	8.2336	±1.57	8.1765	±2.06	8.1980	±1.60	8.3310	±1.60	8.2645	±2.09
54-63	8.0704	±1.67	8.1705	±1.60	8.1205	±2.23	8.1534	±1.67	8.2971	±1.61	8.2252	±2.36
63-72	8.0211	±1.65	8.1182	±1.73	8.0696	±2.32	8.1335	±1.66	8.2963	±1.69	8.2149	±2.65
72-81	7.8096	±2.15	7.7187	±3.16	7.7642	±4.17	7.9990	±1.72	8.0476	±2.11	8.0233	±2.90
81-90	7.3121	*	6.9948	*	7.1534	*	7.8534	*	7.7992	*	7.8263	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.1939	+2.21 / -2.25
45° - 55°	8.1734	±1.82
Composite	8.2330	+2.05 / -13.25
45° (Net IR Corr.)	8.2797	+2.05 / -2.26
45° - 55° (Net IR Corr.)	8.2621	±1.86
Composite (Net IR Corr.)	8.3216	+1.91 / -5.80

† Valid incident angle ranges:

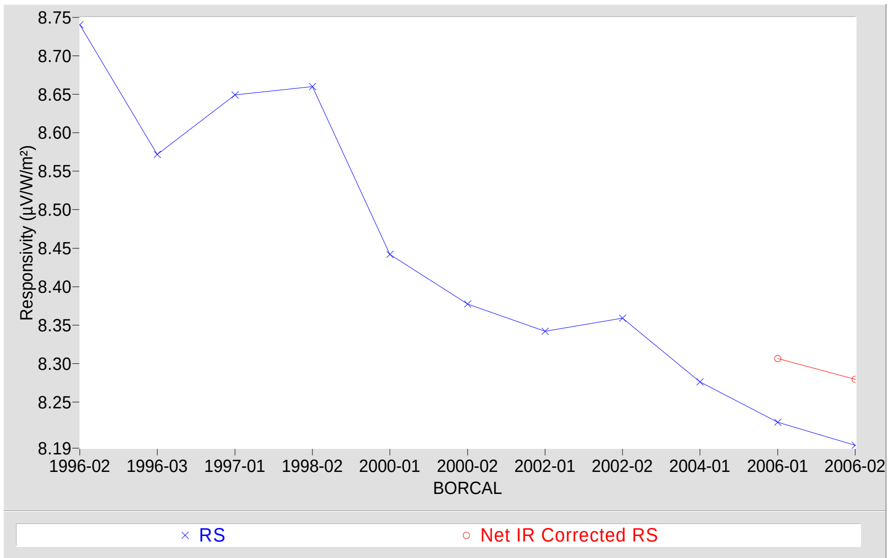
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



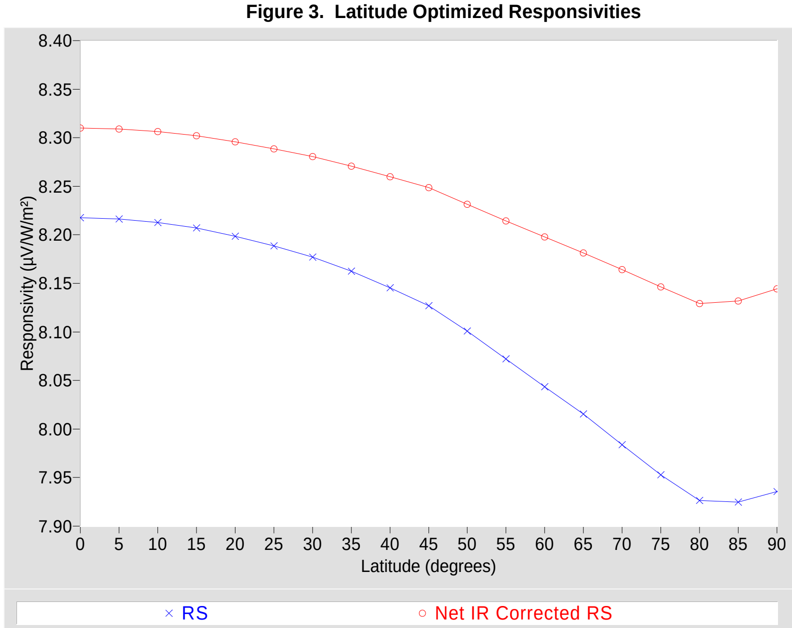
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.2176	+2.28 / -19.90	8.3100	+2.01 / -8.37
5	8.2163	+2.29 / -19.89	8.3090	+2.02 / -8.36
10	8.2128	+2.32 / -19.86	8.3064	+2.04 / -8.33
15	8.2071	+2.38 / -19.80	8.3022	+2.07 / -8.29
20	8.1985	+2.46 / -19.72	8.2958	+2.12 / -8.22
25	8.1884	+2.55 / -19.62	8.2885	+2.18 / -8.14
30	8.1770	+2.61 / -19.50	8.2805	+2.22 / -8.05
35	8.1624	+2.70 / -19.36	8.2707	+2.30 / -7.94
40	8.1455	+2.88 / -19.19	8.2598	+2.40 / -7.83
45	8.1270	+3.08 / -19.01	8.2487	+2.51 / -7.70
50	8.1007	+3.32 / -18.75	8.2316	+2.66 / -7.52
55	8.0723	+3.42 / -18.46	8.2143	+2.71 / -7.33
60	8.0433	+3.75 / -18.17	8.1979	+2.88 / -7.14
65	8.0154	+3.77 / -17.89	8.1814	+2.83 / -6.96
70	7.9838	+3.66 / -17.56	8.1642	+2.66 / -6.77
75	7.9528	+3.78 / -17.24	8.1465	+2.82 / -6.57
80	7.9264	+3.61 / -16.97	8.1291	+3.01 / -6.38
85	7.9247	+3.24 / -16.95	8.1319	+2.98 / -6.41
90	7.9356	+3.12 / -17.06	8.1443	+2.85 / -6.55

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

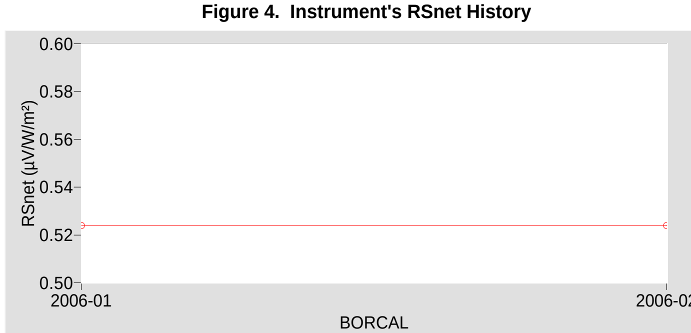
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31159F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	Calibration System	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31159F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

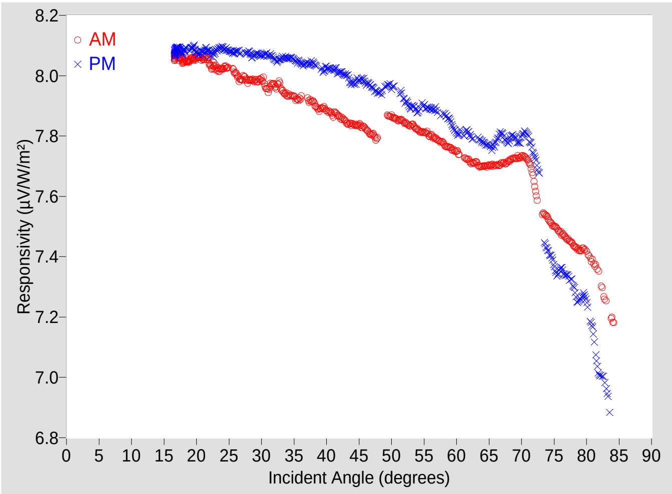


Figure 2. Responsivity vs Local Standard Time

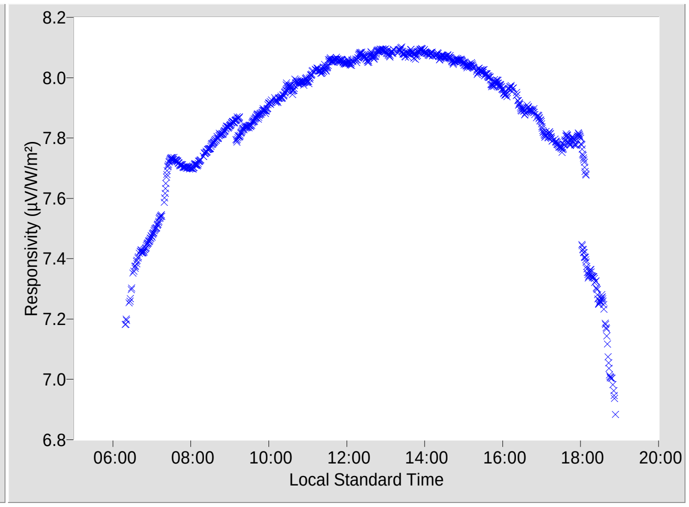


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9104	+2.63 / -2.57	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8243	0.59	97.12	7.9774	0.58	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7918	N/A	95.69	7.9427	0.58	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8643	0.62	101.85	7.9641	0.59	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8446	0.64	99.99	7.9173	0.70	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8219	0.67	98.25	7.8840	0.63	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8015	0.68	96.57	7.8900	0.62	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7762	0.70	94.98	7.8739	0.64	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7475	0.73	93.34	7.8105	0.72	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7161	0.76	91.83	7.8060	0.71	274.96
18	8.0494	0.52	155.43	8.0810	0.49	204.54	64	7.6998	0.80	90.30	7.7812	0.74	276.34
20	8.0592	0.47	142.74	8.0793	0.51	217.16	66	7.7035	0.85	88.84	7.7775	0.87	277.74
22	8.0399	0.55	134.46	8.0789	0.51	225.45	68	7.7170	0.91	87.36	7.7823	0.84	279.13
24	8.0240	0.48	128.32	8.0915	0.48	231.60	70	7.7312	0.98	85.91	7.7978	0.93	280.53
26	8.0081	0.54	123.44	8.0786	0.48	236.45	72	7.6343	1.36	84.46	7.7337	1.25	281.85
28	7.9838	0.50	119.30	8.0773	0.50	240.65	74	7.5299	1.22	83.06	7.4211	1.45	278.99
30	7.9861	0.53	115.80	8.0678	0.49	244.15	76	7.4791	1.42	81.58	7.3608	1.54	280.40
32	7.9690	0.54	112.65	8.0549	0.52	247.30	78	7.4395	1.64	80.19	7.3014	1.89	281.82
34	7.9360	0.50	109.78	8.0582	0.50	250.15	80	7.4166	2.00	78.71	7.2517	2.25	283.25
36	7.9249	0.51	107.36	8.0418	0.52	252.66	82	7.3273	2.75	77.19	7.0089	2.91	284.72
38	7.9113	0.57	104.98	8.0387	0.53	254.99	84	7.1902	3.53	75.77	N/A	N/A	N/A
40	7.8851	0.54	102.85	8.0268	0.54	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8642	0.55	100.77	8.0116	0.55	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8393	0.53	98.95	7.9735	0.58	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

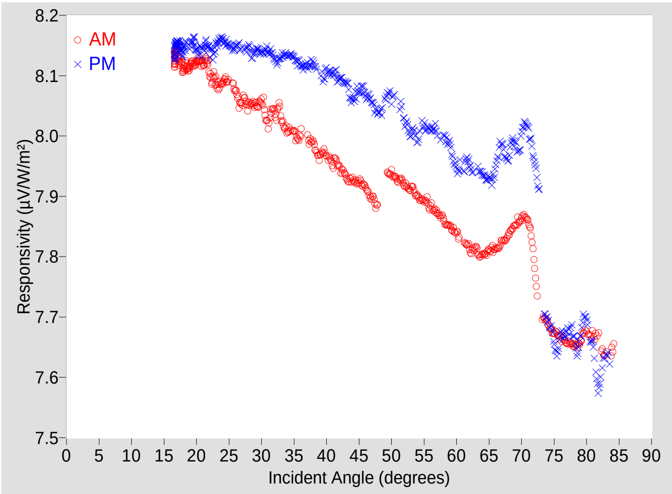

Figure 4. Responsivity vs Local Standard Time

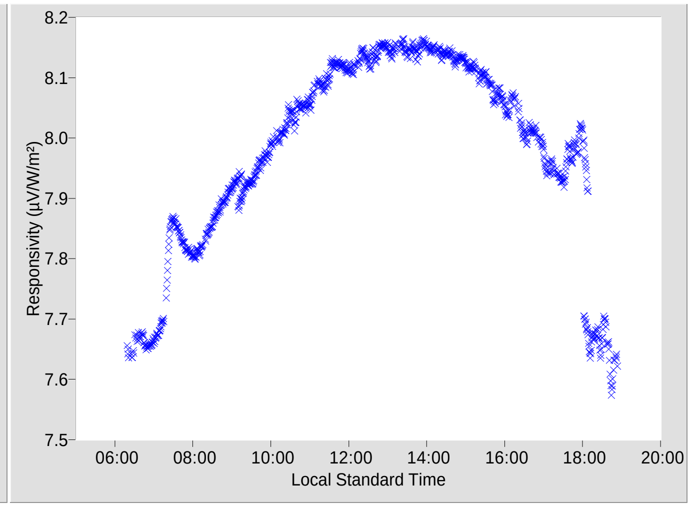

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9989	+2.45 / -2.56	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.53200 µV/W/m², determination date: 03/30/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9145	0.62	97.12	8.0690	0.61	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8857	N/A	95.69	8.0380	0.63	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9367	0.64	101.85	8.0646	0.63	266.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9188	0.66	99.99	8.0241	0.73	267.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9004	0.69	98.25	7.9967	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8824	0.71	96.57	8.0110	0.68	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8627	0.73	94.98	8.0011	0.70	272.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8384	0.76	93.34	7.9463	0.78	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8130	0.79	91.83	7.9527	0.78	274.96
18	8.1140	0.55	155.43	8.1442	0.52	204.54	64	7.8039	0.84	90.30	7.9374	0.82	276.34
20	8.1226	0.49	142.74	8.1438	0.53	217.16	66	7.8132	0.90	88.84	7.9471	0.98	277.74
22	8.1047	0.57	134.46	8.1443	0.54	225.45	68	7.8369	0.96	87.36	7.9658	0.96	279.13
24	8.0887	0.51	128.32	8.1585	0.51	231.60	70	7.8627	1.04	85.91	8.0026	1.06	280.53
26	8.0746	0.56	123.44	8.1477	0.51	236.45	72	7.7809	1.36	84.46	7.9572	1.28	281.85
28	8.0511	0.53	119.30	8.1471	0.52	240.65	74	7.6910	1.27	83.06	7.6937	1.55	278.99
30	8.0555	0.56	115.80	8.1386	0.52	244.15	76	7.6652	1.47	81.58	7.6708	1.73	280.40
32	8.0401	0.58	112.65	8.1280	0.54	247.30	78	7.6540	1.70	80.19	7.6696	2.03	281.82
34	8.0100	0.53	109.78	8.1333	0.53	250.15	80	7.6753	2.08	78.71	7.6954	2.39	283.25
36	8.0016	0.54	107.36	8.1182	0.55	252.66	82	7.6588	2.77	77.19	7.5867	3.08	284.72
38	7.9873	0.59	104.98	8.1179	0.56	254.99	84	7.6461	3.68	75.77	N/A	N/A	N/A
40	7.9667	0.57	102.85	8.1085	0.57	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9476	0.58	100.77	8.0952	0.58	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9273	0.57	98.95	8.0600	0.61	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

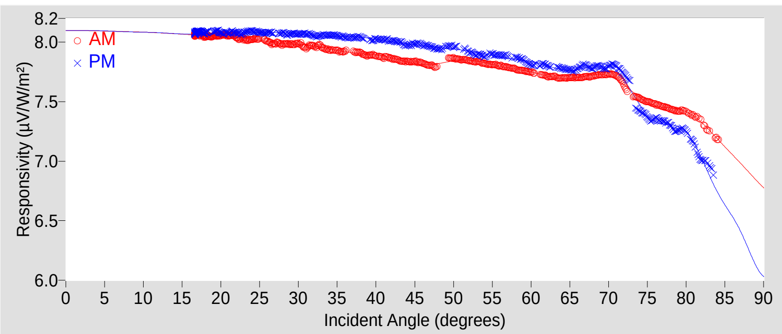
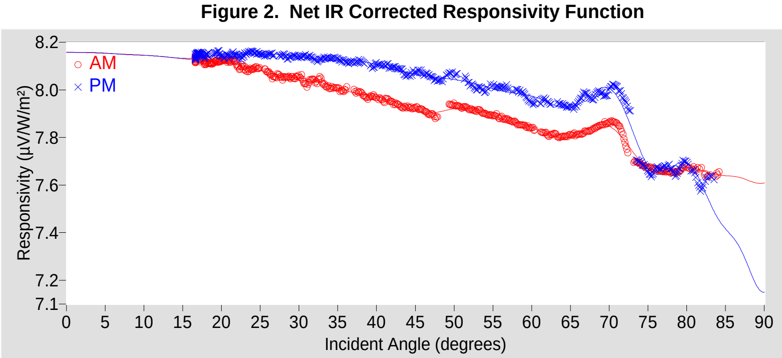


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.59	±1.59
R²	0.9999991	0.9999962
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.64	±1.64
Net IR corrected R²	0.9999993	0.9999969
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.0941	*	8.0941	*	8.0941	*	8.1538	*	8.1538	*	8.1538	*
9-18	8.0733	*	8.0757	*	8.0745	*	8.1359	*	8.1383	*	8.1371	*
18-27	8.0354	±1.63	8.0818	±1.59	8.0586	±1.78	8.1002	±1.68	8.1478	±1.65	8.1240	±1.82
27-36	7.9676	±1.65	8.0626	±1.60	8.0151	±2.10	8.0384	±1.69	8.1351	±1.65	8.0867	±2.10
36-45	7.8820	±1.70	8.0192	±1.64	7.9506	±2.55	7.9635	±1.72	8.1011	±1.68	8.0323	±2.47
45-54	7.8308	±1.61	7.9459	±1.65	7.8883	±2.18	7.9132	±1.65	8.0450	±1.67	7.9791	±2.19
54-63	7.7703	±1.76	7.8525	±1.73	7.8114	±2.35	7.8574	±1.75	7.9819	±1.70	7.9196	±2.47
63-72	7.7066	±1.64	7.7818	±1.69	7.7442	±2.11	7.8245	±1.68	7.9627	±1.73	7.8936	±2.52
72-81	7.4905	±2.26	7.3876	±3.60	7.4391	±4.80	7.6860	±1.86	7.7172	±2.39	7.7016	±3.27
81-90	7.0854	*	6.5802	*	6.8328	*	7.6363	*	7.3942	*	7.5153	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

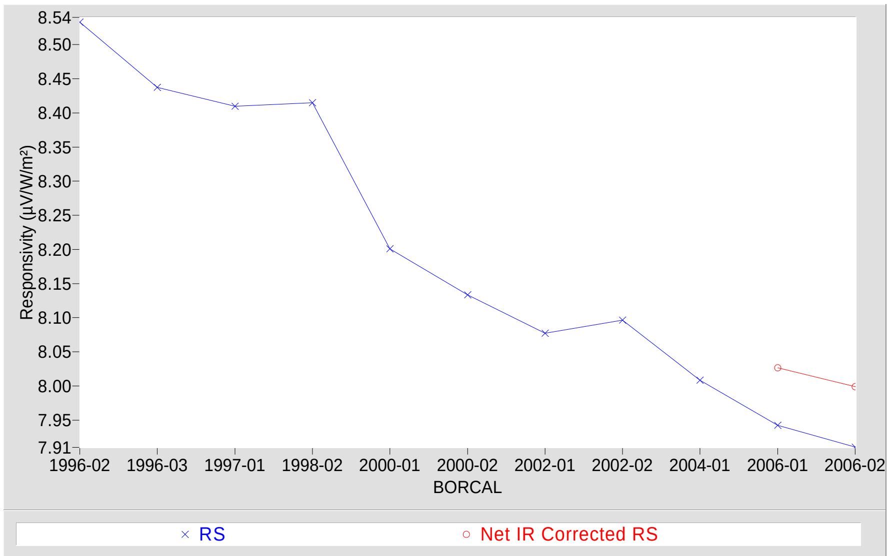
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.9104	+2.63 / -2.57
45° - 55°	7.8840	±1.91
Composite	7.9555	+2.28 / -15.28
45° (Net IR Corr.)	7.9989	+2.45 / -2.56
45° - 55° (Net IR Corr.)	7.9755	±1.97
Composite (Net IR Corr.)	8.0468	+2.09 / -7.46

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



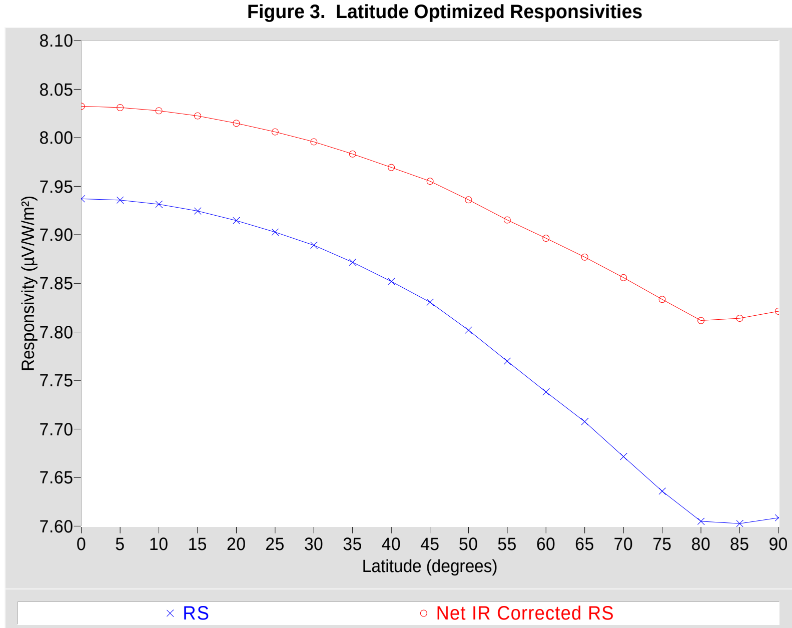
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.9372	+2.58 / -22.90	8.0324	+2.27 / -10.75
5	7.9357	+2.60 / -22.88	8.0312	+2.28 / -10.74
10	7.9314	+2.64 / -22.84	8.0278	+2.31 / -10.70
15	7.9245	+2.71 / -22.78	8.0225	+2.36 / -10.65
20	7.9147	+2.82 / -22.68	8.0149	+2.43 / -10.56
25	7.9029	+2.94 / -22.56	8.0059	+2.51 / -10.46
30	7.8891	+3.02 / -22.43	7.9957	+2.55 / -10.35
35	7.8718	+3.14 / -22.26	7.9831	+2.66 / -10.21
40	7.8519	+3.37 / -22.06	7.9693	+2.81 / -10.06
45	7.8305	+3.62 / -21.85	7.9553	+2.95 / -9.90
50	7.8018	+3.91 / -21.56	7.9360	+3.16 / -9.68
55	7.7699	+4.08 / -21.24	7.9153	+3.22 / -9.45
60	7.7382	+4.31 / -20.92	7.8964	+3.33 / -9.24
65	7.7074	+4.28 / -20.61	7.8771	+3.23 / -9.02
70	7.6716	+4.20 / -20.23	7.8558	+3.08 / -8.77
75	7.6359	+4.22 / -19.86	7.8335	+3.09 / -8.52
80	7.6049	+3.90 / -19.54	7.8116	+3.01 / -8.27
85	7.6028	+3.31 / -19.51	7.8141	+2.98 / -8.30
90	7.6084	+3.17 / -19.57	7.8214	+2.90 / -8.38

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

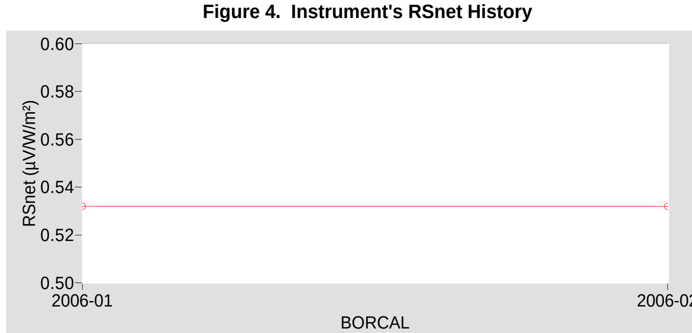
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31160F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	Calibration System	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: __________________	Date: __________________

Calibration Results

31160F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

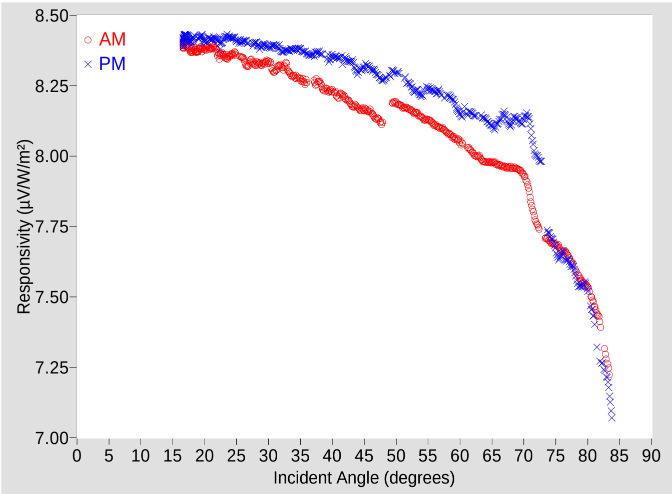


Figure 2. Responsivity vs Local Standard Time

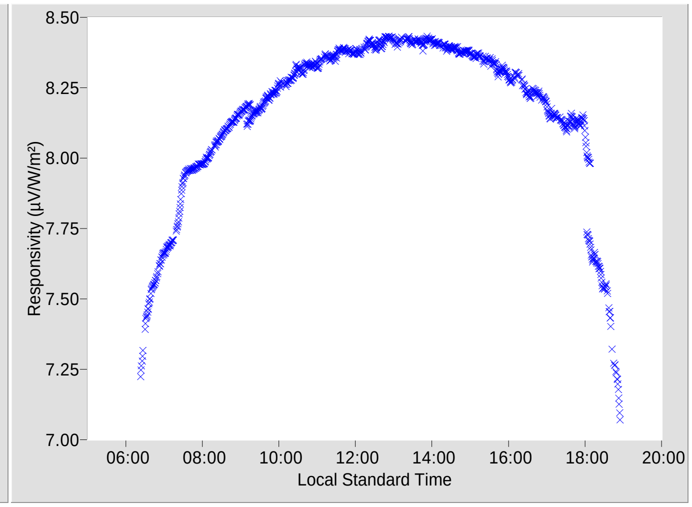


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2423	+2.41 / -2.79	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1569	0.58	97.12	8.3097	0.59	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1123	N/A	95.69	8.2710	0.57	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1885	0.61	101.86	8.2958	0.59	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1668	0.64	99.99	8.2588	0.67	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1382	0.67	98.25	8.2193	0.64	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1116	0.69	96.58	8.2290	0.62	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0825	0.71	94.94	8.2159	0.63	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0506	0.73	93.35	8.1473	0.75	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0119	0.78	91.83	8.1497	0.69	274.97
18	8.3764	0.54	155.47	8.4114	0.51	204.59	64	7.9790	0.81	90.31	8.1315	0.75	276.34
20	8.3810	0.48	142.76	8.4094	0.50	217.19	66	7.9694	0.85	88.80	8.1211	0.87	277.74
22	8.3660	0.55	134.48	8.4111	0.54	225.47	68	7.9592	0.90	87.37	8.1152	0.85	279.13
24	8.3589	0.49	128.33	8.4212	0.50	231.62	70	7.9326	1.16	85.91	8.1346	0.92	280.53
26	8.3481	0.51	123.46	8.4077	0.48	236.46	72	7.7603	1.24	84.46	8.0016	1.21	281.86
28	8.3265	0.49	119.31	8.4012	0.50	240.67	74	7.7004	1.20	83.06	7.7209	1.42	279.00
30	8.3348	0.54	115.71	8.3887	0.49	244.16	76	7.6622	1.40	81.59	7.6558	1.54	280.41
32	8.3195	0.52	112.66	8.3729	0.51	247.31	78	7.6021	1.70	80.17	7.5850	1.88	281.83
34	8.2846	0.51	109.79	8.3796	0.50	250.16	80	7.5350	2.03	78.72	7.5237	2.24	283.26
36	8.2631	0.51	107.44	8.3644	0.53	252.67	82	7.4118	2.81	77.33	7.2677	2.97	284.77
38	8.2629	0.56	104.99	8.3649	0.53	255.00	84	N/A	N/A	N/A	7.0708	N/A	286.08
40	8.2314	0.55	102.85	8.3517	0.54	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2067	0.56	100.78	8.3452	0.56	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1730	0.54	98.96	8.2997	0.62	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

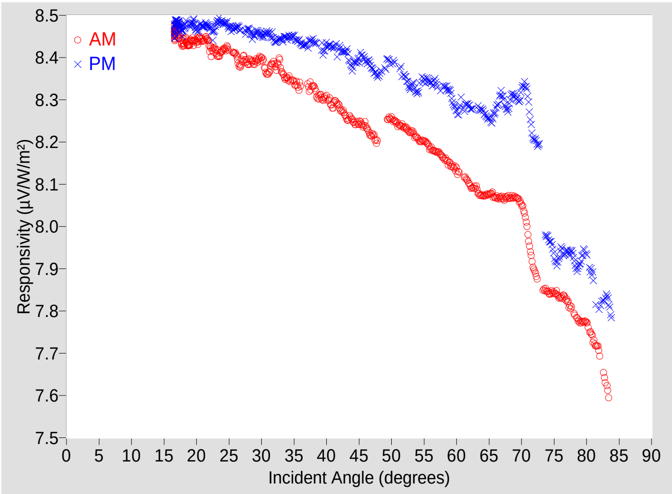

Figure 4. Responsivity vs Local Standard Time

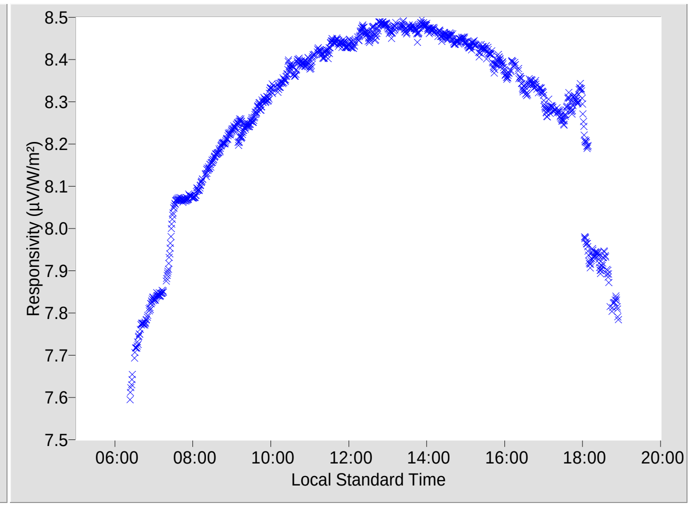

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3224	+2.26 / -2.79	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.49000 µV/W/m², determination date: 03/30/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2383	0.61	97.12	8.3931	0.62	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1969	N/A	95.69	8.3579	0.61	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2543	0.64	101.86	8.3879	0.63	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2341	0.66	99.99	8.3570	0.71	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2093	0.68	98.25	8.3226	0.69	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1852	0.70	96.58	8.3404	0.67	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1614	0.74	94.94	8.3325	0.69	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1336	0.76	93.35	8.2721	0.80	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1001	0.80	91.83	8.2840	0.77	274.97
18	8.4352	0.56	155.47	8.4691	0.53	204.59	64	8.0738	0.84	90.31	8.2744	0.82	276.34
20	8.4386	0.50	142.76	8.4683	0.52	217.19	66	8.0694	0.89	88.80	8.2760	0.97	277.74
22	8.4250	0.57	134.48	8.4709	0.55	225.47	68	8.0688	0.94	87.37	8.2839	0.95	279.13
24	8.4175	0.51	128.33	8.4824	0.52	231.62	70	8.0528	1.16	85.91	8.3224	1.03	280.53
26	8.4085	0.53	123.46	8.4708	0.51	236.46	72	7.8937	1.26	84.46	8.2061	1.26	281.86
28	8.3878	0.51	119.31	8.4651	0.52	240.67	74	7.8469	1.25	83.06	7.9729	1.53	279.00
30	8.3973	0.56	115.71	8.4533	0.51	244.16	76	7.8317	1.45	81.59	7.9429	1.71	280.41
32	8.3837	0.55	112.66	8.4395	0.54	247.31	78	7.7984	1.73	80.17	7.9263	2.01	281.83
34	8.3520	0.53	109.79	8.4480	0.53	250.16	80	7.7718	2.07	78.72	7.9342	2.37	283.26
36	8.3323	0.54	107.44	8.4342	0.55	252.67	82	7.7056	2.71	77.33	7.8082	3.07	284.77
38	8.3318	0.58	104.99	8.4371	0.56	255.00	84	N/A	N/A	N/A	7.7838	N/A	286.08
40	8.3048	0.57	102.85	8.4259	0.58	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2819	0.59	100.78	8.4212	0.59	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2525	0.58	98.96	8.3787	0.65	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

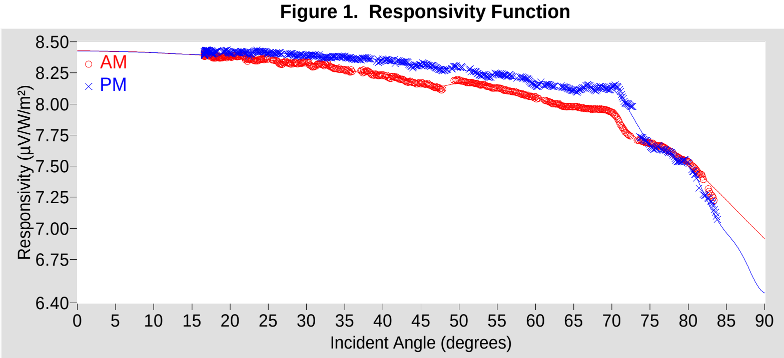
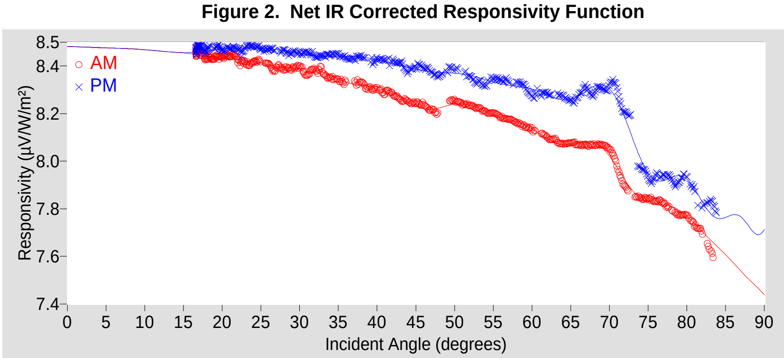


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.41	±1.41
R²	0.9999985	0.9999970
Valid incidence angle range	16.6° to 83.4°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.45	±1.45
Net IR corrected R²	0.9999987	0.9999973
Corr. valid inc. angle range	16.6° to 83.4°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.4228	*	8.4227	*	8.4227	*	8.4771	*	8.4771	*	8.4771	*
9-18	8.4019	*	8.4046	*	8.4033	*	8.4589	*	8.4616	*	8.4603	*
18-27	8.3652	±1.43	8.4122	±1.41	8.3887	±1.55	8.4240	±1.46	8.4725	±1.45	8.4482	±1.58
27-36	8.3145	±1.47	8.3839	±1.43	8.3492	±1.83	8.3786	±1.49	8.4501	±1.46	8.4143	±1.82
36-45	8.2254	±1.55	8.3466	±1.46	8.2860	±2.33	8.2990	±1.55	8.4211	±1.48	8.3601	±2.26
45-54	8.1546	±1.43	8.2787	±1.46	8.2167	±2.04	8.2291	±1.45	8.3694	±1.46	8.2993	±2.04
54-63	8.0753	±1.67	8.1924	±1.54	8.1339	±2.55	8.1547	±1.63	8.3112	±1.51	8.2329	±2.66
63-72	7.9452	±1.77	8.1158	±1.61	8.0305	±3.33	8.0528	±1.67	8.2814	±1.56	8.1671	±3.59
72-81	7.6465	±2.34	7.6734	±3.58	7.6600	±5.01	7.8252	±1.80	7.9779	±2.25	7.9015	±4.28
81-90	7.1944	*	6.9232	*	7.0588	*	7.5888	*	7.7671	*	7.6780	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

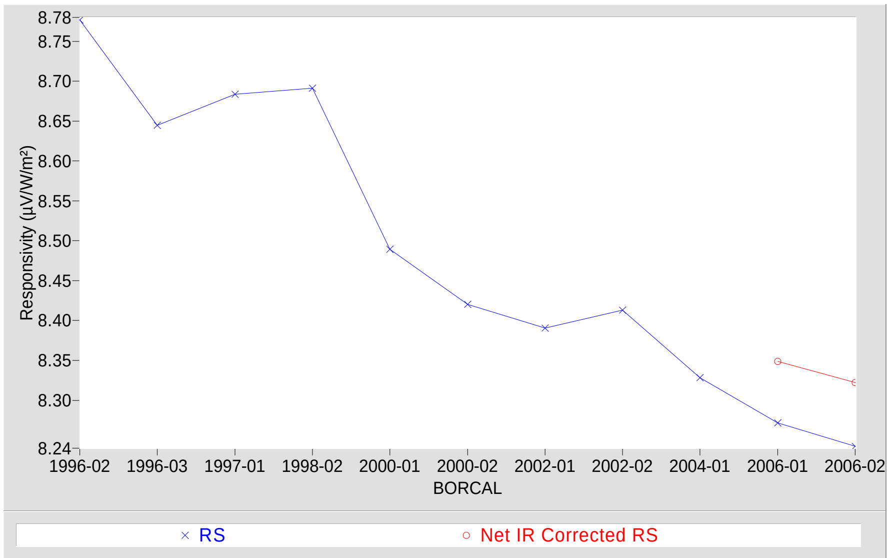
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.2423	+2.41 / -2.79
45° - 55°	8.2118	±1.80
Composite	8.2774	+2.19 / -14.29
45° (Net IR Corr.)	8.3224	+2.26 / -2.79
45° - 55° (Net IR Corr.)	8.2951	±1.85
Composite (Net IR Corr.)	8.3607	+2.00 / -8.56

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.4°, 16.6° to 83.4° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



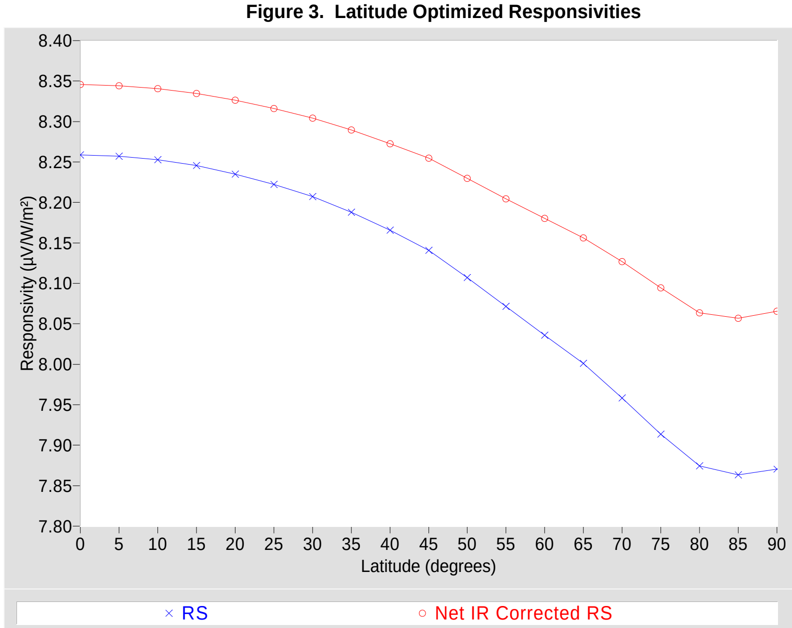
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.2588	+2.49 / -20.79	8.3457	+2.18 / -10.55
5	8.2573	+2.51 / -20.77	8.3444	+2.20 / -10.54
10	8.2528	+2.55 / -20.73	8.3407	+2.23 / -10.50
15	8.2456	+2.63 / -20.66	8.3349	+2.28 / -10.44
20	8.2351	+2.74 / -20.56	8.3264	+2.36 / -10.35
25	8.2221	+2.87 / -20.43	8.3161	+2.46 / -10.24
30	8.2071	+2.96 / -20.29	8.3043	+2.53 / -10.11
35	8.1879	+3.12 / -20.10	8.2896	+2.68 / -9.95
40	8.1656	+3.38 / -19.88	8.2727	+2.85 / -9.77
45	8.1406	+3.66 / -19.64	8.2546	+3.05 / -9.58
50	8.1072	+3.99 / -19.31	8.2298	+3.29 / -9.31
55	8.0717	+4.09 / -18.95	8.2046	+3.29 / -9.03
60	8.0360	+4.40 / -18.59	8.1805	+3.49 / -8.77
65	8.0012	+4.51 / -18.24	8.1563	+3.53 / -8.50
70	7.9585	+4.49 / -17.80	8.1270	+3.44 / -8.17
75	7.9134	+4.73 / -17.34	8.0943	+3.66 / -7.81
80	7.8743	+4.54 / -16.93	8.0636	+3.55 / -7.46
85	7.8633	+4.08 / -16.81	8.0568	+3.59 / -7.39
90	7.8705	+3.77 / -16.89	8.0655	+3.49 / -7.48

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

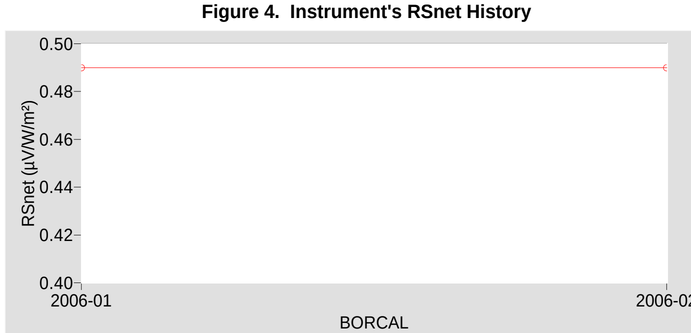
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31274F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	TWP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: __________________	Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

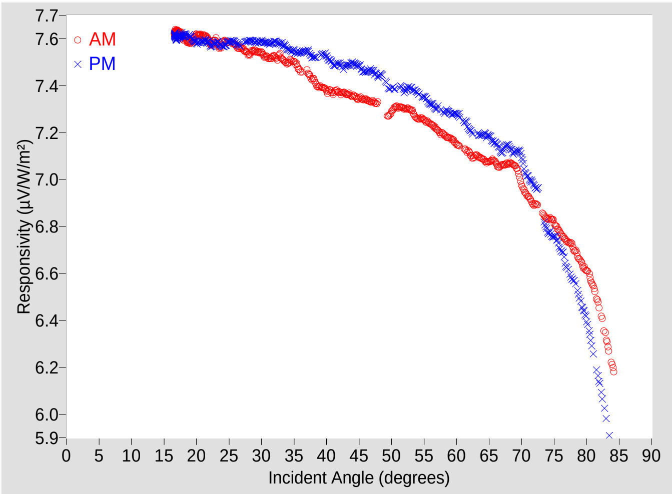

Figure 2. Responsivity vs Local Standard Time

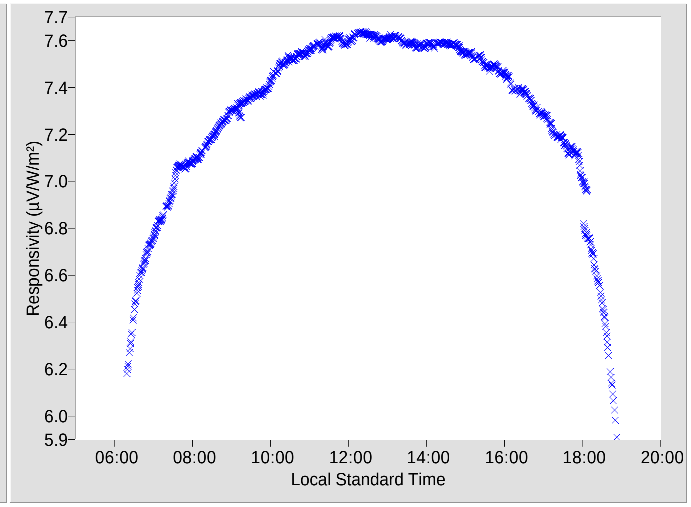

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.4152	+2.89 / -4.04	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.3419	0.56	97.15	7.4588	0.59	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3231	N/A	95.66	7.4421	0.60	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2887	0.69	101.83	7.3911	0.62	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3030	0.64	100.02	7.3801	0.62	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2606	0.70	98.28	7.3694	0.67	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2365	0.73	96.55	7.3223	0.71	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1940	0.73	94.96	7.2859	0.67	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1516	0.76	93.37	7.2784	0.67	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1124	0.81	91.80	7.2119	0.80	274.99
18	7.6073	0.59	155.33	7.6151	0.49	204.67	64	7.0888	0.84	90.33	7.1904	0.74	276.37
20	7.6143	0.54	142.65	7.5853	0.52	217.08	66	7.0731	0.89	88.82	7.1548	0.94	277.77
22	7.5871	0.55	134.55	7.5778	0.52	225.38	68	7.0689	0.92	87.34	7.1442	0.88	279.11
24	7.5812	0.52	128.25	7.5689	0.50	231.54	70	6.9826	1.36	85.93	7.0958	1.20	280.51
26	7.5744	0.49	123.51	7.5823	0.50	236.51	72	6.8947	1.13	84.49	6.9715	1.07	281.88
28	7.5351	0.52	119.25	7.5914	0.48	240.61	74	6.8338	1.23	83.04	6.7812	1.47	278.97
30	7.5406	0.52	115.76	7.5883	0.49	244.21	76	6.7727	1.52	81.61	6.6994	1.85	280.43
32	7.5237	0.52	112.61	7.5878	0.50	247.26	78	6.7072	1.75	80.17	6.5723	2.04	281.76
34	7.4972	0.51	109.74	7.5561	0.56	250.12	80	6.6134	2.18	78.74	6.4047	2.62	283.23
36	7.4639	0.58	107.29	7.5432	0.51	252.63	82	6.4500	3.10	77.25	6.1328	3.36	284.72
38	7.4247	0.70	104.95	7.5205	0.56	254.96	84	6.2035	3.87	75.75	N/A	N/A	N/A
40	7.3786	0.56	102.78	7.5233	0.61	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3702	0.54	100.81	7.4922	0.56	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3562	0.56	98.93	7.4977	0.55	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

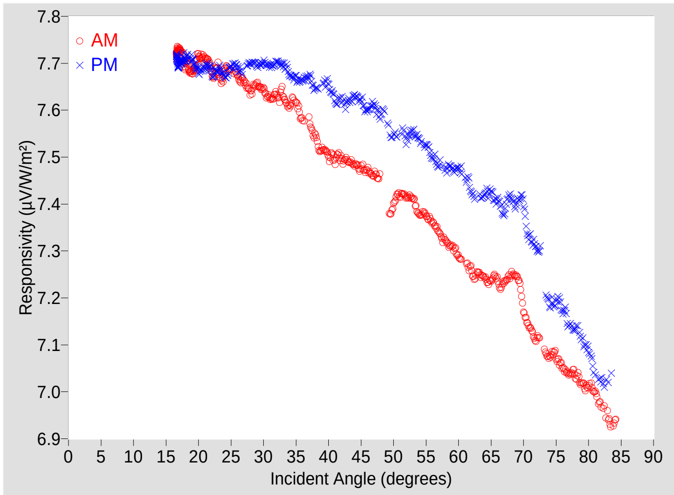

Figure 4. Responsivity vs Local Standard Time

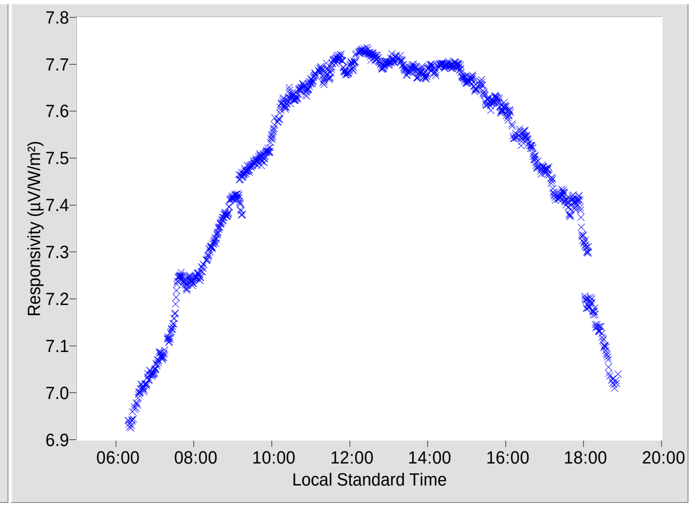

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.5486	+2.68 / -4.03	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.63228 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4724	0.63	97.15	7.6002	0.66	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4536	N/A	95.66	7.5905	0.68	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3983	0.73	101.83	7.5478	0.69	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4152	0.68	100.02	7.5395	0.71	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3782	0.73	98.28	7.5364	0.74	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3599	0.75	96.55	7.4993	0.79	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3231	0.77	94.96	7.4719	0.77	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2880	0.80	93.37	7.4745	0.79	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2573	0.86	91.80	7.4241	0.89	274.99
18	7.7003	0.61	155.33	7.7104	0.53	204.67	64	7.2443	0.89	90.33	7.4200	0.89	276.37
20	7.7133	0.58	142.65	7.6855	0.56	217.08	66	7.2380	0.96	88.82	7.4070	1.01	277.77
22	7.6819	0.58	134.55	7.6817	0.56	225.38	68	7.2484	1.00	87.34	7.4158	1.05	279.11
24	7.6818	0.57	128.25	7.6728	0.55	231.54	70	7.1777	1.33	85.93	7.3976	1.28	280.51
26	7.6751	0.54	123.51	7.6897	0.55	236.51	72	7.1129	1.21	84.49	7.3048	1.25	281.88
28	7.6389	0.56	119.25	7.7000	0.53	240.61	74	7.0753	1.33	83.04	7.1888	1.66	278.97
30	7.6445	0.57	115.76	7.7005	0.55	244.21	76	7.0536	1.57	81.61	7.1722	1.93	280.43
32	7.6330	0.58	112.61	7.7024	0.55	247.26	78	7.0348	1.83	80.17	7.1340	2.21	281.76
34	7.6097	0.56	109.74	7.6757	0.61	250.12	80	7.0123	2.22	78.74	7.0878	2.69	283.23
36	7.5808	0.61	107.29	7.6655	0.57	252.63	82	6.9704	2.97	77.25	7.0244	3.44	284.72
38	7.5429	0.75	104.95	7.6460	0.62	254.96	84	6.9355	4.07	75.75	N/A	N/A	N/A
40	7.5009	0.61	102.78	7.6521	0.66	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4945	0.60	100.81	7.6231	0.63	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4840	0.62	98.93	7.6308	0.62	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

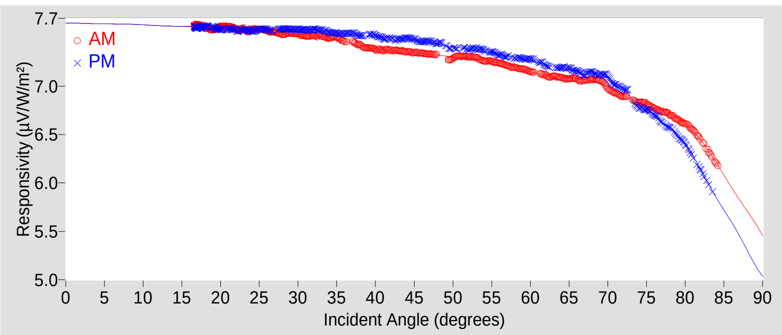
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

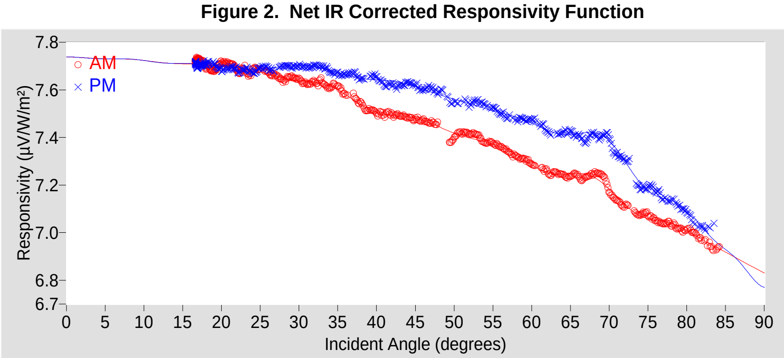


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.72	±1.72
R²	0.9999993	0.9999987
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.77	±1.77
Net IR corrected R²	0.9999993	0.9999990
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	7.6449	*	7.6450	*	7.6449	*	7.7324	*	7.7325	*	7.7324	*
9-18	7.6221	*	7.6226	*	7.6224	*	7.7140	*	7.7147	*	7.7144	*
18-27	7.5906	±1.75	7.5830	±1.73	7.5868	±1.78	7.6885	±1.79	7.6856	±1.78	7.6871	±1.81
27-36	7.5228	±1.80	7.5785	±1.74	7.5507	±2.07	7.6307	±1.82	7.6927	±1.78	7.6617	±2.07
36-45	7.3933	±1.87	7.5129	±1.76	7.4531	±2.48	7.5158	±1.88	7.6415	±1.79	7.5786	±2.44
45-54	7.3101	±1.79	7.4169	±1.88	7.3635	±2.62	7.4306	±1.87	7.5690	±1.86	7.4998	±2.78
54-63	7.1875	±2.06	7.2895	±1.99	7.2385	±3.00	7.3184	±1.98	7.4780	±1.88	7.3982	±3.15
63-72	7.0441	±2.11	7.1345	±2.21	7.0893	±3.28	7.2202	±1.94	7.4017	±1.88	7.3109	±3.36
72-81	6.7566	±2.95	6.6687	±4.92	6.7127	±6.82	7.0533	±1.95	7.1697	±2.35	7.1115	±3.57
81-90	6.0158	*	5.6524	*	5.8341	*	6.9093	*	6.9113	*	6.9103	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.4152	+2.89 / -4.04
45° - 55°	7.3550	±2.29
Composite	7.4486	+2.81 / -21.53
45° (Net IR Corr.)	7.5486	+2.68 / -4.03
45° - 55° (Net IR Corr.)	7.4922	±2.39
Composite (Net IR Corr.)	7.5865	+2.39 / -8.77

† Valid incident angle ranges:

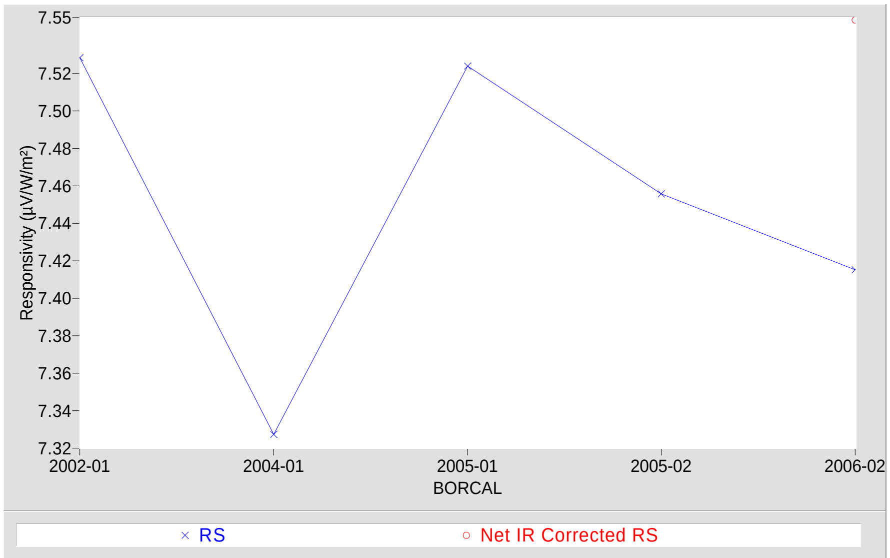
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



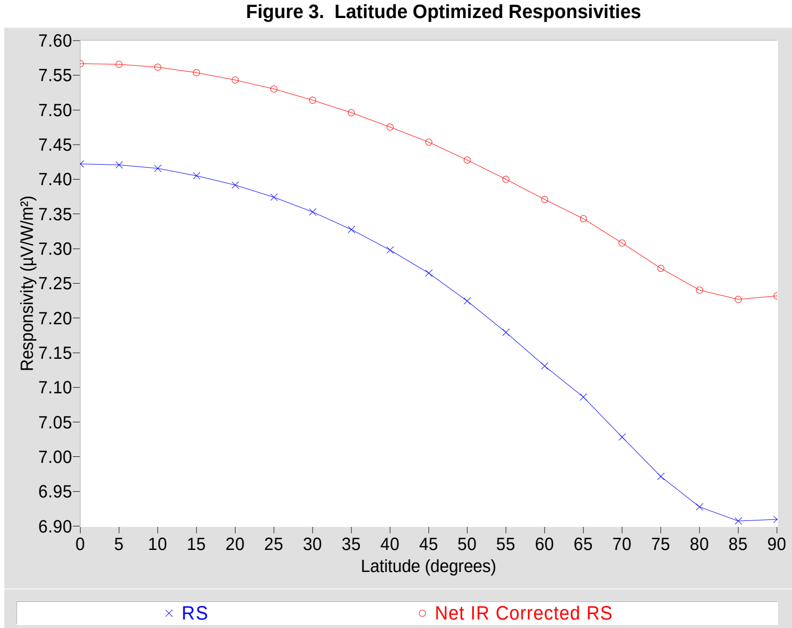
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.4223	+3.53 / -30.56	7.5668	+2.87 / -10.40
5	7.4211	+3.55 / -30.55	7.5659	+2.88 / -10.39
10	7.4156	+3.62 / -30.49	7.5618	+2.93 / -10.34
15	7.4053	+3.74 / -30.40	7.5538	+3.01 / -10.25
20	7.3918	+3.91 / -30.27	7.5434	+3.13 / -10.13
25	7.3743	+4.12 / -30.11	7.5302	+3.27 / -9.97
30	7.3531	+4.29 / -29.90	7.5143	+3.37 / -9.78
35	7.3275	+4.46 / -29.66	7.4960	+3.46 / -9.57
40	7.2978	+4.70 / -29.37	7.4755	+3.61 / -9.32
45	7.2646	+4.92 / -29.05	7.4538	+3.78 / -9.06
50	7.2245	+5.37 / -28.66	7.4278	+4.10 / -8.75
55	7.1793	+5.94 / -28.21	7.3999	+4.44 / -8.41
60	7.1307	+6.00 / -27.72	7.3708	+4.34 / -8.06
65	7.0861	+6.23 / -27.27	7.3433	+4.41 / -7.72
70	7.0285	+6.40 / -26.67	7.3083	+4.39 / -7.29
75	6.9717	+6.29 / -26.07	7.2715	+4.24 / -6.84
80	6.9275	+6.01 / -25.60	7.2405	+4.04 / -6.45
85	6.9074	+5.15 / -25.39	7.2269	+3.50 / -6.28
90	6.9098	+4.03 / -25.41	7.2320	+3.14 / -6.35

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

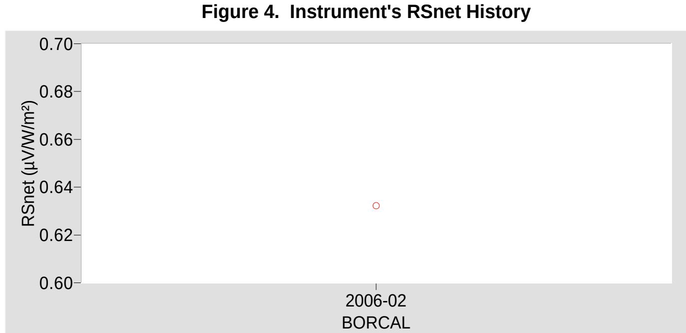
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31276F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	TWP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31276F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

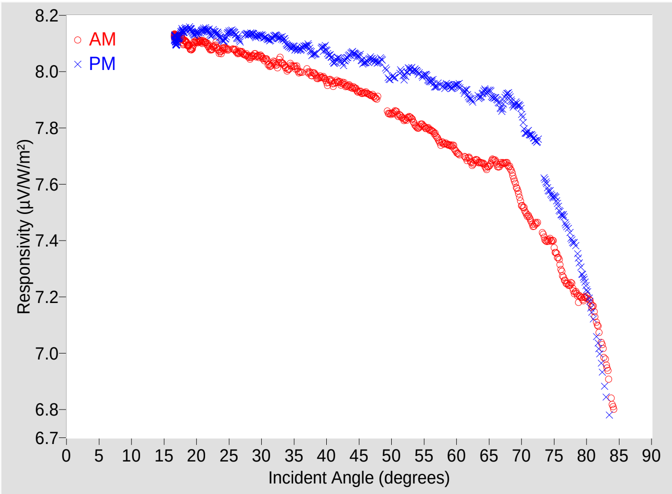


Figure 2. Responsivity vs Local Standard Time

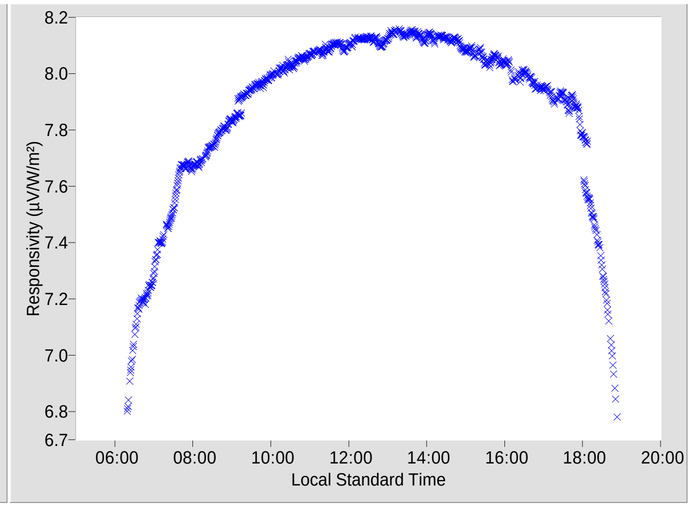


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9913	+2.27 / -3.93	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9253	0.54	97.15	8.0328	0.58	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9020	N/A	95.66	8.0359	0.57	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8509	0.62	101.83	7.9800	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8303	0.64	100.02	7.9846	0.64	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8019	0.68	98.28	7.9982	0.64	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7917	0.70	96.55	7.9660	0.67	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7463	0.70	94.96	7.9460	0.64	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7146	0.75	93.37	7.9518	0.67	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6884	0.78	91.80	7.9051	0.74	274.99
18	8.1093	0.52	155.33	8.1459	0.56	204.67	64	7.6748	0.83	90.33	7.9221	0.75	276.37
20	8.1055	0.51	142.65	8.1369	0.49	217.08	66	7.6807	0.87	88.82	7.9039	0.90	277.77
22	8.0854	0.51	134.55	8.1383	0.51	225.38	68	7.6655	1.00	87.34	7.9197	0.89	279.11
24	8.0778	0.49	128.25	8.1117	0.53	231.54	70	7.5321	1.26	85.93	7.8506	1.14	280.51
26	8.0754	0.48	123.51	8.1290	0.54	236.51	72	7.4557	1.11	84.49	7.7595	1.01	281.88
28	8.0520	0.50	119.25	8.1326	0.48	240.61	74	7.3998	1.21	83.04	7.5898	1.44	278.97
30	8.0535	0.51	115.76	8.1273	0.49	244.21	76	7.3091	1.64	81.61	7.4961	1.70	280.43
32	8.0310	0.53	112.61	8.1259	0.51	247.26	78	7.2259	1.70	80.17	7.3946	1.96	281.76
34	8.0086	0.52	109.74	8.0928	0.56	250.12	80	7.1990	2.00	78.74	7.2340	2.37	283.23
36	7.9976	0.52	107.29	8.0811	0.52	252.63	82	7.0695	2.93	77.25	7.0037	3.18	284.72
38	7.9922	0.54	104.95	8.0614	0.58	254.96	84	6.8175	3.76	75.75	N/A	N/A	N/A
40	7.9635	0.55	102.78	8.0734	0.63	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9609	0.53	100.81	8.0434	0.56	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9435	0.55	98.93	8.0674	0.55	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

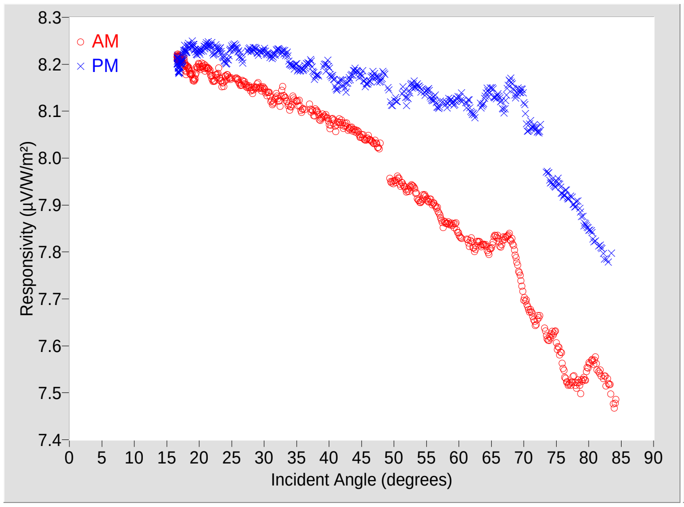

Figure 4. Responsivity vs Local Standard Time

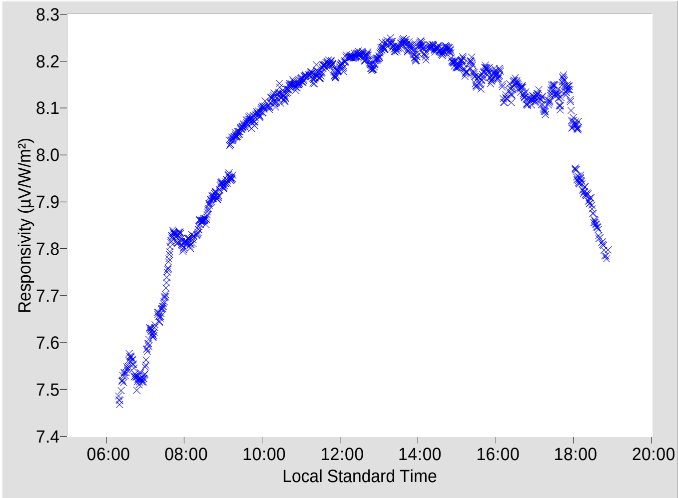

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1115	+2.09 / -3.92	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.56944 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0428	0.60	97.15	8.1601	0.65	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0195	N/A	95.66	8.1695	0.64	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9496	0.66	101.83	8.1212	0.69	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9314	0.68	100.02	8.1281	0.72	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9078	0.72	98.28	8.1486	0.70	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9028	0.74	96.55	8.1253	0.74	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8626	0.75	94.96	8.1135	0.73	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8374	0.80	93.37	8.1284	0.77	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8189	0.83	91.80	8.0962	0.83	274.99
18	8.1931	0.54	155.33	8.2317	0.61	204.67	64	7.8148	0.87	90.33	8.1289	0.89	276.37
20	8.1947	0.55	142.65	8.2272	0.52	217.08	66	7.8291	0.93	88.82	8.1311	0.97	277.77
22	8.1708	0.54	134.55	8.2320	0.54	225.38	68	7.8271	1.05	87.34	8.1642	1.05	279.11
24	8.1684	0.53	128.25	8.2053	0.56	231.54	70	7.7078	1.25	85.93	8.1224	1.20	280.51
26	8.1660	0.52	123.51	8.2258	0.58	236.51	72	7.6522	1.19	84.49	8.0597	1.18	281.88
28	8.1454	0.54	119.25	8.2304	0.53	240.61	74	7.6173	1.31	83.04	7.9569	1.60	278.97
30	8.1471	0.55	115.76	8.2284	0.54	244.21	76	7.5620	1.62	81.61	7.9219	1.82	280.43
32	8.1294	0.59	112.61	8.2291	0.55	247.26	78	7.5210	1.79	80.17	7.9005	2.12	281.76
34	8.1100	0.56	109.74	8.2005	0.60	250.12	80	7.5583	2.17	78.74	7.8493	2.54	283.23
36	8.1029	0.57	107.29	8.1912	0.57	252.63	82	7.5382	2.86	77.25	7.8067	3.25	284.72
38	8.0987	0.59	104.95	8.1744	0.62	254.96	84	7.4768	3.92	75.75	N/A	N/A	N/A
40	8.0736	0.60	102.78	8.1894	0.67	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0729	0.59	100.81	8.1613	0.61	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0587	0.60	98.93	8.1873	0.61	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

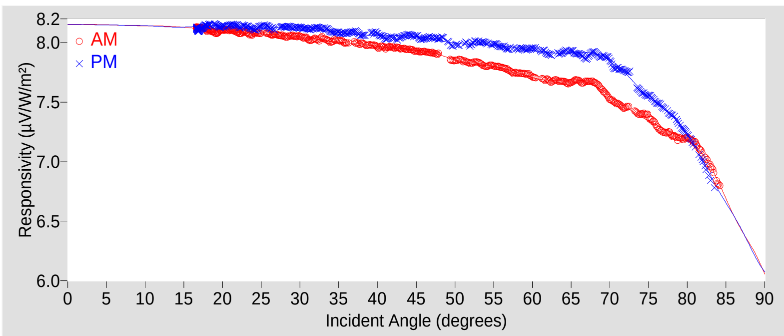
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

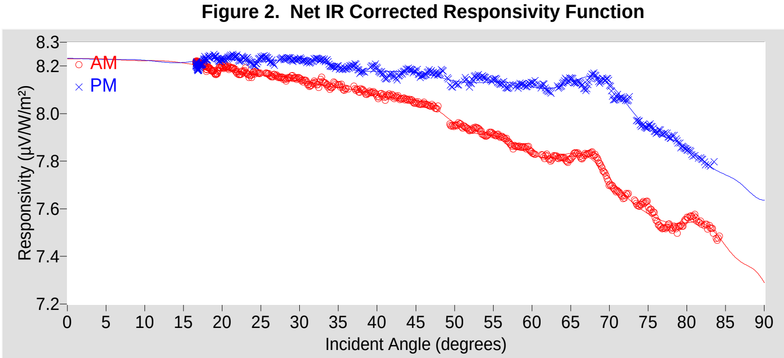


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.64	±1.64
R²	0.9999987	0.9999987
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.70	±1.70
Net IR corrected R²	0.9999989	0.9999990
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.1499	*	8.1499	*	8.1499	*	8.2287	*	8.2287	*	8.2287	*
9-18	8.1333	*	8.1364	*	8.1349	*	8.2161	*	8.2194	*	8.2177	*
18-27	8.0886	±1.66	8.1310	±1.64	8.1098	±1.77	8.1768	±1.71	8.2235	±1.70	8.2001	±1.81
27-36	8.0355	±1.69	8.1173	±1.67	8.0764	±2.01	8.1327	±1.73	8.2201	±1.71	8.1764	±2.02
36-45	7.9695	±1.68	8.0630	±1.64	8.0162	±2.04	8.0797	±1.72	8.1789	±1.70	8.1293	±2.04
45-54	7.8728	±1.83	8.0098	±1.69	7.9413	±2.70	7.9812	±1.92	8.1468	±1.72	8.0640	±2.87
54-63	7.7447	±1.82	7.9515	±1.69	7.8481	±3.16	7.8627	±1.80	8.1213	±1.70	7.9920	±3.31
63-72	7.6289	±2.11	7.8891	±1.86	7.7590	±4.39	7.7875	±1.99	8.1297	±1.77	7.9586	±4.68
72-81	7.3065	±2.63	7.4782	±4.08	7.3924	±5.93	7.5737	±1.87	7.9294	±2.13	7.7516	±5.04
81-90	6.6264	*	6.5967	*	6.6116	*	7.4311	*	7.7305	*	7.5808	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.9913	+2.27 / -3.93
45° - 55°	7.9343	±2.27
Composite	8.0026	+2.39 / -15.58
45° (Net IR Corr.)	8.1115	+2.09 / -3.92
45° - 55° (Net IR Corr.)	8.0578	±2.37
Composite (Net IR Corr.)	8.1269	+2.14 / -8.05

† Valid incident angle ranges:

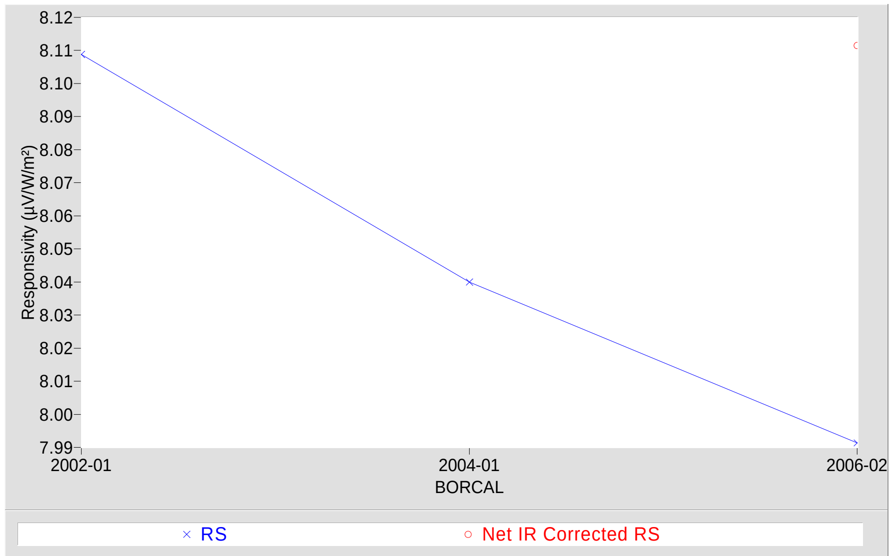
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



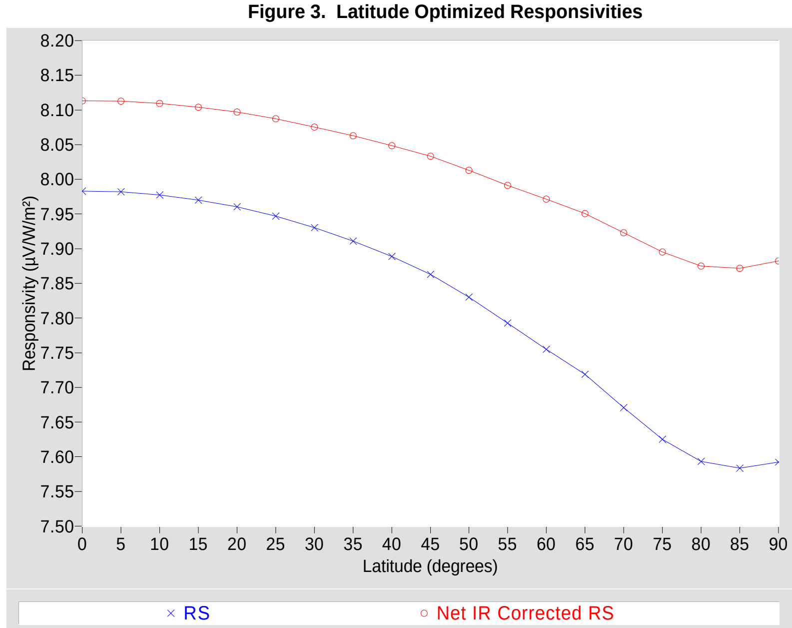
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.9830	+2.70 / -22.69	8.1131	+2.25 / -9.74
5	7.9821	+2.71 / -22.68	8.1125	+2.26 / -9.73
10	7.9777	+2.75 / -22.64	8.1093	+2.28 / -9.70
15	7.9703	+2.83 / -22.57	8.1040	+2.33 / -9.64
20	7.9604	+2.93 / -22.47	8.0969	+2.39 / -9.56
25	7.9469	+3.07 / -22.34	8.0873	+2.48 / -9.45
30	7.9302	+3.20 / -22.18	8.0754	+2.59 / -9.32
35	7.9110	+3.35 / -21.99	8.0627	+2.71 / -9.18
40	7.8887	+3.61 / -21.77	8.0488	+2.85 / -9.03
45	7.8629	+3.85 / -21.51	8.0333	+3.01 / -8.85
50	7.8299	+4.21 / -21.18	8.0130	+3.23 / -8.63
55	7.7928	+4.60 / -20.81	7.9915	+3.43 / -8.39
60	7.7551	+4.48 / -20.42	7.9713	+3.21 / -8.16
65	7.7189	+4.71 / -20.05	7.9507	+3.32 / -7.92
70	7.6710	+5.11 / -19.55	7.9229	+3.53 / -7.61
75	7.6253	+5.06 / -19.07	7.8953	+3.71 / -7.29
80	7.5931	+5.28 / -18.73	7.8749	+3.95 / -7.06
85	7.5837	+4.79 / -18.63	7.8715	+3.99 / -7.02
90	7.5921	+4.58 / -18.72	7.8824	+3.87 / -7.15

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

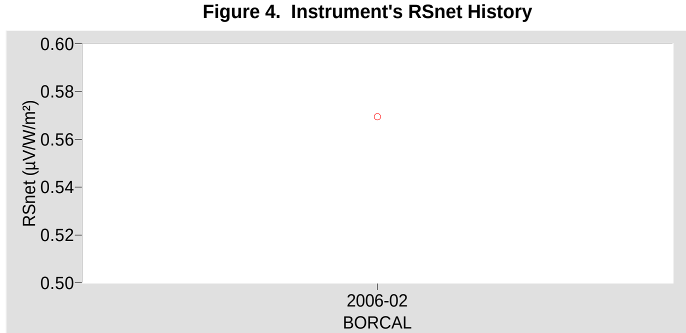
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31279F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	TWP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: __________________	Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

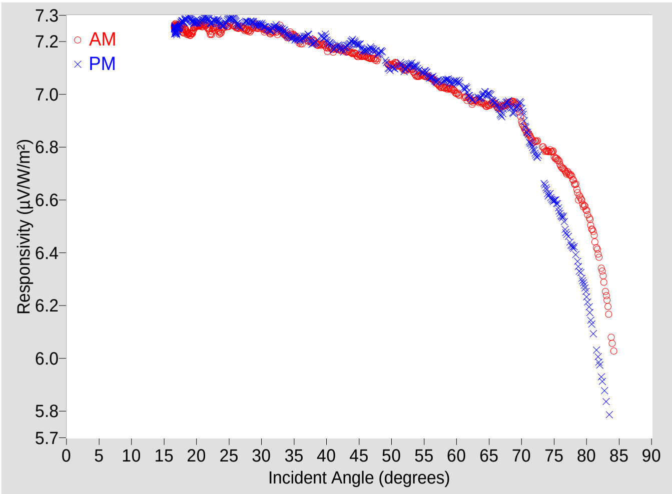

Figure 2. Responsivity vs Local Standard Time

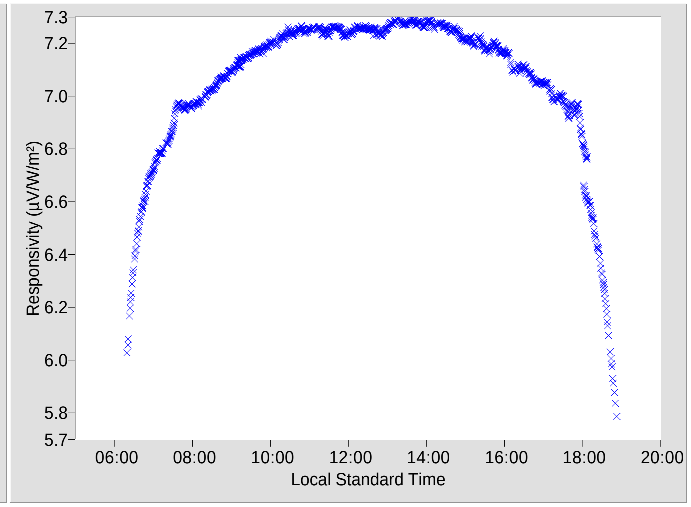

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.1673	+1.89 / -2.78	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.1444	0.55	97.15	7.1661	0.59	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.1273	N/A	95.66	7.1566	0.58	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.1129	0.62	101.83	7.0996	0.64	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.0950	0.65	100.02	7.0975	0.64	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.0700	0.68	98.28	7.0998	0.66	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.0615	0.71	96.55	7.0644	0.69	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.0267	0.70	94.96	7.0516	0.64	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.0049	0.75	93.37	7.0485	0.67	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9828	0.79	91.80	6.9919	0.79	274.99
18	7.2432	0.54	155.33	7.2783	0.60	204.67	64	6.9690	0.82	90.33	6.9969	0.76	276.37
20	7.2588	0.55	142.65	7.2733	0.49	217.08	66	6.9621	0.88	88.82	6.9655	1.00	277.77
22	7.2412	0.54	134.55	7.2778	0.51	225.38	68	6.9672	0.93	87.34	6.9676	0.90	279.11
24	7.2516	0.53	128.25	7.2619	0.52	231.54	70	6.9043	1.30	85.93	6.9491	1.24	280.51
26	7.2579	0.48	123.51	7.2755	0.55	236.51	72	6.8216	1.13	84.49	6.7815	1.18	281.88
28	7.2423	0.51	119.25	7.2740	0.49	240.61	74	6.7851	1.22	83.04	6.6292	1.49	278.97
30	7.2547	0.52	115.76	7.2640	0.51	244.21	76	6.7336	1.50	81.61	6.5437	1.85	280.43
32	7.2410	0.54	112.61	7.2578	0.52	247.26	78	6.6732	1.84	80.17	6.4221	2.09	281.76
34	7.2205	0.52	109.74	7.2241	0.56	250.12	80	6.5618	2.24	78.74	6.2421	2.68	283.23
36	7.1955	0.55	107.29	7.2096	0.52	252.63	82	6.3737	3.24	77.25	5.9747	3.33	284.72
38	7.2025	0.54	104.95	7.1942	0.58	254.96	84	6.0559	4.12	75.77	N/A	N/A	N/A
40	7.1766	0.56	102.78	7.2082	0.64	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.1700	0.53	100.81	7.1813	0.57	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.1570	0.56	98.93	7.2023	0.57	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

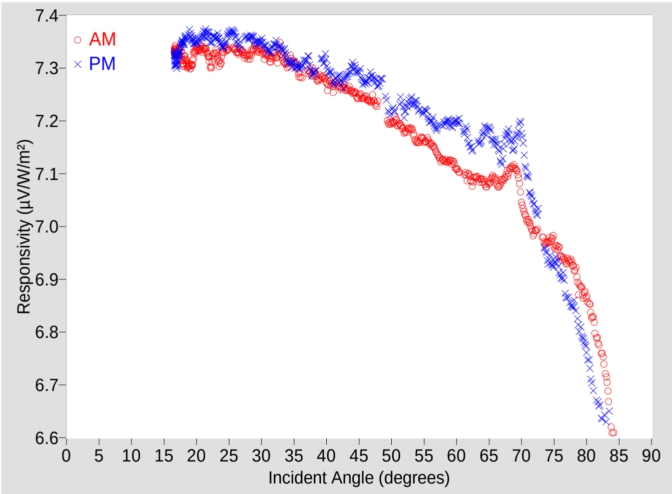

Figure 4. Responsivity vs Local Standard Time

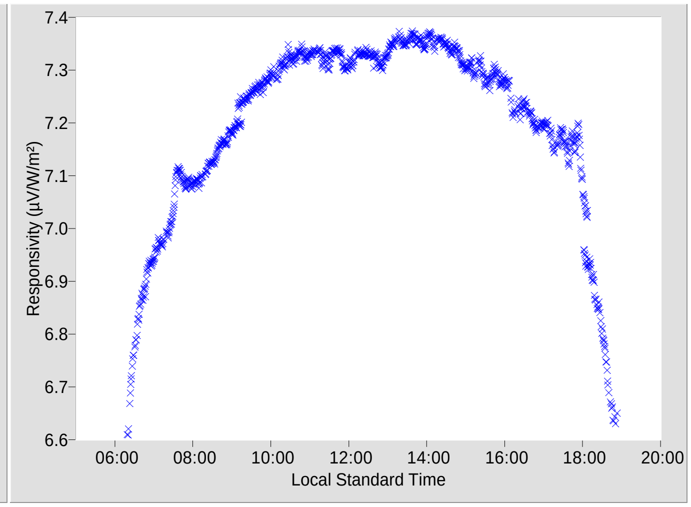

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.2693	+1.76 / -2.80	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.48347 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.2442	0.62	97.15	7.2742	0.67	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2271	N/A	95.66	7.2700	0.67	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.1966	0.67	101.83	7.2194	0.72	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.1808	0.69	100.02	7.2194	0.73	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.1600	0.73	98.28	7.2274	0.74	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1559	0.75	96.55	7.1997	0.78	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1255	0.76	94.96	7.1939	0.77	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1092	0.80	93.37	7.1984	0.80	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.0937	0.85	91.80	7.1542	0.90	274.99
18	7.3143	0.57	155.33	7.3512	0.65	204.67	64	7.0879	0.89	90.33	7.1725	0.92	276.37
20	7.3345	0.59	142.65	7.3499	0.53	217.08	66	7.0881	0.95	88.82	7.1583	1.07	277.77
22	7.3137	0.57	134.55	7.3573	0.56	225.38	68	7.1045	1.02	87.34	7.1752	1.09	279.11
24	7.3285	0.59	128.25	7.3413	0.57	231.54	70	7.0534	1.31	85.93	7.1799	1.34	280.51
26	7.3348	0.53	123.51	7.3576	0.59	236.51	72	6.9885	1.22	84.49	7.0364	1.35	281.88
28	7.3217	0.56	119.25	7.3570	0.54	240.61	74	6.9697	1.34	83.04	6.9409	1.69	278.97
30	7.3342	0.57	115.76	7.3498	0.57	244.21	76	6.9483	1.57	81.61	6.9052	1.98	280.43
32	7.3246	0.60	112.61	7.3455	0.57	247.26	78	6.9238	1.89	80.17	6.8516	2.29	281.76
34	7.3066	0.57	109.74	7.3156	0.61	250.12	80	6.8668	2.27	78.74	6.7645	2.81	283.23
36	7.2848	0.60	107.29	7.3032	0.59	252.63	82	6.7716	3.07	77.25	6.6564	3.54	284.72
38	7.2929	0.60	104.95	7.2902	0.64	254.96	84	6.6132	4.21	75.77	N/A	N/A	N/A
40	7.2701	0.62	102.78	7.3067	0.70	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2651	0.60	100.81	7.2813	0.63	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2547	0.62	98.93	7.3041	0.64	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

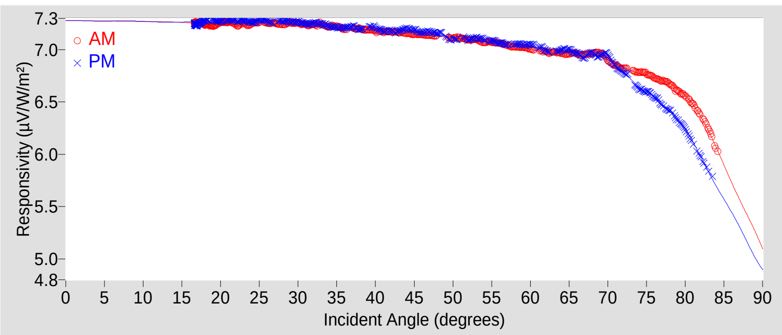
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

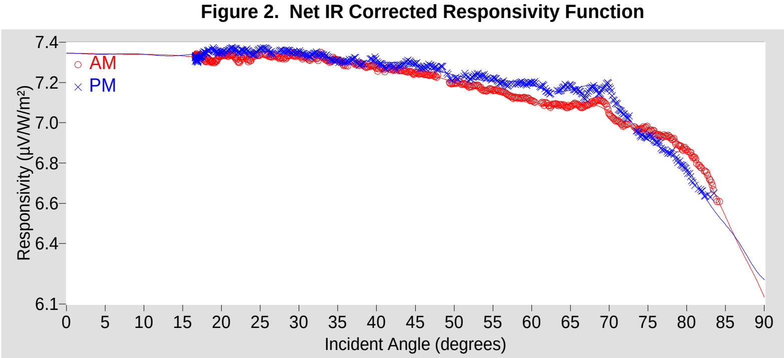


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.77	±1.77
R²	0.9999993	0.9999981
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.83	±1.83
Net IR corrected R²	0.9999994	0.9999982
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.2755	*	7.2756	*	7.2756	*	7.3424	*	7.3425	*	7.3425	*
9-18	7.2642	*	7.2672	*	7.2657	*	7.3345	*	7.3376	*	7.3360	*
18-27	7.2498	±1.77	7.2726	±1.77	7.2612	±1.79	7.3247	±1.83	7.3511	±1.83	7.3379	±1.85
27-36	7.2380	±1.80	7.2524	±1.82	7.2452	±1.89	7.3205	±1.84	7.3397	±1.86	7.3301	±1.92
36-45	7.1793	±1.81	7.1974	±1.78	7.1884	±1.86	7.2729	±1.85	7.2958	±1.83	7.2843	±1.89
45-54	7.1169	±1.84	7.1298	±1.90	7.1234	±2.06	7.2090	±1.92	7.2461	±1.90	7.2276	±2.18
54-63	7.0263	±1.91	7.0498	±1.88	7.0380	±2.09	7.1264	±1.90	7.1939	±1.86	7.1602	±2.21
63-72	6.9425	±1.97	6.9540	±2.10	6.9482	±2.52	7.0771	±1.93	7.1583	±1.97	7.1177	±2.55
72-81	6.7105	±2.91	6.5104	±4.99	6.6104	±7.47	6.9373	±2.13	6.8935	±2.88	6.9154	±3.64
81-90	5.8132	*	5.5019	*	5.6575	*	6.4923	*	6.4644	*	6.4783	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

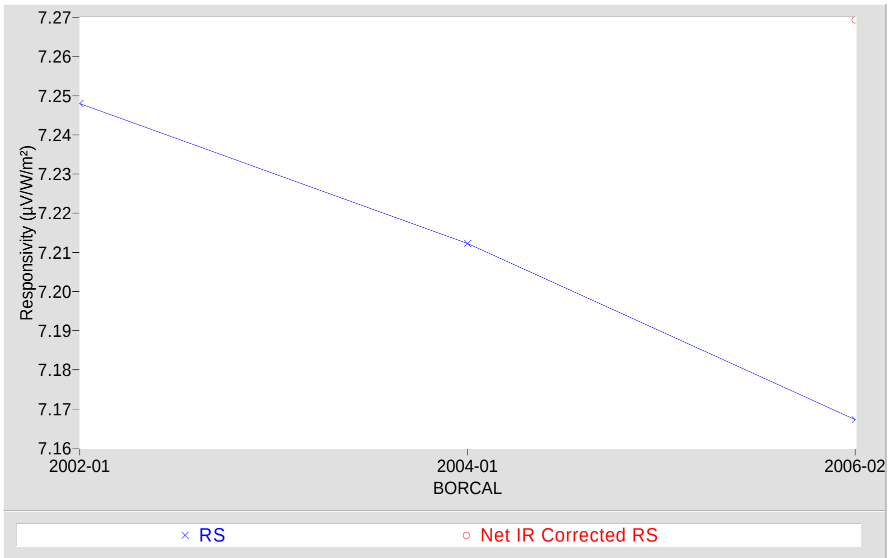
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.1673	+1.89 / -2.78
45° - 55°	7.1164	±1.96
Composite	7.1617	+2.38 / -20.54
45° (Net IR Corr.)	7.2693	+1.76 / -2.80
45° - 55° (Net IR Corr.)	7.2213	±2.04
Composite (Net IR Corr.)	7.2672	+2.19 / -10.15

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



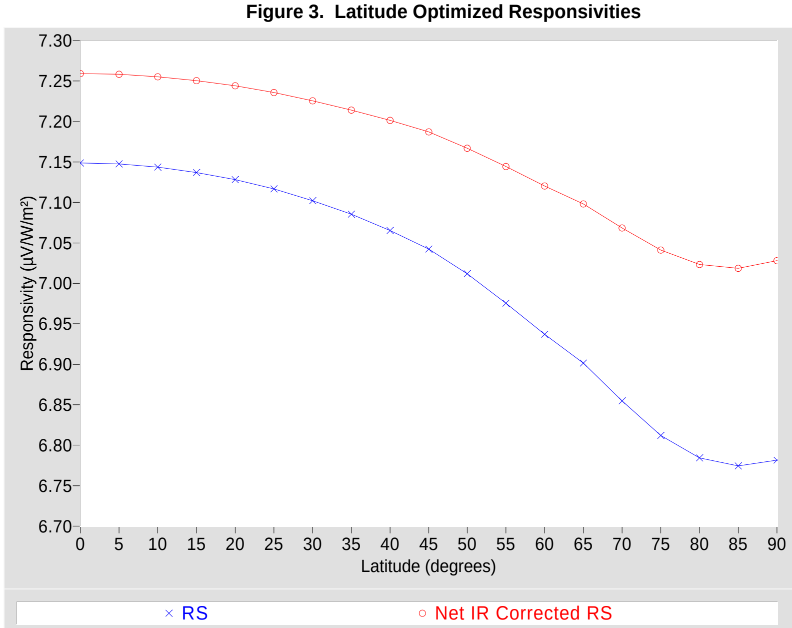
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.1486	+2.55 / -29.89	7.2591	+2.26 / -14.43
5	7.1476	+2.56 / -29.88	7.2583	+2.27 / -14.42
10	7.1436	+2.60 / -29.84	7.2553	+2.29 / -14.38
15	7.1369	+2.67 / -29.78	7.2504	+2.33 / -14.32
20	7.1283	+2.77 / -29.69	7.2442	+2.39 / -14.25
25	7.1166	+2.89 / -29.58	7.2358	+2.47 / -14.15
30	7.1022	+3.02 / -29.43	7.2254	+2.57 / -14.03
35	7.0853	+3.22 / -29.27	7.2141	+2.68 / -13.90
40	7.0654	+3.46 / -29.07	7.2013	+2.82 / -13.74
45	7.0425	+3.73 / -28.84	7.1871	+2.97 / -13.58
50	7.0117	+4.12 / -28.53	7.1671	+3.20 / -13.34
55	6.9756	+4.46 / -28.16	7.1443	+3.39 / -13.06
60	6.9369	+4.29 / -27.76	7.1205	+3.13 / -12.77
65	6.9015	+4.67 / -27.39	7.0981	+3.37 / -12.50
70	6.8546	+4.94 / -26.89	7.0683	+3.48 / -12.14
75	6.8119	+4.68 / -26.43	7.0410	+3.22 / -11.80
80	6.7843	+4.61 / -26.13	7.0234	+3.20 / -11.58
85	6.7745	+4.03 / -26.03	7.0188	+3.01 / -11.52
90	6.7816	+3.46 / -26.10	7.0279	+2.91 / -11.64

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

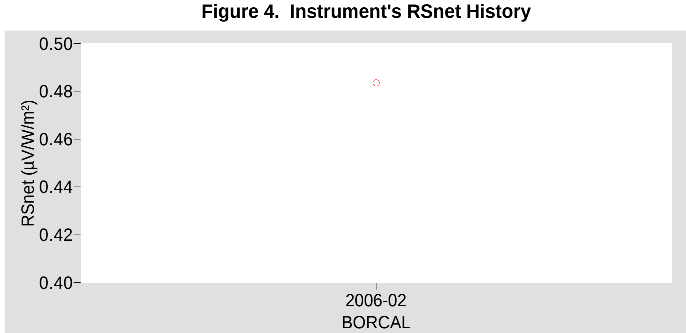
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer **Manufacturer:** Eppley

Model: PSP **Serial Number:** 31285F3

Calibration Date: 8/12/2006 **Due Date:** 8/12/2007

Customer: TWP **Calibration Site Parameters:** see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31285F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

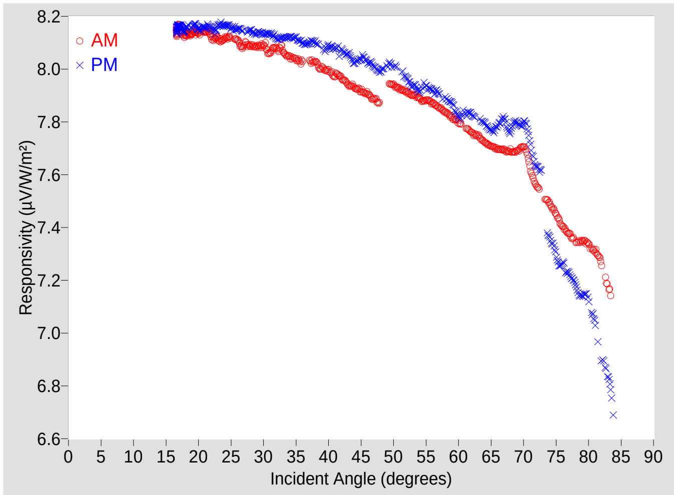


Figure 2. Responsivity vs Local Standard Time

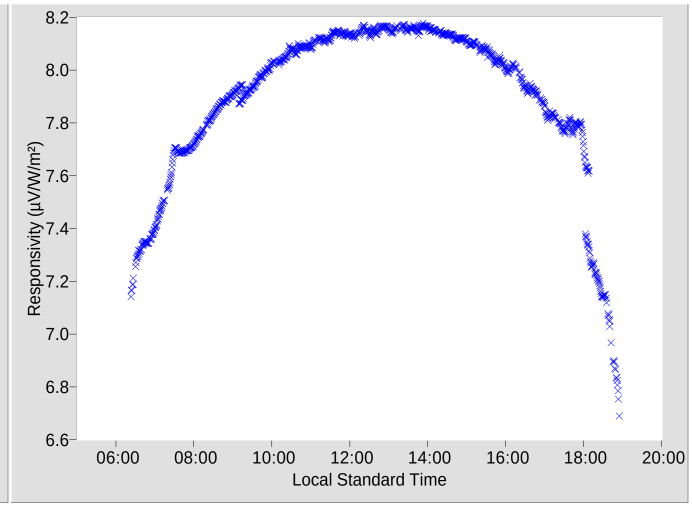


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.9801	+2.51 / -2.71	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc.	AM			PM			Inc.	AM			PM		
Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9074	0.58	97.12	8.0263	0.62	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8704	N/A	95.69	7.9926	0.58	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9395	0.62	101.86	8.0100	0.58	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9135	0.65	99.99	7.9670	0.70	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8895	0.66	98.25	7.9200	0.64	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8719	0.69	96.58	7.9181	0.64	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8359	0.72	94.94	7.8897	0.65	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8001	0.73	93.35	7.8193	0.77	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7607	0.77	91.83	7.8291	0.70	274.97
18	8.1310	0.52	155.47	8.1516	0.50	204.59	64	7.7235	0.84	90.31	7.7958	0.77	276.34
20	8.1388	0.48	142.76	8.1520	0.50	217.19	66	7.6981	0.85	88.80	7.7866	0.86	277.74
22	8.1221	0.53	134.48	8.1547	0.53	225.47	68	7.6896	0.91	87.35	7.7689	0.89	279.13
24	8.1163	0.49	128.33	8.1653	0.50	231.62	70	7.7059	1.09	85.91	7.7964	1.01	280.53
26	8.1107	0.52	123.46	8.1517	0.49	236.46	72	7.5579	1.17	84.46	7.6324	1.11	281.86
28	8.0886	0.49	119.31	8.1454	0.49	240.67	74	7.4928	1.24	83.06	7.3589	1.45	279.00
30	8.0910	0.54	115.71	8.1336	0.49	244.16	76	7.4036	1.46	81.59	7.2647	1.59	280.41
32	8.0787	0.51	112.66	8.1161	0.51	247.31	78	7.3500	1.64	80.17	7.1822	1.88	281.83
34	8.0478	0.51	109.79	8.1220	0.50	250.16	80	7.3366	2.00	78.72	7.1273	2.23	283.26
36	8.0278	0.51	107.44	8.0999	0.54	252.67	82	7.2712	2.68	77.33	6.8972	3.06	284.77
38	8.0278	0.54	104.99	8.0986	0.52	255.00	84	N/A	N/A	N/A	6.6899	N/A	286.08
40	7.9941	0.56	102.85	8.0841	0.54	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9655	0.58	100.78	8.0707	0.58	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9319	0.56	98.96	8.0244	0.59	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31285F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

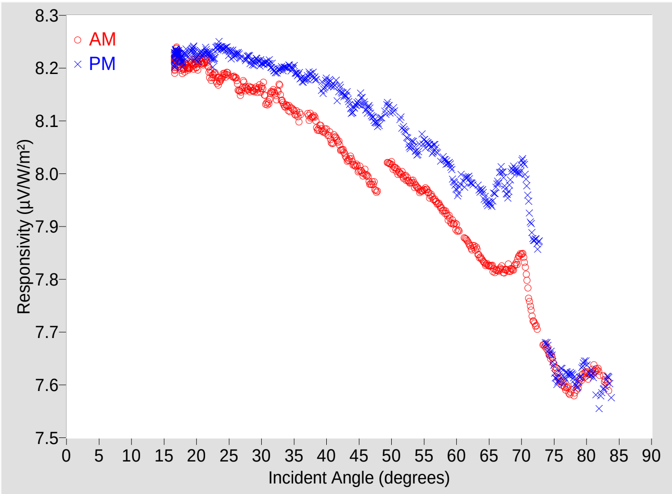


Figure 4. Responsivity vs Local Standard Time

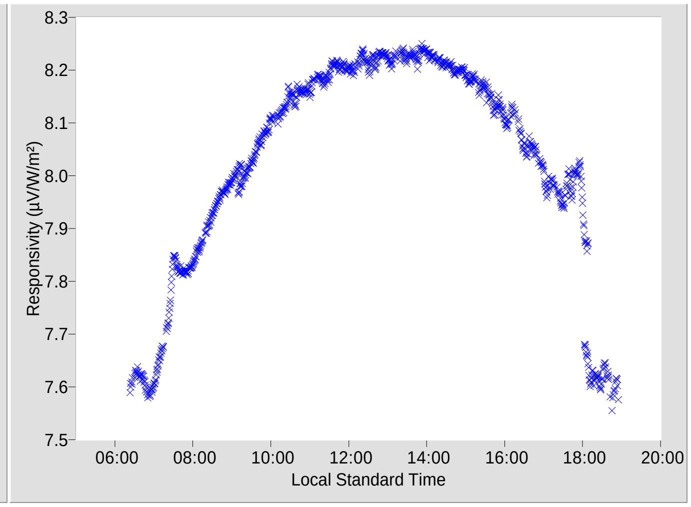


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0734	+2.33 / -2.66	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.58129 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0000	0.61	97.12	8.1247	0.64	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9649	N/A	95.69	8.0953	0.63	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0172	0.64	101.86	8.1187	0.63	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9930	0.66	99.99	8.0832	0.73	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9739	0.68	98.25	8.0426	0.70	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9589	0.71	96.58	8.0502	0.69	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9289	0.74	94.94	8.0283	0.71	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8980	0.76	93.35	7.9679	0.82	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8655	0.80	91.83	7.9886	0.78	274.97
18	8.2005	0.55	155.47	8.2194	0.53	204.59	64	7.8360	0.86	90.31	7.9647	0.84	276.34
20	8.2060	0.50	142.76	8.2211	0.52	217.19	66	7.8167	0.89	88.80	7.9701	0.99	277.74
22	8.1921	0.55	134.48	8.2247	0.55	225.47	68	7.8188	0.95	87.37	7.9698	1.00	279.13
24	8.1848	0.51	128.33	8.2371	0.52	231.62	70	7.8483	1.11	85.91	8.0190	1.10	280.53
26	8.1815	0.54	123.46	8.2257	0.51	236.46	72	7.7166	1.20	84.46	7.8751	1.25	281.86
28	8.1601	0.51	119.31	8.2202	0.51	240.67	74	7.6677	1.28	83.06	7.6717	1.56	279.00
30	8.1642	0.57	115.71	8.2094	0.52	244.16	76	7.6064	1.49	81.59	7.6255	1.75	280.41
32	8.1536	0.55	112.66	8.1943	0.54	247.31	78	7.5852	1.72	80.17	7.6129	2.05	281.83
34	8.1272	0.53	109.79	8.2025	0.53	250.16	80	7.6213	2.09	78.72	7.6417	2.42	283.26
36	8.1087	0.54	107.44	8.1816	0.57	252.67	82	7.6252	2.65	77.33	7.5673	3.14	284.77
38	8.1079	0.56	104.99	8.1834	0.55	255.00	84	N/A	N/A	N/A	7.5758	N/A	286.08
40	8.0797	0.58	102.85	8.1715	0.58	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0531	0.60	100.78	8.1603	0.61	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0236	0.59	98.96	8.1179	0.62	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31285F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

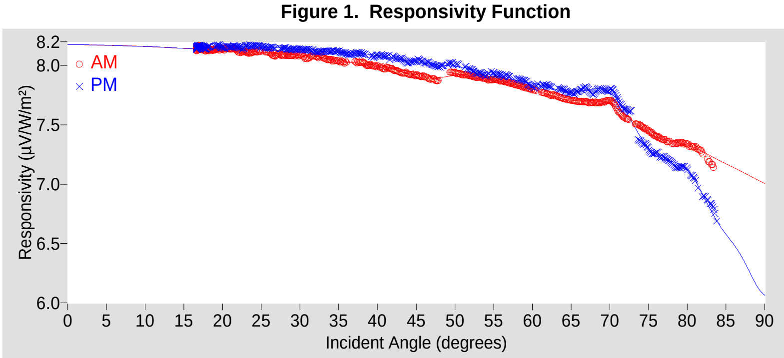
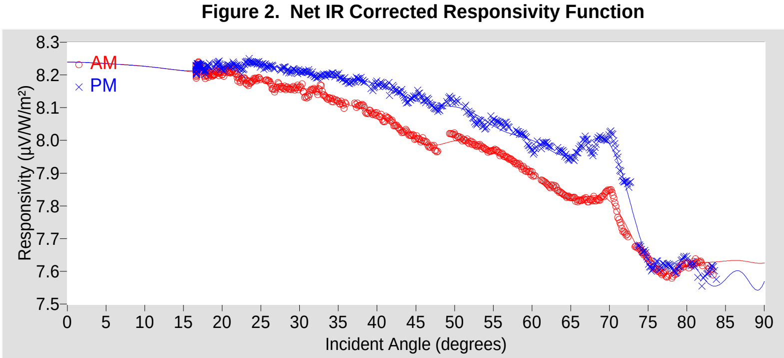


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.40	±1.40
R²	0.9999985	0.9999973
Valid incidence angle range	16.6° to 83.4°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.46	±1.46
Net IR corrected R²	0.9999987	0.9999977
Corr. valid inc. angle range	16.6° to 83.4°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.1711	*	8.1710	*	8.1710	*	8.2354	*	8.2353	*	8.2353	*
9-18	8.1502	*	8.1516	*	8.1509	*	8.2175	*	8.2189	*	8.2182	*
18-27	8.1227	±1.42	8.1554	±1.41	8.1390	±1.50	8.1919	±1.47	8.2261	±1.46	8.2090	±1.55
27-36	8.0750	±1.46	8.1269	±1.43	8.1009	±1.73	8.1500	±1.50	8.2045	±1.47	8.1773	±1.74
36-45	7.9871	±1.58	8.0765	±1.48	8.0318	±2.22	8.0727	±1.59	8.1643	±1.51	8.1185	±2.16
45-54	7.9072	±1.42	7.9935	±1.49	7.9504	±1.85	7.9932	±1.46	8.1007	±1.50	8.0470	±1.89
54-63	7.8285	±1.70	7.8728	±1.63	7.8507	±2.23	7.9224	±1.66	8.0139	±1.57	7.9682	±2.35
63-72	7.6934	±1.61	7.7755	±1.66	7.7344	±2.27	7.8209	±1.54	7.9719	±1.59	7.8964	±2.59
72-81	7.4195	±2.31	7.2889	±3.95	7.3542	±5.37	7.6335	±1.78	7.6688	±2.28	7.6511	±3.30
81-90	7.1561	*	6.5335	*	6.8448	*	7.6285	*	7.5754	*	7.6019	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

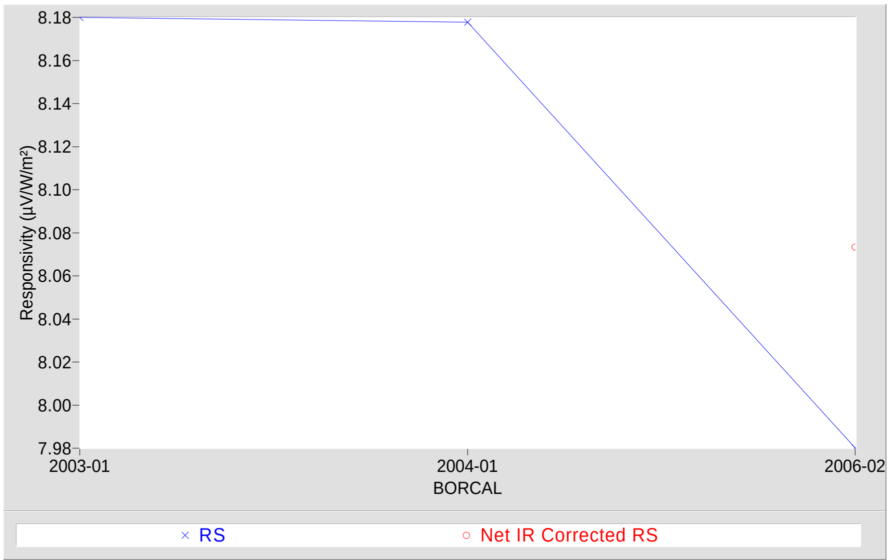
4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.9801	+2.51 / -2.71
45° - 55°	7.9444	±1.68
Composite	8.0176	+2.26 / -16.16
45° (Net IR Corr.)	8.0734	+2.33 / -2.66
45° - 55° (Net IR Corr.)	8.0420	±1.75
Composite (Net IR Corr.)	8.1165	+2.03 / -7.07

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.4°, 16.6° to 83.4° (Net IR corr.)

Figure 2. History of instrument at I = 45°



The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

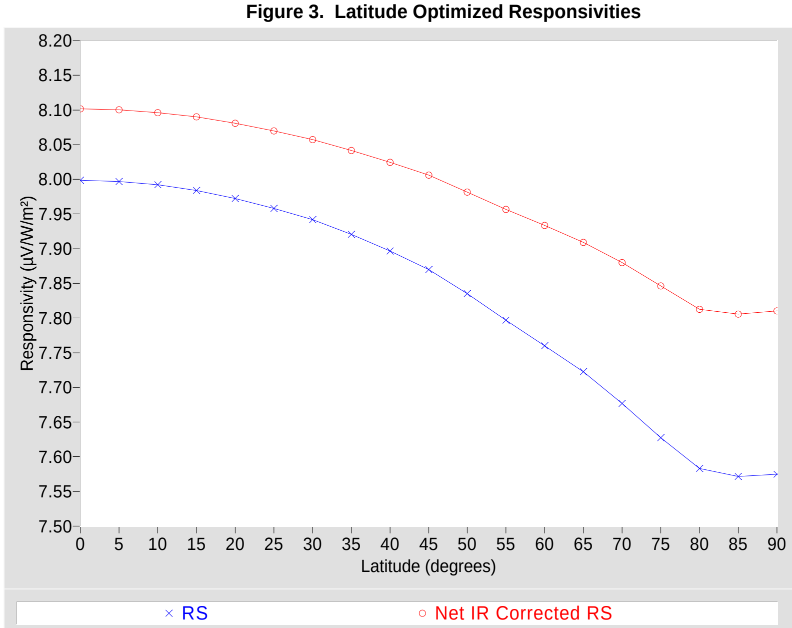
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.9985	+2.63 / -23.23	8.1015	+2.24 / -7.05
5	7.9968	+2.65 / -23.22	8.1002	+2.26 / -7.03
10	7.9920	+2.70 / -23.17	8.0963	+2.29 / -6.99
15	7.9841	+2.79 / -23.10	8.0901	+2.36 / -6.92
20	7.9726	+2.92 / -22.98	8.0810	+2.45 / -6.82
25	7.9583	+3.07 / -22.85	8.0699	+2.56 / -6.69
30	7.9417	+3.19 / -22.69	8.0573	+2.63 / -6.55
35	7.9208	+3.32 / -22.48	8.0417	+2.77 / -6.37
40	7.8967	+3.61 / -22.24	8.0243	+2.96 / -6.18
45	7.8700	+3.94 / -21.98	8.0060	+3.17 / -5.97
50	7.8351	+4.31 / -21.63	7.9817	+3.42 / -5.69
55	7.7970	+4.45 / -21.25	7.9565	+3.43 / -5.40
60	7.7599	+4.69 / -20.88	7.9337	+3.54 / -5.14
65	7.7225	+4.75 / -20.49	7.9091	+3.52 / -4.86
70	7.6768	+4.65 / -20.02	7.8802	+3.31 / -4.52
75	7.6273	+4.89 / -19.50	7.8463	+3.52 / -4.14
80	7.5831	+4.42 / -19.04	7.8125	+3.17 / -3.75
85	7.5717	+3.78 / -18.91	7.8056	+2.97 / -3.67
90	7.5750	+3.32 / -18.95	7.8105	+2.92 / -3.73

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

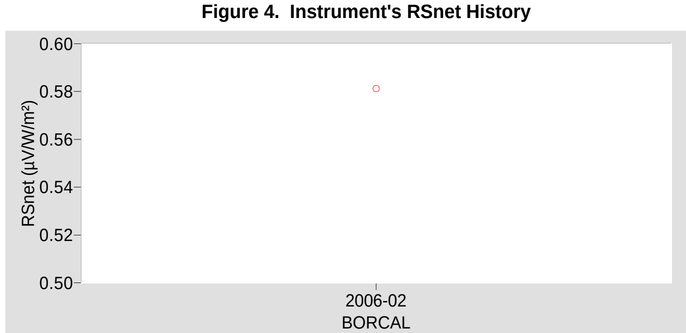
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 31289F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: TWP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31289F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

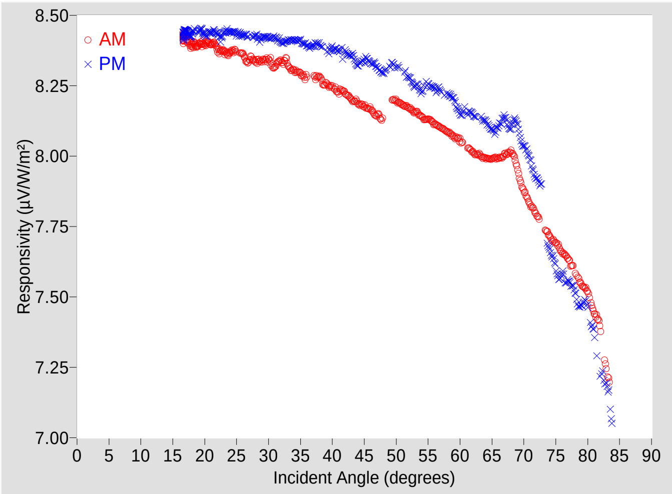


Figure 2. Responsivity vs Local Standard Time

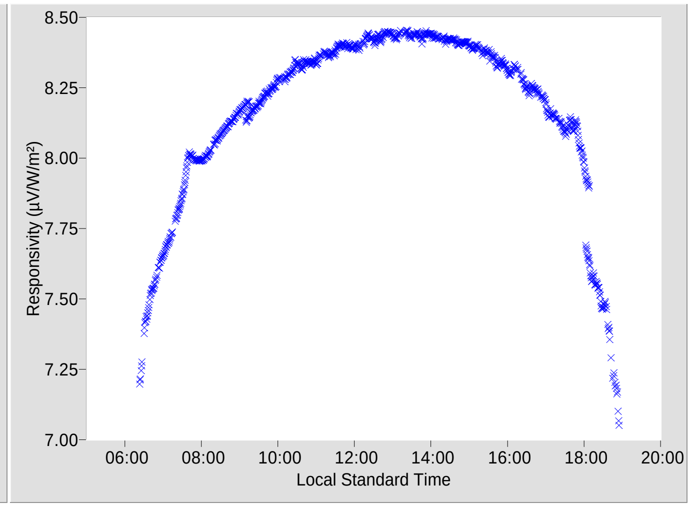


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2596	+2.54 / -2.93	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1664	0.58	97.12	8.3311	0.59	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1275	N/A	95.69	8.2972	0.58	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1961	0.62	101.86	8.3164	0.58	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1705	0.65	99.99	8.2793	0.68	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1408	0.67	98.25	8.2334	0.65	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1148	0.68	96.58	8.2397	0.63	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0858	0.71	94.94	8.2211	0.64	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0556	0.73	93.35	8.1501	0.76	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0149	0.76	91.83	8.1487	0.70	274.97
18	8.3943	0.55	155.47	8.4341	0.50	204.59	64	7.9932	0.80	90.31	8.1230	0.77	276.34
20	8.3991	0.48	142.76	8.4322	0.50	217.19	66	7.9938	0.85	88.80	8.1073	0.88	277.74
22	8.3797	0.53	134.48	8.4334	0.54	225.47	68	8.0135	0.96	87.37	8.1037	0.85	279.13
24	8.3703	0.49	128.33	8.4405	0.50	231.62	70	7.8776	1.25	85.91	8.0328	1.18	280.53
26	8.3620	0.52	123.46	8.4295	0.49	236.46	72	7.7904	1.11	84.46	7.9209	1.12	281.86
28	8.3368	0.50	119.31	8.4268	0.50	240.67	74	7.7192	1.22	83.06	7.6663	1.45	279.00
30	8.3435	0.53	115.71	8.4208	0.48	244.16	76	7.6567	1.43	81.59	7.5826	1.55	280.41
32	8.3366	0.52	112.66	8.4038	0.51	247.31	78	7.5908	1.71	80.17	7.5167	1.88	281.83
34	8.3049	0.50	109.79	8.4120	0.50	250.16	80	7.5171	2.05	78.72	7.4680	2.21	283.26
36	8.2806	0.52	107.44	8.3926	0.54	252.67	82	7.3971	2.83	77.33	7.2226	2.92	284.77
38	8.2809	0.54	104.99	8.3932	0.52	255.00	84	N/A	N/A	N/A	7.0514	N/A	286.08
40	8.2460	0.55	102.85	8.3810	0.54	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2235	0.56	100.78	8.3698	0.58	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1908	0.55	98.96	8.3239	0.60	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31289F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

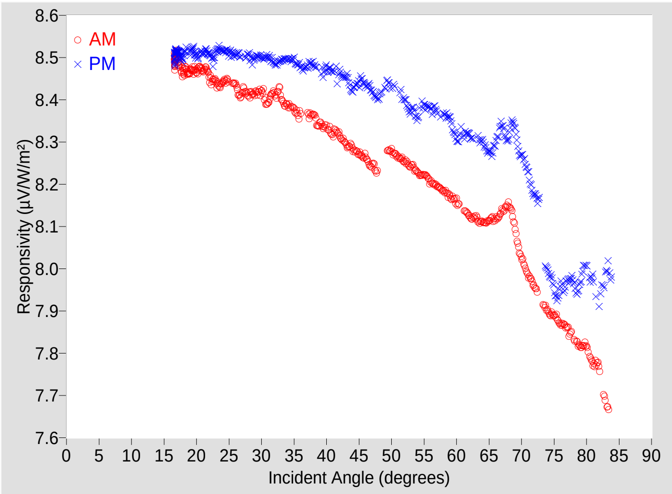


Figure 4. Responsivity vs Local Standard Time

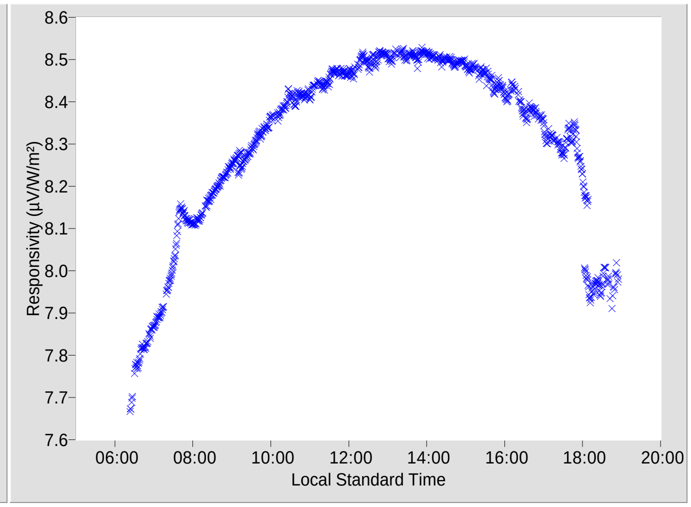


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3575	+2.35 / -2.89	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.60965 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2635	0.61	97.12	8.4343	0.62	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2266	N/A	95.69	8.4049	0.62	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2776	0.64	101.86	8.4304	0.62	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2538	0.66	99.99	8.4012	0.72	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2292	0.68	98.25	8.3620	0.70	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2061	0.70	96.58	8.3783	0.68	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1834	0.73	94.94	8.3665	0.69	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1582	0.75	93.35	8.3060	0.80	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1247	0.79	91.83	8.3160	0.76	274.97
18	8.4673	0.58	155.47	8.5052	0.53	204.59	64	8.1112	0.83	90.31	8.3002	0.84	276.34
20	8.4697	0.49	142.76	8.5046	0.52	217.19	66	8.1183	0.90	88.80	8.2997	0.99	277.74
22	8.4531	0.55	134.48	8.5068	0.55	225.47	68	8.1496	0.99	87.37	8.3144	0.96	279.13
24	8.4422	0.51	128.33	8.5158	0.52	231.62	70	8.0269	1.22	85.91	8.2663	1.18	280.53
26	8.4362	0.53	123.46	8.5071	0.51	236.46	72	7.9569	1.15	84.46	8.1754	1.18	281.86
28	8.4118	0.52	119.31	8.5053	0.53	240.67	74	7.9026	1.25	83.06	7.9945	1.54	279.00
30	8.4202	0.55	115.71	8.5003	0.51	244.16	76	7.8694	1.46	81.59	7.9610	1.74	280.41
32	8.4152	0.55	112.66	8.4859	0.53	247.31	78	7.8374	1.72	80.17	7.9685	2.03	281.83
34	8.3882	0.52	109.79	8.4965	0.53	250.16	80	7.8157	2.09	78.72	8.0074	2.38	283.26
36	8.3655	0.55	107.44	8.4783	0.56	252.67	82	7.7684	2.70	77.33	7.9255	3.10	284.77
38	8.3650	0.56	104.99	8.4821	0.55	255.00	84	N/A	N/A	N/A	7.9806	N/A	286.08
40	8.3359	0.57	102.85	8.4727	0.57	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3153	0.58	100.78	8.4637	0.61	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2870	0.58	98.96	8.4220	0.62	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31289F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

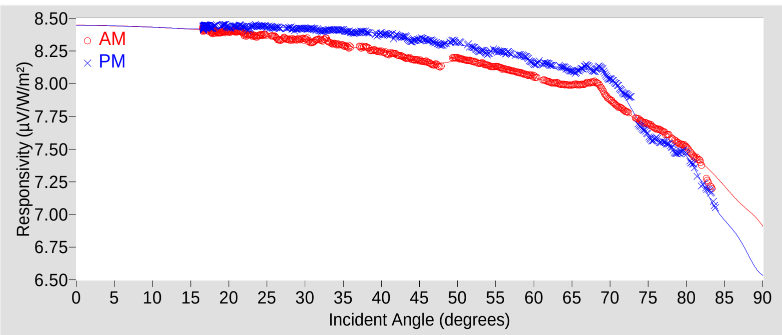
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

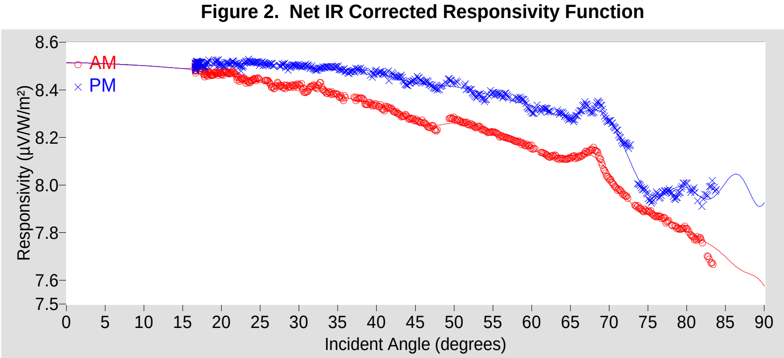


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.40	±1.40
R^2	0.9999986	0.9999979
Valid incidence angle range	16.6° to 83.4°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.44	±1.44
Net IR corrected R^2	0.9999989	0.9999985
Corr. valid inc. angle range	16.6° to 83.4°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.4430	*	8.4428	*	8.4429	*	8.5104	*	8.5102	*	8.5103	*
9-18	8.4220	*	8.4251	*	8.4235	*	8.4925	*	8.4955	*	8.4940	*
18-27	8.3797	±1.43	8.4338	±1.40	8.4067	±1.59	8.4522	±1.47	8.5079	±1.44	8.4801	±1.62
27-36	8.3289	±1.45	8.4137	±1.41	8.3713	±1.85	8.4076	±1.47	8.4951	±1.45	8.4513	±1.83
36-45	8.2419	±1.55	8.3734	±1.46	8.3077	±2.41	8.3317	±1.55	8.4655	±1.48	8.3986	±2.34
45-54	8.1637	±1.41	8.3002	±1.46	8.2320	±2.08	8.2539	±1.45	8.4128	±1.46	8.3333	±2.17
54-63	8.0786	±1.64	8.1977	±1.58	8.1382	±2.57	8.1770	±1.60	8.3458	±1.52	8.2614	±2.70
63-72	7.9599	±1.83	8.0817	±1.83	8.0208	±3.18	8.0937	±1.72	8.2878	±1.63	8.1908	±3.34
72-81	7.6440	±2.47	7.6054	±3.47	7.6247	±4.71	7.8684	±1.76	8.0038	±1.91	7.9361	±3.56
81-90	7.1868	*	6.9247	*	7.0557	*	7.6861	*	7.9740	*	7.8300	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

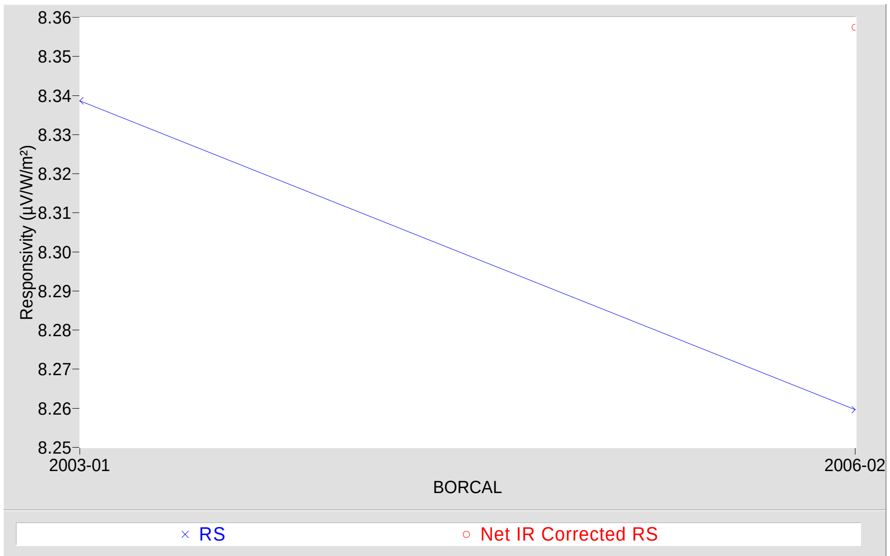
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.2596	+2.54 / -2.93
45° - 55°	8.2263	±1.85
Composite	8.2918	+2.26 / -14.69
45° (Net IR Corr.)	8.3575	+2.35 / -2.89
45° - 55° (Net IR Corr.)	8.3288	±1.92
Composite (Net IR Corr.)	8.3954	+2.00 / -7.95

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.4°, 16.6° to 83.4° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



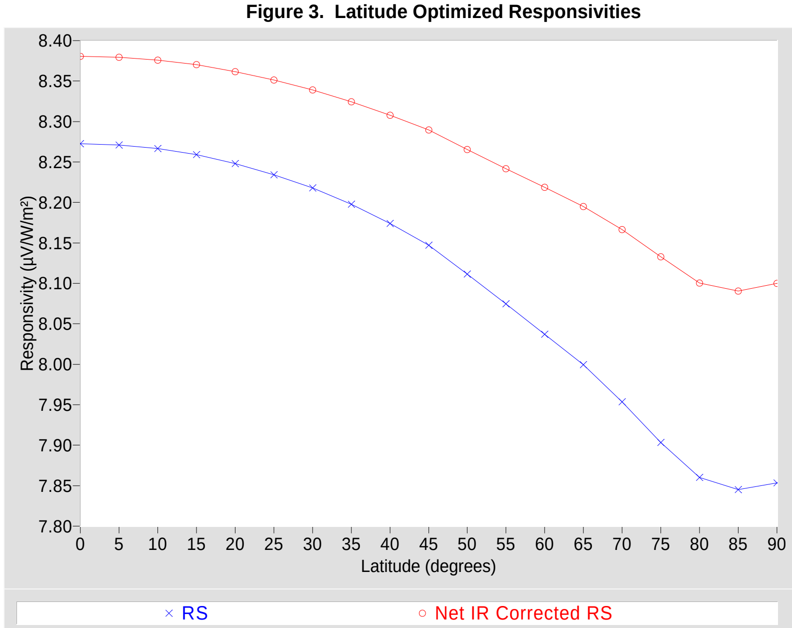
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.2725	+2.54 / -20.28	8.3805	+2.15 / -9.28
5	8.2710	+2.56 / -20.26	8.3793	+2.17 / -9.27
10	8.2666	+2.60 / -20.22	8.3760	+2.20 / -9.23
15	8.2591	+2.68 / -20.15	8.3702	+2.25 / -9.17
20	8.2480	+2.80 / -20.04	8.3617	+2.33 / -9.08
25	8.2343	+2.95 / -19.91	8.3512	+2.43 / -8.97
30	8.2181	+3.05 / -19.75	8.3392	+2.52 / -8.84
35	8.1977	+3.25 / -19.55	8.3245	+2.67 / -8.68
40	8.1740	+3.52 / -19.32	8.3078	+2.85 / -8.50
45	8.1470	+3.84 / -19.05	8.2896	+3.04 / -8.30
50	8.1116	+4.17 / -18.70	8.2653	+3.27 / -8.03
55	8.0745	+4.44 / -18.33	8.2416	+3.40 / -7.77
60	8.0369	+4.72 / -17.95	8.2189	+3.55 / -7.52
65	7.9997	+4.84 / -17.57	8.1949	+3.58 / -7.26
70	7.9534	+4.84 / -17.09	8.1663	+3.47 / -6.94
75	7.9034	+5.09 / -16.56	8.1327	+3.68 / -6.56
80	7.8600	+4.88 / -16.11	8.1002	+3.57 / -6.20
85	7.8452	+4.26 / -15.95	8.0903	+3.20 / -6.08
90	7.8534	+3.55 / -16.04	8.1000	+3.03 / -6.19

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

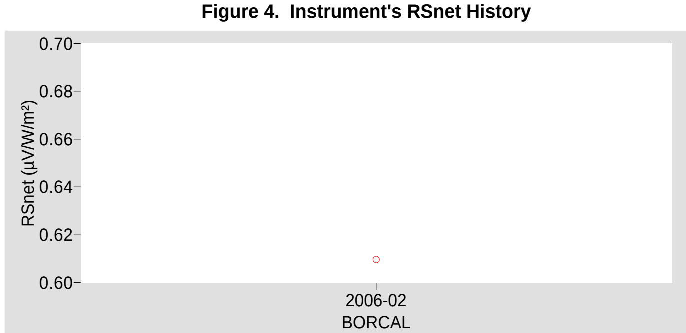
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 31290F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: TWP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

31290F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

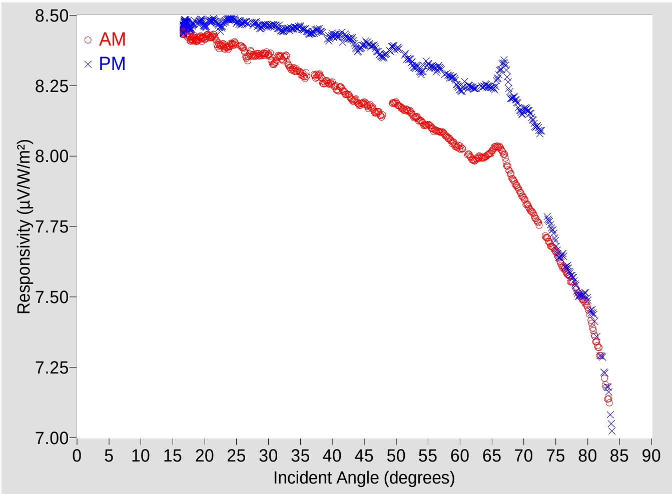


Figure 2. Responsivity vs Local Standard Time

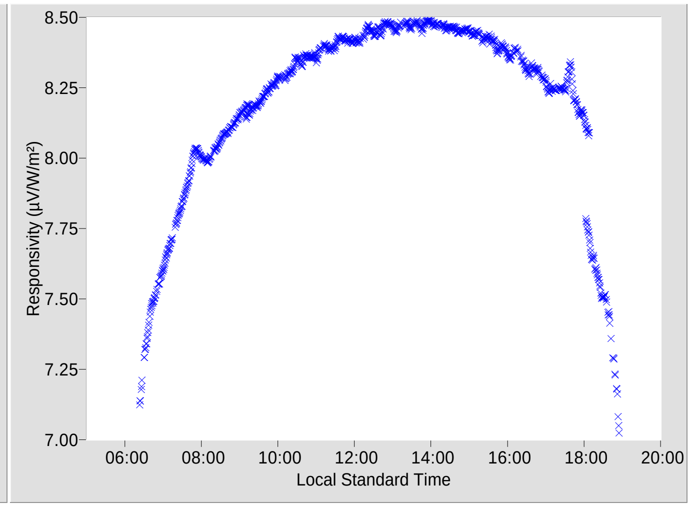


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2934	+2.65 / -3.69	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1766	0.58	97.12	8.3926	0.59	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1391	N/A	95.69	8.3536	0.58	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1872	0.62	101.86	8.3811	0.58	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1601	0.66	99.99	8.3447	0.66	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1228	0.67	98.25	8.3020	0.66	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0931	0.68	96.58	8.3115	0.63	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0673	0.73	94.94	8.2890	0.65	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0307	0.72	93.35	8.2348	0.73	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9876	0.76	91.83	8.2434	0.69	274.97
18	8.4160	0.57	155.47	8.4606	0.52	204.59	64	7.9989	0.81	90.31	8.2502	0.72	276.34
20	8.4203	0.48	142.76	8.4639	0.50	217.19	66	8.0329	0.86	88.80	8.2868	1.00	277.74
22	8.3987	0.56	134.48	8.4694	0.54	225.47	68	7.9324	1.09	87.37	8.2099	1.15	279.13
24	8.3946	0.50	128.33	8.4861	0.49	231.62	70	7.8508	1.10	85.91	8.1623	0.91	280.53
26	8.3837	0.57	123.46	8.4731	0.48	236.46	72	7.7721	1.12	84.46	8.1041	1.06	281.86
28	8.3578	0.49	119.31	8.4716	0.50	240.67	74	7.6948	1.24	83.06	7.7633	1.46	279.00
30	8.3620	0.55	115.71	8.4627	0.48	244.16	76	7.6094	1.47	81.59	7.6479	1.60	280.41
32	8.3507	0.50	112.66	8.4459	0.51	247.31	78	7.5382	1.69	80.17	7.5466	1.88	281.83
34	8.3085	0.51	109.79	8.4555	0.51	250.16	80	7.4618	2.11	78.72	7.4932	2.15	283.26
36	8.2854	0.51	107.44	8.4428	0.53	252.67	82	7.3015	2.83	77.33	7.2908	2.96	284.77
38	8.2869	0.54	104.99	8.4450	0.52	255.00	84	N/A	N/A	N/A	7.0242	N/A	286.08
40	8.2572	0.56	102.85	8.4270	0.54	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2236	0.58	100.78	8.4258	0.57	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1899	0.54	98.96	8.3763	0.62	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31290F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

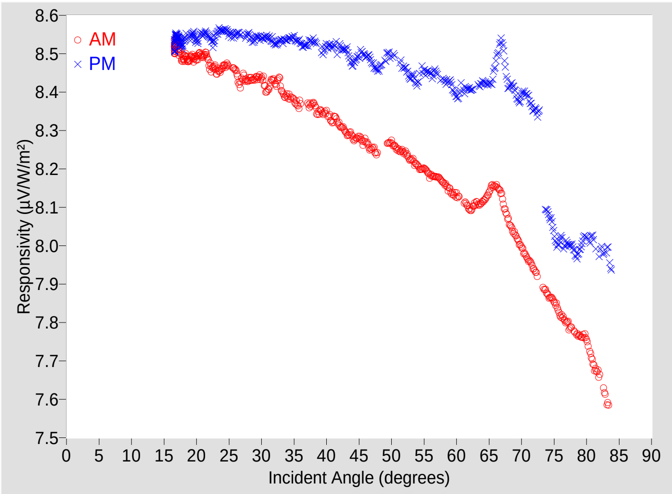


Figure 4. Responsivity vs Local Standard Time

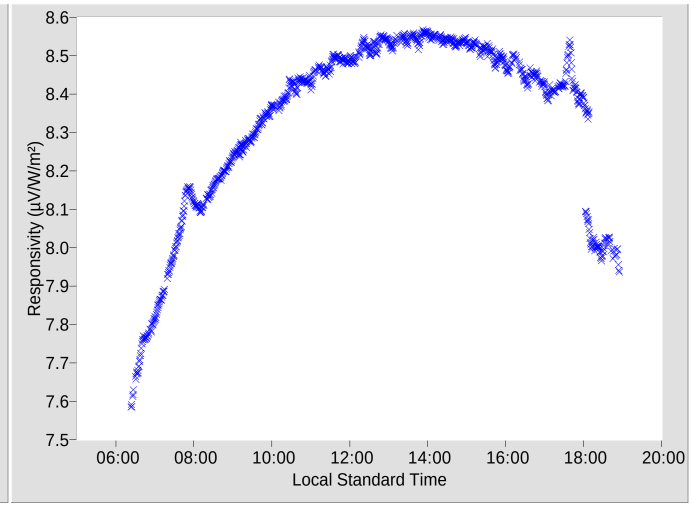


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3895	+2.46 / -3.65	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.59895 µV/W/m², determination date: 06/09/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2721	0.61	97.12	8.4940	0.61	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2365	N/A	95.69	8.4595	0.62	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2673	0.65	101.86	8.4931	0.63	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2419	0.67	99.99	8.4644	0.69	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2097	0.69	98.25	8.4282	0.71	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1827	0.70	96.58	8.4476	0.68	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1631	0.74	94.94	8.4319	0.70	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1316	0.75	93.35	8.3880	0.78	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0956	0.79	91.83	8.4078	0.76	274.97
18	8.4877	0.59	155.47	8.5305	0.54	204.59	64	8.1148	0.85	90.31	8.4243	0.80	276.34
20	8.4896	0.50	142.76	8.5350	0.52	217.19	66	8.1552	0.89	88.80	8.4759	1.11	277.74
22	8.4708	0.58	134.48	8.5416	0.55	225.47	68	8.0661	1.09	87.37	8.4169	1.14	279.13
24	8.4653	0.52	128.33	8.5602	0.51	231.62	70	7.9975	1.10	85.91	8.3917	1.01	280.53
26	8.4566	0.58	123.46	8.5493	0.51	236.46	72	7.9356	1.16	84.46	8.3542	1.13	281.86
28	8.4315	0.51	119.31	8.5487	0.52	240.67	74	7.8750	1.27	83.06	8.0857	1.55	279.00
30	8.4374	0.57	115.71	8.5408	0.51	244.16	76	7.8183	1.49	81.59	8.0197	1.72	280.41
32	8.4279	0.54	112.66	8.5265	0.53	247.31	78	7.7805	1.72	80.17	7.9904	2.02	281.83
34	8.3904	0.53	109.79	8.5384	0.53	250.16	80	7.7551	2.11	78.72	8.0231	2.38	283.26
36	8.3688	0.54	107.44	8.5270	0.56	252.67	82	7.6662	2.69	77.33	7.9813	3.06	284.77
38	8.3695	0.55	104.99	8.5323	0.55	255.00	84	N/A	N/A	N/A	7.9371	N/A	286.08
40	8.3455	0.58	102.85	8.5171	0.57	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3138	0.60	100.78	8.5181	0.60	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2844	0.58	98.96	8.4726	0.64	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31290F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

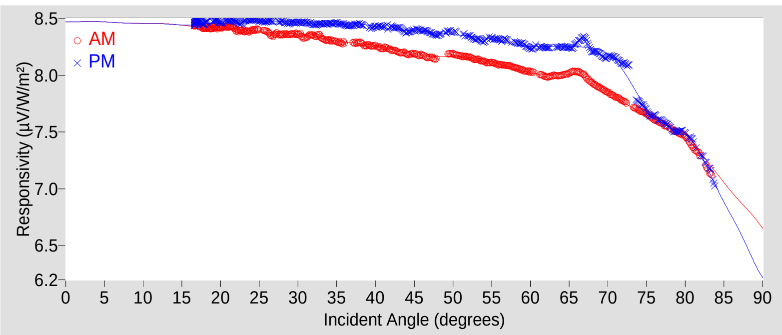
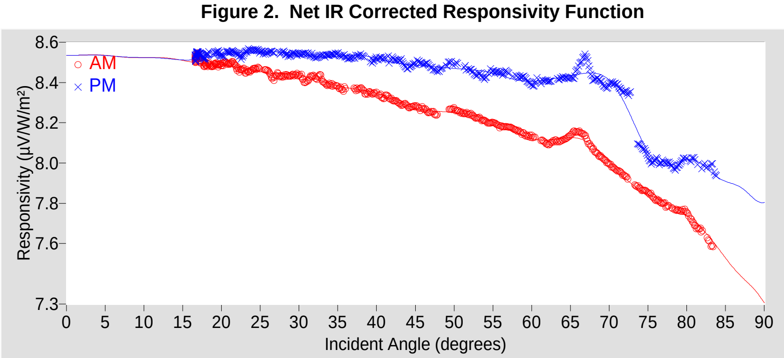


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.45	±1.45
R²	0.9999984	0.9999955
Valid incidence angle range	16.6° to 83.4°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.47	±1.47
Net IR corrected R²	0.9999987	0.9999966
Corr. valid inc. angle range	16.6° to 83.4°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.4666	*	8.4666	*	8.4666	*	8.5328	*	8.5328	*	8.5328	*
9-18	8.4455	*	8.4491	*	8.4473	*	8.5148	*	8.5183	*	8.5166	*
18-27	8.4010	±1.48	8.4712	±1.46	8.4361	±1.70	8.4722	±1.49	8.5440	±1.48	8.5081	±1.71
27-36	8.3428	±1.52	8.4573	±1.46	8.4001	±2.11	8.4201	±1.52	8.5373	±1.47	8.4787	±2.07
36-45	8.2469	±1.60	8.4248	±1.49	8.3359	±2.74	8.3351	±1.58	8.5153	±1.49	8.4252	±2.64
45-54	8.1623	±1.46	8.3624	±1.49	8.2624	±2.57	8.2509	±1.49	8.4729	±1.48	8.3619	±2.66
54-63	8.0583	±1.65	8.2763	±1.53	8.1673	±3.15	8.1550	±1.60	8.4217	±1.50	8.2883	±3.26
63-72	7.9417	±2.01	8.2203	±1.77	8.0810	±4.46	8.0732	±1.85	8.4227	±1.61	8.2479	±4.63
72-81	7.6025	±2.72	7.6788	±4.07	7.6407	±6.17	7.8230	±1.95	8.0702	±2.43	7.9466	±5.42
81-90	7.0207	*	6.8218	*	6.9212	*	7.5113	*	7.9038	*	7.7075	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.2934	+2.65 / -3.69
45° - 55°	8.2569	±2.19
Composite	8.3195	+2.39 / -14.85
45° (Net IR Corr.)	8.3895	+2.46 / -3.65
45° - 55° (Net IR Corr.)	8.3575	±2.23
Composite (Net IR Corr.)	8.4214	+2.13 / -9.79

† Valid incident angle ranges:

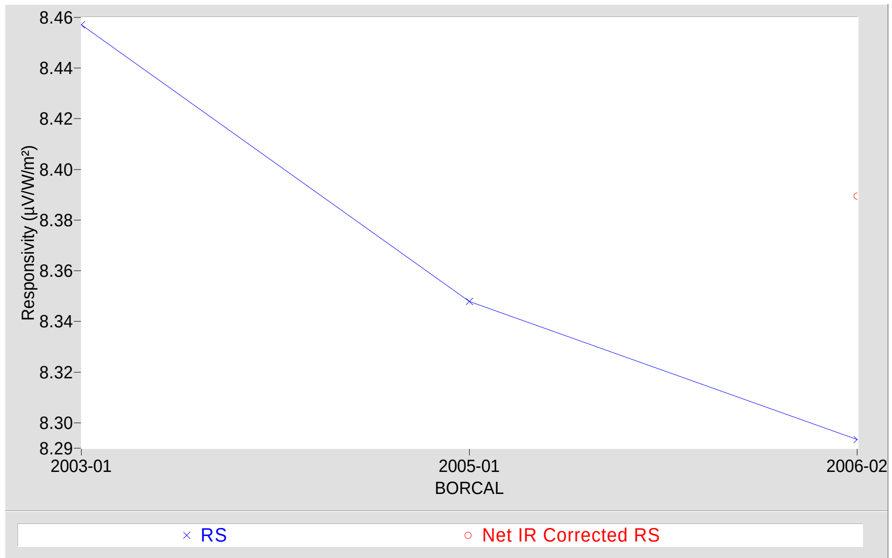
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.4°, 16.6° to 83.4° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



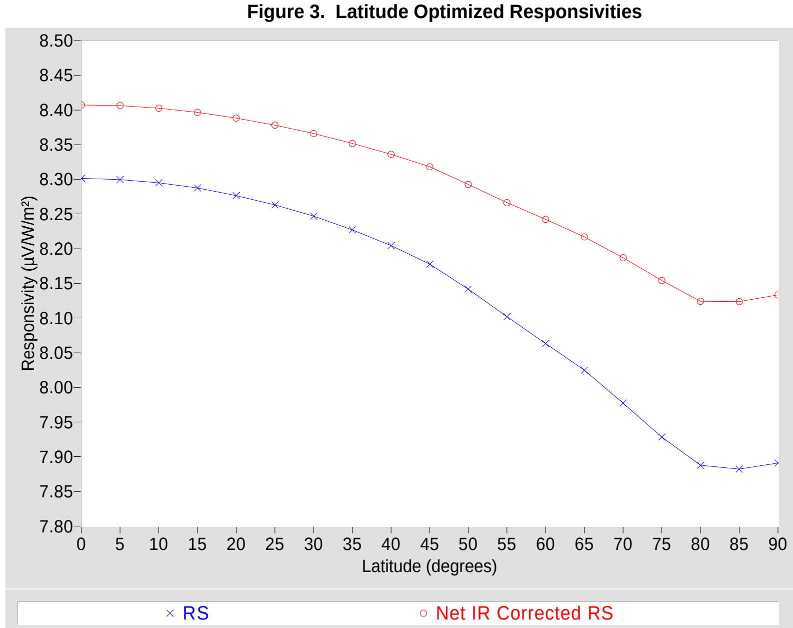
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.3012	+2.57 / -23.65	8.4074	+2.26 / -12.54
5	8.2996	+2.58 / -23.64	8.4061	+2.27 / -12.53
10	8.2950	+2.63 / -23.60	8.4025	+2.30 / -12.49
15	8.2875	+2.71 / -23.53	8.3968	+2.36 / -12.43
20	8.2766	+2.82 / -23.43	8.3883	+2.44 / -12.34
25	8.2631	+2.97 / -23.30	8.3781	+2.54 / -12.24
30	8.2470	+3.14 / -23.15	8.3661	+2.66 / -12.11
35	8.2269	+3.37 / -22.96	8.3516	+2.81 / -11.96
40	8.2046	+3.62 / -22.76	8.3362	+2.97 / -11.80
45	8.1778	+3.93 / -22.50	8.3181	+3.17 / -11.61
50	8.1416	+4.35 / -22.16	8.2927	+3.45 / -11.34
55	8.1019	+4.60 / -21.78	8.2663	+3.58 / -11.06
60	8.0632	+5.03 / -21.40	8.2423	+3.86 / -10.80
65	8.0246	+5.11 / -21.03	8.2171	+3.85 / -10.53
70	7.9775	+5.30 / -20.56	8.1872	+3.91 / -10.21
75	7.9282	+5.52 / -20.07	8.1539	+4.11 / -9.84
80	7.8878	+5.42 / -19.66	8.1243	+4.23 / -9.52
85	7.8823	+4.92 / -19.60	8.1235	+4.24 / -9.51
90	7.8907	+4.77 / -19.69	8.1336	+4.12 / -9.62

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

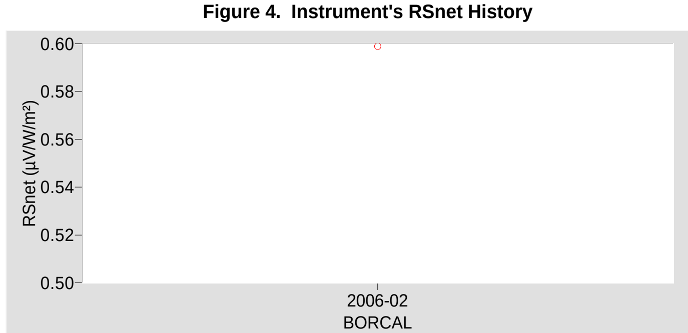
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer | **Manufacturer:** Eppley

Model: PSP | **Serial Number:** 31295F3

Calibration Date: 8/12/2006 | **Due Date:** 8/12/2007

Customer: TWP | **Calibration Site Parameters:** see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

31295F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

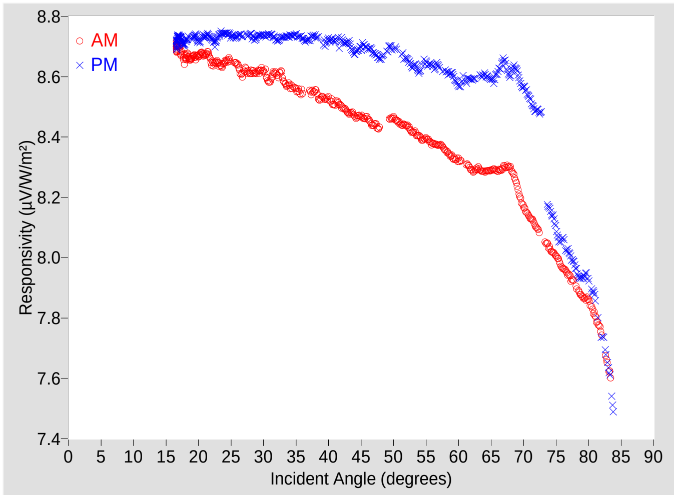


Figure 2. Responsivity vs Local Standard Time

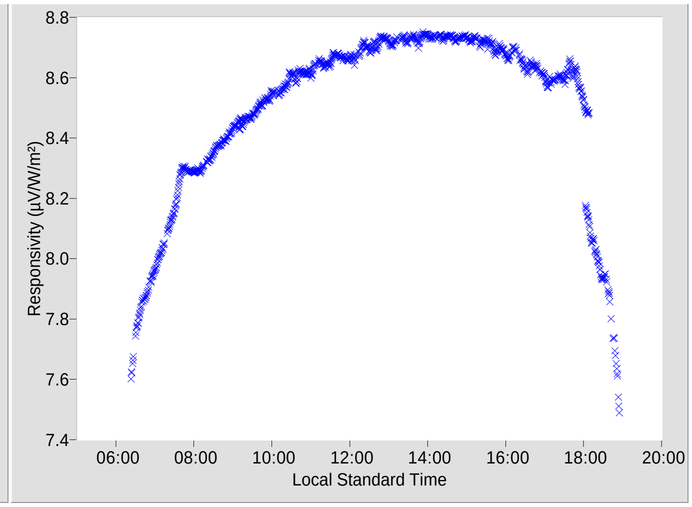


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5845	+2.38 / -3.56	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4619	0.57	97.12	8.6937	0.58	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4264	N/A	95.69	8.6610	0.58	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4621	0.62	101.86	8.6928	0.58	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4374	0.65	99.99	8.6599	0.65	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4025	0.67	98.25	8.6222	0.65	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3783	0.67	96.58	8.6347	0.62	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3550	0.72	94.94	8.6182	0.64	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3240	0.71	93.35	8.5703	0.71	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2910	0.76	91.83	8.5918	0.68	274.97
18	8.6629	0.61	155.47	8.7152	0.50	204.59	64	8.2861	0.79	90.31	8.6054	0.72	276.34
20	8.6695	0.48	142.76	8.7191	0.50	217.19	66	8.2897	0.85	88.80	8.6157	0.90	277.74
22	8.6494	0.54	134.48	8.7251	0.54	225.47	68	8.2950	0.96	87.37	8.6099	0.87	279.13
24	8.6485	0.51	128.33	8.7432	0.49	231.62	70	8.1709	1.16	85.91	8.5631	1.02	280.53
26	8.6396	0.54	123.46	8.7346	0.48	236.46	72	8.0999	1.10	84.46	8.4883	1.00	281.86
28	8.6133	0.49	119.31	8.7386	0.49	240.67	74	8.0334	1.21	83.06	8.1589	1.42	279.00
30	8.6208	0.55	115.71	8.7368	0.48	244.16	76	7.9659	1.42	81.59	8.0631	1.57	280.41
32	8.6097	0.52	112.66	8.7225	0.50	247.31	78	7.9095	1.66	80.17	7.9677	1.84	281.83
34	8.5713	0.50	109.79	8.7351	0.50	250.16	80	7.8584	1.98	78.72	7.9268	2.12	283.26
36	8.5474	0.51	107.44	8.7266	0.53	252.67	82	7.7566	2.67	77.33	7.7369	2.96	284.77
38	8.5518	0.54	104.99	8.7314	0.52	255.00	84	N/A	N/A	N/A	7.4887	N/A	286.08
40	8.5269	0.53	102.85	8.7201	0.54	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5008	0.56	100.78	8.7206	0.57	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4711	0.54	98.96	8.6778	0.60	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31295F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

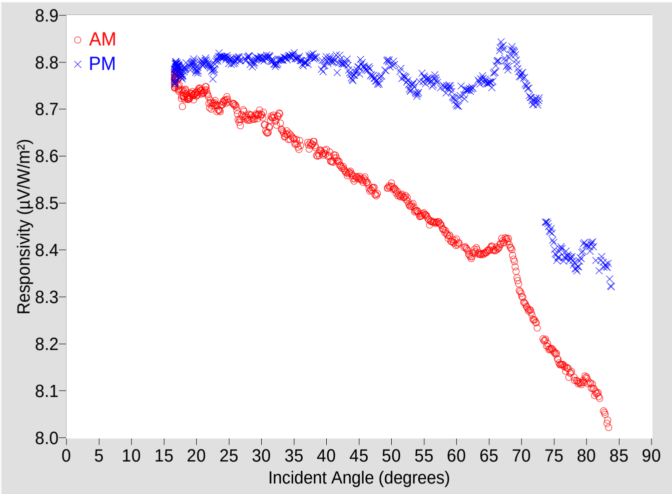


Figure 4. Responsivity vs Local Standard Time

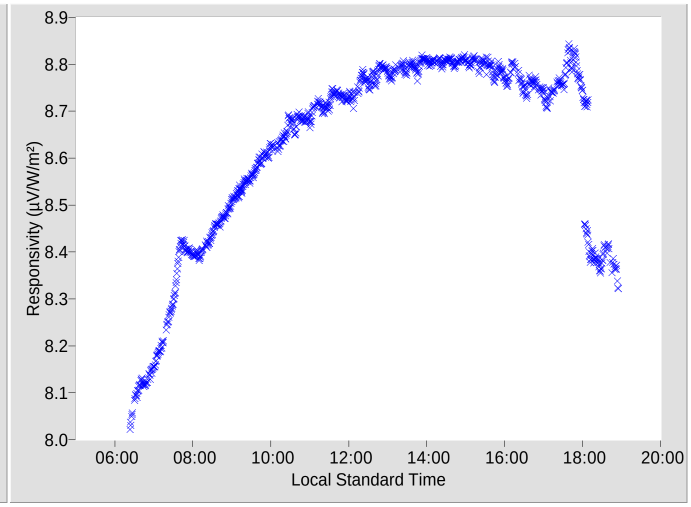


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6722	+2.27 / -3.53	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.54645 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5489	0.59	97.12	8.7862	0.61	262.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5153	N/A	95.69	8.7576	0.62	264.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5352	0.64	101.86	8.7950	0.62	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5121	0.66	99.99	8.7691	0.68	267.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4818	0.68	98.25	8.7374	0.70	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4601	0.69	96.58	8.7590	0.67	270.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4424	0.74	94.94	8.7485	0.69	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4160	0.74	93.35	8.7101	0.76	273.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3894	0.79	91.83	8.7417	0.76	274.97
18	8.7282	0.63	155.47	8.7789	0.52	204.59	64	8.3919	0.82	90.31	8.7642	0.79	276.34
20	8.7327	0.50	142.76	8.7840	0.51	217.19	66	8.4013	0.89	88.80	8.7882	1.01	277.74
22	8.7152	0.56	134.48	8.7910	0.55	225.47	68	8.4170	0.98	87.37	8.7988	0.94	279.13
24	8.7130	0.52	128.33	8.8108	0.51	231.62	70	8.3047	1.15	85.91	8.7724	1.06	280.53
26	8.7061	0.56	123.46	8.8041	0.50	236.46	72	8.2492	1.14	84.46	8.7164	1.09	281.86
28	8.6806	0.51	119.31	8.8089	0.51	240.67	74	8.1979	1.24	83.06	8.4530	1.51	279.00
30	8.6895	0.57	115.71	8.8080	0.51	244.16	76	8.1565	1.45	81.59	8.4022	1.69	280.41
32	8.6802	0.55	112.66	8.7960	0.53	247.31	78	8.1306	1.69	80.17	8.3726	1.98	281.83
34	8.6460	0.52	109.79	8.8108	0.53	250.16	80	8.1260	2.04	78.72	8.4103	2.33	283.26
36	8.6235	0.54	107.44	8.8035	0.55	252.67	82	8.0894	2.61	77.33	8.3669	3.00	284.77
38	8.6272	0.55	104.99	8.8111	0.55	255.00	84	N/A	N/A	N/A	8.3216	N/A	286.08
40	8.6075	0.56	102.85	8.8023	0.57	257.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5832	0.58	100.78	8.8047	0.60	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5573	0.57	98.96	8.7657	0.62	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31295F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

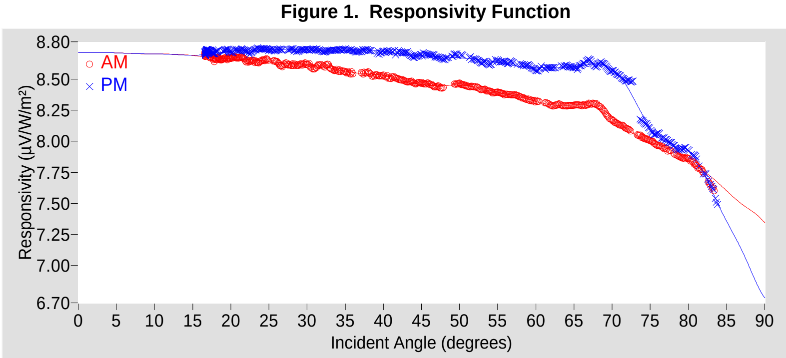
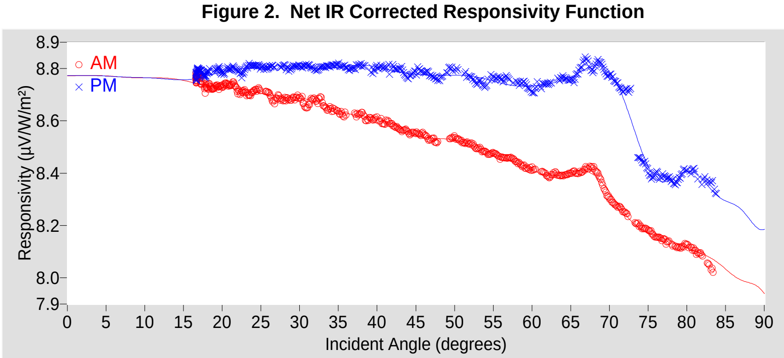


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.39	±1.39
R²	0.9999990	0.9999970
Valid incidence angle range	16.6° to 83.4°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.42	±1.42
Net IR corrected R²	0.9999992	0.9999977
Corr. valid inc. angle range	16.6° to 83.4°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.7099	*	8.7099	*	8.7099	*	8.7704	*	8.7703	*	8.7704	*
9-18	8.6936	*	8.6978	*	8.6957	*	8.7568	*	8.7610	*	8.7589	*
18-27	8.6526	±1.41	8.7281	±1.40	8.6904	±1.65	8.7176	±1.43	8.7946	±1.43	8.7561	±1.68
27-36	8.6020	±1.45	8.7321	±1.39	8.6670	±2.06	8.6725	±1.46	8.8050	±1.42	8.7388	±2.03
36-45	8.5186	±1.49	8.7171	±1.41	8.6178	±2.65	8.5990	±1.49	8.7996	±1.43	8.6993	±2.57
45-54	8.4432	±1.41	8.6722	±1.41	8.5577	±2.65	8.5241	±1.45	8.7730	±1.42	8.6485	±2.75
54-63	8.3473	±1.56	8.6078	±1.42	8.4775	±3.28	8.4355	±1.52	8.7404	±1.43	8.5880	±3.37
63-72	8.2514	±1.74	8.5913	±1.61	8.4214	±4.51	8.3713	±1.66	8.7760	±1.53	8.5736	±4.76
72-81	7.9624	±2.20	8.0912	±3.63	8.0268	±5.84	8.1636	±1.65	8.4483	±2.29	8.3059	±5.19
81-90	7.5785	*	7.2998	*	7.4392	*	8.0261	*	8.2870	*	8.1566	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.5845	+2.38 / -3.56
45° - 55°	8.5523	±2.21
Composite	8.5976	+2.16 / -12.29
45° (Net IR Corr.)	8.6722	+2.27 / -3.53
45° - 55° (Net IR Corr.)	8.6441	±2.26
Composite (Net IR Corr.)	8.6906	+2.00 / -7.30

† Valid incident angle ranges:

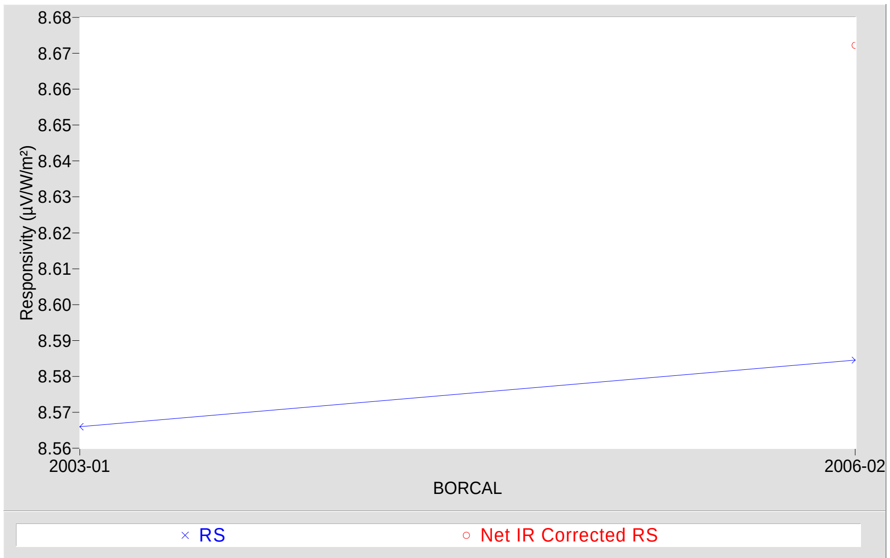
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)

45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)

Composite: 16.6° to 83.4°, 16.6° to 83.4° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



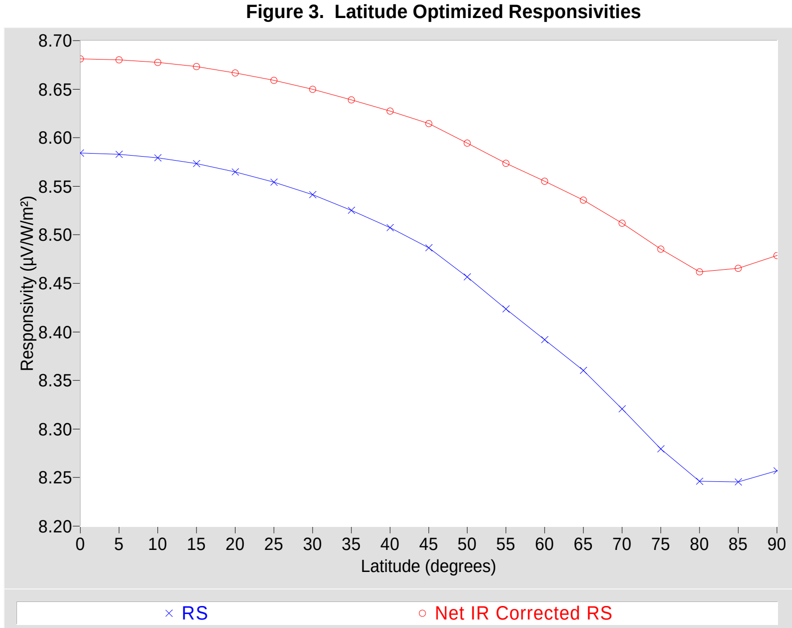
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5842	+2.29 / -20.25	8.6811	+2.07 / -8.31
5	8.5830	+2.30 / -20.24	8.6801	+2.08 / -8.30
10	8.5794	+2.33 / -20.20	8.6775	+2.11 / -8.28
15	8.5735	+2.39 / -20.15	8.6732	+2.14 / -8.23
20	8.5649	+2.47 / -20.07	8.6668	+2.20 / -8.17
25	8.5541	+2.58 / -19.97	8.6591	+2.27 / -8.08
30	8.5413	+2.71 / -19.85	8.6500	+2.35 / -7.99
35	8.5253	+2.88 / -19.70	8.6391	+2.46 / -7.87
40	8.5075	+3.07 / -19.53	8.6275	+2.57 / -7.75
45	8.4866	+3.30 / -19.33	8.6146	+2.70 / -7.62
50	8.4566	+3.63 / -19.05	8.5945	+2.91 / -7.40
55	8.4236	+3.94 / -18.73	8.5736	+3.13 / -7.18
60	8.3919	+4.31 / -18.42	8.5553	+3.33 / -6.99
65	8.3602	+4.46 / -18.12	8.5358	+3.52 / -6.78
70	8.3208	+4.58 / -17.73	8.5122	+3.78 / -6.53
75	8.2794	+4.89 / -17.32	8.4854	+4.08 / -6.24
80	8.2462	+4.76 / -16.99	8.4620	+4.35 / -5.99
85	8.2454	+4.77 / -16.98	8.4654	+4.31 / -6.02
90	8.2572	+4.63 / -17.10	8.4788	+4.16 / -6.17

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

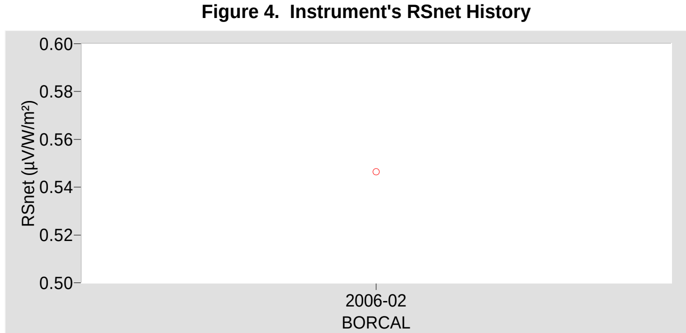
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31344E6
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	NSA	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: _________________	Date: _________________

Calibration Results

31344E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

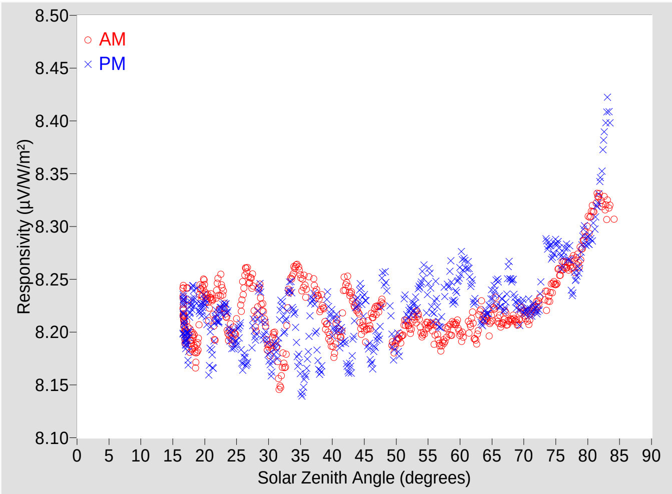


Figure 2. Responsivity vs Local Standard Time

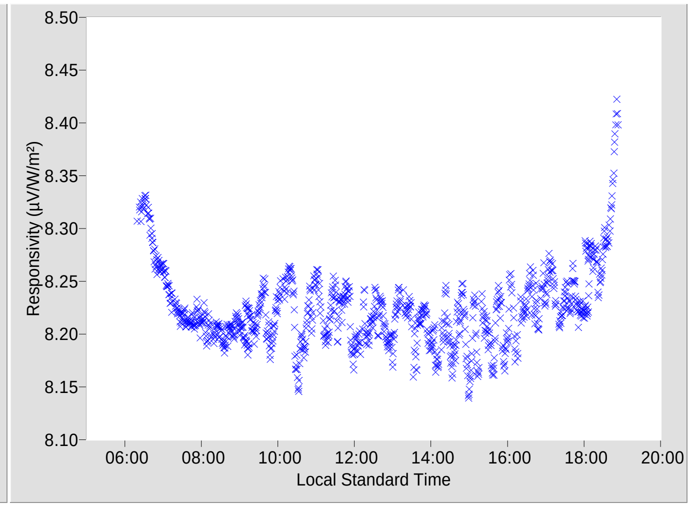


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.2152	+1.01 / -1.29	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2090	0.42	97.17	8.1739	0.57	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2312	N/A	95.63	8.2523	0.54	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1902	0.39	101.85	8.1966	0.49	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2047	0.40	100.04	8.2199	0.40	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1993	0.40	98.24	8.2503	0.47	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2006	0.41	96.56	8.2261	0.51	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2011	0.40	94.92	8.2438	0.49	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1983	0.40	93.39	8.2608	0.47	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2085	0.42	91.82	8.2365	0.45	275.00
18	8.1931	0.59	155.18	8.2314	0.59	204.51	64	8.2119	0.43	90.30	8.2166	0.43	276.38
20	8.2413	0.50	142.71	8.2247	0.59	217.33	66	8.2147	0.42	88.84	8.2362	0.42	277.74
22	8.2340	0.53	134.61	8.2127	0.52	225.43	68	8.2115	0.39	87.36	8.2495	0.46	279.12
24	8.1985	0.44	128.44	8.1959	0.45	231.45	70	8.2161	0.40	85.90	8.2229	0.41	280.48
26	8.2382	0.45	123.43	8.1741	0.46	236.43	72	8.2247	0.40	84.50	8.2211	0.43	281.89
28	8.2133	0.49	119.29	8.2033	0.52	240.64	74	8.2352	0.43	83.01	8.2827	0.43	278.99
30	8.1846	0.48	115.69	8.1779	0.48	244.24	76	8.2611	0.43	81.62	8.2680	0.45	280.40
32	8.1605	0.52	112.56	8.2240	0.50	247.38	78	8.2663	0.45	80.15	8.2521	0.53	281.91
34	8.2585	0.45	109.85	8.2169	0.65	250.07	80	8.3012	0.51	78.66	8.2856	0.49	283.25
36	8.2393	0.39	107.50	8.1681	0.68	252.58	82	8.3257	0.51	77.27	8.3431	0.86	284.70
38	8.2269	0.47	104.97	8.1648	0.60	254.91	84	8.3071	N/A	75.67	N/A	N/A	N/A
40	8.1831	0.43	102.79	8.2104	0.45	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2446	0.51	100.83	8.1798	0.45	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2196	0.44	98.95	8.2306	0.56	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31344E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

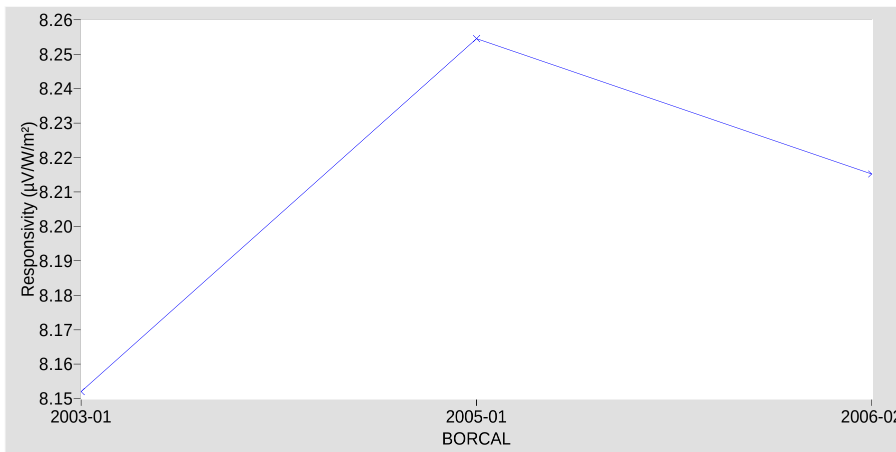
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2152	+1.01 / -1.29 †
Average	8.2242	+2.31 / -1.36 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer | **Manufacturer:** Eppley

Model: NIP | **Serial Number:** 31345E6

Calibration Date: 8/12/2006 | **Due Date:** 8/12/2007

Customer: TWP | **Calibration Site Parameters:** see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31345E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

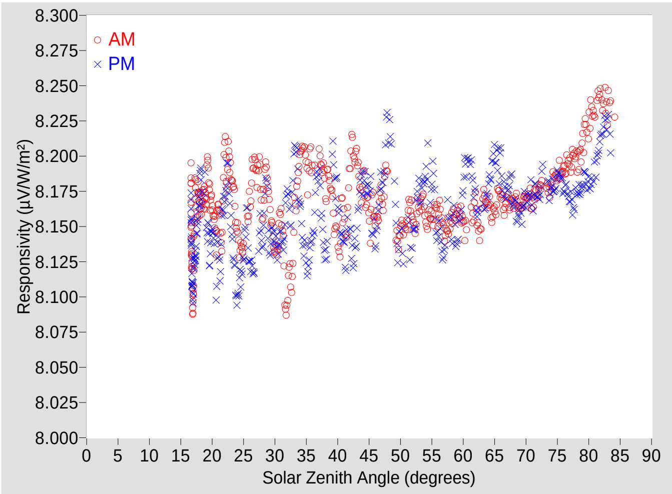


Figure 2. Responsivity vs Local Standard Time

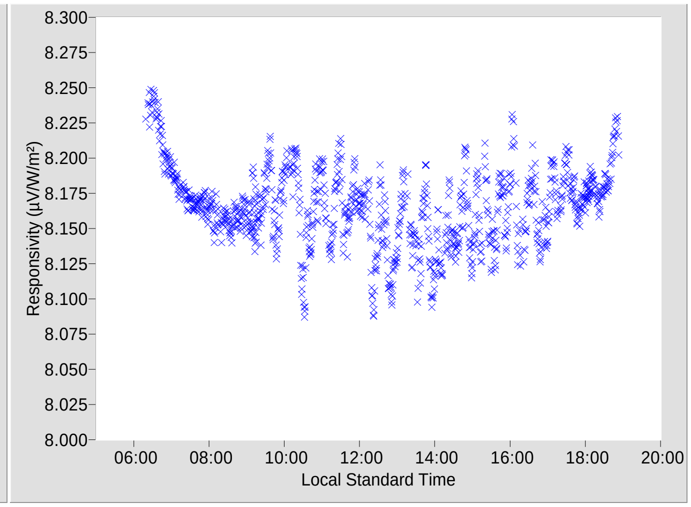


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1671	+1.15 / -1.35	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1566	0.45	97.17	8.1447	0.50	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1896	N/A	95.63	8.2235	0.48	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1481	0.40	101.85	8.1476	0.52	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1566	0.41	100.04	8.1446	0.51	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1547	0.41	98.24	8.1860	0.46	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1609	0.42	96.56	8.1458	0.57	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1543	0.39	94.92	8.1451	0.43	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1513	0.41	93.39	8.1829	0.52	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1638	0.44	91.82	8.1661	0.45	275.00
18	8.1685	0.60	155.18	8.1736	0.62	204.51	64	8.1665	0.41	90.30	8.1792	0.47	276.38
20	8.1649	0.56	142.71	8.1438	0.50	217.33	66	8.1724	0.40	88.84	8.1900	0.44	277.74
22	8.1941	0.62	134.61	8.1704	0.63	225.43	68	8.1672	0.39	87.36	8.1661	0.43	279.12
24	8.1479	0.50	128.44	8.1001	0.54	231.45	70	8.1711	0.40	85.90	8.1690	0.43	280.48
26	8.1665	0.46	123.43	8.1258	0.47	236.43	72	8.1753	0.41	84.50	8.1719	0.43	281.89
28	8.1668	0.46	119.29	8.1448	0.49	240.64	74	8.1781	0.41	83.01	8.1783	0.44	278.99
30	8.1332	0.44	115.69	8.1407	0.40	244.24	76	8.1903	0.42	81.62	8.1774	0.44	280.40
32	8.1030	0.54	112.56	8.1714	0.48	247.38	78	8.1986	0.44	80.15	8.1744	0.47	281.91
34	8.1979	0.52	109.85	8.1639	0.63	250.07	80	8.2211	0.50	78.66	8.1794	0.49	283.25
36	8.1961	0.42	107.50	8.1429	0.59	252.58	82	8.2410	0.51	77.27	8.2141	0.61	284.70
38	8.1779	0.43	104.97	8.1317	0.54	254.91	84	8.2278	N/A	75.67	N/A	N/A	N/A
40	8.1391	0.47	102.79	8.1711	0.57	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1958	0.58	100.83	8.1402	0.44	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1810	0.46	98.95	8.1809	0.45	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31345E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

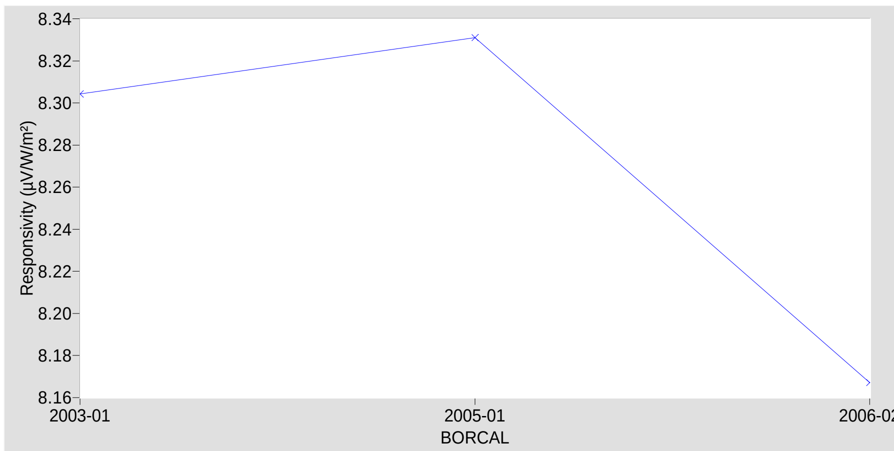
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1671	+1.15 / -1.35 †
Average	8.1672	+1.42 / -1.36 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley

Model: NIP
Serial Number: 31361E6

Calibration Date: 8/12/2006
Due Date: 8/12/2007

Customer: TWP
Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: _________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: _________________

Calibration Results

31361E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

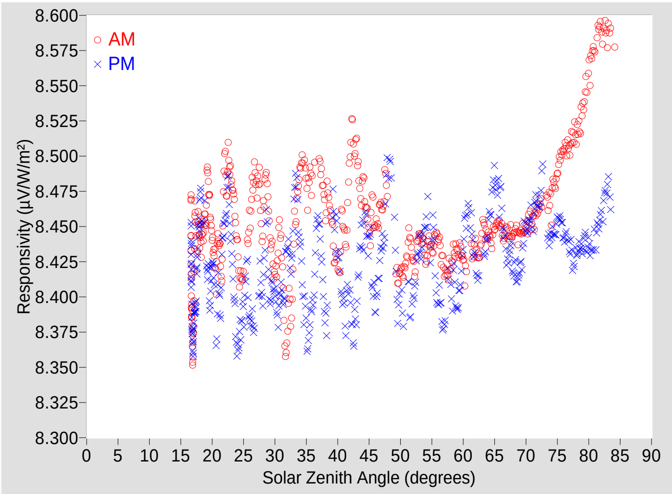


Figure 2. Responsivity vs Local Standard Time

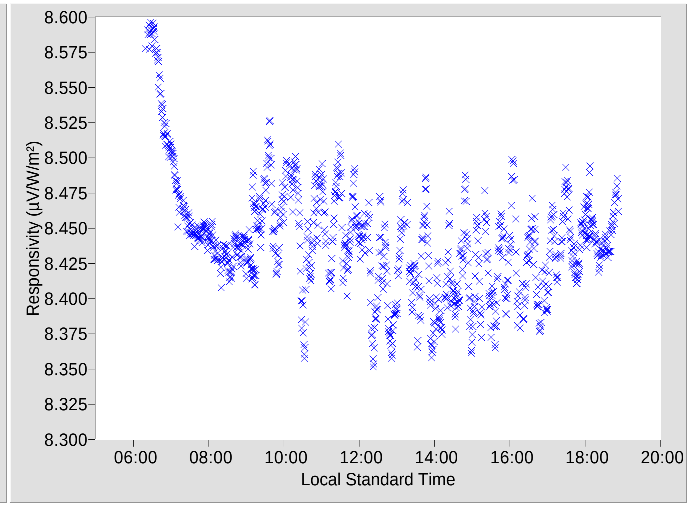


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.4443	+1.34 / -1.39	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4510	0.43	97.17	8.3984	0.52	262.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4794	N/A	95.63	8.4919	0.53	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4186	0.39	101.85	8.4034	0.59	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4259	0.43	100.04	8.4007	0.51	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4283	0.40	98.24	8.4513	0.46	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4418	0.42	96.56	8.3985	0.61	270.67
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4234	0.41	94.92	8.3991	0.44	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4238	0.42	93.39	8.4400	0.58	273.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4352	0.39	91.82	8.4210	0.47	275.00
18	8.4453	0.64	155.18	8.4567	0.74	204.51	64	8.4432	0.40	90.30	8.4515	0.53	276.38
20	8.4430	0.65	142.71	8.4163	0.51	217.33	66	8.4501	0.39	88.84	8.4649	0.52	277.74
22	8.4826	0.69	134.61	8.4533	0.70	225.43	68	8.4448	0.39	87.36	8.4187	0.41	279.12
24	8.4374	0.58	128.44	8.3650	0.64	231.45	70	8.4482	0.40	85.90	8.4494	0.47	280.48
26	8.4541	0.50	123.43	8.3865	0.48	236.43	72	8.4632	0.41	84.50	8.4663	0.47	281.89
28	8.4547	0.48	119.29	8.4084	0.55	240.64	74	8.4701	0.45	83.01	8.4447	0.43	278.99
30	8.4166	0.44	115.69	8.3991	0.42	244.24	76	8.5048	0.43	81.62	8.4441	0.45	280.40
32	8.3810	0.56	112.56	8.4347	0.48	247.38	78	8.5172	0.46	80.15	8.4317	0.46	281.91
34	8.4882	0.52	109.85	8.4377	0.74	250.07	80	8.5591	0.51	78.66	8.4353	0.48	283.25
36	8.4819	0.42	107.50	8.3948	0.68	252.58	82	8.5888	0.49	77.27	8.4570	0.60	284.70
38	8.4639	0.45	104.97	8.3865	0.60	254.91	84	8.5775	N/A	75.67	N/A	N/A	N/A
40	8.4213	0.46	102.79	8.4402	0.61	257.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5025	0.65	100.83	8.3905	0.45	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4793	0.53	98.95	8.4453	0.53	260.95	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31361E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

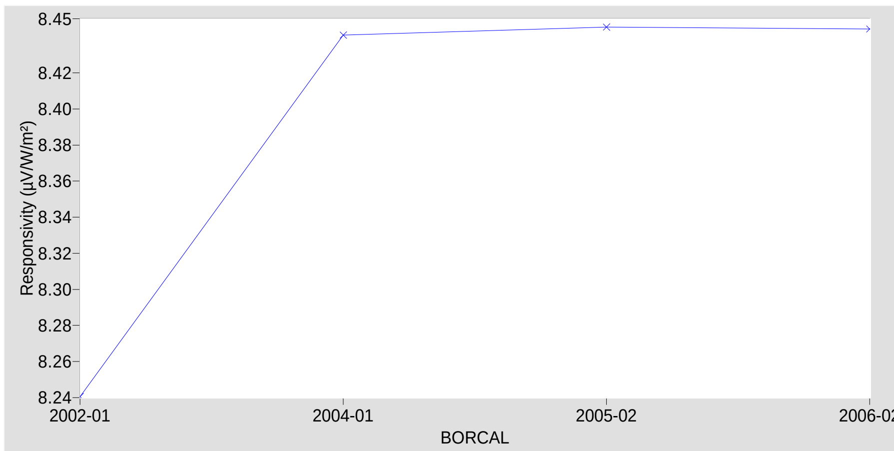
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4443	+1.34 / -1.39 †
Average	8.4432	+2.22 / -1.56 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.5°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 31386E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31386E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

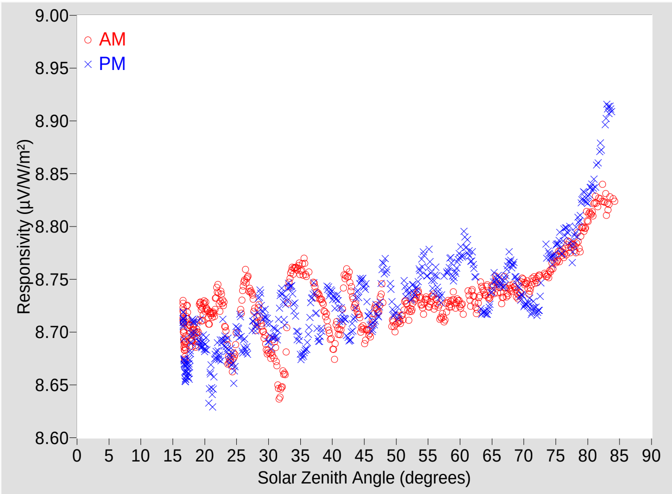


Figure 2. Responsivity vs Local Standard Time

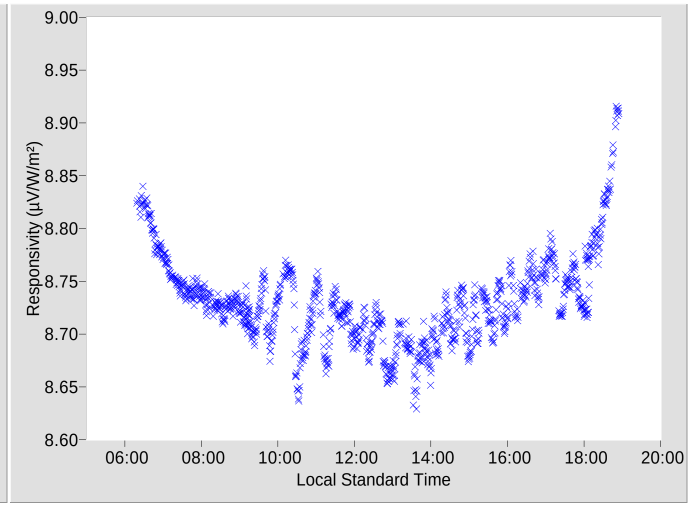


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7211	+1.03 / -1.34	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7021	0.42	97.17	8.7085	0.45	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7458	N/A	95.63	8.7629	0.48	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7080	0.38	101.85	8.7211	0.42	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7202	0.40	100.05	8.7366	0.38	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7250	0.39	98.25	8.7652	0.42	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7285	0.40	96.57	8.7502	0.47	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7256	0.41	94.93	8.7579	0.42	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7265	0.38	93.39	8.7734	0.45	273.54
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7369	0.40	91.83	8.7668	0.42	274.96
18	8.6972	0.44	155.21	8.6980	0.49	204.54	64	8.7391	0.39	90.30	8.7182	0.39	276.38
20	8.7245	0.40	142.74	8.6885	0.59	217.16	66	8.7439	0.41	88.84	8.7490	0.38	277.74
22	8.7369	0.41	134.46	8.6795	0.60	225.29	68	8.7411	0.39	87.37	8.7648	0.41	279.13
24	8.6730	0.53	128.46	8.6759	0.48	231.46	70	8.7479	0.40	85.91	8.7291	0.40	280.48
26	8.7380	0.44	123.44	8.6882	0.43	236.44	72	8.7490	0.39	84.51	8.7196	0.42	281.90
28	8.7126	0.43	119.30	8.7093	0.43	240.65	74	8.7562	0.41	83.01	8.7732	0.42	278.99
30	8.6834	0.40	115.70	8.6998	0.42	244.25	76	8.7744	0.42	81.63	8.7824	0.44	280.40
32	8.6487	0.46	112.57	8.7334	0.46	247.30	78	8.7803	0.43	80.15	8.7919	0.54	281.82
34	8.7598	0.43	109.86	8.7251	0.53	250.07	80	8.8092	0.46	78.71	8.8263	0.48	283.25
36	8.7537	0.38	107.43	8.6878	0.51	252.59	82	8.8258	0.50	77.28	8.8741	0.69	284.72
38	8.7337	0.41	104.98	8.6951	0.49	254.92	84	8.8251	0.55	75.67	8.9087	N/A	286.03
40	8.6871	0.45	102.79	8.7356	0.39	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7521	0.51	100.84	8.7086	0.41	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7179	0.44	98.89	8.7378	0.47	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31386E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

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The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°

Application of the responsivities and uncertainties:

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Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
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Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 31387E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
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Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

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[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

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Calibrated by: Craig Webb and Rod Soper

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Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31387E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

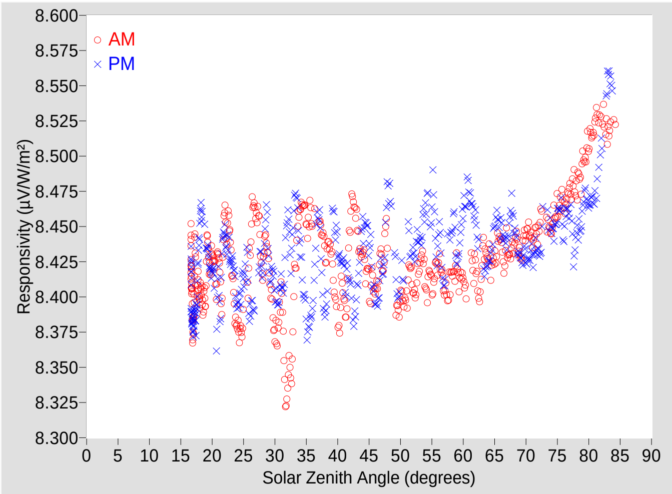


Figure 2. Responsivity vs Local Standard Time

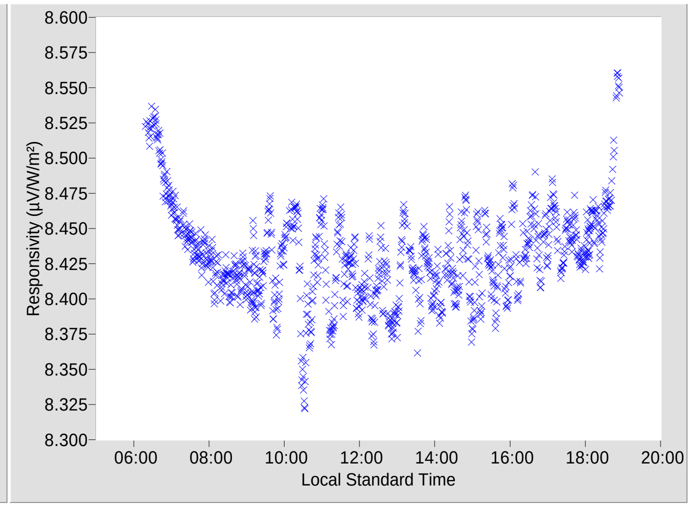


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.4237	+1.16 / -1.58	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4058	0.44	97.17	8.3985	0.48	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4558	N/A	95.63	8.4742	0.54	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3978	0.39	101.85	8.4148	0.42	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4082	0.42	100.05	8.4305	0.41	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4082	0.43	98.25	8.4630	0.43	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4235	0.41	96.57	8.4390	0.61	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4139	0.43	94.93	8.4447	0.47	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4122	0.40	93.39	8.4612	0.52	273.54
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4229	0.43	91.83	8.4525	0.44	274.96
18	8.4045	0.56	155.21	8.4452	0.67	204.54	64	8.4307	0.42	90.30	8.4241	0.43	276.38
20	8.4277	0.46	142.74	8.4182	0.58	217.16	66	8.4390	0.43	88.84	8.4488	0.41	277.74
22	8.4530	0.59	134.46	8.4428	0.55	225.29	68	8.4363	0.40	87.37	8.4527	0.46	279.13
24	8.3802	0.54	128.46	8.3953	0.43	231.46	70	8.4456	0.42	85.91	8.4288	0.39	280.48
26	8.4291	0.56	123.44	8.3935	0.48	236.44	72	8.4465	0.42	84.51	8.4317	0.46	281.90
28	8.4235	0.48	119.30	8.4247	0.48	240.65	74	8.4482	0.43	83.01	8.4499	0.44	278.99
30	8.3743	0.48	115.70	8.4044	0.40	244.25	76	8.4671	0.43	81.63	8.4489	0.46	280.40
32	8.3378	0.61	112.57	8.4514	0.51	247.30	78	8.4773	0.45	80.15	8.4430	0.52	281.82
34	8.4618	0.54	109.86	8.4367	0.64	250.07	80	8.5115	0.47	78.71	8.4659	0.48	283.25
36	8.4511	0.40	107.43	8.3948	0.66	252.59	82	8.5267	0.51	77.28	8.5063	0.76	284.72
38	8.4320	0.41	104.98	8.3904	0.58	254.92	84	8.5242	0.57	75.67	8.5463	N/A	286.03
40	8.3837	0.51	102.79	8.4371	0.44	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4524	0.64	100.84	8.4079	0.46	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4301	0.48	98.89	8.4478	0.47	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results
31387E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (μV/W/m²)

1. The Single Responsivities:

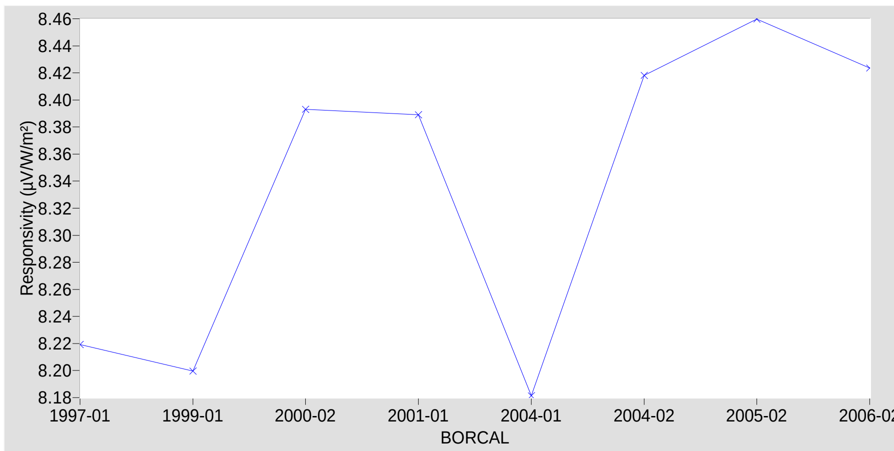
Table 1. Single Responsivities

Responsivity Characterization	RS (μV/W/m²)	U95 (%)
45°	8.4237	+1.16 / -1.58 †
Average	8.4361	+1.62 / -1.77 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 μV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 μV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31388E6
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: ___________________	Date: ___________________

Calibration Results
31388E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

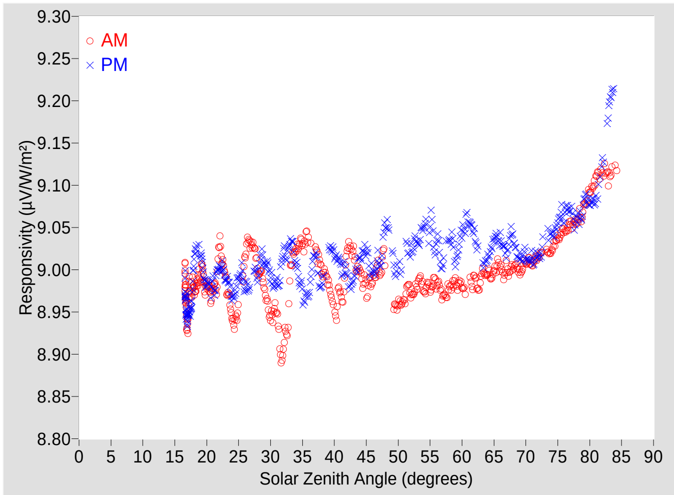


Figure 2. Responsivity vs Local Standard Time

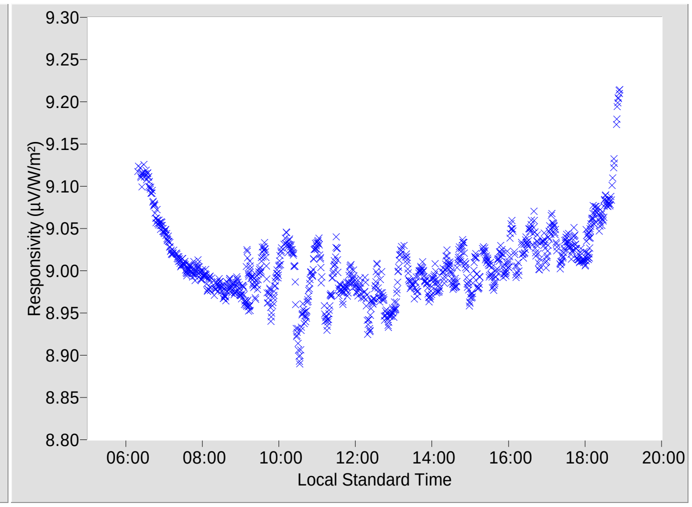


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9996	+1.16 / -1.59	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9869	0.44	97.17	8.9999	0.41	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0250	N/A	95.63	9.0518	0.48	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9583	0.38	101.85	9.0076	0.41	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9728	0.39	100.05	9.0221	0.39	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9762	0.39	98.25	9.0505	0.41	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9832	0.40	96.57	9.0313	0.53	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9793	0.40	94.93	9.0338	0.43	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9809	0.38	93.39	9.0446	0.48	273.54
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9919	0.39	91.83	9.0394	0.41	274.96
18	8.9790	0.56	155.21	9.0032	0.60	204.54	64	8.9967	0.38	90.30	9.0143	0.42	276.38
20	8.9796	0.45	142.74	8.9837	0.47	217.16	66	9.0032	0.40	88.84	9.0340	0.41	277.74
22	9.0249	0.53	134.46	9.0018	0.43	225.29	68	9.0030	0.39	87.37	9.0365	0.43	279.13
24	8.9435	0.50	128.46	8.9680	0.40	231.46	70	9.0085	0.40	85.91	9.0168	0.39	280.48
26	9.0113	0.47	123.44	8.9811	0.41	236.44	72	9.0151	0.40	84.51	9.0167	0.42	281.90
28	9.0021	0.47	119.30	8.9961	0.43	240.65	74	9.0228	0.41	83.01	9.0423	0.42	278.99
30	8.9455	0.43	115.70	8.9914	0.41	244.25	76	9.0465	0.42	81.63	9.0633	0.43	280.40
32	8.9087	0.49	112.57	9.0180	0.45	247.30	78	9.0577	0.43	80.15	9.0627	0.46	281.82
34	9.0240	0.46	109.86	9.0063	0.49	250.07	80	9.0926	0.47	78.71	9.0787	0.46	283.25
36	9.0355	0.39	107.43	8.9737	0.49	252.59	82	9.1149	0.49	77.28	9.1272	0.80	284.72
38	8.9998	0.44	104.98	8.9830	0.44	254.92	84	9.1206	0.55	75.67	9.2143	N/A	286.03
40	8.9514	0.46	102.79	9.0191	0.38	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0206	0.54	100.84	8.9929	0.41	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9969	0.46	98.89	9.0132	0.42	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31388E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9996	+1.16 / -1.59 †
Average	9.0159	+2.04 / -1.67 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°

Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31633F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:
[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31633F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

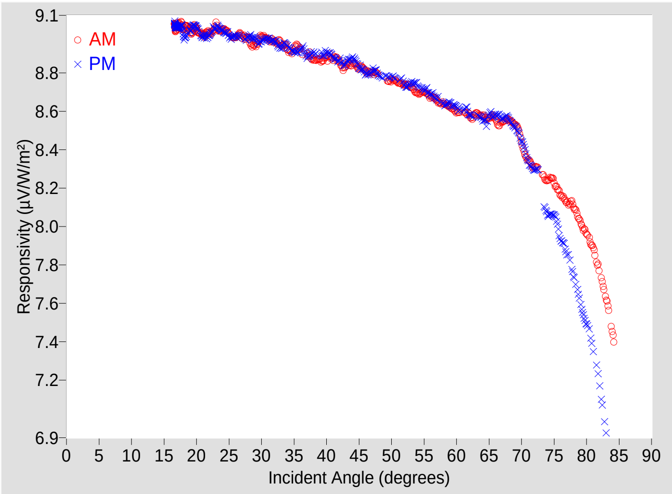


Figure 2. Responsivity vs Local Standard Time

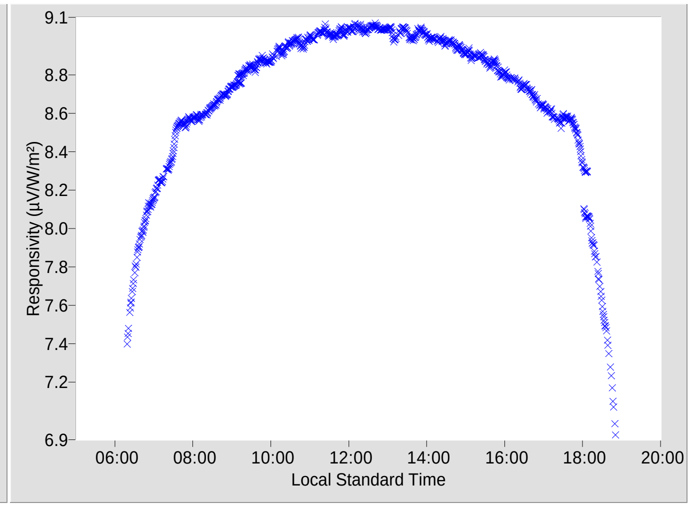


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8281	+2.43 / -3.12	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8093	0.57	97.15	8.7996	0.62	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7984	N/A	95.66	8.7881	0.63	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7625	0.61	101.83	8.7797	0.57	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7395	0.63	100.02	8.7361	0.64	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6945	0.68	98.28	8.7357	0.64	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6750	0.70	96.55	8.6896	0.69	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6418	0.70	94.96	8.6384	0.68	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5969	0.74	93.37	8.6201	0.70	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5793	0.77	91.80	8.5811	0.75	274.99
18	9.0386	0.52	155.33	9.0053	0.65	204.67	64	8.5774	0.81	90.33	8.5573	0.79	276.37
20	9.0276	0.54	142.65	9.0372	0.60	217.08	66	8.5572	0.90	88.82	8.5797	0.80	277.77
22	9.0101	0.57	134.55	8.9989	0.59	225.38	68	8.5560	0.91	87.34	8.5631	0.89	279.11
24	9.0246	0.52	128.25	9.0186	0.55	231.54	70	8.4432	1.46	85.93	8.4435	1.36	280.51
26	8.9858	0.49	123.51	8.9907	0.49	236.51	72	8.3097	1.10	84.49	8.2946	1.01	281.88
28	8.9774	0.59	119.25	8.9891	0.51	240.61	74	8.2411	1.19	83.04	8.0660	1.39	278.97
30	8.9900	0.58	115.76	8.9669	0.51	244.21	76	8.1687	1.49	81.61	7.9301	2.00	280.43
32	8.9639	0.52	112.61	8.9659	0.57	247.26	78	8.1066	1.70	80.17	7.7538	2.29	281.76
34	8.9228	0.56	109.74	8.9391	0.56	250.12	80	7.9656	2.10	78.74	7.4949	2.48	283.23
36	8.9192	0.58	107.29	8.9229	0.58	252.63	82	7.7701	3.02	77.25	7.1672	3.70	284.75
38	8.8691	0.56	104.95	8.9001	0.55	254.96	84	7.4420	3.78	75.75	N/A	N/A	N/A
40	8.8796	0.57	102.78	8.9054	0.56	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8570	0.65	100.81	8.8628	0.58	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8453	0.56	98.93	8.8752	0.63	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

31633F3 Eppley PSP

Figure 3. Responsivity vs Incident Angle

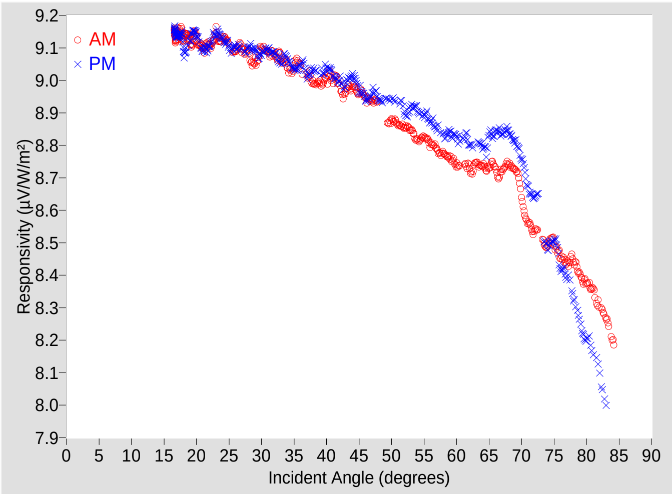


Figure 4. Responsivity vs Local Standard Time

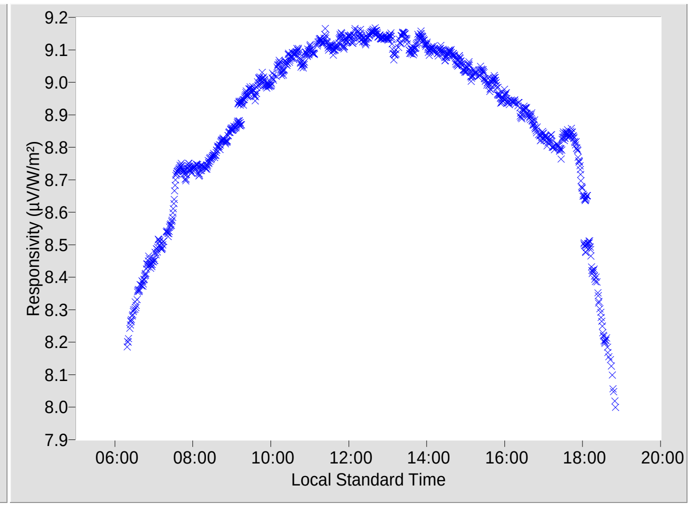


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9662	+2.12 / -3.11	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.65459 µV/W/m², determination date: 06/07/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9444	0.63	97.15	8.9460	0.66	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9335	N/A	95.66	8.9417	0.67	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8759	0.64	101.83	8.9420	0.63	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8557	0.66	100.02	8.9011	0.70	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8162	0.71	98.28	8.9085	0.69	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8028	0.72	96.55	8.8728	0.75	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7755	0.73	94.96	8.8310	0.74	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7380	0.77	93.37	8.8231	0.77	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7294	0.81	91.80	8.8008	0.82	274.99
18	9.1348	0.54	155.33	9.1039	0.67	204.67	64	8.7383	0.85	90.33	8.7950	0.91	276.37
20	9.1301	0.57	142.65	9.1410	0.61	217.08	66	8.7279	0.94	88.82	8.8408	0.90	277.77
22	9.1083	0.59	134.55	9.1065	0.61	225.38	68	8.7418	0.96	87.34	8.8442	0.98	279.11
24	9.1288	0.54	128.25	9.1261	0.59	231.54	70	8.6452	1.41	85.93	8.7560	1.31	280.51
26	9.0900	0.52	123.51	9.1020	0.53	236.51	72	8.5356	1.16	84.49	8.6396	1.16	281.88
28	9.0848	0.60	119.25	9.1015	0.54	240.61	74	8.4911	1.27	83.04	8.4880	1.56	278.97
30	9.0976	0.60	115.76	9.0831	0.55	244.21	76	8.4595	1.50	81.61	8.4196	1.91	280.43
32	9.0770	0.54	112.61	9.0845	0.59	247.26	78	8.4459	1.74	80.17	8.3353	2.21	281.76
34	9.0394	0.58	109.74	9.0629	0.59	250.12	80	8.3787	2.10	78.74	8.2022	2.52	283.23
36	9.0402	0.60	107.29	9.0495	0.60	252.63	82	8.3089	2.78	77.25	8.0941	3.32	284.75
38	8.9915	0.58	104.95	9.0300	0.59	254.96	84	8.1998	3.79	75.75	N/A	N/A	N/A
40	9.0062	0.61	102.78	9.0388	0.60	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9858	0.69	100.81	8.9983	0.62	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9776	0.60	98.93	9.0130	0.66	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31633F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

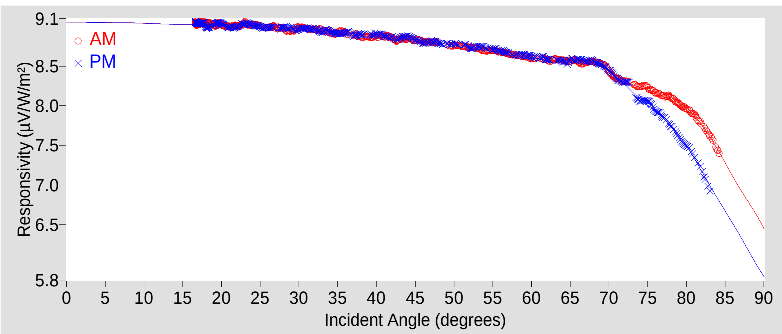
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

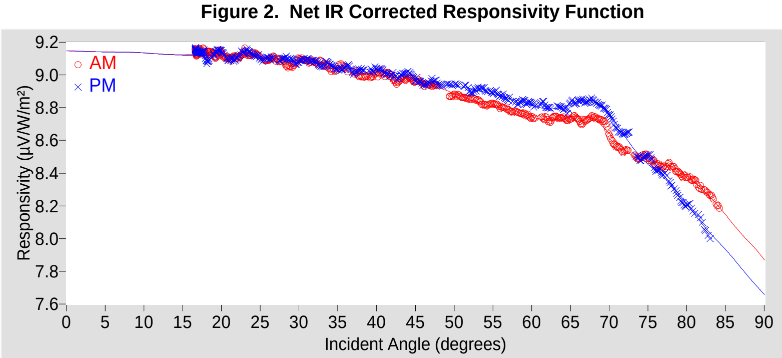


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.73	±1.73
R^2	0.9999992	0.9999988
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.0°
Net IR corr. uncert. U95 (%)	±1.67	±1.67
Net IR corrected R^2	0.9999992	0.9999990
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.0°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	9.0516	*	9.0514	*	9.0515	*	9.1421	*	9.1420	*	9.1421	*
9-18	9.0330	*	9.0305	*	9.0317	*	9.1281	*	9.1258	*	9.1270	*
18-27	9.0159	±1.75	9.0112	±1.74	9.0135	±1.76	9.1173	±1.68	9.1175	±1.68	9.1174	±1.70
27-36	8.9617	±1.79	8.9624	±1.77	8.9621	±1.85	9.0734	±1.71	9.0806	±1.70	9.0770	±1.77
36-45	8.8696	±1.77	8.8891	±1.79	8.8793	±1.86	8.9963	±1.70	9.0222	±1.71	9.0093	±1.78
45-54	8.7732	±1.86	8.7784	±1.83	8.7758	±2.00	8.8979	±1.84	8.9358	±1.72	8.9169	±2.06
54-63	8.6341	±1.89	8.6457	±1.94	8.6399	±2.13	8.7697	±1.76	8.8408	±1.77	8.8053	±2.17
63-72	8.5180	±2.18	8.5217	±2.28	8.5198	±2.95	8.7003	±1.97	8.7983	±1.98	8.7493	±2.89
72-81	8.1506	±2.97	7.8844	±5.69	8.0175	±8.53	8.4577	±1.98	8.4031	±3.14	8.4304	±4.13
81-90	7.1913	*	6.5888	*	6.8900	*	8.1163	*	7.9026	*	8.0095	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

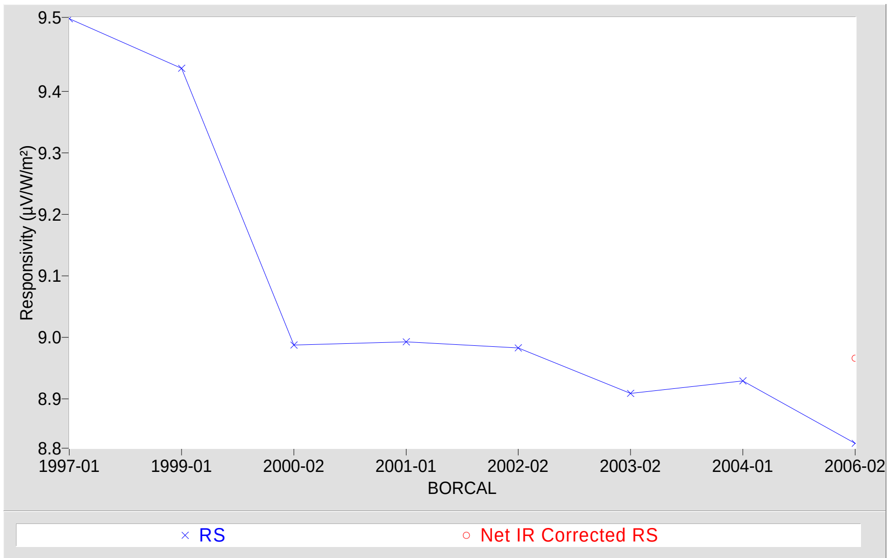
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.8281	+2.43 / -3.12
45° - 55°	8.7655	±1.92
Composite	8.8559	+2.62 / -22.92
45° (Net IR Corr.)	8.9662	+2.12 / -3.11
45° - 55° (Net IR Corr.)	8.9075	±1.91
Composite (Net IR Corr.)	8.9987	+2.21 / -11.40

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.0°, 16.6° to 83.0° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



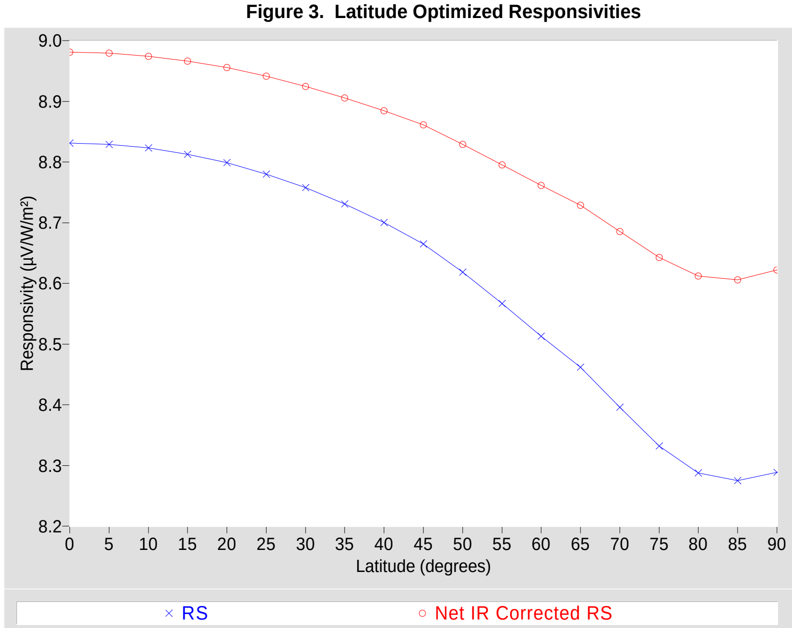
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.8314	+3.09 / -32.07	8.9810	+2.49 / -14.24
5	8.8292	+3.11 / -32.06	8.9792	+2.51 / -14.22
10	8.8230	+3.17 / -32.01	8.9744	+2.55 / -14.17
15	8.8126	+3.27 / -31.93	8.9664	+2.62 / -14.10
20	8.7987	+3.41 / -31.82	8.9558	+2.71 / -14.00
25	8.7802	+3.59 / -31.68	8.9416	+2.84 / -13.86
30	8.7577	+3.75 / -31.50	8.9247	+2.94 / -13.70
35	8.7309	+3.92 / -31.29	8.9054	+3.04 / -13.51
40	8.7005	+4.16 / -31.05	8.8845	+3.22 / -13.31
45	8.6650	+4.52 / -30.77	8.8610	+3.43 / -13.08
50	8.6182	+4.72 / -30.40	8.8289	+3.57 / -12.77
55	8.5669	+5.06 / -29.98	8.7955	+3.70 / -12.44
60	8.5127	+5.08 / -29.53	8.7615	+3.65 / -12.10
65	8.4620	+5.37 / -29.11	8.7287	+3.80 / -11.77
70	8.3956	+5.29 / -28.55	8.6856	+3.57 / -11.34
75	8.3318	+5.45 / -28.01	8.6425	+3.69 / -10.90
80	8.2878	+5.13 / -27.62	8.6120	+3.44 / -10.59
85	8.2749	+4.20 / -27.51	8.6060	+3.27 / -10.53
90	8.2885	+3.89 / -27.63	8.6224	+3.10 / -10.70

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

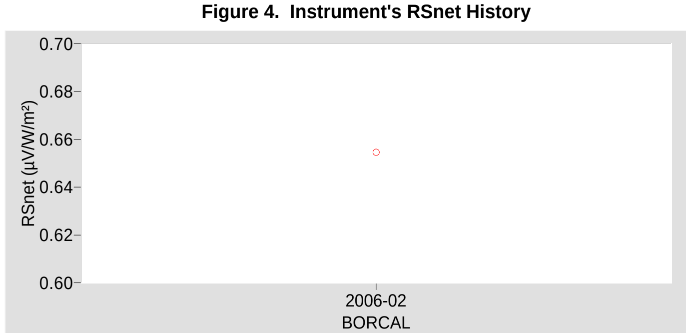
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 31762E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: NSA

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

31762E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

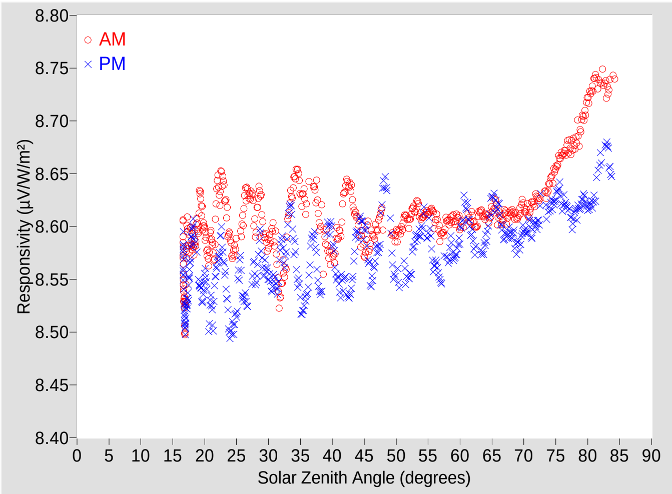


Figure 2. Responsivity vs Local Standard Time

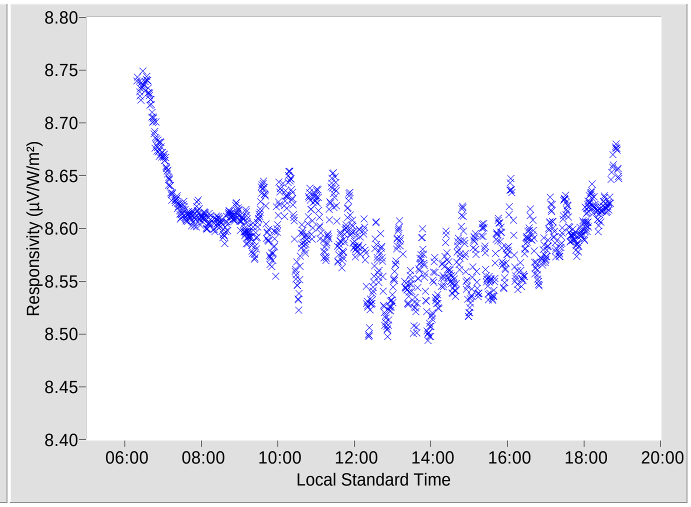


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5865	+1.16 / -1.18	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5855	0.42	97.17	8.5518	0.50	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6179	N/A	95.63	8.6368	0.56	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5900	0.38	101.85	8.5564	0.53	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6052	0.39	100.05	8.5534	0.44	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6091	0.39	98.25	8.6003	0.41	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6055	0.42	96.57	8.5627	0.51	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6054	0.39	94.93	8.5690	0.46	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6039	0.39	93.39	8.5908	0.51	273.54
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6084	0.39	91.83	8.5887	0.47	274.96
18	8.5850	0.59	155.21	8.5885	0.68	204.54	64	8.6098	0.39	90.30	8.5883	0.49	276.38
20	8.5965	0.55	142.74	8.5483	0.51	217.16	66	8.6111	0.41	88.84	8.6177	0.46	277.74
22	8.6361	0.61	134.46	8.5652	0.68	225.29	68	8.6140	0.39	87.37	8.5918	0.41	279.13
24	8.5873	0.55	128.46	8.4995	0.56	231.46	70	8.6188	0.40	85.91	8.5961	0.42	280.48
26	8.6084	0.46	123.44	8.5368	0.48	236.44	72	8.6266	0.40	84.51	8.6024	0.45	281.90
28	8.6048	0.46	119.30	8.5553	0.48	240.65	74	8.6415	0.43	83.01	8.6176	0.42	278.99
30	8.5840	0.40	115.70	8.5526	0.41	244.25	76	8.6678	0.43	81.63	8.6230	0.45	280.40
32	8.5454	0.56	112.57	8.5813	0.49	247.30	78	8.6796	0.46	80.15	8.6133	0.46	281.82
34	8.6407	0.46	109.86	8.5844	0.63	250.07	80	8.7196	0.49	78.71	8.6187	0.48	283.25
36	8.6165	0.41	107.43	8.5355	0.58	252.59	82	8.7370	0.50	77.28	8.6628	0.62	284.72
38	8.6032	0.64	104.98	8.5408	0.51	254.92	84	8.7415	0.56	75.67	8.6473	N/A	286.03
40	8.5738	0.42	102.79	8.5892	0.49	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6358	0.48	100.84	8.5476	0.39	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6034	0.54	98.89	8.5962	0.51	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31762E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

- *IRR* = solar irradiance (Watts per square meter)
- *V* = radiometer output voltage (microvolts)
- *RS* = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

Table 1. Single Responsivities

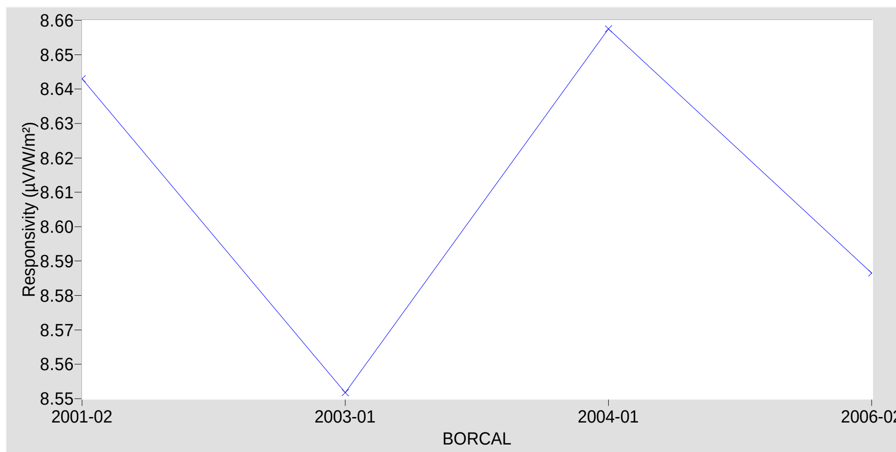
Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5865	+1.16 / -1.18 †
Average	8.6019	+2.20 / -1.74 ‡

† Valid zenith angle range: 30.0° to 60.0°

‡ Valid zenith angle range: 16.6° to 83.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 32012F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: NSA

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

32012F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

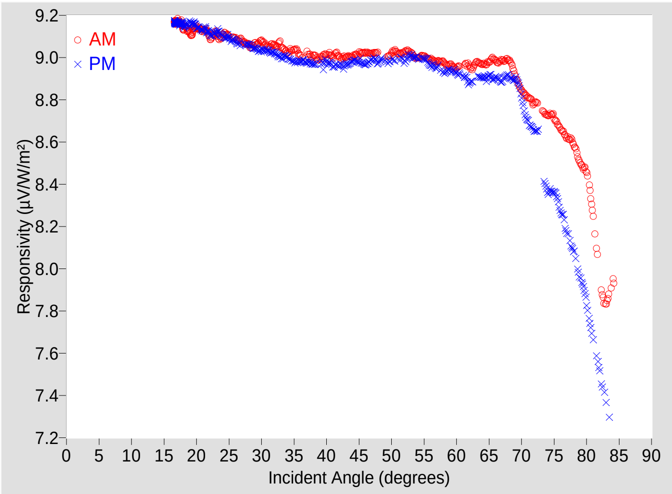


Figure 2. Responsivity vs Local Standard Time

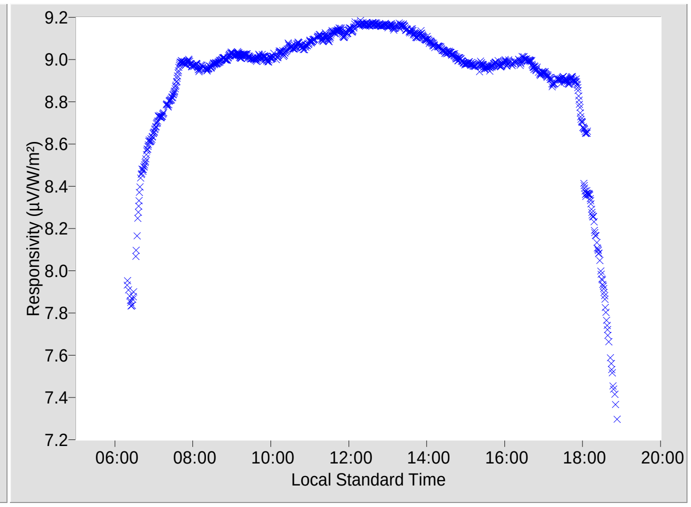


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.9987	+1.43 / -1.35	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0226	0.53	97.15	8.9683	0.57	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0211	N/A	95.66	8.9788	0.58	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0204	0.63	101.83	8.9881	0.58	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0267	0.63	100.02	8.9854	0.62	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9988	0.65	98.28	8.9971	0.60	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9915	0.68	96.55	8.9628	0.66	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9790	0.69	94.96	8.9303	0.66	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9511	0.72	93.37	8.9247	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9591	0.77	91.80	8.8799	0.72	274.99
18	9.1439	0.58	155.33	9.1557	0.50	204.67	64	8.9705	0.79	90.33	8.9057	0.73	276.37
20	9.1405	0.52	142.65	9.1478	0.52	217.08	66	8.9857	0.85	88.82	8.9039	0.79	277.77
22	9.1001	0.55	134.55	9.1136	0.53	225.38	68	8.9875	0.97	87.34	8.9127	0.82	279.11
24	9.1062	0.50	128.25	9.1026	0.53	231.54	70	8.8474	1.12	85.93	8.8096	1.45	280.51
26	9.0916	0.48	123.51	9.0756	0.51	236.51	72	8.7828	1.07	84.49	8.6542	1.00	281.88
28	9.0607	0.50	119.25	9.0612	0.49	240.61	74	8.7276	1.17	83.04	8.3695	1.39	278.97
30	9.0779	0.50	115.76	9.0339	0.49	244.21	76	8.6636	1.45	81.61	8.2681	1.93	280.43
32	9.0589	0.51	112.61	9.0230	0.52	247.26	78	8.5902	1.71	80.17	8.0901	2.16	281.76
34	9.0234	0.52	109.74	8.9988	0.52	250.12	80	8.4594	2.33	78.74	7.8438	2.66	283.23
36	9.0091	0.54	107.29	8.9814	0.51	252.63	82	7.9004	N/A	77.03	7.5158	3.11	284.72
38	9.0100	0.54	104.95	8.9688	0.52	254.96	84	7.9315	3.52	75.73	N/A	N/A	N/A
40	9.0098	0.54	102.78	8.9802	0.58	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0022	0.54	100.81	8.9637	0.55	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0058	0.53	98.93	8.9830	0.55	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

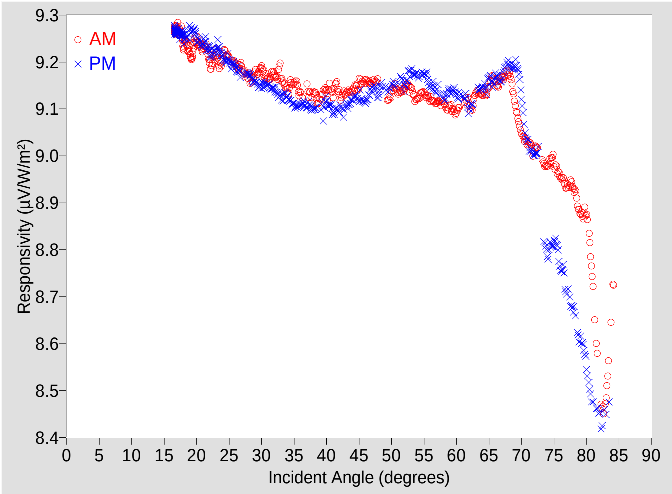

Figure 4. Responsivity vs Local Standard Time

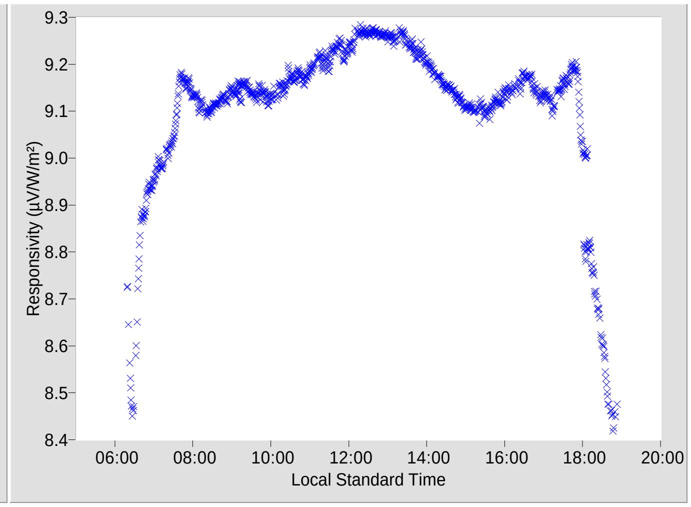

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.1379	+1.23 / -1.28	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.65965 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1587	0.58	97.15	9.1158	0.62	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1573	N/A	95.66	9.1335	0.64	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1347	0.66	101.83	9.1517	0.64	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1438	0.66	100.02	9.1517	0.68	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1215	0.69	98.28	9.1712	0.67	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1203	0.70	96.55	9.1474	0.72	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1137	0.72	94.96	9.1244	0.72	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0934	0.75	93.37	9.1293	0.74	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1104	0.81	91.80	9.1013	0.80	274.99
18	9.2410	0.59	155.33	9.2551	0.53	204.67	64	9.1327	0.83	90.33	9.1453	0.84	276.37
20	9.2438	0.56	142.65	9.2524	0.54	217.08	66	9.1577	0.89	88.82	9.1670	0.89	277.77
22	9.1991	0.57	134.55	9.2220	0.55	225.38	68	9.1747	1.01	87.34	9.1960	0.95	279.11
24	9.2111	0.54	128.25	9.2110	0.57	231.54	70	9.0510	1.12	85.93	9.1245	1.40	280.51
26	9.1966	0.51	123.51	9.1877	0.54	236.51	72	9.0105	1.13	84.49	9.0019	1.14	281.88
28	9.1689	0.53	119.25	9.1744	0.53	240.61	74	8.9796	1.25	83.04	8.7947	1.54	278.97
30	9.1863	0.53	115.76	9.1510	0.53	244.21	76	8.9567	1.46	81.61	8.7613	1.86	280.43
32	9.1729	0.55	112.61	9.1425	0.55	247.26	78	8.9321	1.71	80.17	8.6762	2.13	281.76
34	9.1408	0.55	109.74	9.1236	0.56	250.12	80	8.8756	2.20	78.74	8.5565	2.56	283.23
36	9.1310	0.57	107.29	9.1090	0.55	252.63	82	8.4706	N/A	77.03	8.4459	3.14	284.72
38	9.1333	0.58	104.95	9.0997	0.56	254.96	84	8.6990	3.94	75.73	N/A	N/A	N/A
40	9.1374	0.58	102.78	9.1146	0.63	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1320	0.59	100.81	9.1002	0.59	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1392	0.57	98.93	9.1218	0.60	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

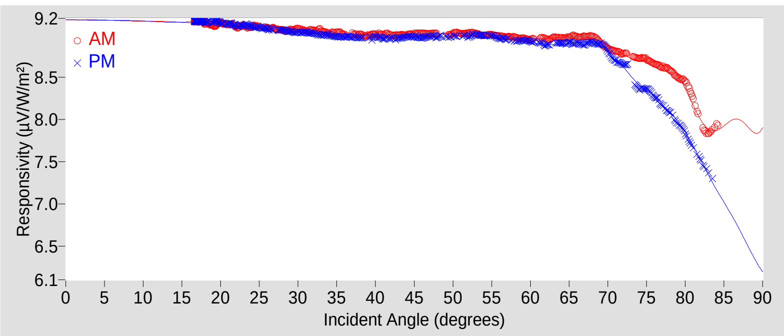
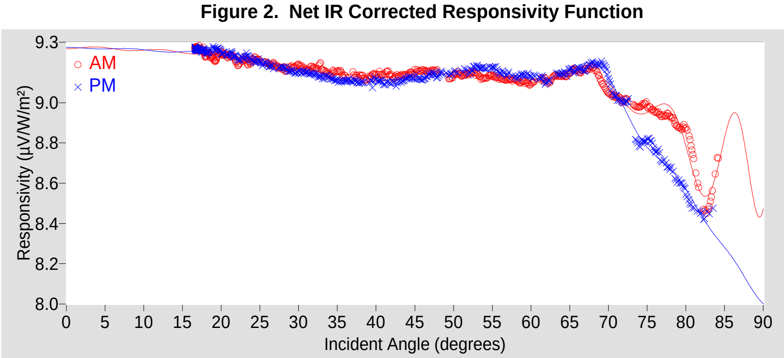


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.70	±1.70
R²	0.9999922	0.9999986
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.69	±1.69
Net IR corrected R²	0.9999937	0.9999989
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	9.1781	*	9.1783	*	9.1782	*	9.2692	*	9.2696	*	9.2694	*
9-18	9.1585	*	9.1600	*	9.1592	*	9.2542	*	9.2560	*	9.2551	*
18-27	9.1127	±1.74	9.1168	±1.76	9.1148	±1.82	9.2148	±1.72	9.2239	±1.74	9.2194	±1.78
27-36	9.0547	±1.74	9.0265	±1.76	9.0406	±1.86	9.1673	±1.72	9.1456	±1.73	9.1564	±1.80
36-45	9.0076	±1.70	8.9741	±1.70	8.9909	±1.74	9.1354	±1.70	9.1083	±1.70	9.1218	±1.74
45-54	9.0195	±1.70	8.9827	±1.71	9.0011	±1.75	9.1453	±1.70	9.1414	±1.71	9.1434	±1.73
54-63	8.9749	±1.73	8.9360	±1.79	8.9555	±1.96	9.1118	±1.71	9.1327	±1.71	9.1223	±1.76
63-72	8.9395	±1.98	8.8658	±2.19	8.9027	±3.17	9.1238	±1.83	9.1446	±1.96	9.1342	±2.23
72-81	8.6247	±3.37	8.2203	±5.44	8.4225	±8.91	8.9354	±2.33	8.7429	±3.03	8.8392	±4.22
81-90	7.9432	*	6.9361	*	7.4396	*	8.6750	*	8.2494	*	8.4622	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

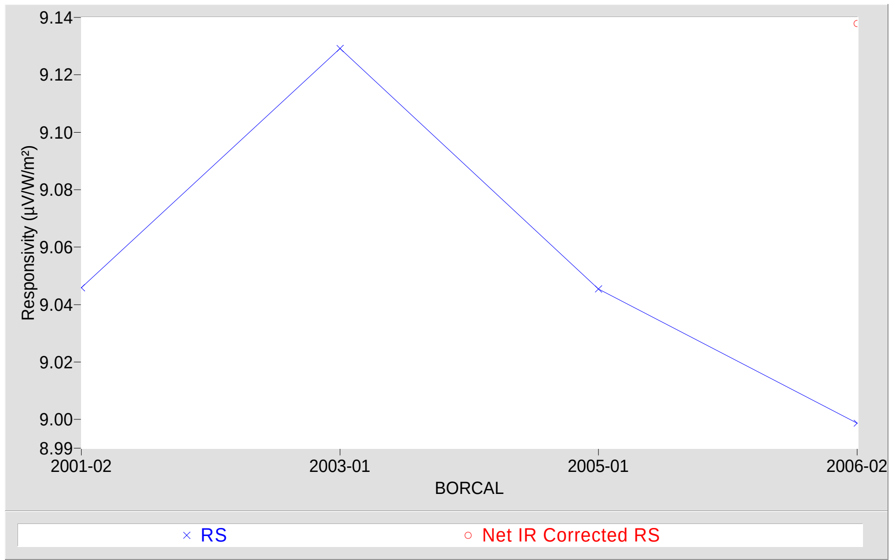
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.9987	+1.43 / -1.35
45° - 55°	9.0000	±1.73
Composite	9.0256	+2.24 / -20.56
45° (Net IR Corr.)	9.1379	+1.23 / -1.28
45° - 55° (Net IR Corr.)	9.1435	±1.71
Composite (Net IR Corr.)	9.1693	+1.94 / -9.32

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



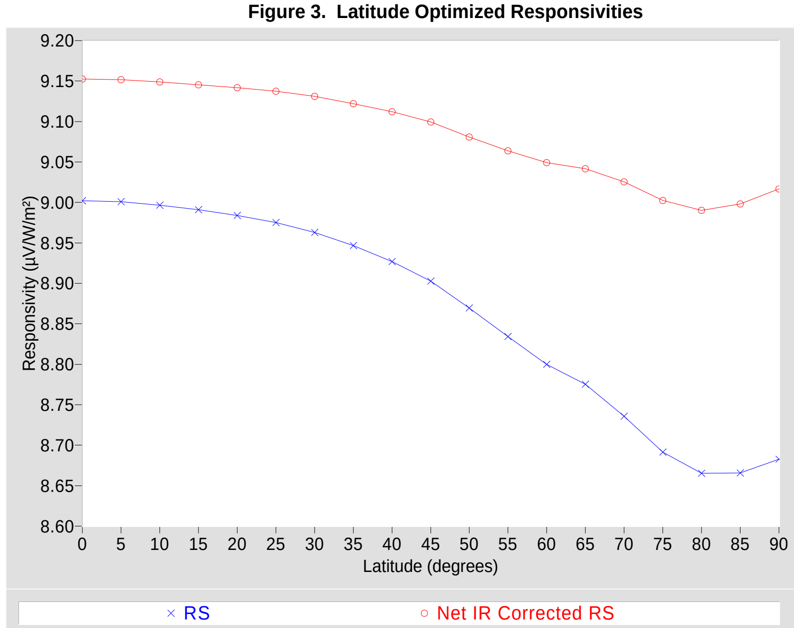
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.0019	+2.65 / -29.58	9.1524	+2.17 / -12.19
5	9.0009	+2.66 / -29.57	9.1517	+2.17 / -12.18
10	8.9968	+2.70 / -29.54	9.1490	+2.19 / -12.16
15	8.9909	+2.75 / -29.50	9.1455	+2.22 / -12.13
20	8.9839	+2.81 / -29.44	9.1418	+2.24 / -12.09
25	8.9750	+2.88 / -29.37	9.1374	+2.28 / -12.05
30	8.9631	+2.93 / -29.28	9.1310	+2.27 / -11.99
35	8.9467	+3.00 / -29.15	9.1221	+2.30 / -11.90
40	8.9270	+3.09 / -28.99	9.1120	+2.32 / -11.81
45	8.9028	+3.08 / -28.80	9.0996	+2.27 / -11.69
50	8.8694	+2.94 / -28.53	9.0810	+2.11 / -11.51
55	8.8343	+3.09 / -28.25	9.0637	+2.24 / -11.34
60	8.7999	+3.05 / -27.97	9.0494	+2.34 / -11.20
65	8.7754	+3.29 / -27.77	9.0418	+2.40 / -11.13
70	8.7357	+3.69 / -27.44	9.0256	+2.54 / -10.97
75	8.6912	+4.15 / -27.07	9.0027	+2.73 / -10.74
80	8.6655	+4.12 / -26.85	8.9904	+2.85 / -10.62
85	8.6656	+4.04 / -26.85	8.9980	+2.78 / -10.70
90	8.6827	+3.86 / -27.00	9.0168	+2.61 / -10.88

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

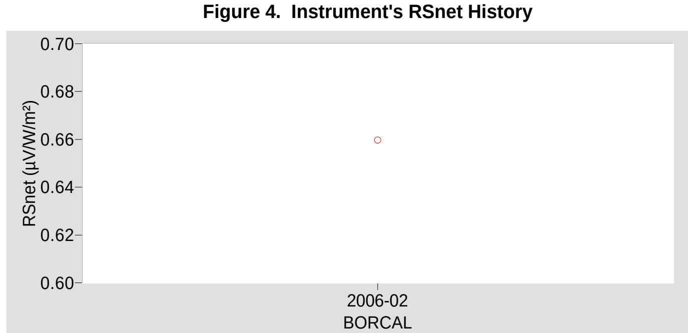
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	32016F3
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	NSA	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: __________________	Date: __________________

Calibration Results
32016F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

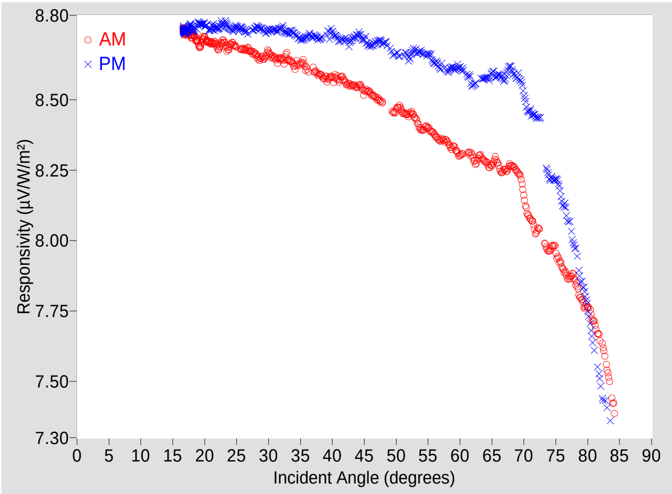


Figure 2. Responsivity vs Local Standard Time

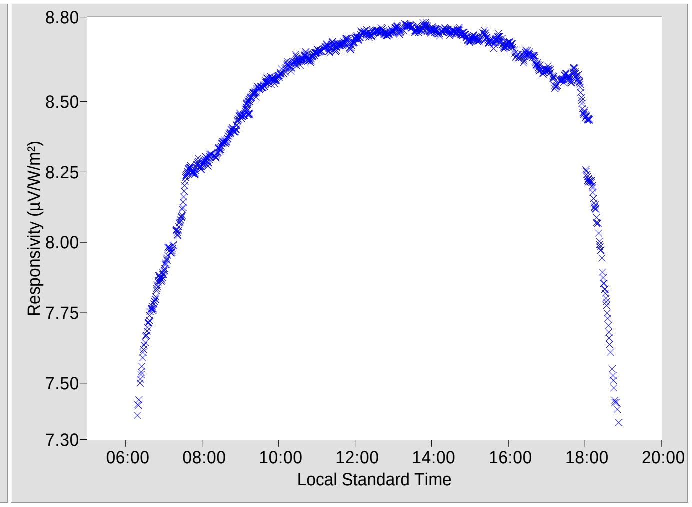


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6222	+2.17 / -4.27	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5231	0.57	97.15	8.6936	0.58	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4888	N/A	95.66	8.7014	0.57	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4652	0.63	101.83	8.6654	0.59	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4481	0.64	100.02	8.6509	0.63	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3940	0.69	98.28	8.6673	0.61	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3759	0.72	96.55	8.6302	0.68	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3525	0.72	94.96	8.6026	0.65	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3029	0.74	93.37	8.6107	0.67	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2957	0.79	91.80	8.5514	0.72	274.99
18	8.7277	0.54	155.33	8.7550	0.52	204.67	64	8.2808	0.84	90.33	8.5776	0.73	276.37
20	8.7156	0.51	142.65	8.7661	0.50	217.08	66	8.2689	0.91	88.82	8.5869	0.79	277.77
22	8.6872	0.51	134.55	8.7537	0.51	225.38	68	8.2671	0.91	87.34	8.6124	0.85	279.11
24	8.6933	0.50	128.25	8.7519	0.52	231.54	70	8.1624	1.39	85.93	8.5192	1.20	280.51
26	8.6793	0.47	123.51	8.7497	0.50	236.51	72	8.0331	1.12	84.49	8.4369	0.98	281.88
28	8.6601	0.51	119.25	8.7568	0.48	240.61	74	7.9654	1.19	83.04	8.2259	1.37	278.97
30	8.6692	0.51	115.76	8.7467	0.49	244.21	76	7.9070	1.49	81.61	8.1330	1.78	280.43
32	8.6449	0.53	112.61	8.7561	0.51	247.26	78	7.8598	1.69	80.17	7.9801	2.21	281.76
34	8.6201	0.52	109.74	8.7353	0.52	250.12	80	7.7666	2.01	78.74	7.7613	2.50	283.23
36	8.6070	0.56	107.29	8.7241	0.52	252.63	82	7.6490	2.74	77.25	7.4900	2.90	284.72
38	8.5902	0.55	104.95	8.7167	0.52	254.96	84	7.4183	3.63	75.75	N/A	N/A	N/A
40	8.5768	0.54	102.78	8.7396	0.58	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5644	0.55	100.81	8.7143	0.56	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5478	0.57	98.93	8.7325	0.56	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

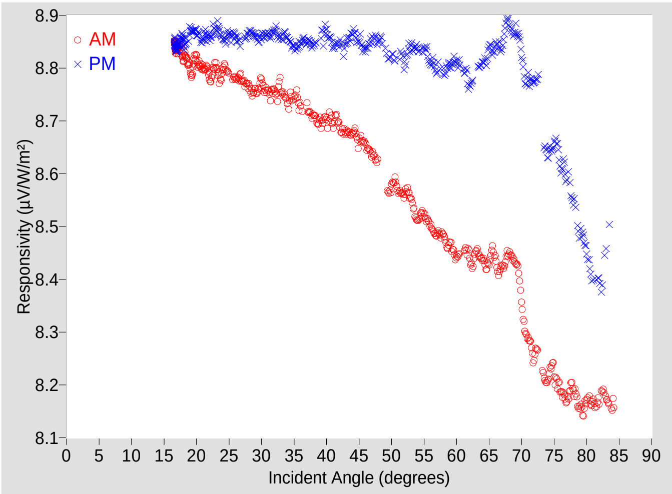

Figure 4. Responsivity vs Local Standard Time

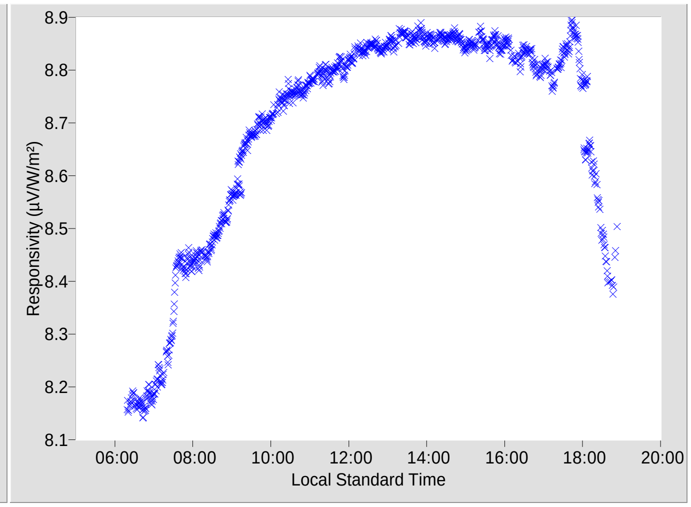

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7574	+2.02 / -4.24	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.64054 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6553	0.63	97.15	8.8369	0.63	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6210	N/A	95.66	8.8517	0.62	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5762	0.66	101.83	8.8242	0.65	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5618	0.67	100.02	8.8123	0.70	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5132	0.72	98.28	8.8364	0.67	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5009	0.74	96.55	8.8095	0.74	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4833	0.75	94.96	8.7910	0.72	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4411	0.78	93.37	8.8093	0.75	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4425	0.83	91.80	8.7663	0.81	274.99
18	8.8220	0.56	155.33	8.8515	0.55	204.67	64	8.4382	0.87	90.33	8.8103	0.85	276.37
20	8.8159	0.55	142.65	8.8676	0.52	217.08	66	8.4359	0.95	88.82	8.8424	0.90	277.77
22	8.7833	0.54	134.55	8.8590	0.54	225.38	68	8.4489	0.98	87.34	8.8875	0.98	279.11
24	8.7952	0.55	128.25	8.8572	0.57	231.54	70	8.3601	1.34	85.93	8.8250	1.22	280.51
26	8.7812	0.51	123.51	8.8585	0.53	236.51	72	8.2541	1.18	84.49	8.7746	1.14	281.88
28	8.7653	0.54	119.25	8.8667	0.52	240.61	74	8.2100	1.29	83.04	8.6389	1.54	278.97
30	8.7745	0.54	115.76	8.8604	0.53	244.21	76	8.1916	1.50	81.61	8.6120	1.81	280.43
32	8.7556	0.58	112.61	8.8722	0.55	247.26	78	8.1918	1.75	80.17	8.5492	2.17	281.76
34	8.7341	0.55	109.74	8.8565	0.57	250.12	80	8.1708	2.11	78.74	8.4533	2.50	283.23
36	8.7253	0.59	107.29	8.8480	0.57	252.63	82	8.1762	2.75	77.25	8.3932	3.16	284.72
38	8.7100	0.59	104.95	8.8439	0.57	254.96	84	8.1599	3.76	75.75	N/A	N/A	N/A
40	8.7007	0.58	102.78	8.8701	0.62	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6904	0.60	100.81	8.8469	0.61	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6773	0.61	98.93	8.8674	0.60	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

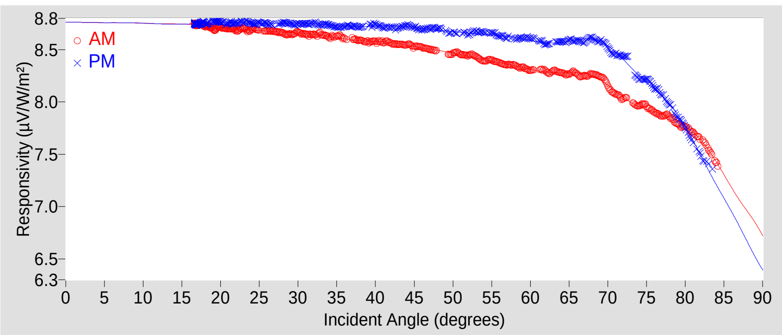
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

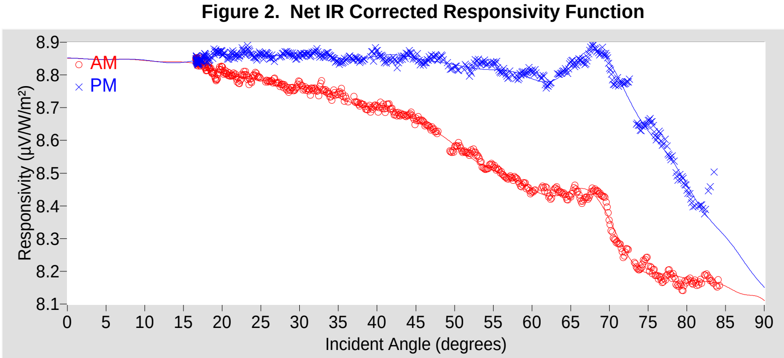


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.60	±1.60
R^2	0.9999994	0.9999985
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.65	±1.65
Net IR corrected R^2	0.9999995	0.9999988
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.7600	*	8.7598	*	8.7599	*	8.8486	*	8.8485	*	8.8485	*
9-18	8.7465	*	8.7487	*	8.7476	*	8.8396	*	8.8420	*	8.8408	*
18-27	8.6979	±1.63	8.7553	±1.60	8.7266	±1.75	8.7971	±1.67	8.8593	±1.65	8.8282	±1.78
27-36	8.6475	±1.65	8.7465	±1.61	8.6970	±2.01	8.7568	±1.68	8.8622	±1.65	8.8095	±2.02
36-45	8.5749	±1.65	8.7246	±1.60	8.6497	±2.25	8.6989	±1.67	8.8549	±1.65	8.7769	±2.26
45-54	8.4755	±1.75	8.6800	±1.64	8.5777	±2.97	8.5975	±1.84	8.8340	±1.66	8.7158	±3.14
54-63	8.3411	±1.76	8.6096	±1.68	8.4753	±3.46	8.4737	±1.73	8.8005	±1.66	8.6371	±3.58
63-72	8.2308	±2.05	8.5643	±1.86	8.3976	±4.85	8.4092	±1.93	8.8349	±1.75	8.6221	±5.17
72-81	7.8994	±2.48	8.0875	±4.64	7.9934	±6.53	8.1999	±1.74	8.5950	±2.43	8.3975	±5.25
81-90	7.2416	*	7.0109	*	7.1262	*	8.1468	*	8.2862	*	8.2165	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

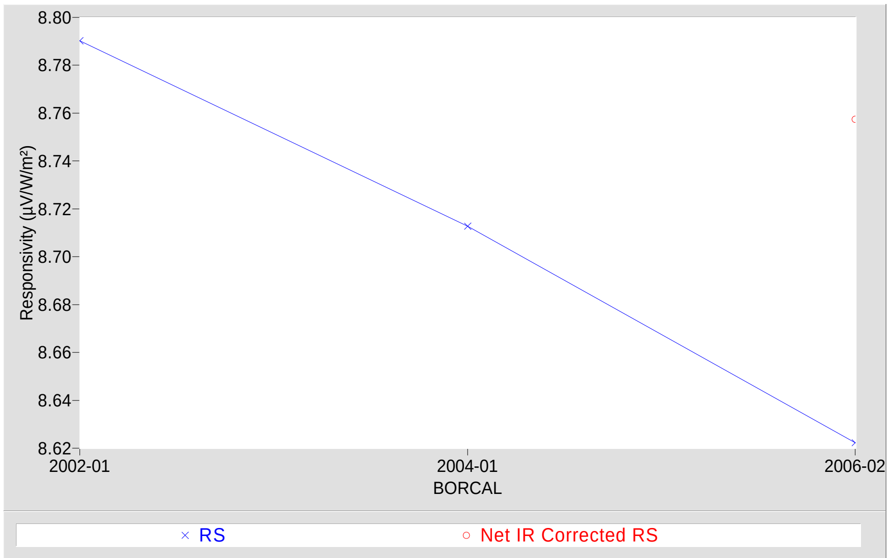
4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6222	+2.17 / -4.27
45° - 55°	8.5696	±2.48
Composite	8.6226	+2.26 / -16.45
45° (Net IR Corr.)	8.7574	+2.02 / -4.24
45° - 55° (Net IR Corr.)	8.7085	±2.57
Composite (Net IR Corr.)	8.7624	+2.11 / -7.03

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

Figure 2. History of instrument at I = 45°



The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

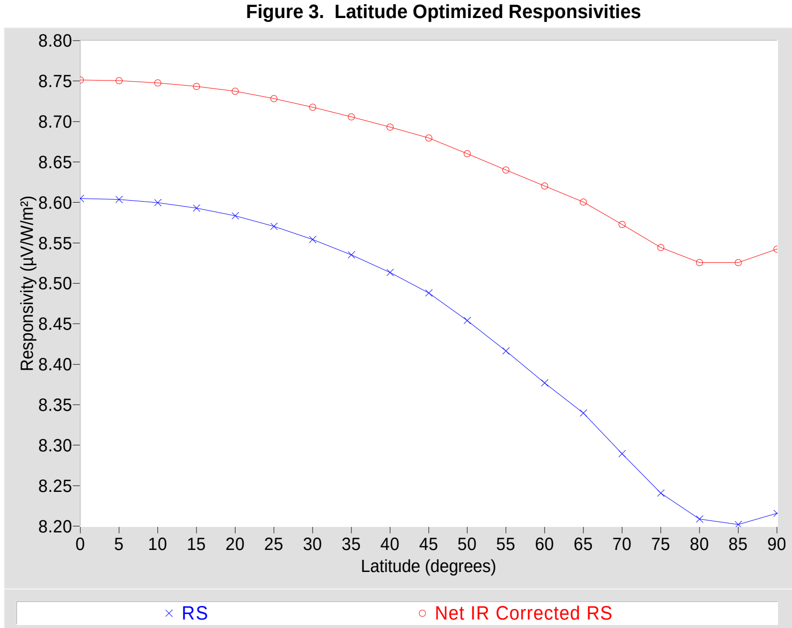
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6048	+2.44 / -24.24	8.7512	+2.19 / -7.35
5	8.6038	+2.45 / -24.23	8.7506	+2.20 / -7.35
10	8.5999	+2.49 / -24.19	8.7479	+2.22 / -7.32
15	8.5930	+2.55 / -24.13	8.7434	+2.25 / -7.27
20	8.5837	+2.64 / -24.05	8.7373	+2.30 / -7.21
25	8.5706	+2.76 / -23.94	8.7285	+2.37 / -7.12
30	8.5544	+2.89 / -23.79	8.7178	+2.47 / -7.01
35	8.5352	+3.08 / -23.62	8.7059	+2.57 / -6.88
40	8.5133	+3.31 / -23.42	8.6933	+2.68 / -6.75
45	8.4881	+3.58 / -23.20	8.6798	+2.81 / -6.61
50	8.4543	+3.90 / -22.89	8.6603	+3.00 / -6.41
55	8.4165	+4.32 / -22.55	8.6400	+3.21 / -6.20
60	8.3771	+4.50 / -22.18	8.6203	+3.41 / -5.99
65	8.3398	+4.94 / -21.83	8.6005	+3.62 / -5.78
70	8.2893	+5.26 / -21.36	8.5727	+3.92 / -5.49
75	8.2406	+5.41 / -20.90	8.5443	+4.23 / -5.19
80	8.2085	+5.45 / -20.59	8.5255	+4.45 / -4.99
85	8.2019	+5.16 / -20.52	8.5257	+4.44 / -4.99
90	8.2157	+4.99 / -20.66	8.5422	+4.26 / -5.16

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

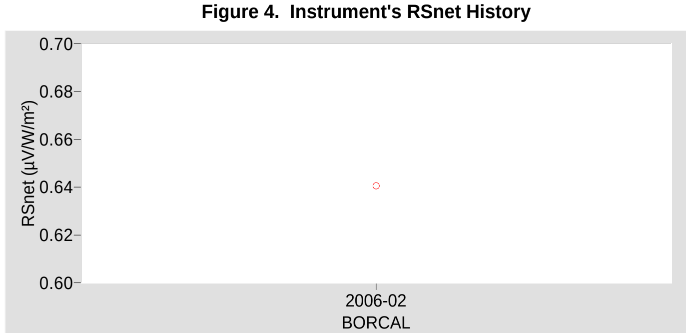
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 32018F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: NSA

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

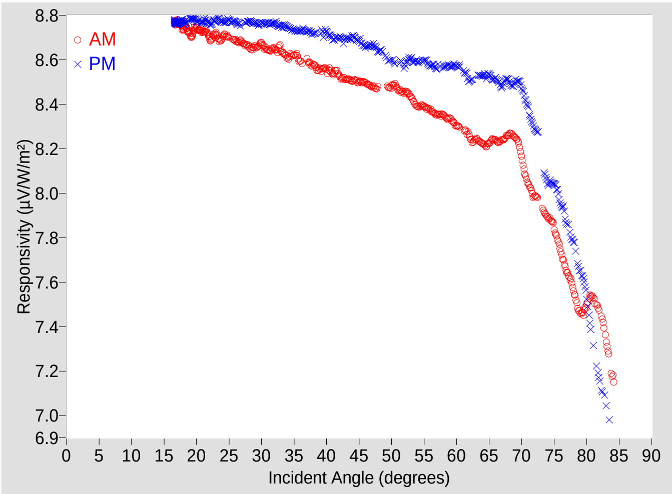

Figure 2. Responsivity vs Local Standard Time

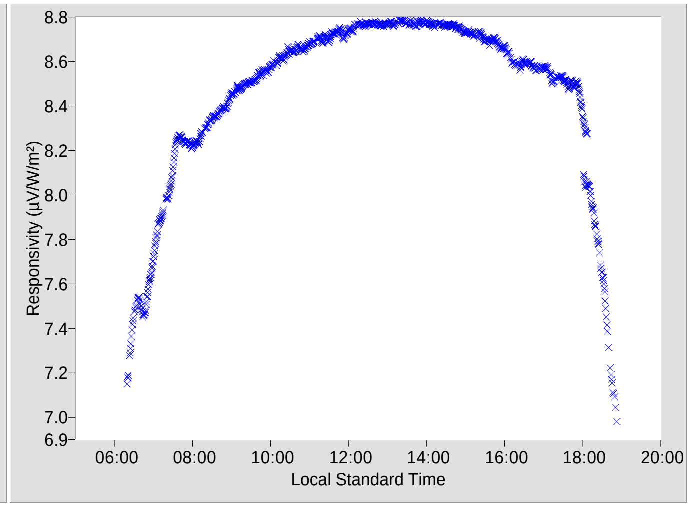

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5935	+2.61 / -3.89	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4958	0.55	97.15	8.6615	0.60	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4687	N/A	95.66	8.6380	0.60	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4811	0.62	101.83	8.5990	0.61	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4546	0.65	100.02	8.5773	0.65	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3914	0.69	98.28	8.5931	0.61	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3727	0.70	96.55	8.5738	0.65	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3519	0.70	94.96	8.5668	0.63	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3026	0.75	93.37	8.5718	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2561	0.83	91.80	8.5054	0.74	274.99
18	8.7440	0.57	155.33	8.7705	0.51	204.67	64	8.2241	0.82	90.33	8.5283	0.73	276.37
20	8.7396	0.55	142.65	8.7763	0.49	217.08	66	8.2383	0.85	88.82	8.5132	0.84	277.77
22	8.6986	0.54	134.55	8.7645	0.50	225.38	68	8.2640	0.91	87.34	8.5070	0.83	279.11
24	8.7026	0.51	128.25	8.7712	0.50	231.54	70	8.1666	1.57	85.93	8.4765	1.12	280.51
26	8.6877	0.48	123.51	8.7681	0.50	236.51	72	7.9858	1.14	84.49	8.2899	1.17	281.88
28	8.6604	0.51	119.25	8.7724	0.48	240.61	74	7.8924	1.25	83.04	8.0506	1.40	278.97
30	8.6726	0.51	115.76	8.7638	0.49	244.21	76	7.7450	1.85	81.61	7.9496	1.90	280.43
32	8.6493	0.52	112.61	8.7649	0.51	247.26	78	7.5639	1.97	80.17	7.7850	2.21	281.76
34	8.6112	0.53	109.74	8.7463	0.52	250.12	80	7.4950	2.05	78.74	7.5387	2.74	283.23
36	8.5909	0.56	107.29	8.7318	0.51	252.63	82	7.4681	2.81	77.25	7.1578	3.09	284.72
38	8.5769	0.58	104.95	8.7176	0.52	254.96	84	7.1748	3.74	75.75	N/A	N/A	N/A
40	8.5544	0.53	102.78	8.7251	0.59	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5266	0.57	100.81	8.6994	0.56	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5065	0.53	98.93	8.7037	0.55	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

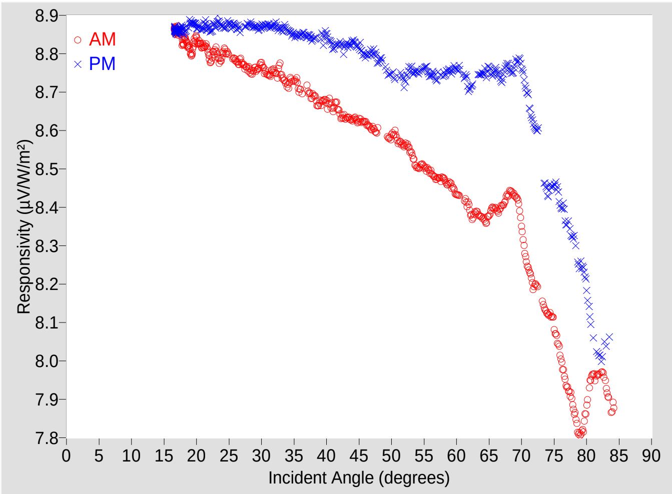

Figure 4. Responsivity vs Local Standard Time

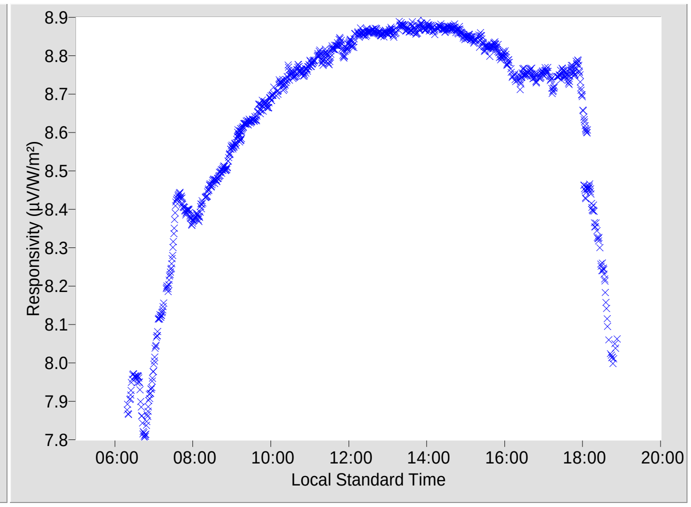

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7213	+2.43 / -3.87	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.60555 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6208	0.61	97.15	8.7970	0.64	262.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5936	N/A	95.66	8.7801	0.65	264.49
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5860	0.66	101.83	8.7491	0.66	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5621	0.68	100.02	8.7299	0.72	267.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5040	0.72	98.28	8.7529	0.68	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4909	0.73	96.55	8.7433	0.72	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4755	0.73	94.96	8.7450	0.73	272.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4332	0.78	93.37	8.7596	0.75	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3949	0.86	91.80	8.7086	0.82	274.99
18	8.8331	0.59	155.33	8.8617	0.54	204.67	64	8.3730	0.86	90.33	8.7482	0.84	276.37
20	8.8344	0.58	142.65	8.8723	0.52	217.08	66	8.3961	0.91	88.82	8.7548	0.92	277.77
22	8.7894	0.57	134.55	8.8640	0.54	225.38	68	8.4359	0.98	87.34	8.7671	0.97	279.11
24	8.7990	0.55	128.25	8.8707	0.54	231.54	70	8.3534	1.51	85.93	8.7655	1.16	280.51
26	8.7840	0.51	123.51	8.8710	0.53	236.51	72	8.1948	1.20	84.49	8.6091	1.26	281.88
28	8.7598	0.54	119.25	8.8763	0.52	240.61	74	8.1237	1.30	83.04	8.4410	1.56	278.97
30	8.7721	0.54	115.76	8.8713	0.53	244.21	76	8.0140	1.75	81.61	8.4023	1.88	280.43
32	8.7539	0.56	112.61	8.8747	0.54	247.26	78	7.8777	1.91	80.17	8.3230	2.19	281.76
34	8.7190	0.56	109.74	8.8609	0.57	250.12	80	7.8771	2.35	78.74	8.1929	2.66	283.23
36	8.7028	0.59	107.29	8.8489	0.55	252.63	82	7.9665	2.78	77.25	8.0117	3.22	284.72
38	8.6901	0.62	104.95	8.8378	0.57	254.96	84	7.8758	3.84	75.75	N/A	N/A	N/A
40	8.6715	0.58	102.78	8.8485	0.63	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6457	0.62	100.81	8.8247	0.61	259.06	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6289	0.58	98.93	8.8312	0.59	260.99	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

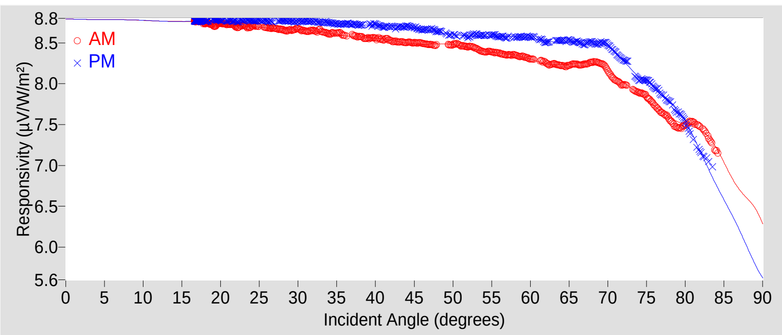
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

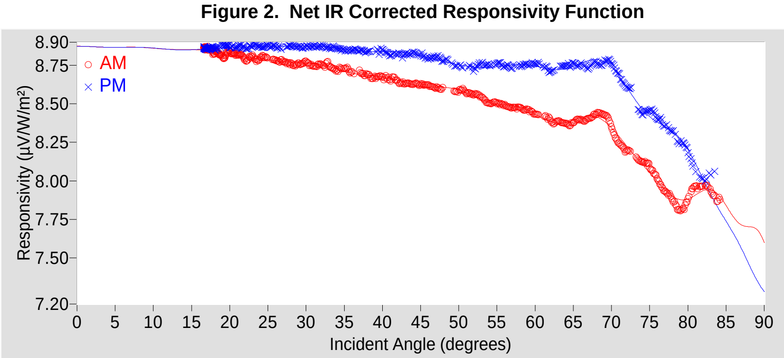


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.71	±1.71
R^2	0.9999974	0.9999986
Valid incidence angle range	16.6° to 84.2°	16.6° to 83.5°
Net IR corr. uncert. U95 (%)	±1.73	±1.73
Net IR corrected R^2	0.9999980	0.9999987
Corr. valid inc. angle range	16.6° to 84.2°	16.6° to 83.5°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.7852	*	8.7850	*	8.7851	*	8.8690	*	8.8688	*	8.8689	*
9-18	8.7656	*	8.7676	*	8.7666	*	8.8536	*	8.8558	*	8.8547	*
18-27	8.7111	±1.76	8.7698	±1.71	8.7405	±1.88	8.8049	±1.76	8.8682	±1.73	8.8365	±1.90
27-36	8.6467	±1.78	8.7597	±1.72	8.7032	±2.25	8.7501	±1.77	8.8690	±1.73	8.8096	±2.22
36-45	8.5482	±1.80	8.7140	±1.73	8.6311	±2.61	8.6654	±1.79	8.8371	±1.73	8.7513	±2.55
45-54	8.4680	±1.78	8.6199	±1.81	8.5440	±2.84	8.5834	±1.82	8.7656	±1.78	8.6745	±2.97
54-63	8.3317	±1.97	8.5627	±1.75	8.4472	±3.39	8.4571	±1.89	8.7433	±1.74	8.6002	±3.60
63-72	8.2076	±2.10	8.4877	±2.07	8.3476	±4.46	8.3763	±1.99	8.7435	±1.91	8.5599	±4.75
72-81	7.7234	±3.85	7.9021	±5.50	7.8127	±7.73	8.0075	±2.78	8.3819	±3.19	8.1947	±6.60
81-90	6.9479	*	6.4849	*	6.7164	*	7.8036	*	7.6905	*	7.7471	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

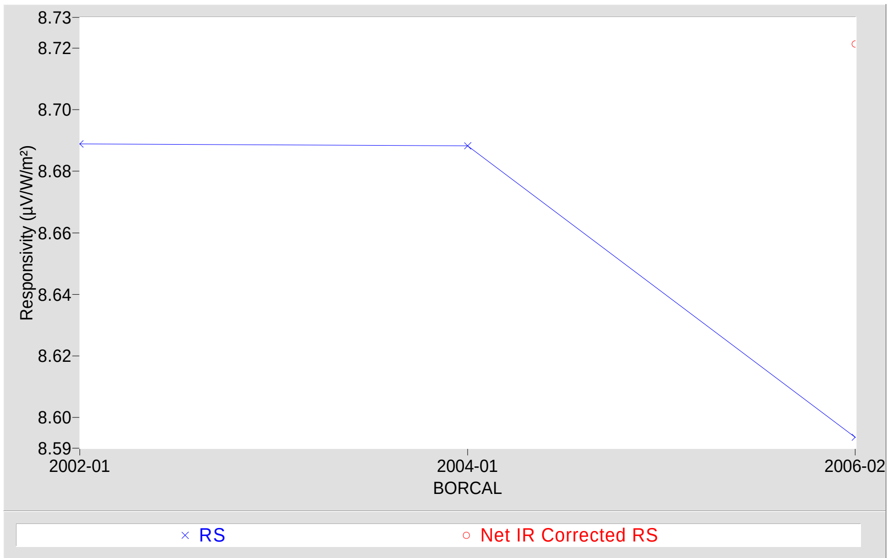
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.5935	+2.61 / -3.89
45° - 55°	8.5355	±2.44
Composite	8.6106	+2.53 / -21.54
45° (Net IR Corr.)	8.7213	+2.43 / -3.87
45° - 55° (Net IR Corr.)	8.6669	±2.50
Composite (Net IR Corr.)	8.7427	+2.29 / -10.69

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.5°, 16.6° to 83.5° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



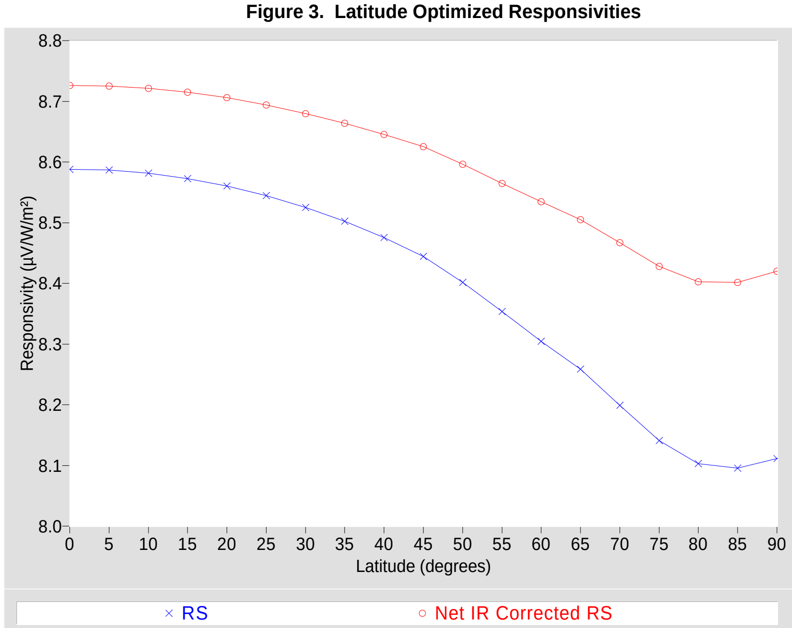
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5879	+2.92 / -32.58	8.7263	+2.42 / -15.77
5	8.5866	+2.94 / -32.57	8.7253	+2.43 / -15.76
10	8.5815	+2.99 / -32.53	8.7215	+2.46 / -15.72
15	8.5727	+3.07 / -32.46	8.7149	+2.52 / -15.66
20	8.5606	+3.19 / -32.36	8.7058	+2.60 / -15.57
25	8.5447	+3.35 / -32.24	8.6940	+2.70 / -15.46
30	8.5253	+3.48 / -32.08	8.6797	+2.83 / -15.32
35	8.5025	+3.60 / -31.90	8.6639	+2.98 / -15.17
40	8.4754	+3.88 / -31.68	8.6456	+3.16 / -14.99
45	8.4442	+4.23 / -31.43	8.6254	+3.37 / -14.79
50	8.4018	+4.70 / -31.08	8.5965	+3.67 / -14.50
55	8.3533	+5.22 / -30.68	8.5646	+4.01 / -14.19
60	8.3044	+5.42 / -30.28	8.5343	+4.07 / -13.88
65	8.2586	+5.79 / -29.89	8.5050	+4.30 / -13.59
70	8.1990	+5.94 / -29.38	8.4669	+4.29 / -13.20
75	8.1409	+5.82 / -28.88	8.4280	+4.60 / -12.81
80	8.1028	+6.12 / -28.54	8.4025	+4.90 / -12.54
85	8.0957	+5.76 / -28.48	8.4018	+4.91 / -12.54
90	8.1113	+5.42 / -28.62	8.4200	+4.69 / -12.72

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

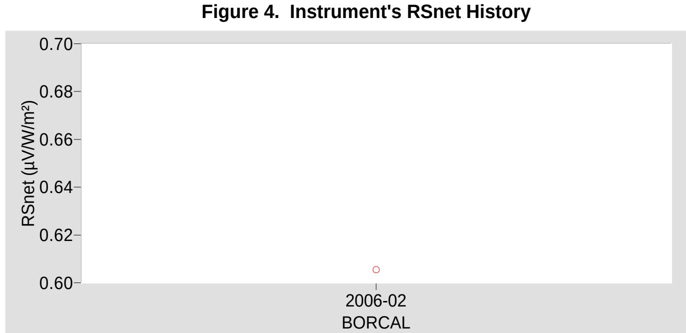
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 32026F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: NSA

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology
* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

32026F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

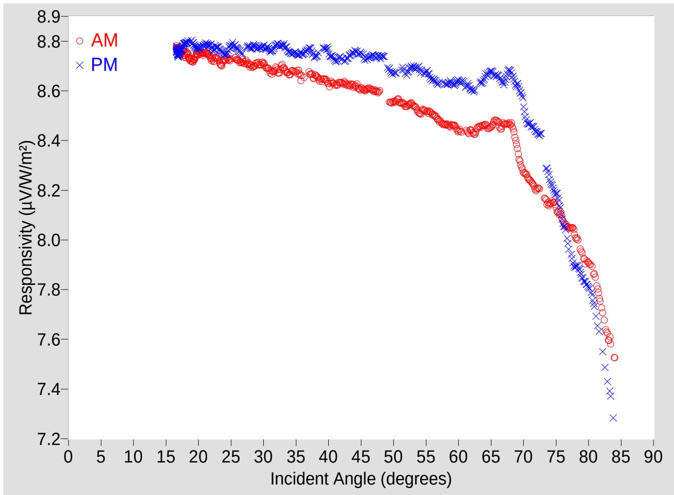


Figure 2. Responsivity vs Local Standard Time

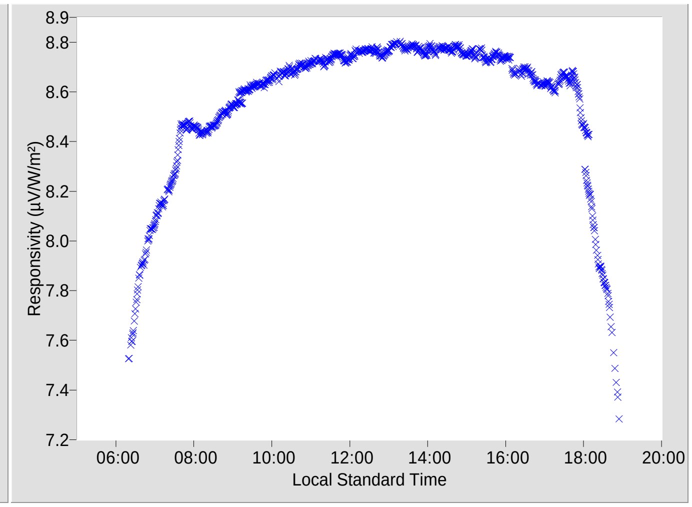


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6798	+1.81 / -3.26	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6088	0.54	97.15	8.7321	0.56	262.73
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5961	N/A	95.67	8.7369	0.56	264.50
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5558	0.61	101.83	8.6726	0.59	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5394	0.63	99.97	8.6710	0.62	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5113	0.67	98.29	8.6871	0.62	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5061	0.69	96.55	8.6453	0.69	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4654	0.70	94.97	8.6271	0.63	272.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4405	0.73	93.38	8.6391	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4379	0.76	91.81	8.6049	0.70	274.95
18	8.7469	0.55	155.36	8.7919	0.55	204.69	64	8.4624	0.79	90.33	8.6543	0.77	276.37
20	8.7497	0.51	142.67	8.7727	0.50	217.10	66	8.4776	0.86	88.83	8.6582	0.83	277.77
22	8.7309	0.52	134.57	8.7743	0.51	225.40	68	8.4653	1.03	87.35	8.6755	0.90	279.11
24	8.7256	0.52	128.27	8.7472	0.52	231.55	70	8.2778	1.24	85.94	8.5398	1.30	280.51
26	8.7242	0.48	123.40	8.7680	0.55	236.53	72	8.2041	1.09	84.49	8.4332	1.01	281.88
28	8.7012	0.50	119.26	8.7736	0.49	240.62	74	8.1453	1.19	83.04	8.2476	1.49	278.98
30	8.7102	0.52	115.77	8.7775	0.49	244.12	76	8.0844	1.46	81.61	8.0714	2.06	280.43
32	8.6849	0.53	112.63	8.7870	0.53	247.27	78	8.0170	1.70	80.18	7.8935	1.86	281.81
34	8.6700	0.51	109.76	8.7545	0.55	250.13	80	7.9080	2.03	78.70	7.8113	2.20	283.23
36	8.6523	0.55	107.31	8.7502	0.52	252.64	82	7.7292	2.92	77.25	7.5498	N/A	284.85
38	8.6588	0.54	104.96	8.7374	0.56	254.96	84	7.5264	3.50	75.76	7.2836	N/A	286.06
40	8.6292	0.54	102.79	8.7538	0.60	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6324	0.52	100.82	8.7325	0.54	259.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6202	0.54	98.93	8.7562	0.56	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

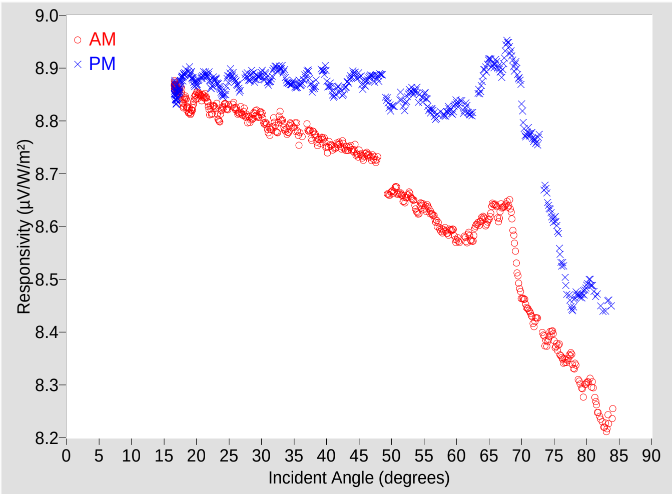

Figure 4. Responsivity vs Local Standard Time

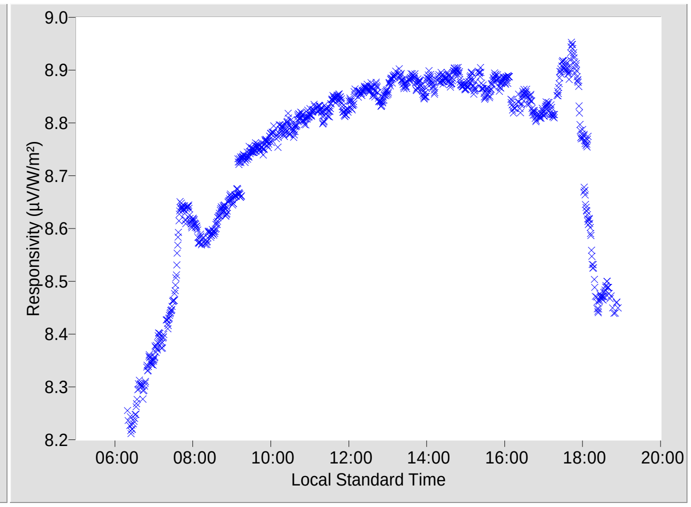

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8111	+1.65 / -3.25	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.62415 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7378	0.59	97.15	8.8721	0.62	262.73
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7261	N/A	95.67	8.8837	0.62	264.50
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6642	0.64	101.83	8.8265	0.65	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6499	0.67	99.97	8.8295	0.68	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6273	0.70	98.29	8.8520	0.68	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6273	0.72	96.55	8.8202	0.74	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5937	0.73	94.97	8.8108	0.71	272.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5746	0.77	93.38	8.8329	0.75	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5811	0.81	91.81	8.8140	0.79	274.95
18	8.8389	0.56	155.36	8.8859	0.59	204.69	64	8.6156	0.84	90.33	8.8811	0.90	276.37
20	8.8474	0.55	142.67	8.8717	0.52	217.10	66	8.6402	0.91	88.83	8.9073	0.90	277.77
22	8.8248	0.55	134.57	8.8771	0.54	225.40	68	8.6417	1.06	87.35	8.9436	0.99	279.11
24	8.8248	0.54	128.27	8.8495	0.55	231.55	70	8.4703	1.22	85.94	8.8387	1.31	280.51
26	8.8234	0.52	123.40	8.8742	0.57	236.53	72	8.4186	1.15	84.49	8.7621	1.15	281.88
28	8.8036	0.53	119.26	8.8808	0.53	240.62	74	8.3836	1.27	83.04	8.6511	1.59	278.98
30	8.8131	0.55	115.77	8.8884	0.54	244.12	76	8.3607	1.48	81.61	8.5391	1.95	280.43
32	8.7926	0.58	112.63	8.9003	0.57	247.27	78	8.3399	1.74	80.18	8.4516	2.07	281.81
34	8.7814	0.54	109.76	8.8728	0.58	250.13	80	8.3035	2.11	78.70	8.4862	2.44	283.23
36	8.7672	0.59	107.31	8.8706	0.57	252.64	82	8.2411	2.76	77.25	8.4494	N/A	284.85
38	8.7746	0.59	104.96	8.8615	0.61	254.96	84	8.2457	3.74	75.76	8.4499	N/A	286.06
40	8.7502	0.58	102.79	8.8810	0.65	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7558	0.57	100.82	8.8608	0.59	259.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7462	0.59	98.93	8.8874	0.61	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

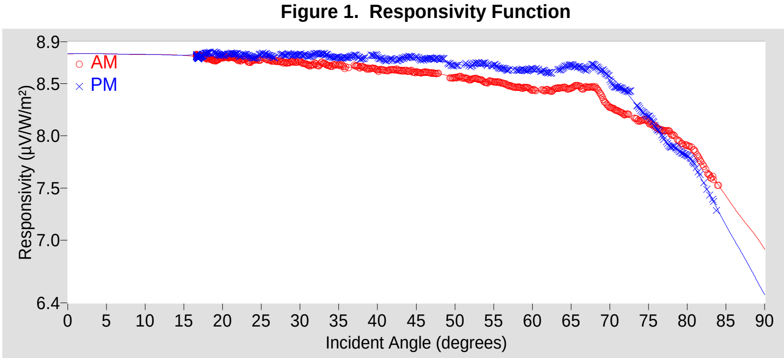
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

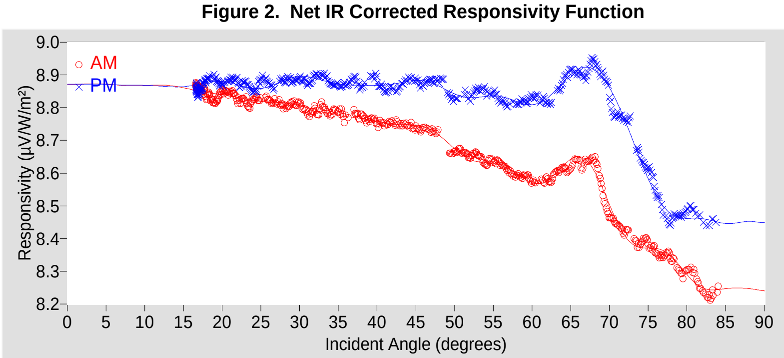


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.50	±1.50
R²	0.9999989	0.9999979
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	±1.54	±1.54
Net IR corrected R²	0.9999989	0.9999985
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.8°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.7841	*	8.7841	*	8.7841	*	8.8706	*	8.8707	*	8.8707	*
9-18	8.7722	*	8.7760	*	8.7741	*	8.8631	*	8.8670	*	8.8651	*
18-27	8.7339	±1.51	8.7683	±1.51	8.7511	±1.60	8.8306	±1.55	8.8697	±1.55	8.8502	±1.63
27-36	8.6905	±1.53	8.7719	±1.51	8.7312	±1.82	8.7970	±1.56	8.8847	±1.55	8.8409	±1.83
36-45	8.6373	±1.52	8.7447	±1.50	8.6910	±1.84	8.7581	±1.55	8.8715	±1.55	8.8148	±1.88
45-54	8.5711	±1.60	8.7039	±1.57	8.6375	±2.40	8.6903	±1.68	8.8541	±1.57	8.7722	±2.55
54-63	8.4692	±1.59	8.6383	±1.53	8.5538	±2.49	8.5984	±1.59	8.8245	±1.55	8.7115	±2.70
63-72	8.4078	±2.18	8.6190	±1.89	8.5134	±4.16	8.5814	±2.02	8.8828	±1.72	8.7321	±4.40
72-81	8.0614	±2.57	8.0645	±4.54	8.0630	±6.26	8.3540	±1.73	8.5604	±2.34	8.4572	±4.46
81-90	7.3742	*	7.0846	*	7.2294	*	8.2475	*	8.4522	*	8.3499	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

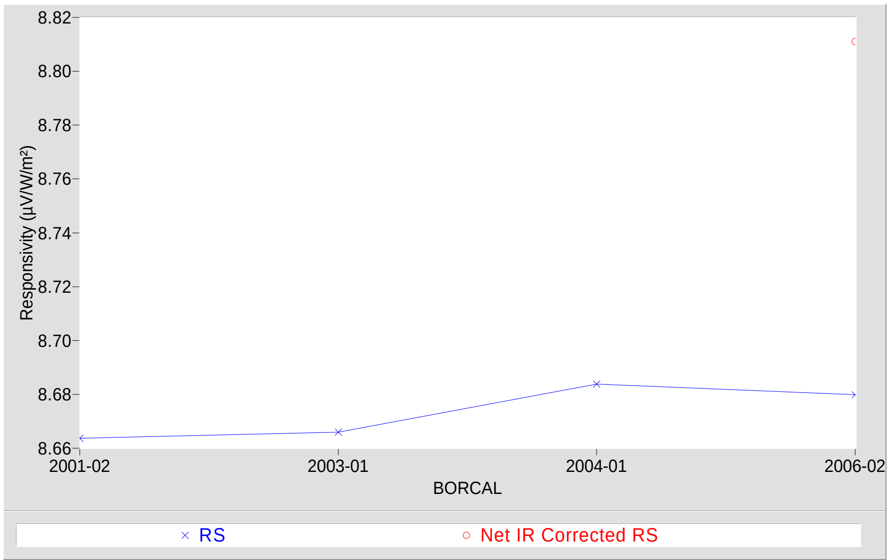
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6798	+1.81 / -3.26
45° - 55°	8.6310	±2.03
Composite	8.6669	+2.03 / -16.03
45° (Net IR Corr.)	8.8111	+1.65 / -3.25
45° - 55° (Net IR Corr.)	8.7666	±2.12
Composite (Net IR Corr.)	8.8036	+2.06 / -6.55

† Valid incident angle ranges:
45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
Composite: 16.6° to 83.8°, 16.6° to 83.8° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



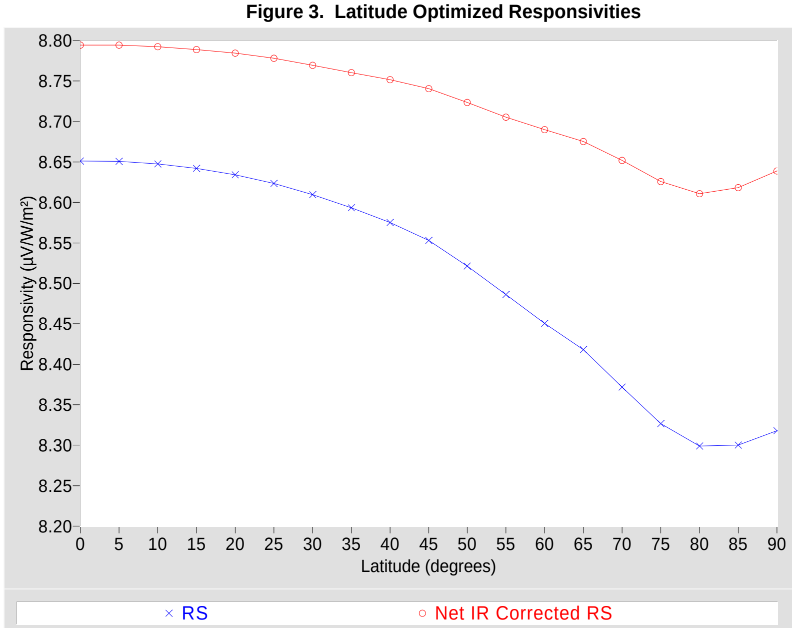
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6513	+2.17 / -23.60	8.7945	+2.13 / -6.45
5	8.6508	+2.17 / -23.59	8.7944	+2.13 / -6.45
10	8.6476	+2.20 / -23.56	8.7925	+2.15 / -6.43
15	8.6419	+2.25 / -23.51	8.7891	+2.18 / -6.40
20	8.6342	+2.32 / -23.45	8.7846	+2.21 / -6.35
25	8.6235	+2.42 / -23.35	8.7781	+2.27 / -6.28
30	8.6095	+2.54 / -23.23	8.7694	+2.34 / -6.19
35	8.5934	+2.69 / -23.08	8.7605	+2.42 / -6.10
40	8.5753	+2.88 / -22.92	8.7516	+2.50 / -6.01
45	8.5529	+3.11 / -22.72	8.7407	+2.60 / -5.89
50	8.5214	+3.45 / -22.43	8.7234	+2.77 / -5.71
55	8.4860	+3.80 / -22.11	8.7055	+2.95 / -5.53
60	8.4507	+3.84 / -21.79	8.6901	+3.10 / -5.37
65	8.4180	+4.21 / -21.48	8.6751	+3.26 / -5.21
70	8.3719	+4.69 / -21.05	8.6518	+3.51 / -4.96
75	8.3266	+4.47 / -20.62	8.6259	+3.79 / -4.69
80	8.2988	+4.69 / -20.36	8.6109	+3.95 / -4.54
85	8.3000	+4.68 / -20.37	8.6184	+3.87 / -4.62
90	8.3179	+4.46 / -20.54	8.6390	+3.64 / -4.83

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

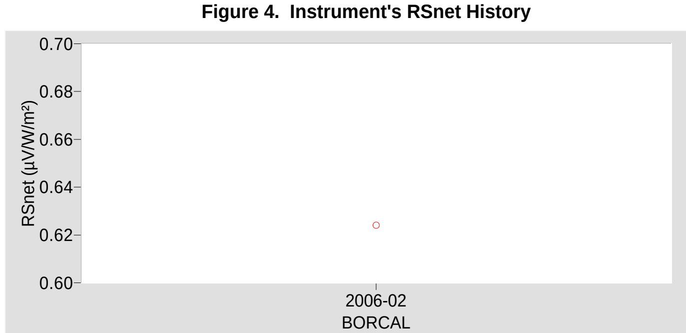
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 32039F3

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: NSA

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007
Infrared Irradiance *	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/24/2006	02/24/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

* Traceable to the World Infrared Standard Group

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

32039F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

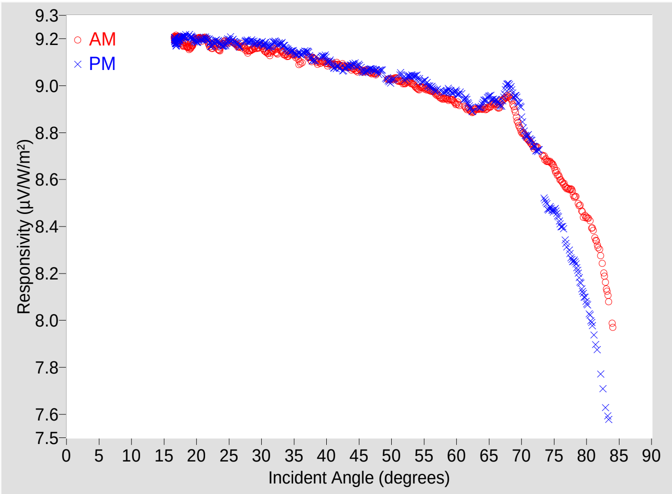


Figure 2. Responsivity vs Local Standard Time

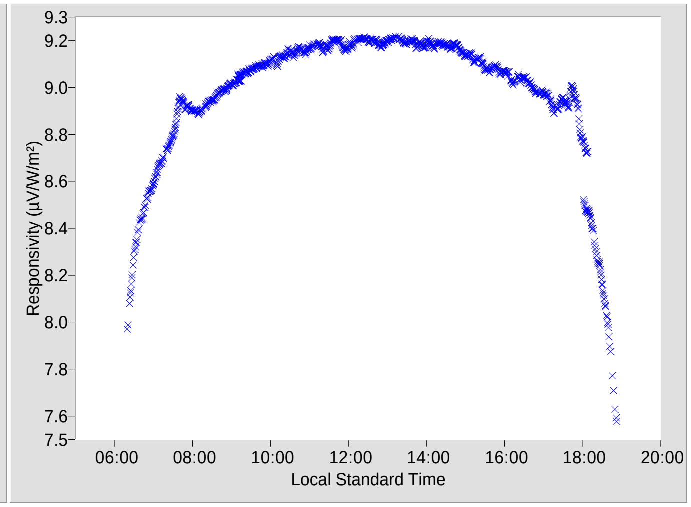


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.0765	+1.80 / -2.18	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -10.000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0647	0.54	97.15	9.0620	0.57	262.73
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0526	N/A	95.67	9.0602	0.57	264.50
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0280	0.61	101.83	9.0215	0.58	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0107	0.63	99.97	9.0297	0.61	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9881	0.65	98.29	9.0330	0.61	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9790	0.67	96.55	8.9958	0.66	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9456	0.69	94.97	8.9726	0.63	272.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9245	0.72	93.38	8.9708	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8975	0.76	91.81	8.9149	0.76	274.95
18	9.1829	0.56	155.36	9.2087	0.50	204.69	64	8.9026	0.78	90.33	8.9260	0.76	276.37
20	9.1998	0.53	142.67	9.1895	0.49	217.10	66	8.9225	0.85	88.83	8.9347	0.80	277.77
22	9.1755	0.54	134.57	9.1838	0.52	225.40	68	8.9541	0.96	87.35	9.0034	0.90	279.11
24	9.1794	0.52	128.27	9.1702	0.50	231.55	70	8.8071	1.16	85.94	8.8707	1.33	280.51
26	9.1770	0.48	123.40	9.1829	0.53	236.53	72	8.7380	1.08	84.49	8.7361	1.04	281.88
28	9.1465	0.50	119.26	9.1887	0.49	240.62	74	8.6794	1.19	83.04	8.4839	1.39	278.98
30	9.1687	0.52	115.77	9.1808	0.49	244.12	76	8.6002	1.45	81.61	8.4062	1.79	280.43
32	9.1520	0.52	112.63	9.1877	0.51	247.27	78	8.5387	1.63	80.18	8.2531	1.93	281.81
34	9.1293	0.50	109.76	9.1538	0.54	250.13	80	8.4392	2.01	78.70	8.0787	2.34	283.23
36	9.0965	0.56	107.30	9.1367	0.51	252.64	82	8.2959	2.82	77.25	7.7717	N/A	284.85
38	9.1135	0.54	104.96	9.1078	0.56	254.96	84	7.9792	3.55	75.76	N/A	N/A	N/A
40	9.0937	0.52	102.79	9.1114	0.58	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0868	0.52	100.82	9.0798	0.54	259.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0730	0.54	98.93	9.0896	0.54	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

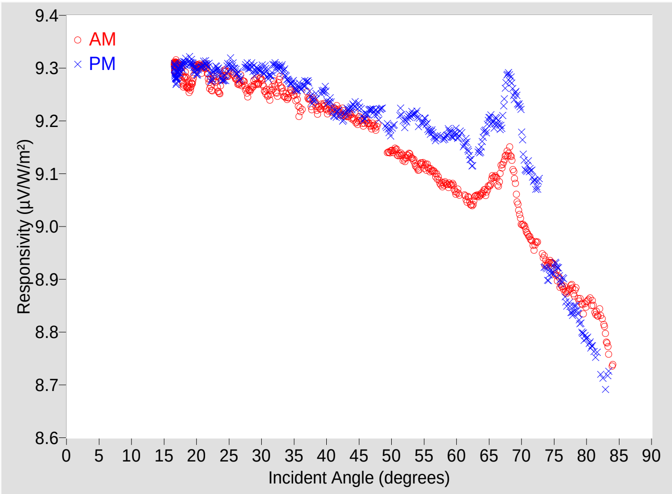


Figure 4. Responsivity vs Local Standard Time

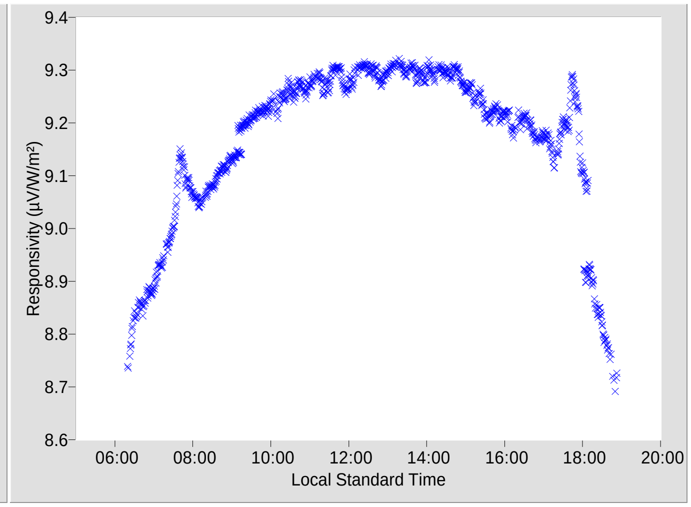


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.2148	+1.61 / -2.19	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ RSnet = 0.65771 µV/W/m², determination date: 06/13/2006

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2006	0.59	97.15	9.2096	0.61	262.73
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1896	N/A	95.67	9.2148	0.62	264.50
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1422	0.64	101.83	9.1836	0.64	266.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1271	0.66	99.97	9.1967	0.67	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1104	0.68	98.29	9.2067	0.67	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1067	0.70	96.55	9.1800	0.71	270.66
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0807	0.72	94.97	9.1661	0.71	272.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0658	0.75	93.38	9.1751	0.74	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0484	0.79	91.81	9.1352	0.82	274.95
18	9.2798	0.57	155.36	9.3078	0.54	204.69	64	9.0641	0.83	90.33	9.1650	0.89	276.37
20	9.3027	0.56	142.67	9.2938	0.52	217.10	66	9.0939	0.91	88.83	9.1972	0.89	277.77
22	9.2744	0.57	134.57	9.2921	0.54	225.40	68	9.1401	0.99	87.35	9.2859	1.02	279.11
24	9.2838	0.55	128.27	9.2779	0.53	231.55	70	9.0100	1.15	85.94	9.1856	1.31	280.51
26	9.2815	0.51	123.40	9.2948	0.56	236.53	72	8.9639	1.13	84.49	9.0827	1.15	281.88
28	9.2543	0.53	119.26	9.3017	0.53	240.62	74	8.9306	1.25	83.04	8.9091	1.53	278.98
30	9.2771	0.54	115.77	9.2975	0.53	244.12	76	8.8913	1.46	81.61	8.8990	1.79	280.43
32	9.2654	0.57	112.63	9.3072	0.55	247.27	78	8.8789	1.69	80.18	8.8413	2.03	281.81
34	9.2467	0.53	109.76	9.2785	0.57	250.13	80	8.8560	2.06	78.70	8.7898	2.41	283.23
36	9.2182	0.59	107.30	9.2636	0.55	252.64	82	8.8354	2.67	77.25	8.7197	N/A	284.85
38	9.2355	0.58	104.96	9.2386	0.60	254.96	84	8.7372	3.65	75.76	N/A	N/A	N/A
40	9.2212	0.56	102.79	9.2454	0.62	257.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2169	0.56	100.82	9.2150	0.58	259.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2058	0.58	98.93	9.2279	0.59	261.00	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

32039F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

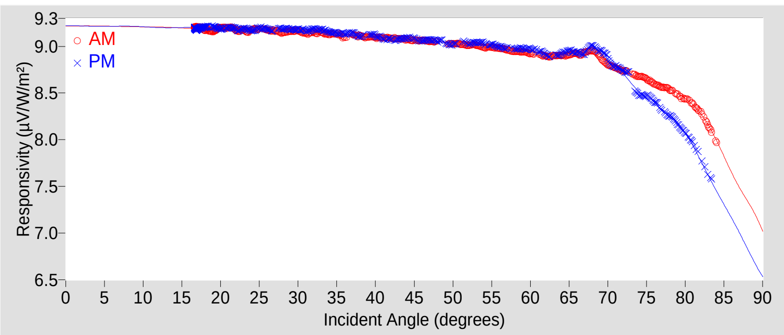
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

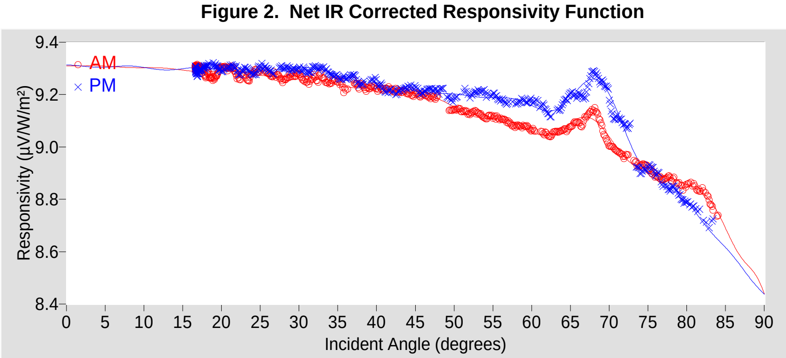


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.48	±1.48
R²	0.9999987	0.9999982
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	±1.50	±1.50
Net IR corrected R²	0.9999989	0.9999986
Corr. valid inc. angle range	16.6° to 84.1°	16.6° to 83.4°

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	9.2166	*	9.2168	*	9.2167	*	9.3078	*	9.3080	*	9.3079	*
9-18	9.2015	*	9.2039	*	9.2027	*	9.2973	*	9.2999	*	9.2986	*
18-27	9.1814	±1.49	9.1848	±1.49	9.1831	±1.51	9.2832	±1.51	9.2916	±1.51	9.2874	±1.52
27-36	9.1475	±1.51	9.1751	±1.50	9.1613	±1.60	9.2598	±1.52	9.2940	±1.52	9.2769	±1.60
36-45	9.0929	±1.50	9.1021	±1.51	9.0975	±1.56	9.2203	±1.51	9.2357	±1.52	9.2280	±1.56
45-54	9.0354	±1.54	9.0438	±1.51	9.0396	±1.61	9.1610	±1.59	9.2021	±1.51	9.1816	±1.73
54-63	8.9439	±1.57	8.9742	±1.58	8.9591	±1.77	9.0800	±1.54	9.1704	±1.53	9.1252	±1.88
63-72	8.8879	±1.78	8.9207	±1.91	8.9043	±2.33	9.0707	±1.68	9.1987	±1.73	9.1347	±2.65
72-81	8.5900	±2.42	8.3682	±4.46	8.4791	±6.52	8.8983	±1.63	8.8911	±2.21	8.8947	±2.78
81-90	7.7370	*	7.2302	*	7.4836	*	8.6620	*	8.5952	*	8.6286	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

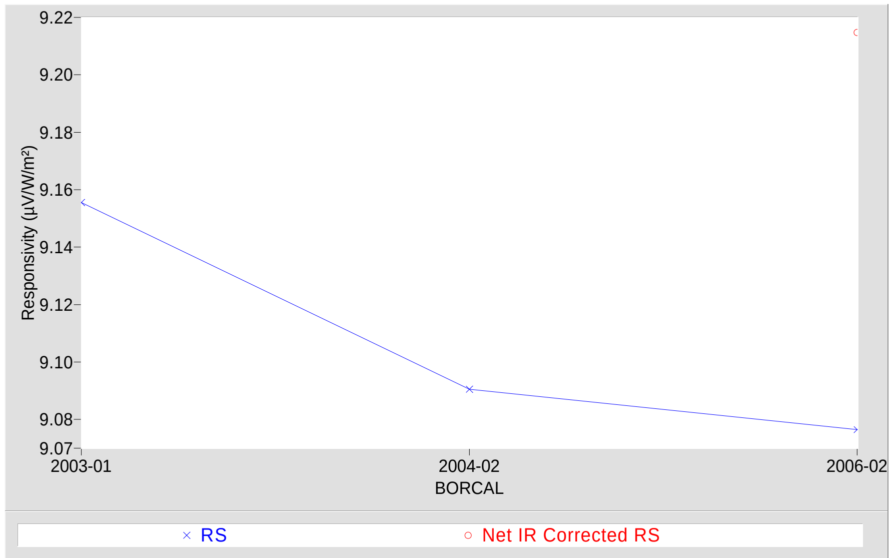
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.0765	+1.80 / -2.18
45° - 55°	9.0339	±1.56
Composite	9.0852	+1.98 / -17.99
45° (Net IR Corr.)	9.2148	+1.61 / -2.19
45° - 55° (Net IR Corr.)	9.1768	±1.61
Composite (Net IR Corr.)	9.2290	+1.71 / -6.48

† Valid incident angle ranges:
- 45°: 30.0° to 60.0°, 30.0° to 60.0° (Net IR corr.)
- 45° - 55°: 45.0° to 55.0°, 45.0° to 55.0° (Net IR corr.)
- Composite: 16.6° to 83.4°, 16.6° to 83.4° (Net IR corr.)

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



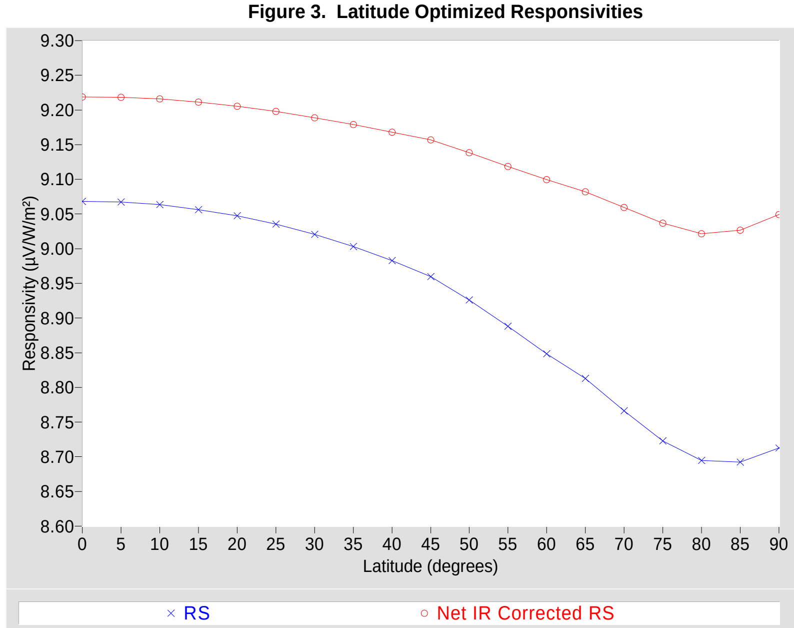
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.0681	+2.26 / -26.39	9.2188	+1.82 / -8.27
5	9.0673	+2.26 / -26.39	9.2183	+1.82 / -8.27
10	9.0634	+2.30 / -26.36	9.2158	+1.84 / -8.24
15	9.0564	+2.36 / -26.30	9.2112	+1.87 / -8.20
20	9.0473	+2.44 / -26.23	9.2055	+1.90 / -8.14
25	9.0354	+2.54 / -26.13	9.1980	+1.95 / -8.07
30	9.0208	+2.63 / -26.01	9.1890	+1.99 / -7.98
35	9.0033	+2.72 / -25.87	9.1790	+2.03 / -7.88
40	8.9828	+2.88 / -25.70	9.1681	+2.11 / -7.77
45	8.9595	+2.96 / -25.50	9.1569	+2.20 / -7.66
50	8.9261	+3.28 / -25.22	9.1383	+2.35 / -7.48
55	8.8882	+3.66 / -24.91	9.1186	+2.53 / -7.28
60	8.8484	+3.54 / -24.57	9.0994	+2.32 / -7.09
65	8.8128	+3.57 / -24.26	9.0821	+2.46 / -6.92
70	8.7664	+3.70 / -23.86	9.0593	+2.67 / -6.69
75	8.7229	+3.86 / -23.49	9.0366	+2.89 / -6.46
80	8.6945	+3.86 / -23.24	9.0217	+3.03 / -6.31
85	8.6926	+3.57 / -23.22	9.0265	+2.98 / -6.36
90	8.7127	+3.36 / -23.40	9.0495	+2.76 / -6.59

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

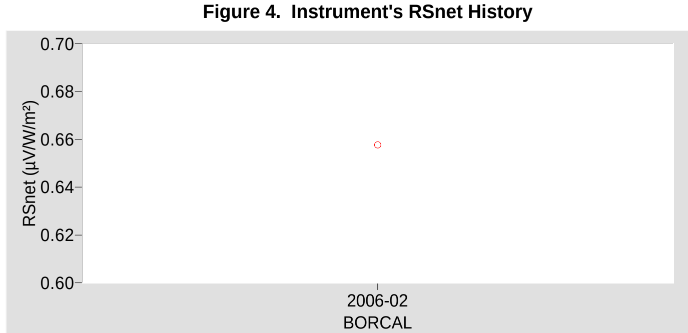
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 32330

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

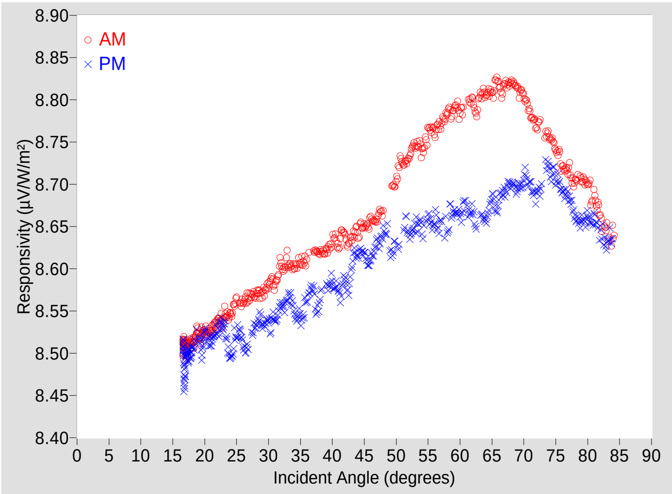

Figure 2. Responsivity vs Local Standard Time

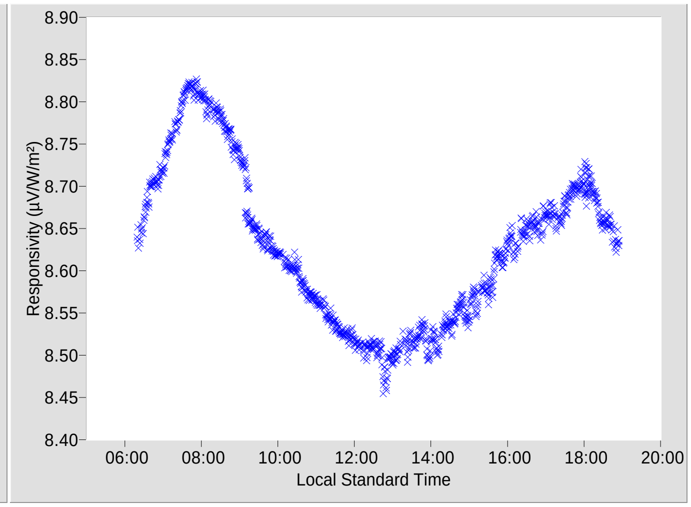

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6337	+2.44 / -1.82	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6570	0.54	97.14	8.6113	0.57	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6626	N/A	95.60	8.6422	0.58	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7027	0.64	101.88	8.6275	0.58	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7320	0.64	100.01	8.6409	0.60	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7402	0.67	98.22	8.6475	0.61	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7624	0.67	96.60	8.6581	0.63	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7852	0.69	94.96	8.6488	0.66	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7861	0.72	93.37	8.6630	0.67	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7972	0.75	91.85	8.6657	0.70	274.98
18	8.5132	0.51	155.56	8.5025	0.52	204.42	64	8.8056	0.78	90.32	8.6579	0.73	276.36
20	8.5262	0.48	142.83	8.5207	0.52	217.26	66	8.8200	0.85	88.82	8.6761	0.78	277.72
22	8.5357	0.48	134.54	8.5258	0.51	225.37	68	8.8198	0.89	87.39	8.6999	0.81	279.15
24	8.5446	0.49	128.39	8.4960	0.54	231.66	70	8.8032	0.98	85.88	8.7083	0.88	280.51
26	8.5605	0.48	123.38	8.5106	0.51	236.50	72	8.7699	1.06	84.48	8.6888	0.97	281.88
28	8.5688	0.48	119.35	8.5332	0.50	240.60	74	8.7564	1.17	83.04	8.7157	1.35	279.01
30	8.5814	0.50	115.75	8.5356	0.50	244.20	76	8.7201	1.36	81.60	8.6924	1.50	280.38
32	8.6038	0.52	112.61	8.5574	0.51	247.34	78	8.7024	1.58	80.17	8.6611	1.76	281.85
34	8.6020	0.49	109.82	8.5512	0.54	250.03	80	8.7013	1.91	78.74	8.6631	2.05	283.27
36	8.6098	0.50	107.47	8.5628	0.58	252.62	82	8.6613	2.47	77.26	8.6383	2.59	284.76
38	8.6195	0.50	105.02	8.5619	0.55	254.95	84	8.6384	3.30	75.80	8.6356	N/A	286.10
40	8.6329	0.53	102.85	8.5828	0.53	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6380	0.53	100.81	8.5852	0.58	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6418	0.54	98.92	8.6170	0.55	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

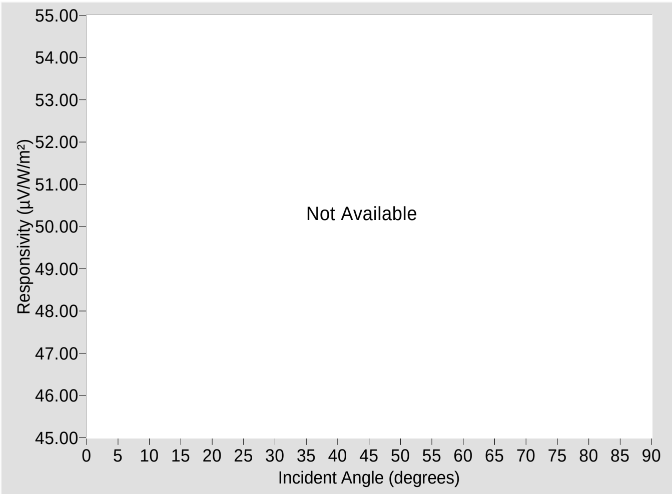


Figure 4. Responsivity vs Local Standard Time

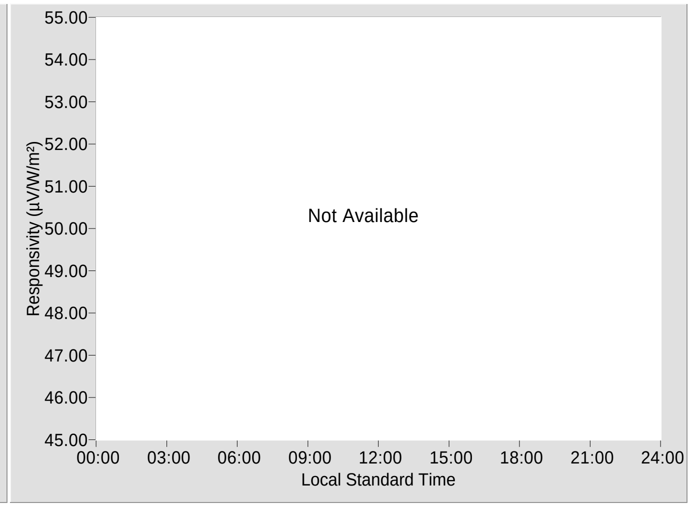


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RSc (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RSc (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

32330 Eppley 8-48

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

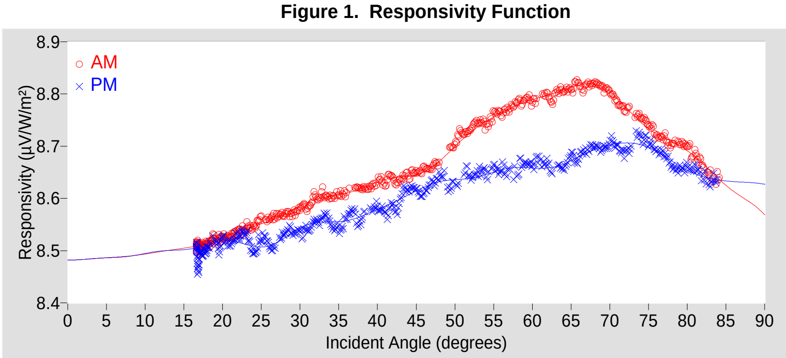
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

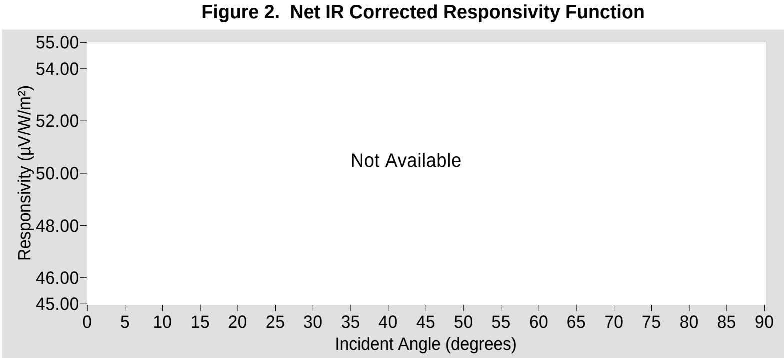


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.41	±1.41
R^2	0.9999998	0.9999994
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R^2	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.4857	*	8.4855	*	8.4856	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.5011	*	8.5001	*	8.5006	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.5371	±1.43	8.5130	±1.41	8.5250	±1.48	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.5902	±1.43	8.5442	±1.43	8.5672	±1.61	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.6300	±1.42	8.5815	±1.44	8.6058	±1.58	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.6904	±1.51	8.6324	±1.42	8.6614	±1.78	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.7773	±1.44	8.6560	±1.41	8.7167	±1.89	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.8091	±1.42	8.6862	±1.43	8.7477	±1.91	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.7259	±1.50	8.6843	±1.44	8.7051	±1.74	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.6224	*	8.6345	*	8.6285	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6337	+2.44 / -1.82
45° - 55°	8.6669	±1.63
Composite	8.5815	+3.11 / -1.66
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:

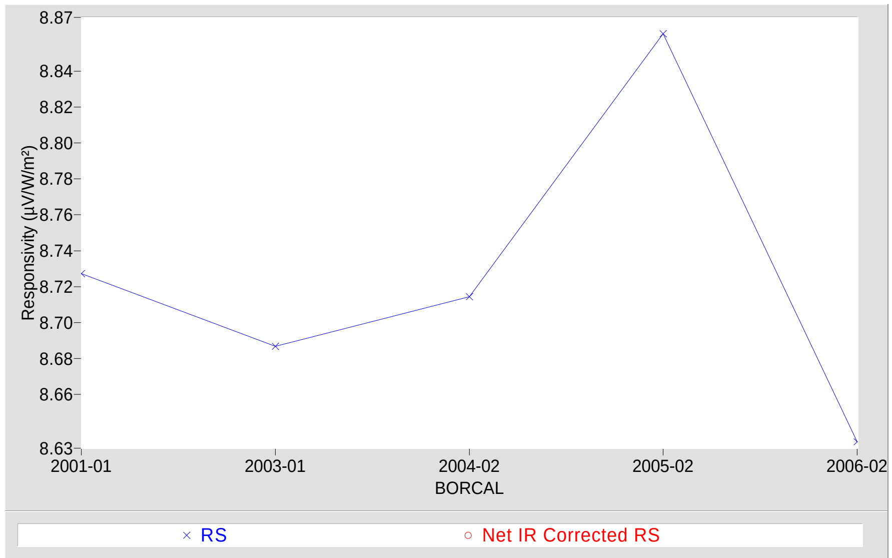
45°: 30.0° to 60.0°

45° - 55°: 45.0° to 55.0°

Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



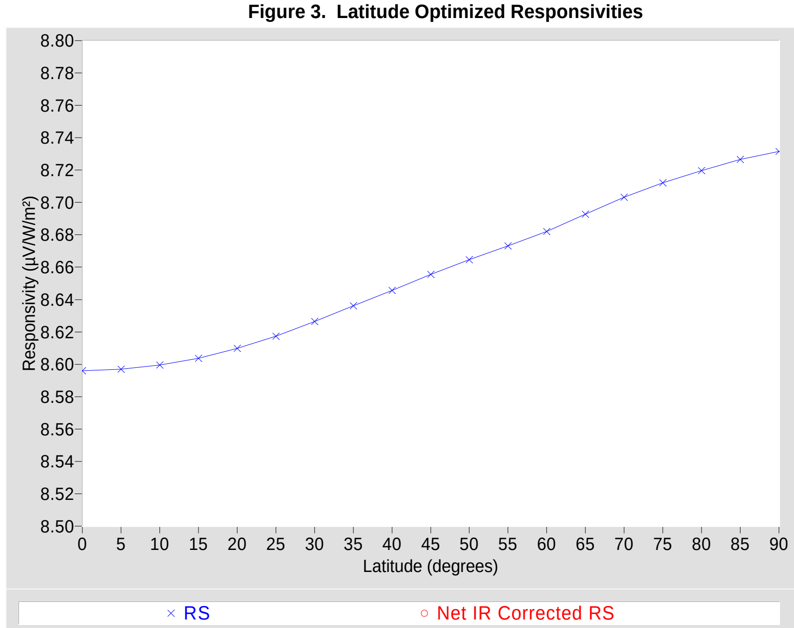
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5960	+2.96 / -1.94	N/A	N/A
5	8.5969	+2.95 / -1.94	N/A	N/A
10	8.5996	+2.92 / -1.96	N/A	N/A
15	8.6037	+2.88 / -2.00	N/A	N/A
20	8.6097	+2.81 / -2.05	N/A	N/A
25	8.6174	+2.74 / -2.11	N/A	N/A
30	8.6264	+2.64 / -2.15	N/A	N/A
35	8.6361	+2.55 / -2.15	N/A	N/A
40	8.6457	+2.45 / -2.16	N/A	N/A
45	8.6555	+2.36 / -2.22	N/A	N/A
50	8.6647	+2.28 / -2.28	N/A	N/A
55	8.6732	+2.20 / -2.00	N/A	N/A
60	8.6821	+2.12 / -2.01	N/A	N/A
65	8.6928	+2.03 / -1.89	N/A	N/A
70	8.7032	+1.94 / -1.97	N/A	N/A
75	8.7122	+1.87 / -2.05	N/A	N/A
80	8.7196	+1.82 / -2.11	N/A	N/A
85	8.7266	+1.77 / -2.17	N/A	N/A
90	8.7314	+1.73 / -2.21	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

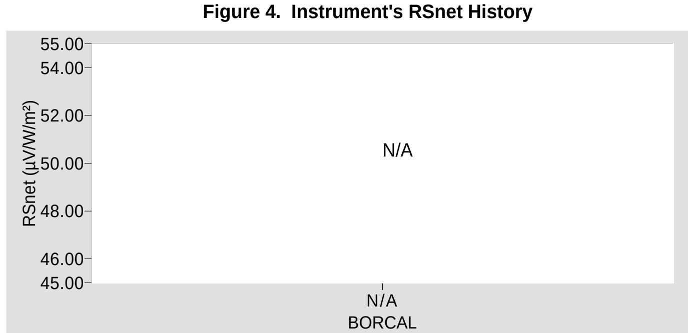
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 32972

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

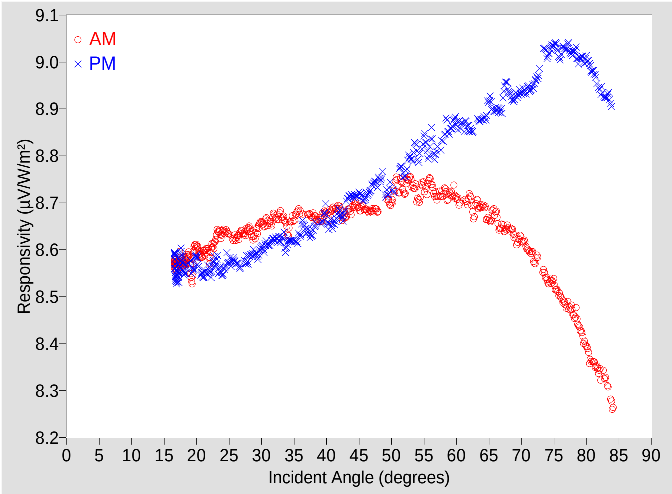

Figure 2. Responsivity vs Local Standard Time

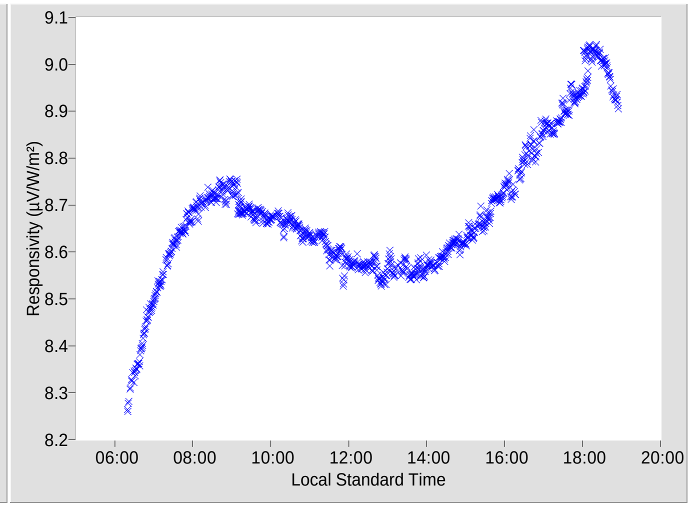

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7030	+2.60 / -1.78	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6855	0.54	97.14	8.7121	0.58	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6802	N/A	95.60	8.7452	0.59	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6998	0.70	101.88	8.7317	0.60	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7261	0.66	100.01	8.7598	0.64	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7108	0.70	98.22	8.8033	0.67	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7461	0.70	96.60	8.8305	0.72	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7225	0.69	94.96	8.8391	0.73	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7111	0.75	93.37	8.8695	0.67	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7101	0.80	91.85	8.8562	0.69	274.98
18	8.5743	0.50	155.56	8.5605	0.63	204.42	64	8.6934	0.82	90.32	8.8788	0.75	276.36
20	8.6066	0.67	142.83	8.5806	0.54	217.26	66	8.6785	0.88	88.82	8.8967	0.78	277.72
22	8.5910	0.56	134.54	8.5515	0.54	225.37	68	8.6449	0.90	87.39	8.9408	0.89	279.15
24	8.6367	0.48	128.39	8.5519	0.55	231.66	70	8.6215	0.98	85.88	8.9363	0.88	280.51
26	8.6261	0.48	123.38	8.5727	0.49	236.50	72	8.5791	1.07	84.48	8.9545	0.99	281.88
28	8.6455	0.50	119.35	8.5829	0.51	240.60	74	8.5337	1.18	83.04	9.0161	1.35	279.01
30	8.6570	0.54	115.75	8.6044	0.53	244.20	76	8.5008	1.38	81.60	9.0143	1.50	280.38
32	8.6712	0.51	112.61	8.6232	0.50	247.34	78	8.4623	1.61	80.17	9.0218	1.76	281.85
34	8.6437	0.54	109.82	8.6092	0.56	250.03	80	8.3960	1.96	78.74	9.0057	2.04	283.27
36	8.6821	0.51	107.47	8.6367	0.58	252.62	82	8.3391	2.49	77.26	8.9392	2.58	284.76
38	8.6713	0.51	105.02	8.6456	0.55	254.95	84	8.2709	3.35	75.80	8.9051	N/A	286.10
40	8.6749	0.53	102.85	8.6731	0.60	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6873	0.54	100.81	8.6785	0.57	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6877	0.55	98.92	8.7141	0.54	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

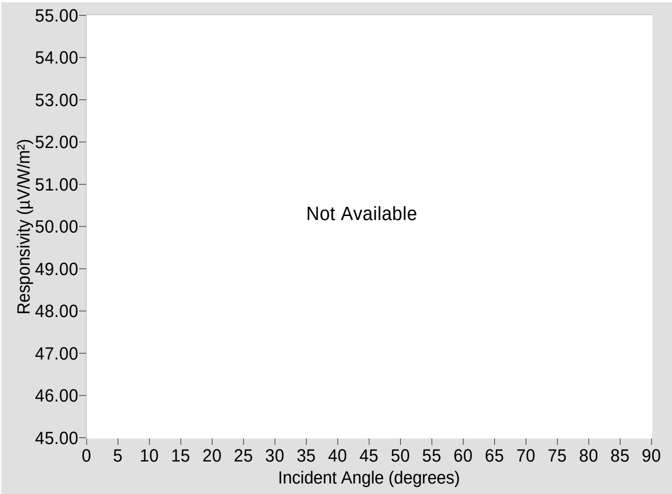

Figure 4. Responsivity vs Local Standard Time

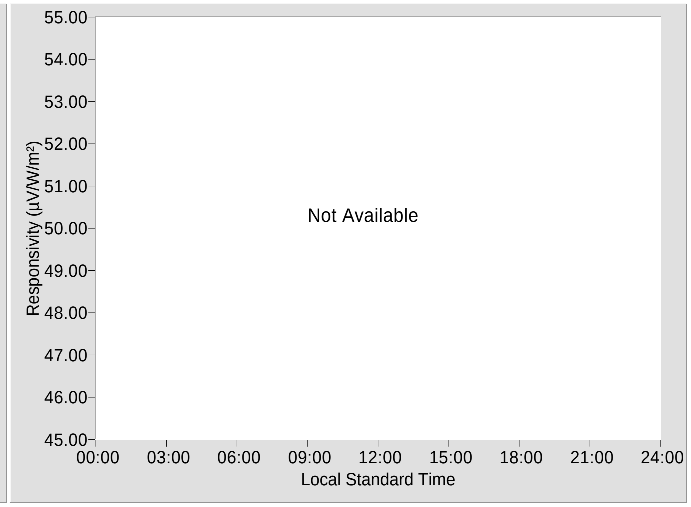

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° ($\mu V/W/m^2$) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RSc ($\mu V/W/m^2$)	U95 ± (%)	Azm. Angle‡	RSc ($\mu V/W/m^2$)	U95 ± (%)	Azm. Angle‡		RSc ($\mu V/W/m^2$)	U95 ± (%)	Azm. Angle‡	RSc ($\mu V/W/m^2$)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

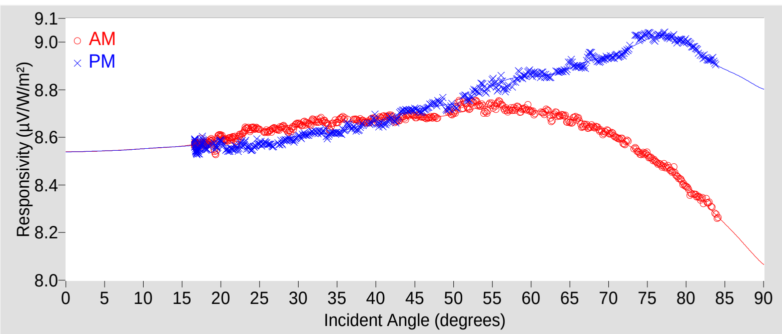
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

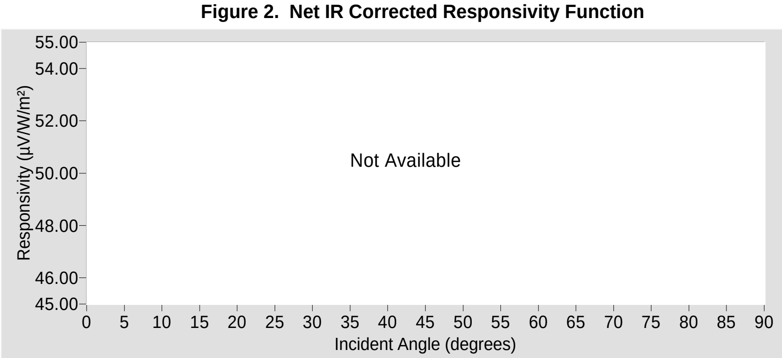


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.42	±1.42
R²	0.9999993	0.9999993
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	Responsivity AM U95 (%)	Responsivity PM RS (µV/W/m²)	Responsivity PM U95 (%)	Responsivity Combined RS (µV/W/m²)	Responsivity Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	Net IR Corr. Responsivity AM U95 (%)	Net IR Corr. Responsivity PM RSc (µV/W/m²)	Net IR Corr. Responsivity PM U95 (%)	Net IR Corr. Responsivity Combined RSc (µV/W/m²)	Net IR Corr. Responsivity Combined U95 (%)
0-9	8.5430	*	8.5430	*	8.5430	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.5603	*	8.5593	*	8.5598	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.6091	±1.46	8.5625	±1.43	8.5858	±1.59	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.6569	±1.43	8.6075	±1.45	8.6322	±1.61	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.6791	±1.43	8.6701	±1.49	8.6746	±1.56	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.6983	±1.44	8.7424	±1.48	8.7204	±1.66	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.7216	±1.43	8.8425	±1.47	8.7821	±1.93	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.6547	±1.57	8.9155	±1.51	8.7851	±3.32	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.4903	±1.81	9.0055	±1.47	8.7479	±5.42	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.2187	*	8.8809	*	8.5498	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

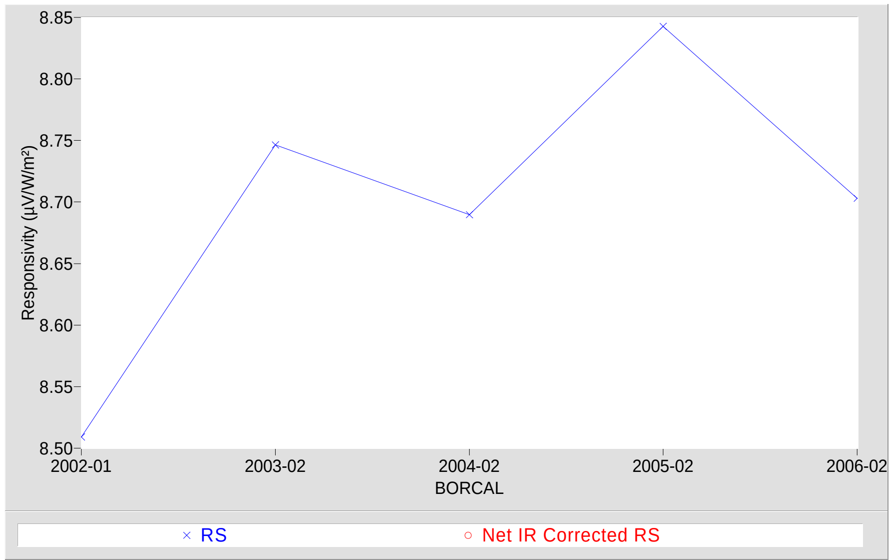
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.7030	+2.60 / -1.78
45° - 55°	8.7271	±1.61
Composite	8.6399	+4.72 / -4.51
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



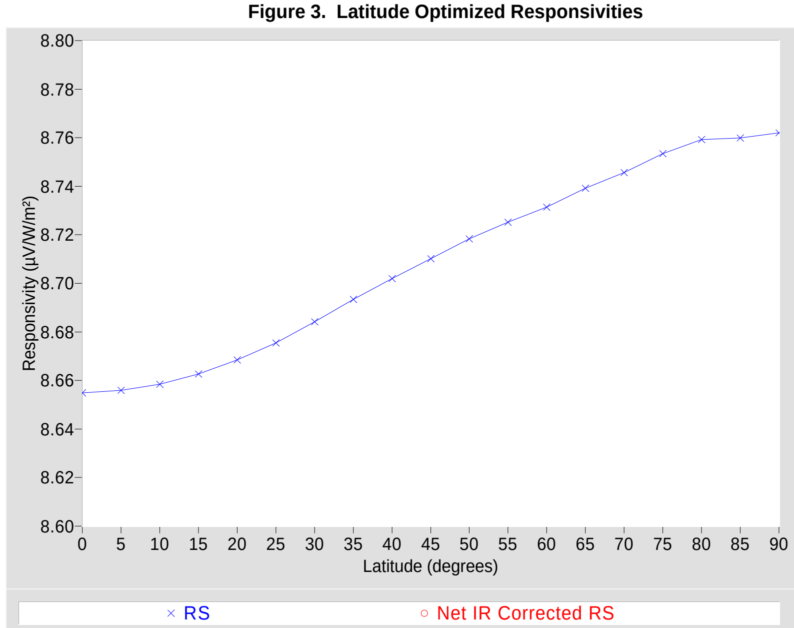
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6549	+4.55 / -6.60	N/A	N/A
5	8.6560	+4.54 / -6.61	N/A	N/A
10	8.6585	+4.51 / -6.64	N/A	N/A
15	8.6626	+4.46 / -6.68	N/A	N/A
20	8.6684	+4.40 / -6.74	N/A	N/A
25	8.6755	+4.32 / -6.82	N/A	N/A
30	8.6842	+4.22 / -6.91	N/A	N/A
35	8.6935	+4.11 / -7.00	N/A	N/A
40	8.7019	+4.02 / -7.09	N/A	N/A
45	8.7102	+3.93 / -7.18	N/A	N/A
50	8.7184	+3.84 / -7.27	N/A	N/A
55	8.7251	+3.76 / -7.34	N/A	N/A
60	8.7314	+3.69 / -7.40	N/A	N/A
65	8.7392	+3.61 / -7.48	N/A	N/A
70	8.7457	+3.54 / -7.55	N/A	N/A
75	8.7534	+3.45 / -7.63	N/A	N/A
80	8.7593	+3.39 / -7.69	N/A	N/A
85	8.7599	+3.38 / -7.70	N/A	N/A
90	8.7620	+3.36 / -7.72	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

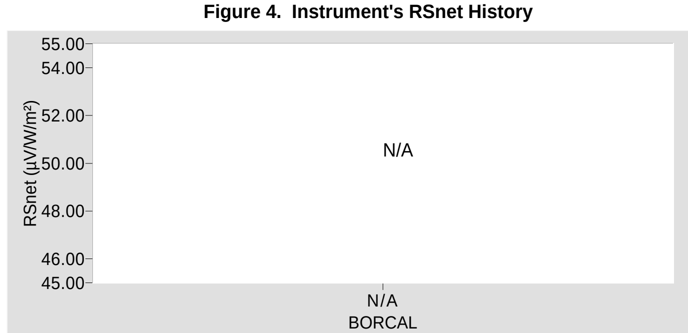
Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33236

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

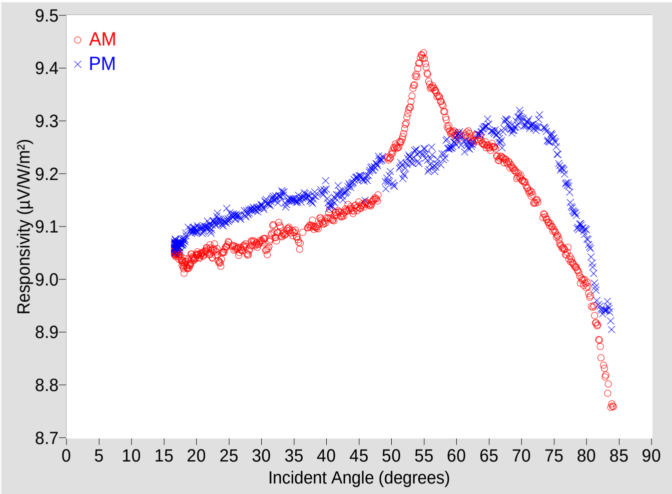

Figure 2. Responsivity vs Local Standard Time

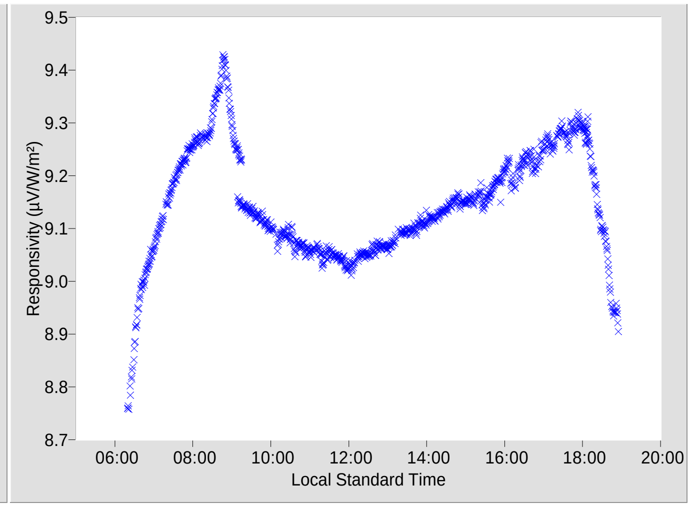

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.1653	+3.41 / -1.82	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1428	0.53	97.14	9.1819	0.64	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1485	N/A	95.60	9.2238	0.57	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2358	0.62	101.88	9.1880	0.59	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2843	0.74	100.01	9.2035	0.62	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3982	0.80	98.22	9.2313	0.61	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3666	0.74	96.60	9.2277	0.65	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3240	0.76	94.96	9.2331	0.67	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2724	0.71	93.37	9.2648	0.67	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2716	0.75	91.85	9.2526	0.68	274.98
18	9.0289	0.52	155.56	9.0720	0.53	204.42	64	9.2584	0.79	90.32	9.2835	0.73	276.36
20	9.0447	0.48	142.83	9.0934	0.47	217.26	66	9.2432	0.85	88.82	9.2769	0.76	277.72
22	9.0548	0.49	134.54	9.0965	0.49	225.37	68	9.2195	0.89	87.39	9.2919	0.85	279.15
24	9.0447	0.53	128.39	9.1065	0.50	231.66	70	9.1899	0.98	85.88	9.3061	0.88	280.51
26	9.0588	0.48	123.38	9.1198	0.48	236.50	72	9.1487	1.05	84.48	9.2878	0.96	281.88
28	9.0507	0.50	119.35	9.1278	0.48	240.60	74	9.1104	1.17	83.04	9.2654	1.34	279.01
30	9.0725	0.50	115.75	9.1388	0.50	244.20	76	9.0661	1.36	81.60	9.2124	1.54	280.38
32	9.0877	0.54	112.61	9.1538	0.50	247.34	78	9.0286	1.59	80.17	9.1288	1.80	281.85
34	9.0941	0.49	109.82	9.1454	0.52	250.03	80	8.9913	1.92	78.74	9.0853	2.08	283.27
36	9.0652	0.53	107.47	9.1519	0.51	252.62	82	8.8818	2.56	77.26	8.9484	2.60	284.76
38	9.1019	0.51	105.02	9.1547	0.52	254.95	84	8.7600	3.30	75.80	8.9051	N/A	286.10
40	9.1124	0.53	102.85	9.1646	0.59	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1247	0.52	100.81	9.1661	0.56	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1294	0.54	98.92	9.1842	0.56	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

Figure 4. Responsivity vs Local Standard Time

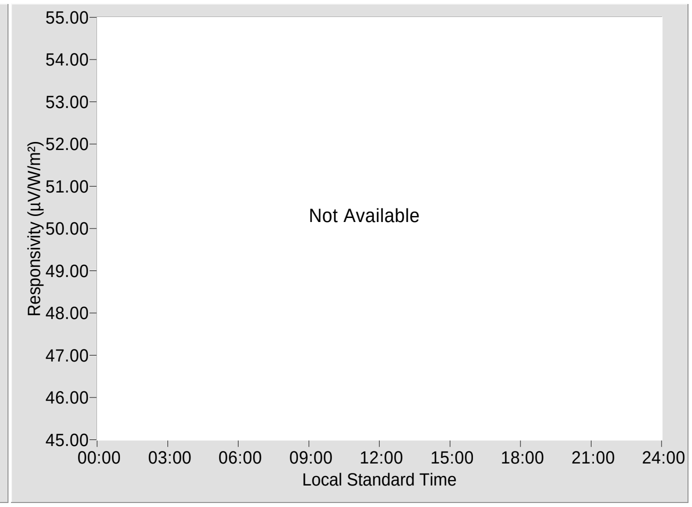


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

33236 Eppley 8-48

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

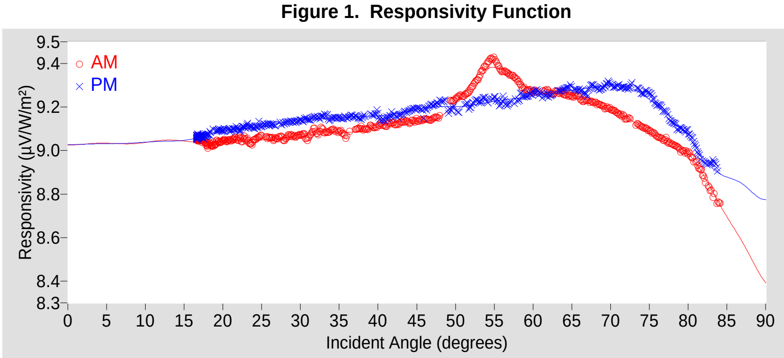
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \quad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

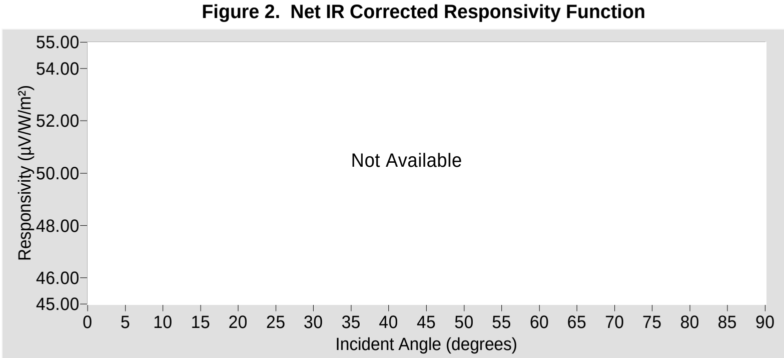


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.43	±1.43
R²	0.9999993	0.9999993
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	9.0308	*	9.0309	*	9.0309	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	9.0420	*	9.0459	*	9.0439	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	9.0473	±1.43	9.0987	±1.45	9.0730	±1.57	N/A	N/A	N/A	N/A	N/A	N/A
27-36	9.0754	±1.44	9.1422	±1.44	9.1088	±1.63	N/A	N/A	N/A	N/A	N/A	N/A
36-45	9.1109	±1.46	9.1643	±1.44	9.1376	±1.63	N/A	N/A	N/A	N/A	N/A	N/A
45-54	9.2171	±1.90	9.2024	±1.44	9.2098	±2.36	N/A	N/A	N/A	N/A	N/A	N/A
54-63	9.3207	±1.57	9.2431	±1.45	9.2819	±1.92	N/A	N/A	N/A	N/A	N/A	N/A
63-72	9.2235	±1.53	9.2879	±1.44	9.2557	±1.82	N/A	N/A	N/A	N/A	N/A	N/A
72-81	9.0636	±1.76	9.1897	±1.99	9.1266	±2.93	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.6679	*	8.8757	*	8.7718	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

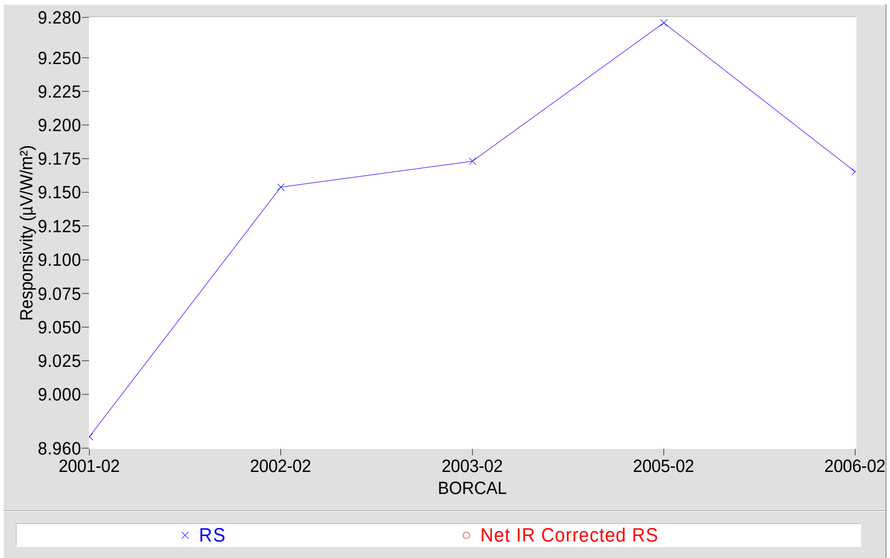
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.1653	+3.41 / -1.82
45° - 55°	9.2229	±1.97
Composite	9.1159	+3.26 / -4.19
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



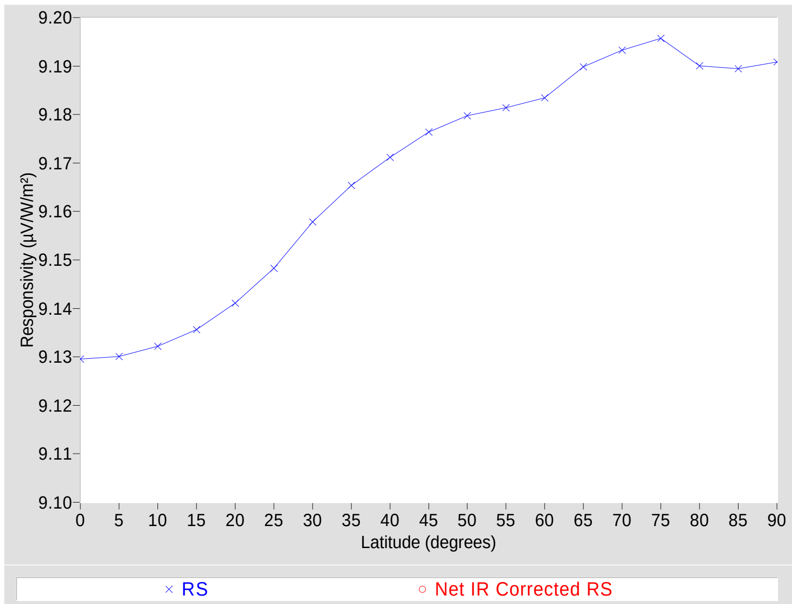
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.1296	+3.12 / -7.60	N/A	N/A
5	9.1301	+3.12 / -7.61	N/A	N/A
10	9.1322	+3.10 / -7.63	N/A	N/A
15	9.1356	+3.06 / -7.66	N/A	N/A
20	9.1411	+3.01 / -7.72	N/A	N/A
25	9.1483	+2.94 / -7.79	N/A	N/A
30	9.1578	+2.85 / -7.88	N/A	N/A
35	9.1653	+2.77 / -7.96	N/A	N/A
40	9.1712	+2.72 / -8.02	N/A	N/A
45	9.1764	+2.67 / -8.07	N/A	N/A
50	9.1798	+2.64 / -8.10	N/A	N/A
55	9.1814	+2.62 / -8.12	N/A	N/A
60	9.1835	+2.60 / -8.14	N/A	N/A
65	9.1898	+2.54 / -8.20	N/A	N/A
70	9.1933	+2.51 / -8.23	N/A	N/A
75	9.1957	+2.49 / -8.26	N/A	N/A
80	9.1900	+2.46 / -8.20	N/A	N/A
85	9.1895	+1.88 / -8.20	N/A	N/A
90	9.1908	+1.87 / -8.21	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

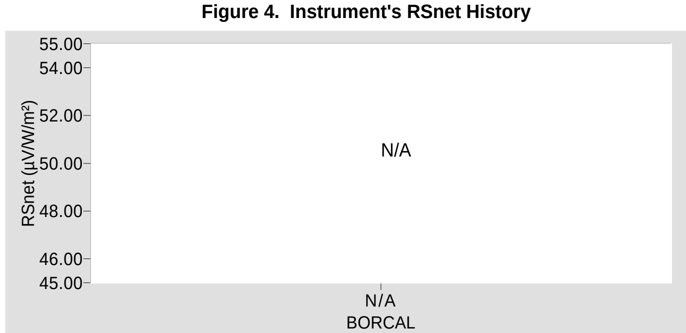
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33239

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

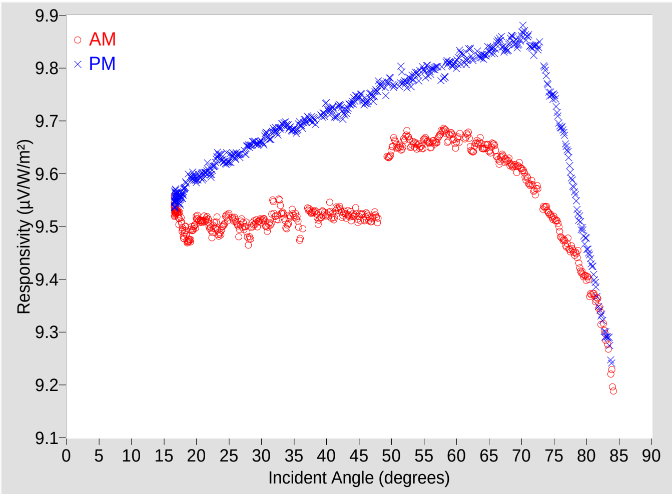

Figure 2. Responsivity vs Local Standard Time

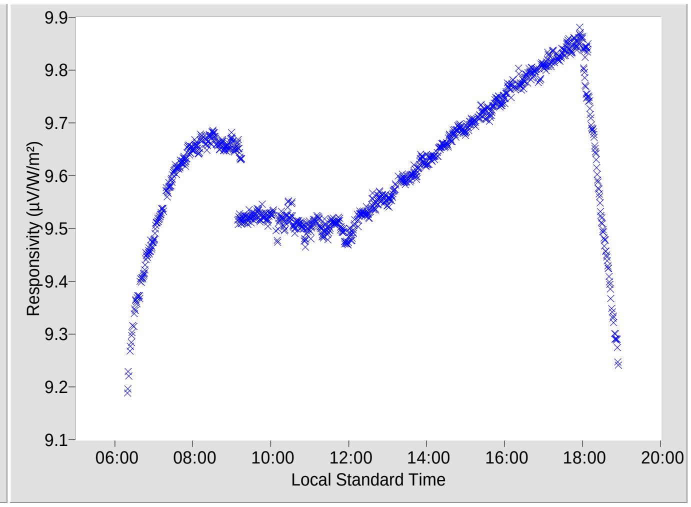

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.6305	+2.44 / -2.15	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc.	AM			PM			Inc.	AM			PM		
Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.5184	0.53	97.14	9.7334	0.55	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.5075	N/A	95.60	9.7652	0.59	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6428	0.63	101.88	9.7710	0.59	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6648	0.65	100.01	9.7731	0.61	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.6524	0.64	98.22	9.7863	0.62	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6548	0.66	96.60	9.7951	0.61	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6826	0.69	94.96	9.7875	0.65	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.6604	0.72	93.37	9.8084	0.67	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6631	0.76	91.85	9.8298	0.69	274.98
18	9.4920	0.57	155.56	9.5655	0.55	204.42	64	9.6501	0.79	90.32	9.8225	0.71	276.36
20	9.5110	0.53	142.83	9.5911	0.48	217.26	66	9.6436	0.85	88.82	9.8393	0.77	277.72
22	9.5021	0.51	134.54	9.6036	0.49	225.37	68	9.6234	0.89	87.39	9.8434	0.81	279.15
24	9.4972	0.52	128.39	9.6259	0.48	231.66	70	9.6088	0.97	85.88	9.8656	0.89	280.51
26	9.5102	0.50	123.38	9.6338	0.48	236.50	72	9.5694	1.05	84.48	9.8393	0.96	281.88
28	9.4783	0.53	119.35	9.6529	0.49	240.60	74	9.5306	1.16	83.04	9.7652	1.37	279.01
30	9.5119	0.49	115.75	9.6604	0.49	244.20	76	9.4854	1.36	81.60	9.6898	1.55	280.38
32	9.5290	0.54	112.61	9.6832	0.50	247.34	78	9.4523	1.58	80.17	9.5727	1.86	281.85
34	9.5035	0.52	109.82	9.6916	0.50	250.03	80	9.4046	1.89	78.74	9.4678	2.07	283.27
36	9.4834	0.56	107.47	9.6932	0.52	252.62	82	9.3420	2.47	77.26	9.3401	2.62	284.76
38	9.5274	0.52	105.02	9.7018	0.51	254.95	84	9.2086	3.29	75.80	9.2411	N/A	286.10
40	9.5224	0.53	102.85	9.7234	0.53	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5333	0.53	100.81	9.7286	0.54	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.5181	0.54	98.92	9.7369	0.56	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

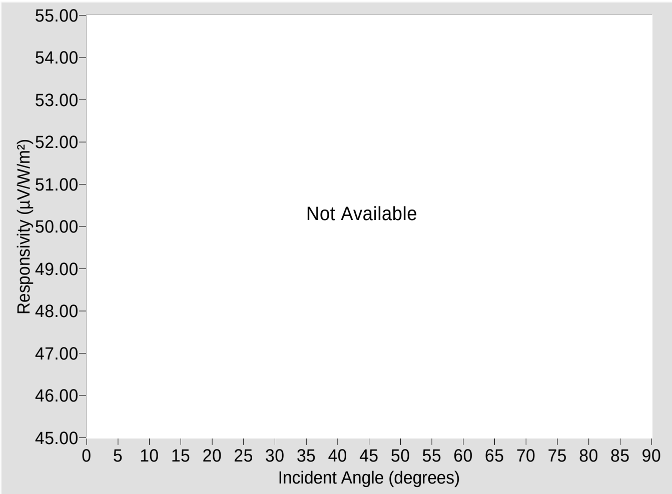

Figure 4. Responsivity vs Local Standard Time

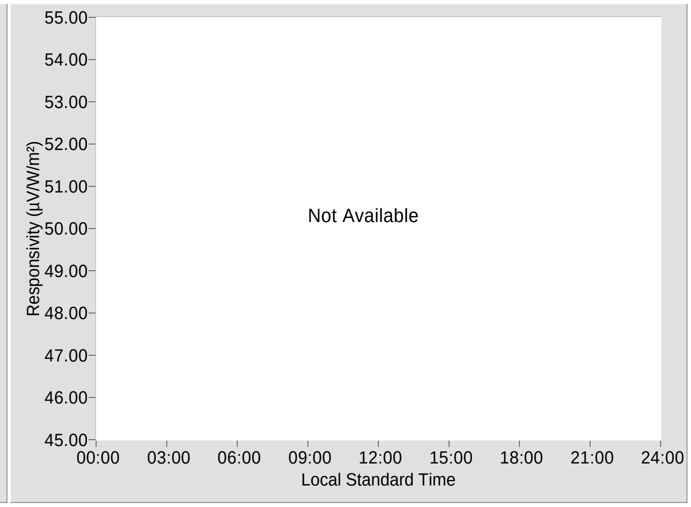

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

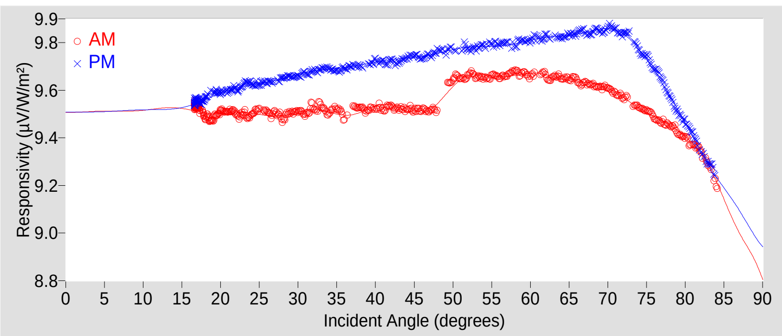
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

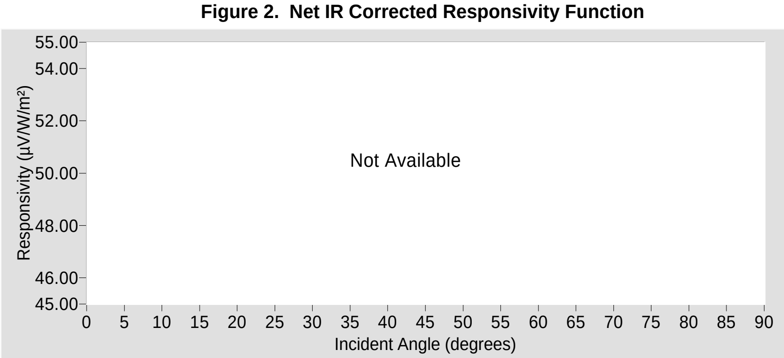


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.43	±1.43
R^2	0.9999988	0.9999998
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R^2	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	9.5107	*	9.5107	*	9.5107	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	9.5197	*	9.5260	*	9.5229	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	9.5017	±1.43	9.6063	±1.48	9.5540	±1.79	N/A	N/A	N/A	N/A	N/A	N/A
27-36	9.5064	±1.43	9.6722	±1.45	9.5893	±2.06	N/A	N/A	N/A	N/A	N/A	N/A
36-45	9.5194	±1.45	9.7182	±1.44	9.6188	±2.28	N/A	N/A	N/A	N/A	N/A	N/A
45-54	9.5863	±1.67	9.7635	±1.44	9.6749	±2.56	N/A	N/A	N/A	N/A	N/A	N/A
54-63	9.6649	±1.43	9.8004	±1.44	9.7327	±1.87	N/A	N/A	N/A	N/A	N/A	N/A
63-72	9.6275	±1.48	9.8430	±1.44	9.7352	±2.49	N/A	N/A	N/A	N/A	N/A	N/A
72-81	9.4835	±1.71	9.6579	±2.53	9.5707	±3.65	N/A	N/A	N/A	N/A	N/A	N/A
81-90	9.1068	*	9.1669	*	9.1369	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.6305	+2.44 / -2.15
45° - 55°	9.6820	±2.05
Composite	9.5897	+3.16 / -4.13
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:

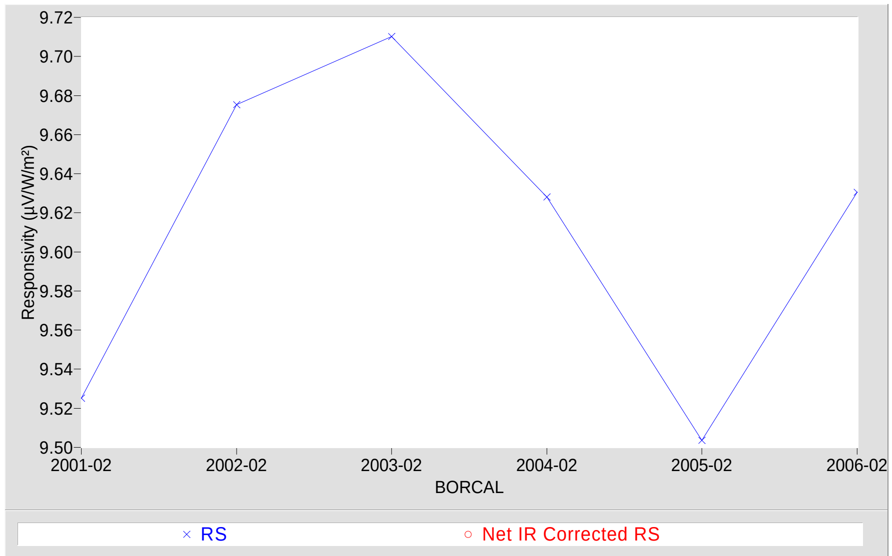
45°: 30.0° to 60.0°

45° - 55°: 45.0° to 55.0°

Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



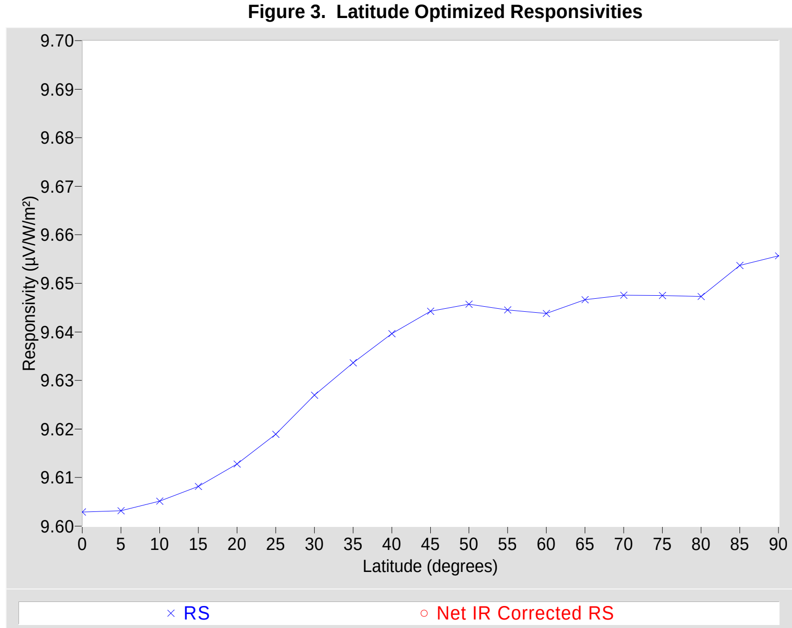
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.6029	+3.03 / -7.61	N/A	N/A
5	9.6032	+3.03 / -7.61	N/A	N/A
10	9.6051	+3.01 / -7.63	N/A	N/A
15	9.6082	+2.98 / -7.66	N/A	N/A
20	9.6128	+2.94 / -7.70	N/A	N/A
25	9.6189	+2.88 / -7.76	N/A	N/A
30	9.6270	+2.81 / -7.84	N/A	N/A
35	9.6336	+2.75 / -7.90	N/A	N/A
40	9.6397	+2.69 / -7.96	N/A	N/A
45	9.6443	+2.65 / -8.00	N/A	N/A
50	9.6457	+2.64 / -8.01	N/A	N/A
55	9.6445	+2.65 / -8.00	N/A	N/A
60	9.6438	+2.65 / -8.00	N/A	N/A
65	9.6466	+2.63 / -8.02	N/A	N/A
70	9.6476	+2.62 / -8.03	N/A	N/A
75	9.6475	+2.62 / -8.03	N/A	N/A
80	9.6473	+2.62 / -8.03	N/A	N/A
85	9.6537	+2.57 / -8.09	N/A	N/A
90	9.6557	+2.55 / -8.11	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

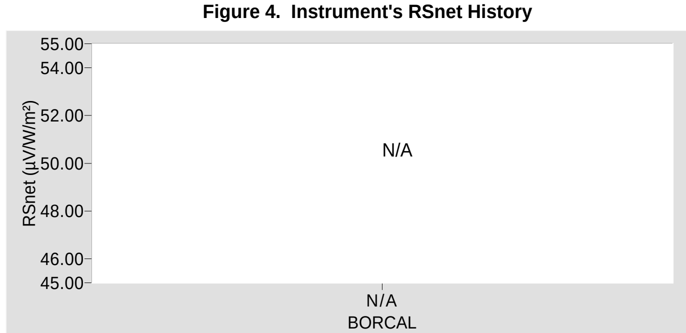
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33247

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

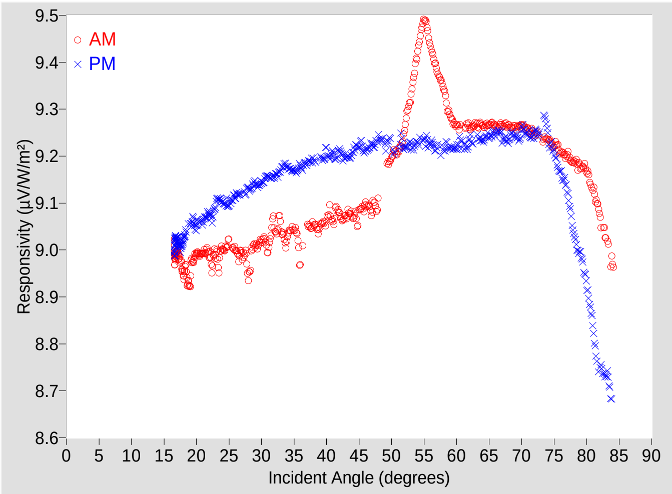

Figure 2. Responsivity vs Local Standard Time

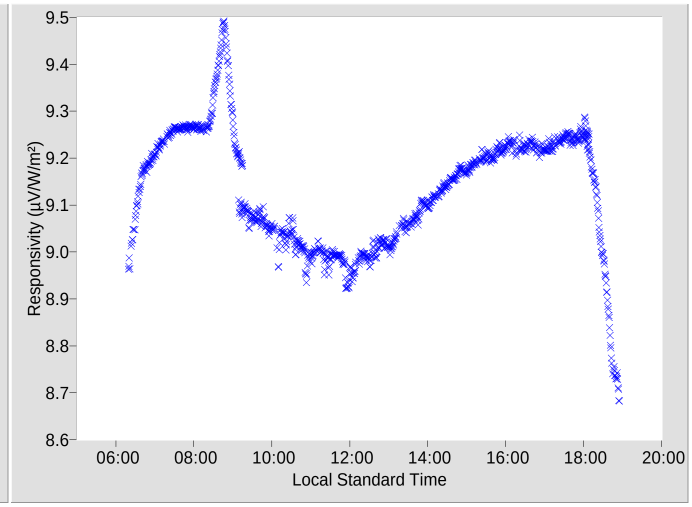

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.1469	+4.30 / -2.50	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0936	0.55	97.14	9.2115	0.56	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0857	N/A	95.60	9.2349	0.57	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1952	0.63	101.88	9.2186	0.60	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2564	0.84	100.01	9.2179	0.60	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4236	1.06	98.22	9.2287	0.61	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4349	0.85	96.60	9.2283	0.63	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3457	0.83	94.96	9.2159	0.64	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2656	0.72	93.37	9.2176	0.66	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2629	0.74	91.85	9.2334	0.69	274.98
18	8.9548	0.64	155.56	9.0221	0.58	204.42	64	9.2647	0.78	90.32	9.2342	0.71	276.36
20	8.9914	0.62	142.83	9.0530	0.49	217.26	66	9.2631	0.84	88.82	9.2488	0.76	277.72
22	8.9901	0.56	134.70	9.0755	0.50	225.37	68	9.2641	0.88	87.39	9.2352	0.81	279.15
24	9.0018	0.62	128.39	9.1007	0.48	231.66	70	9.2651	0.96	85.88	9.2554	0.89	280.51
26	8.9997	0.50	123.38	9.1157	0.50	236.50	72	9.2484	1.05	84.48	9.2501	0.95	281.88
28	8.9526	0.64	119.35	9.1306	0.50	240.60	74	9.2358	1.16	83.04	9.2438	1.40	279.01
30	9.0198	0.51	115.75	9.1438	0.50	244.20	76	9.2083	1.35	81.60	9.1649	1.52	280.38
32	9.0498	0.60	112.61	9.1589	0.50	247.34	78	9.1872	1.57	80.17	9.0357	1.88	281.85
34	9.0262	0.54	109.82	9.1781	0.50	250.03	80	9.1712	1.91	78.74	8.9275	2.22	283.27
36	8.9804	0.67	107.47	9.1785	0.52	252.62	82	9.0759	2.50	77.26	8.7486	2.63	284.76
38	9.0527	0.51	105.02	9.1905	0.51	254.95	84	8.9710	3.28	75.80	8.6824	N/A	286.10
40	9.0637	0.56	102.85	9.2057	0.54	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0770	0.55	100.81	9.2111	0.55	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0724	0.56	98.92	9.2094	0.55	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

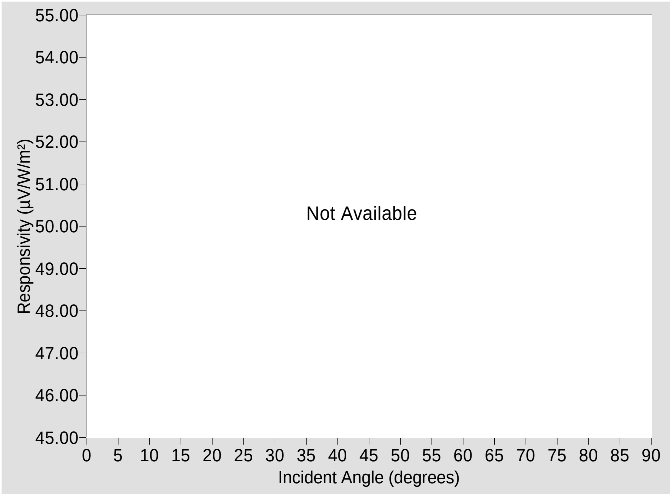

Figure 4. Responsivity vs Local Standard Time

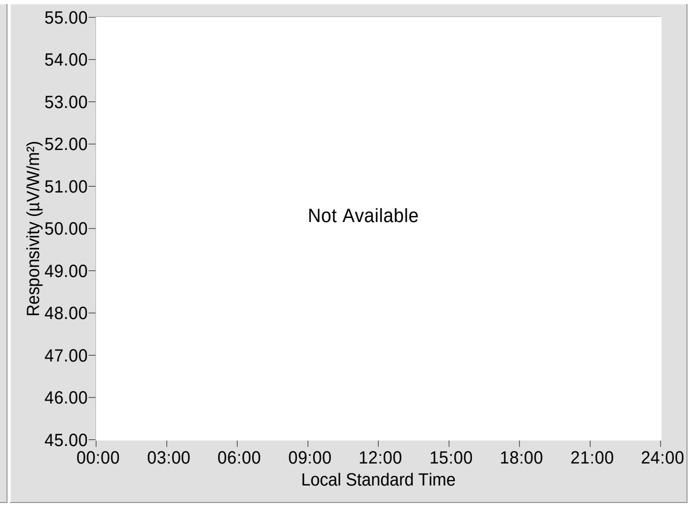

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

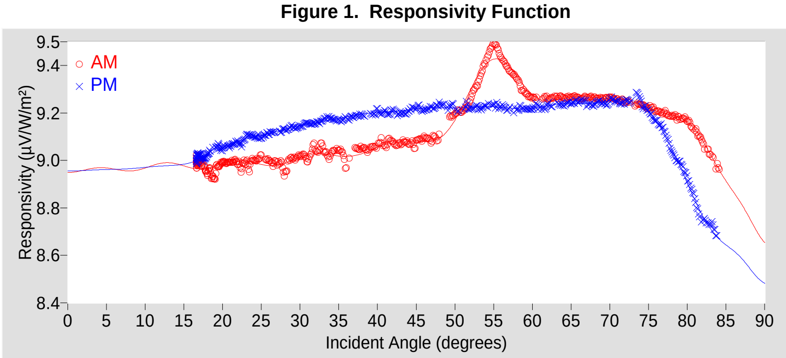
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

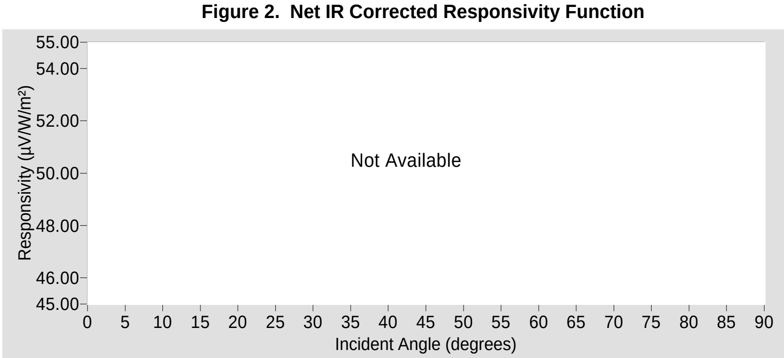


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.45	±1.45
R²	0.9999976	0.9999995
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.9602	*	8.9605	*	8.9604	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.9758	*	8.9821	*	8.9789	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.9877	±1.47	9.0764	±1.55	9.0321	±1.88	N/A	N/A	N/A	N/A	N/A	N/A
27-36	9.0130	±1.48	9.1534	±1.49	9.0832	±2.13	N/A	N/A	N/A	N/A	N/A	N/A
36-45	9.0566	±1.51	9.2012	±1.47	9.1289	±2.13	N/A	N/A	N/A	N/A	N/A	N/A
45-54	9.1771	±2.21	9.2220	±1.46	9.1995	±2.81	N/A	N/A	N/A	N/A	N/A	N/A
54-63	9.3406	±1.74	9.2233	±1.46	9.2820	±2.25	N/A	N/A	N/A	N/A	N/A	N/A
63-72	9.2628	±1.46	9.2442	±1.46	9.2535	±1.48	N/A	N/A	N/A	N/A	N/A	N/A
72-81	9.2075	±1.56	9.1179	±2.58	9.1627	±3.67	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.8919	*	8.6364	*	8.7642	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

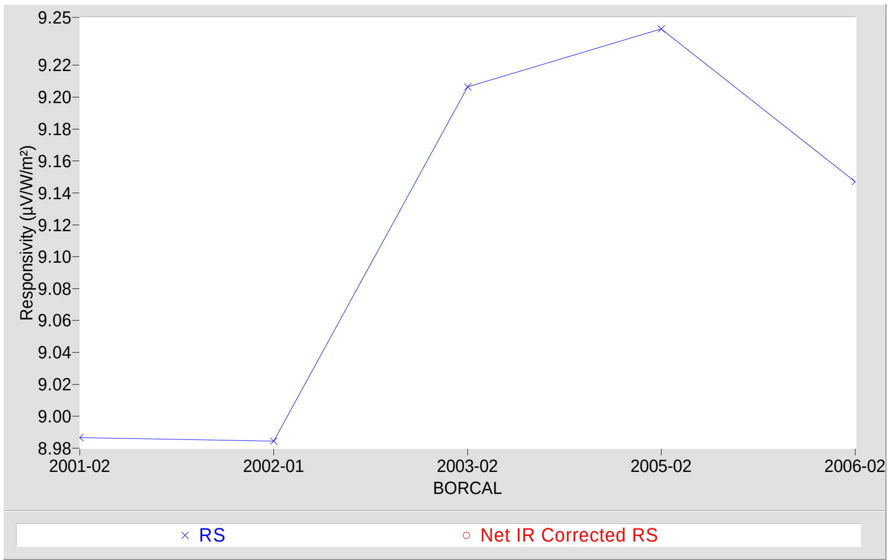
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.1469	+4.30 / -2.50
45° - 55°	9.2170	±2.38
Composite	9.0848	+4.04 / -4.76
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
- 45°: 30.0° to 60.0°
- 45° - 55°: 45.0° to 55.0°
- Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



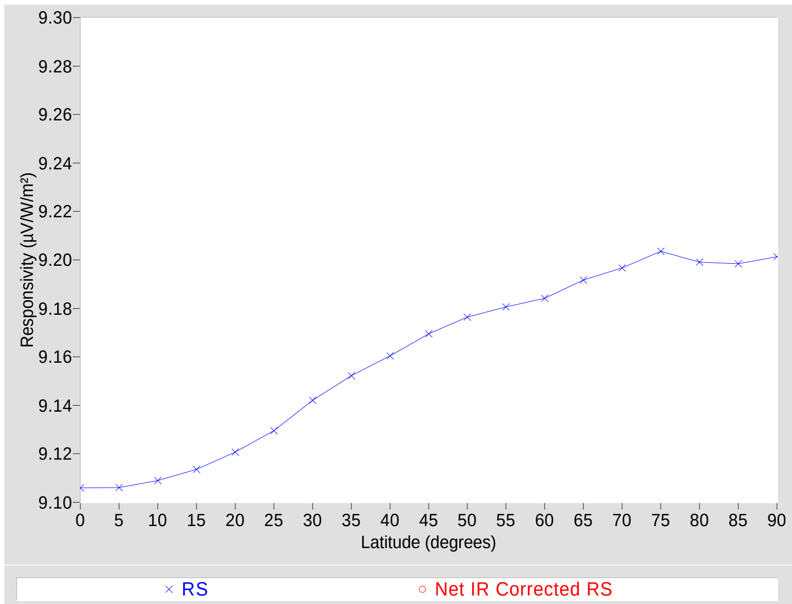
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.1059	+3.81 / -6.71	N/A	N/A
5	9.1060	+3.81 / -6.72	N/A	N/A
10	9.1090	+3.78 / -6.75	N/A	N/A
15	9.1136	+3.73 / -6.79	N/A	N/A
20	9.1207	+3.66 / -6.86	N/A	N/A
25	9.1295	+3.57 / -6.95	N/A	N/A
30	9.1420	+3.44 / -7.08	N/A	N/A
35	9.1522	+3.33 / -7.18	N/A	N/A
40	9.1605	+3.25 / -7.26	N/A	N/A
45	9.1695	+3.16 / -7.35	N/A	N/A
50	9.1764	+3.09 / -7.42	N/A	N/A
55	9.1806	+3.05 / -7.46	N/A	N/A
60	9.1841	+3.02 / -7.49	N/A	N/A
65	9.1917	+2.94 / -7.57	N/A	N/A
70	9.1967	+2.89 / -7.62	N/A	N/A
75	9.2035	+2.83 / -7.69	N/A	N/A
80	9.1991	+2.83 / -7.64	N/A	N/A
85	9.1984	+1.66 / -7.63	N/A	N/A
90	9.2013	+1.64 / -7.66	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

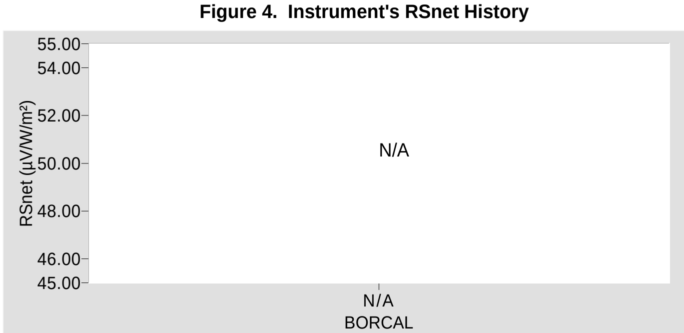
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33252

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

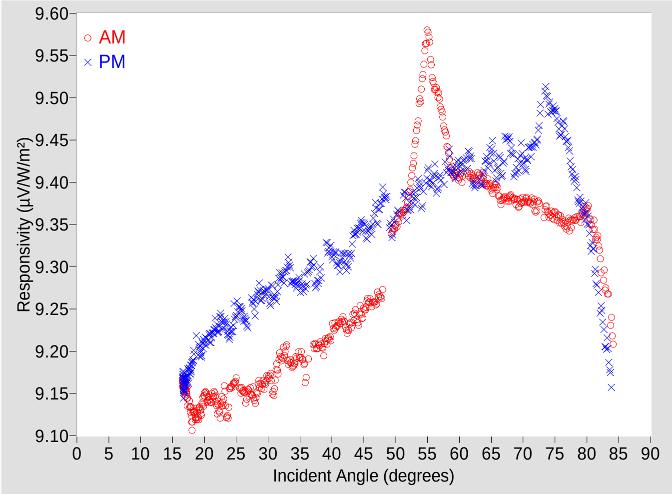

Figure 2. Responsivity vs Local Standard Time

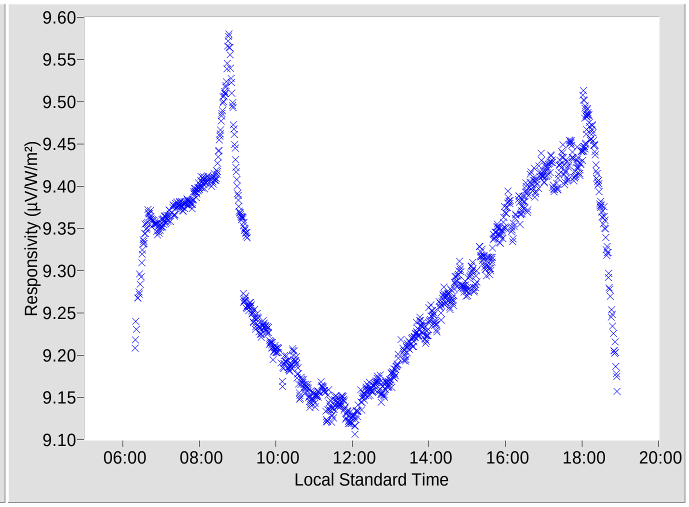

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.2965	+3.58 / -2.13	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡		RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2576	0.53	97.14	9.3441	0.59	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2627	N/A	95.60	9.3837	0.60	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3472	0.62	101.88	9.3606	0.59	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3821	0.73	100.01	9.3673	0.60	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.5110	0.95	98.22	9.3824	0.64	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.5160	0.77	96.60	9.4089	0.63	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4497	0.80	94.96	9.4168	0.66	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.4079	0.71	93.37	9.4175	0.66	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.4064	0.74	91.85	9.4112	0.71	274.98
18	9.1259	0.54	155.56	9.1826	0.56	204.42	64	9.4007	0.78	90.32	9.4208	0.75	276.36
20	9.1458	0.49	142.83	9.2108	0.49	217.26	66	9.3900	0.84	88.82	9.4147	0.79	277.72
22	9.1363	0.50	134.54	9.2258	0.51	225.37	68	9.3815	0.88	87.39	9.4422	0.84	279.15
24	9.1471	0.53	128.39	9.2208	0.52	231.66	70	9.3779	0.96	85.88	9.4265	0.88	280.51
26	9.1527	0.48	123.38	9.2426	0.50	236.50	72	9.3708	1.05	84.48	9.4480	1.00	281.88
28	9.1443	0.49	119.35	9.2572	0.52	240.60	74	9.3623	1.16	83.04	9.4906	1.34	279.01
30	9.1689	0.50	115.75	9.2681	0.50	244.20	76	9.3547	1.34	81.60	9.4614	1.49	280.38
32	9.1925	0.53	112.61	9.2890	0.53	247.34	78	9.3558	1.55	80.17	9.4063	1.77	281.85
34	9.1833	0.49	109.82	9.2819	0.53	250.03	80	9.3679	1.88	78.74	9.3625	2.05	283.27
36	9.1725	0.53	107.47	9.2812	0.54	252.62	82	9.3166	2.46	77.26	9.2561	2.63	284.76
38	9.2065	0.50	105.02	9.2896	0.54	254.95	84	9.2243	3.26	75.80	9.1571	N/A	286.10
40	9.2225	0.52	102.85	9.3158	0.54	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2331	0.52	100.81	9.3071	0.54	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2362	0.54	98.92	9.3427	0.57	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

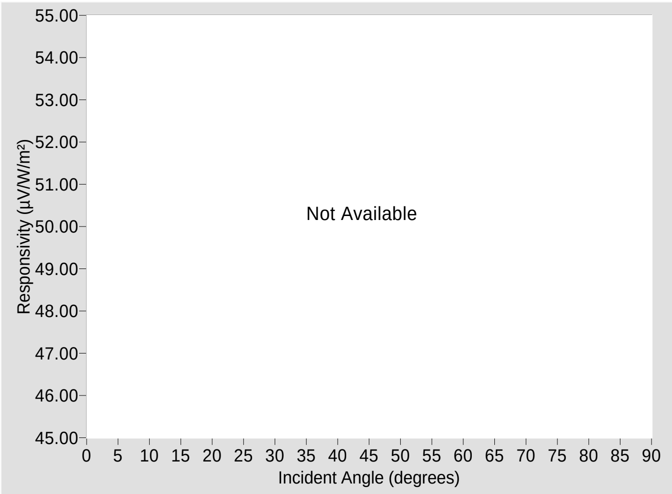

Figure 4. Responsivity vs Local Standard Time

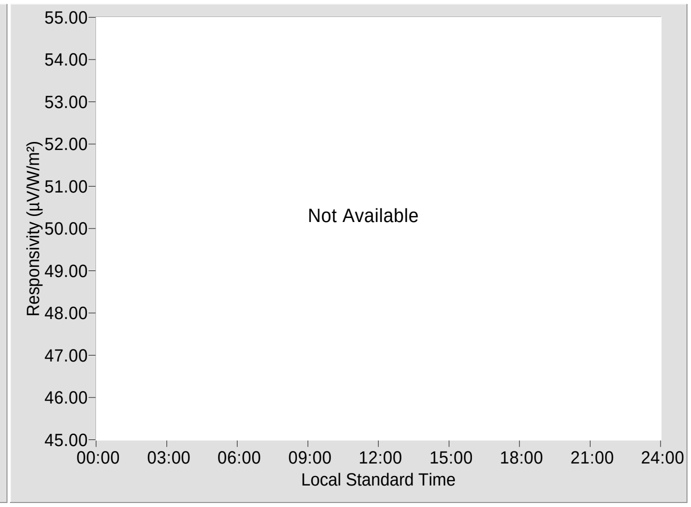

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

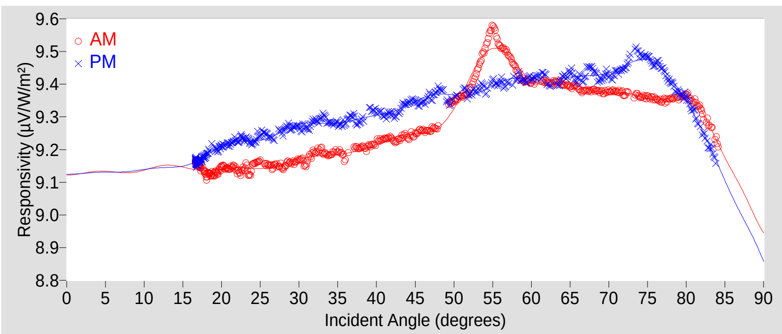
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

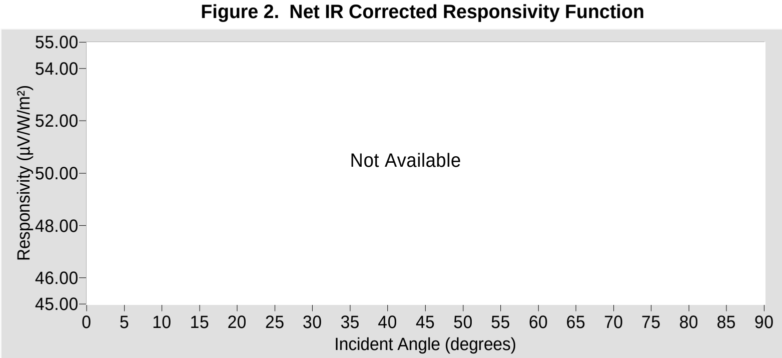


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.41	±1.41
R²	0.9999990	0.9999995
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	9.1293	*	9.1294	*	9.1293	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	9.1435	*	9.1484	*	9.1460	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	9.1417	±1.41	9.2185	±1.45	9.1801	±1.63	N/A	N/A	N/A	N/A	N/A	N/A
27-36	9.1730	±1.43	9.2737	±1.43	9.2233	±1.74	N/A	N/A	N/A	N/A	N/A	N/A
36-45	9.2184	±1.45	9.3081	±1.45	9.2633	±1.83	N/A	N/A	N/A	N/A	N/A	N/A
45-54	9.3273	±1.88	9.3656	±1.42	9.3465	±2.26	N/A	N/A	N/A	N/A	N/A	N/A
54-63	9.4533	±1.54	9.4098	±1.43	9.4316	±1.72	N/A	N/A	N/A	N/A	N/A	N/A
63-72	9.3868	±1.42	9.4277	±1.43	9.4073	±1.53	N/A	N/A	N/A	N/A	N/A	N/A
72-81	9.3613	±1.42	9.4336	±1.62	9.3975	±1.80	N/A	N/A	N/A	N/A	N/A	N/A
81-90	9.1538	*	9.0838	*	9.1188	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

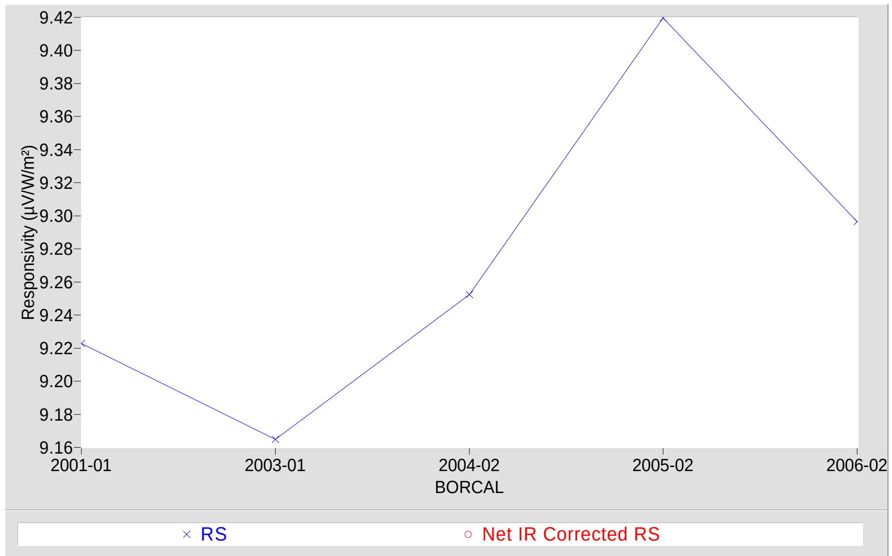
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.2965	+3.58 / -2.13
45° - 55°	9.3607	±1.98
Composite	9.2423	+3.22 / -1.82
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



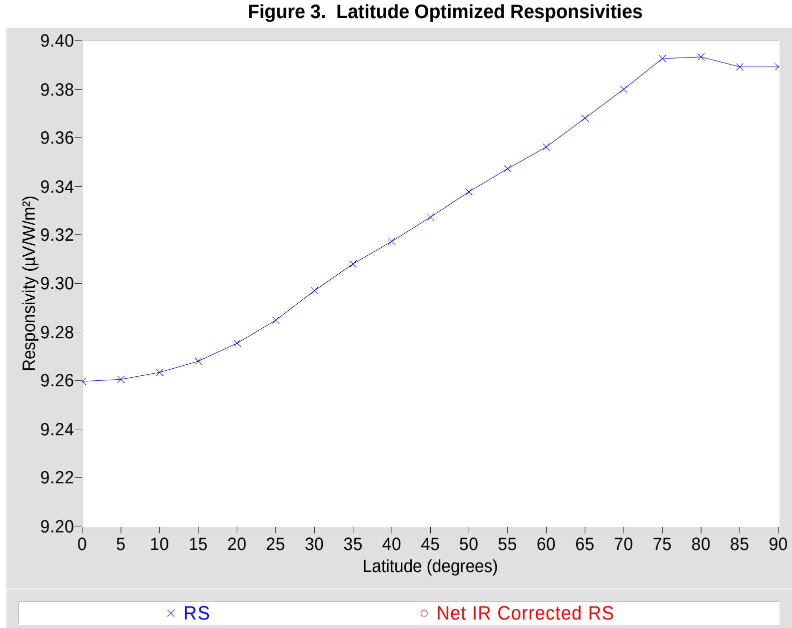
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.2597	+3.04 / -4.00	N/A	N/A
5	9.2604	+3.04 / -4.01	N/A	N/A
10	9.2633	+3.01 / -4.04	N/A	N/A
15	9.2680	+2.96 / -4.09	N/A	N/A
20	9.2753	+2.89 / -4.16	N/A	N/A
25	9.2849	+2.80 / -4.25	N/A	N/A
30	9.2970	+2.69 / -4.37	N/A	N/A
35	9.3080	+2.58 / -4.48	N/A	N/A
40	9.3173	+2.50 / -4.57	N/A	N/A
45	9.3273	+2.41 / -4.66	N/A	N/A
50	9.3378	+2.32 / -4.77	N/A	N/A
55	9.3472	+2.24 / -4.86	N/A	N/A
60	9.3562	+2.16 / -4.95	N/A	N/A
65	9.3681	+2.07 / -5.06	N/A	N/A
70	9.3800	+1.98 / -5.18	N/A	N/A
75	9.3926	+1.88 / -5.30	N/A	N/A
80	9.3932	+1.86 / -5.31	N/A	N/A
85	9.3892	+1.68 / -5.27	N/A	N/A
90	9.3892	+1.68 / -5.27	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

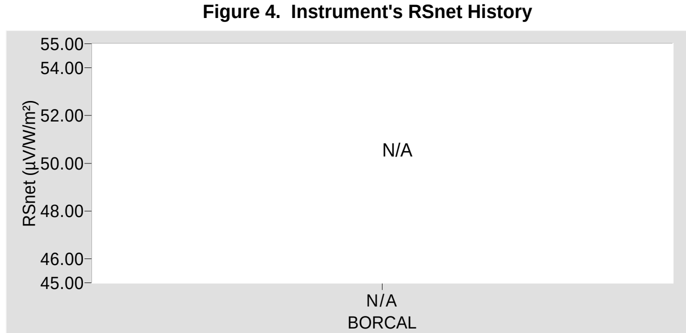
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33256
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: _________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: _________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

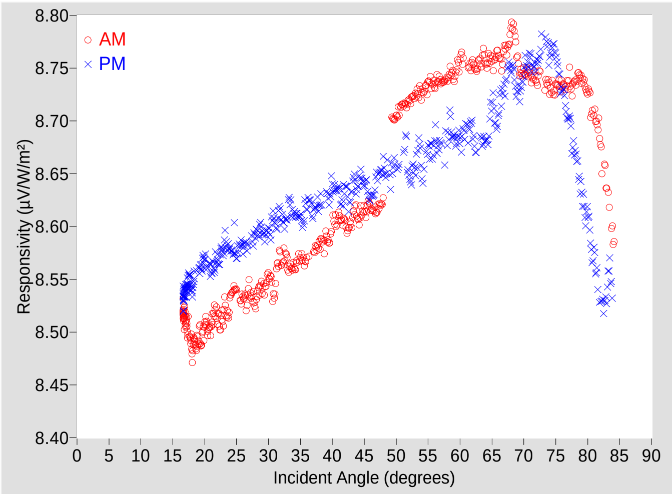

Figure 2. Responsivity vs Local Standard Time

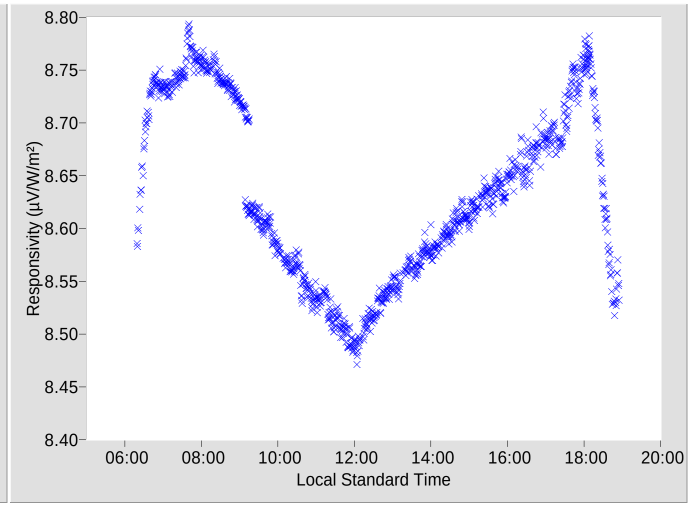

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6277	+2.04 / -1.67	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6184	0.54	97.14	8.6274	0.57	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6208	N/A	95.60	8.6547	0.57	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7034	0.61	101.88	8.6563	0.59	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7183	0.63	100.01	8.6481	0.64	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7269	0.65	98.22	8.6546	0.64	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7342	0.66	96.60	8.6807	0.63	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7401	0.68	94.96	8.6848	0.69	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7576	0.72	93.37	8.6810	0.67	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7529	0.74	91.85	8.6887	0.70	274.98
18	8.4881	0.53	155.56	8.5429	0.49	204.42	64	8.7552	0.79	90.32	8.6823	0.75	276.36
20	8.5057	0.49	142.83	8.5676	0.48	217.26	66	8.7629	0.85	88.82	8.7048	0.80	277.72
22	8.5143	0.49	134.54	8.5671	0.49	225.37	68	8.7847	0.90	87.39	8.7501	0.83	279.15
24	8.5287	0.50	128.39	8.5782	0.51	231.66	70	8.7448	0.97	85.88	8.7480	0.91	280.51
26	8.5328	0.50	123.38	8.5808	0.49	236.50	72	8.7398	1.06	84.48	8.7543	0.97	281.88
28	8.5279	0.50	119.35	8.5944	0.49	240.60	74	8.7331	1.17	83.04	8.7628	1.35	279.01
30	8.5522	0.50	115.75	8.5959	0.51	244.20	76	8.7336	1.35	81.60	8.7293	1.53	280.38
32	8.5687	0.52	112.61	8.6089	0.50	247.34	78	8.7368	1.58	80.17	8.6702	1.80	281.85
34	8.5609	0.49	109.82	8.6119	0.51	250.03	80	8.7282	1.91	78.74	8.6127	2.08	283.27
36	8.5681	0.50	107.47	8.6205	0.53	252.62	82	8.6778	2.49	77.26	8.5289	2.61	284.76
38	8.5830	0.51	105.02	8.6215	0.52	254.95	84	8.5918	3.32	75.80	8.5320	N/A	286.10
40	8.6011	0.53	102.85	8.6366	0.54	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6028	0.52	100.81	8.6370	0.55	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6066	0.54	98.92	8.6398	0.55	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

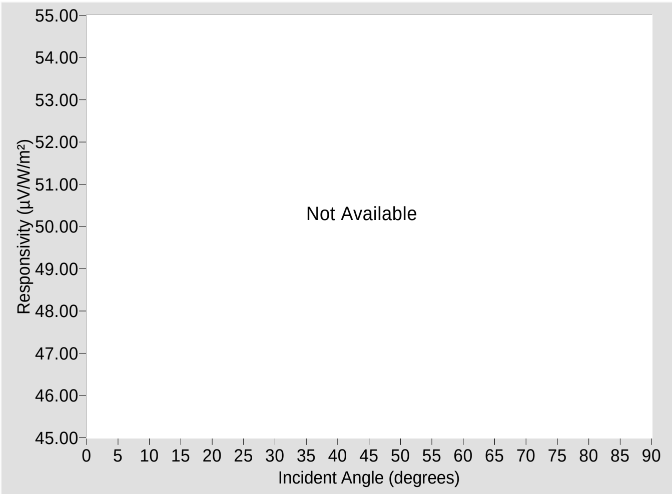

Figure 4. Responsivity vs Local Standard Time

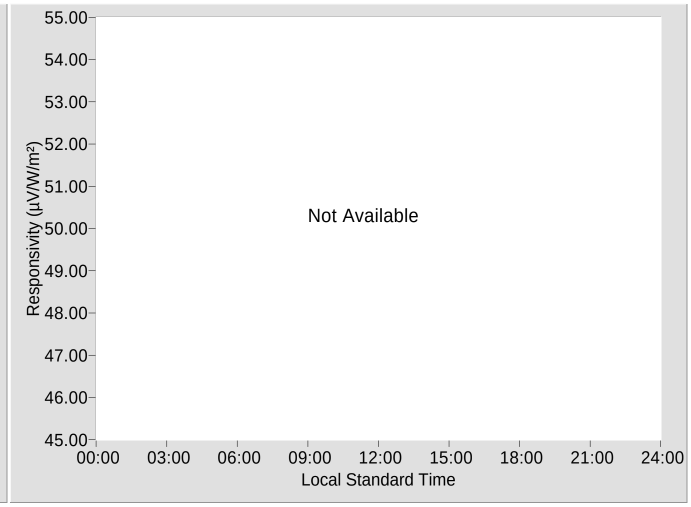

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

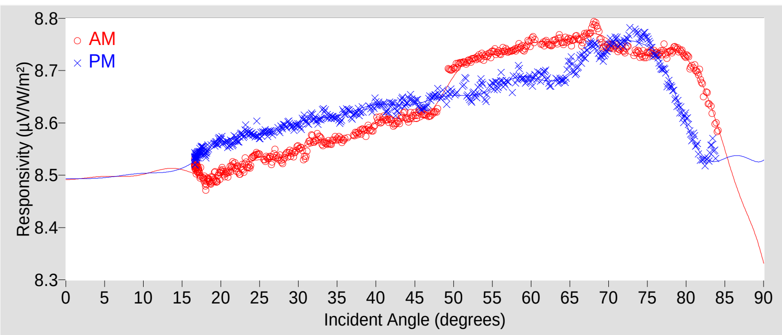
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

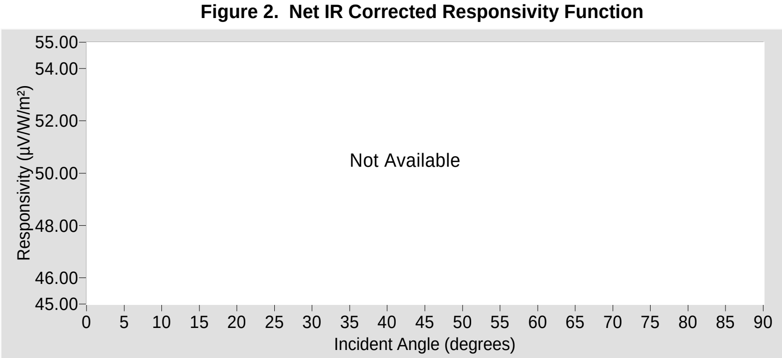


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.42	±1.42
R^2	0.9999995	0.9999996
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R^2	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.4958	*	8.4958	*	8.4958	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.5066	*	8.5116	*	8.5091	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.5154	±1.43	8.5690	±1.44	8.5422	±1.59	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.5542	±1.44	8.6031	±1.43	8.5786	±1.58	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.5940	±1.44	8.6311	±1.42	8.6125	±1.54	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.6682	±1.60	8.6484	±1.43	8.6583	±1.76	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.7433	±1.43	8.6788	±1.43	8.7110	±1.63	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.7612	±1.43	8.7243	±1.49	8.7428	±1.62	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.7327	±1.43	8.7030	±1.75	8.7179	±2.17	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.5269	*	8.5342	*	8.5305	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6277	+2.04 / -1.67
45° - 55°	8.6637	±1.60
Composite	8.5877	+2.57 / -1.77
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:

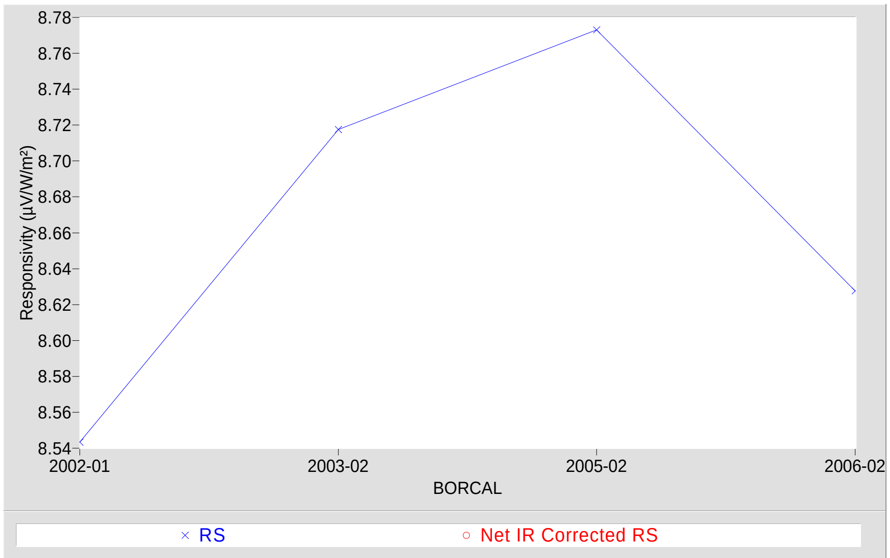
45°: 30.0° to 60.0°

45° - 55°: 45.0° to 55.0°

Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



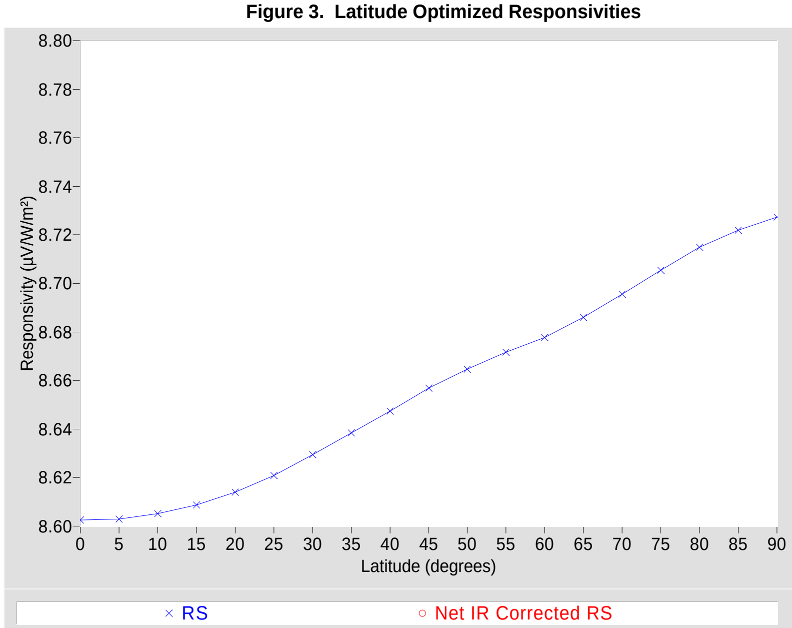
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6025	+2.42 / -2.92	N/A	N/A
5	8.6028	+2.42 / -2.92	N/A	N/A
10	8.6051	+2.40 / -2.94	N/A	N/A
15	8.6088	+2.36 / -2.98	N/A	N/A
20	8.6139	+2.31 / -3.03	N/A	N/A
25	8.6208	+2.25 / -3.10	N/A	N/A
30	8.6295	+2.17 / -3.19	N/A	N/A
35	8.6383	+2.09 / -3.28	N/A	N/A
40	8.6473	+2.02 / -3.37	N/A	N/A
45	8.6568	+1.94 / -3.46	N/A	N/A
50	8.6647	+1.88 / -3.54	N/A	N/A
55	8.6716	+1.83 / -3.61	N/A	N/A
60	8.6777	+1.78 / -3.68	N/A	N/A
65	8.6860	+1.73 / -3.76	N/A	N/A
70	8.6956	+1.67 / -3.86	N/A	N/A
75	8.7055	+1.61 / -3.96	N/A	N/A
80	8.7149	+1.56 / -4.06	N/A	N/A
85	8.7219	+1.53 / -4.13	N/A	N/A
90	8.7273	+1.51 / -4.19	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

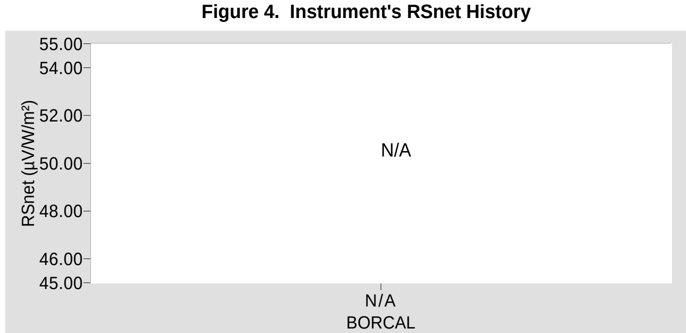
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33261

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

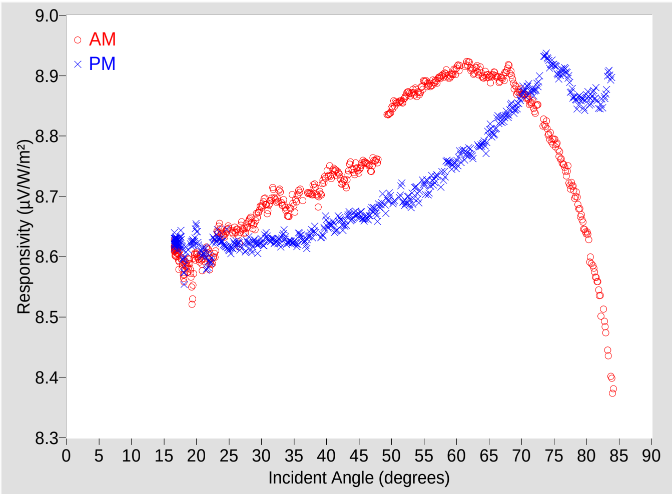

Figure 2. Responsivity vs Local Standard Time

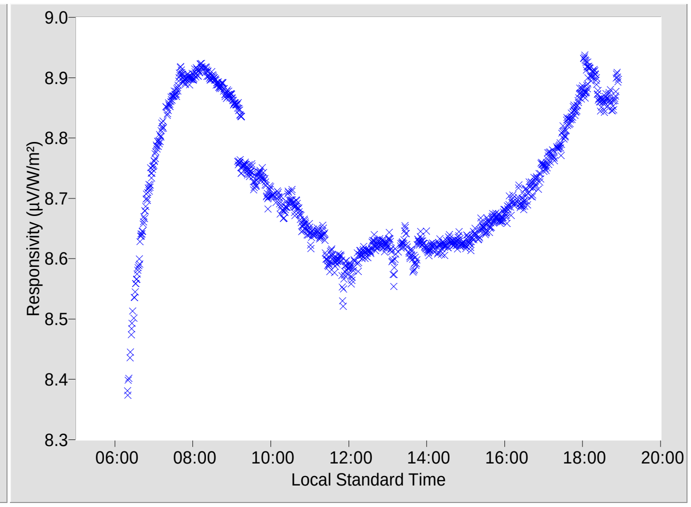

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.7064	+2.88 / -1.60	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7557	0.54	97.14	8.6637	0.56	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7554	N/A	95.60	8.6755	0.61	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8431	0.62	101.88	8.6930	0.60	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8621	0.63	100.01	8.6889	0.62	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8712	0.66	98.22	8.7016	0.65	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8843	0.66	96.60	8.7203	0.63	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9013	0.69	94.96	8.7354	0.67	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9115	0.71	93.37	8.7530	0.67	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9170	0.75	91.85	8.7731	0.69	274.98
18	8.5809	0.56	155.56	8.5925	0.70	204.42	64	8.8989	0.79	90.32	8.7875	0.74	276.36
20	8.6025	0.68	142.83	8.6387	0.56	217.26	66	8.9014	0.84	88.82	8.8119	0.78	277.72
22	8.5945	0.52	134.54	8.5919	0.57	225.37	68	8.9120	0.91	87.39	8.8395	0.82	279.15
24	8.6370	0.49	128.39	8.6222	0.51	231.66	70	8.8717	0.97	85.88	8.8703	0.90	280.51
26	8.6438	0.52	123.38	8.6211	0.49	236.50	72	8.8465	1.06	84.48	8.8743	0.97	281.88
28	8.6556	0.50	119.35	8.6253	0.50	240.60	74	8.8105	1.19	83.04	8.9266	1.34	279.01
30	8.6838	0.56	115.75	8.6237	0.52	244.20	76	8.7638	1.39	81.60	8.9039	1.49	280.38
32	8.7010	0.51	112.61	8.6249	0.49	247.34	78	8.7102	1.62	80.17	8.8662	1.77	281.85
34	8.6711	0.52	109.82	8.6248	0.52	250.03	80	8.6404	1.97	78.74	8.8661	2.05	283.27
36	8.7095	0.54	107.47	8.6350	0.53	252.62	82	8.5354	2.54	77.26	8.8478	2.58	284.76
38	8.7120	0.54	105.02	8.6414	0.53	254.95	84	8.3887	3.35	75.80	8.8973	N/A	286.10
40	8.7347	0.58	102.85	8.6544	0.56	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7331	0.53	100.81	8.6628	0.55	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7433	0.58	98.92	8.6652	0.55	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

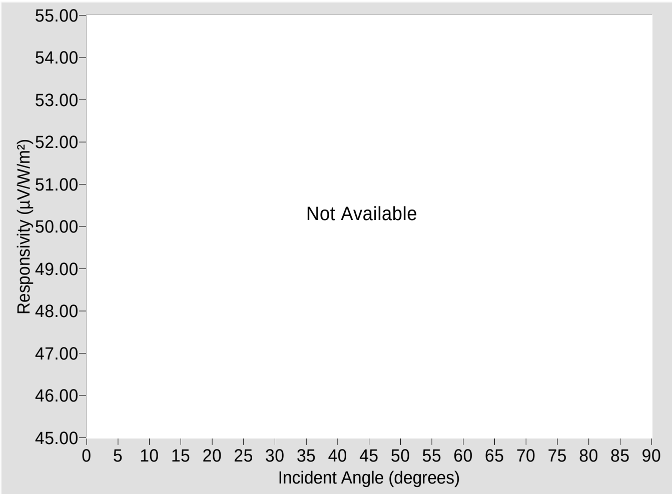


Figure 4. Responsivity vs Local Standard Time

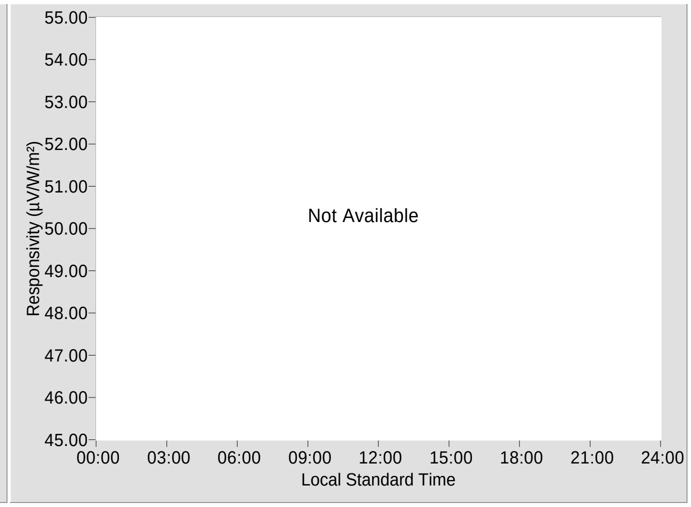


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

33261 Eppley 8-48

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

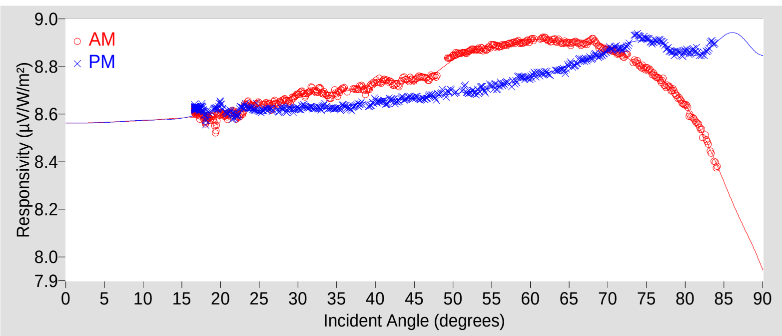
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

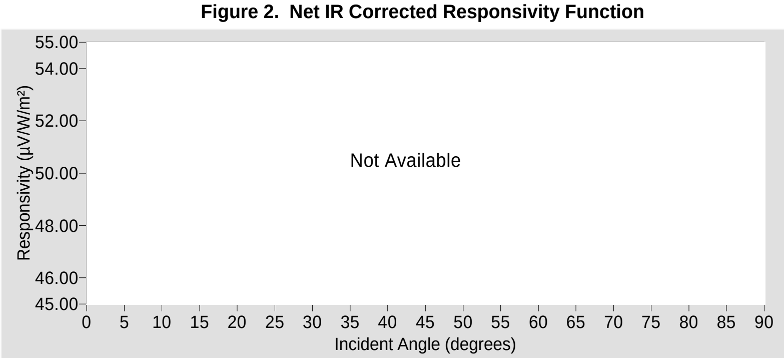


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.43	±1.43
R^2	0.9999993	0.9999992
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R^2	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.5652	*	8.5651	*	8.5652	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.5793	*	8.5808	*	8.5801	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.6127	±1.48	8.6139	±1.43	8.6133	±1.52	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.6813	±1.45	8.6253	±1.43	8.6533	±1.55	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.7267	±1.46	8.6526	±1.44	8.6896	±1.69	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.8072	±1.63	8.6823	±1.45	8.7448	±2.24	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.8984	±1.45	8.7383	±1.49	8.8184	±2.22	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.8946	±1.46	8.8298	±1.55	8.8622	±1.78	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.7488	±1.95	8.8887	±1.47	8.8188	±2.91	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.2776	*	8.8906	*	8.5841	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

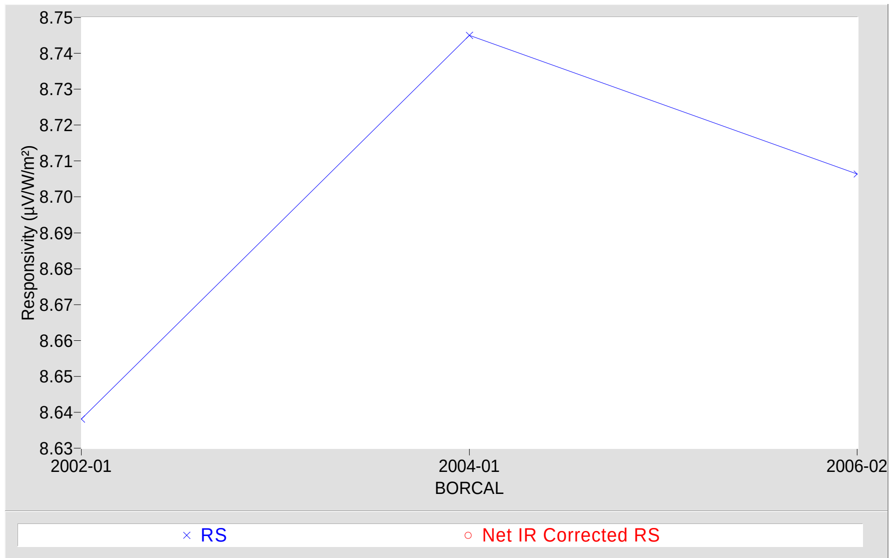
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.7064	+2.88 / -1.60
45° - 55°	8.7516	±1.88
Composite	8.6684	+3.17 / -3.47
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



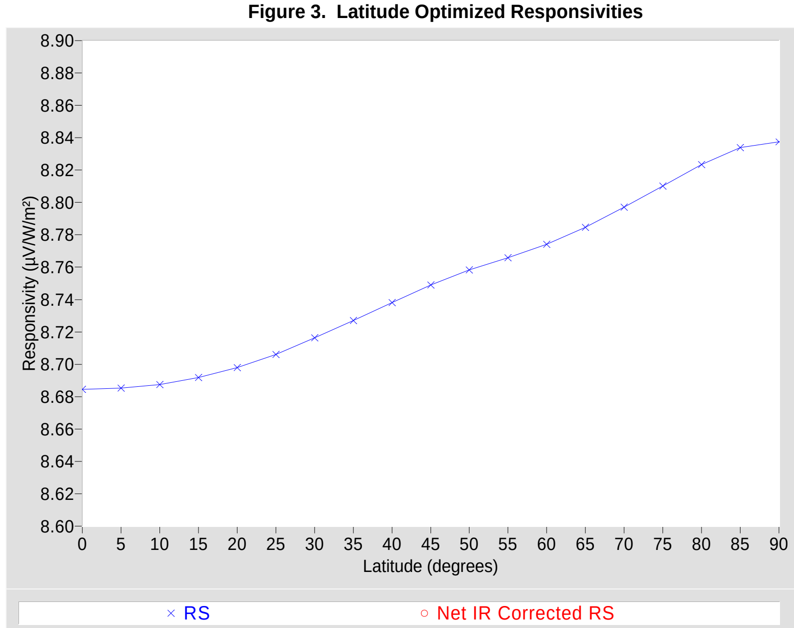
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6845	+3.29 / -7.71	N/A	N/A
5	8.6852	+3.29 / -7.72	N/A	N/A
10	8.6875	+3.26 / -7.74	N/A	N/A
15	8.6918	+3.22 / -7.79	N/A	N/A
20	8.6979	+3.15 / -7.85	N/A	N/A
25	8.7060	+3.07 / -7.94	N/A	N/A
30	8.7163	+2.96 / -8.04	N/A	N/A
35	8.7271	+2.85 / -8.16	N/A	N/A
40	8.7382	+2.74 / -8.27	N/A	N/A
45	8.7489	+2.63 / -8.38	N/A	N/A
50	8.7584	+2.54 / -8.48	N/A	N/A
55	8.7657	+2.47 / -8.56	N/A	N/A
60	8.7740	+2.39 / -8.64	N/A	N/A
65	8.7847	+2.29 / -8.75	N/A	N/A
70	8.7971	+2.18 / -8.88	N/A	N/A
75	8.8103	+2.07 / -9.01	N/A	N/A
80	8.8234	+1.97 / -9.15	N/A	N/A
85	8.8338	+1.88 / -9.25	N/A	N/A
90	8.8375	+1.86 / -9.29	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

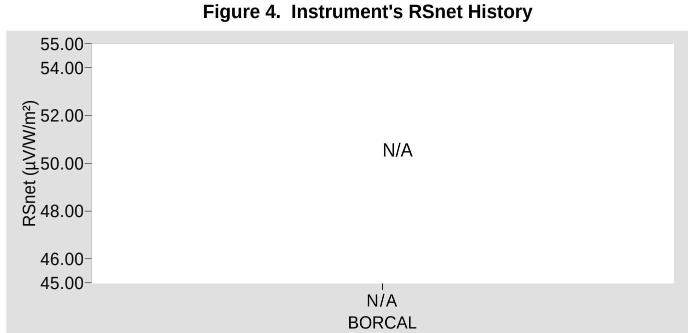
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33262

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

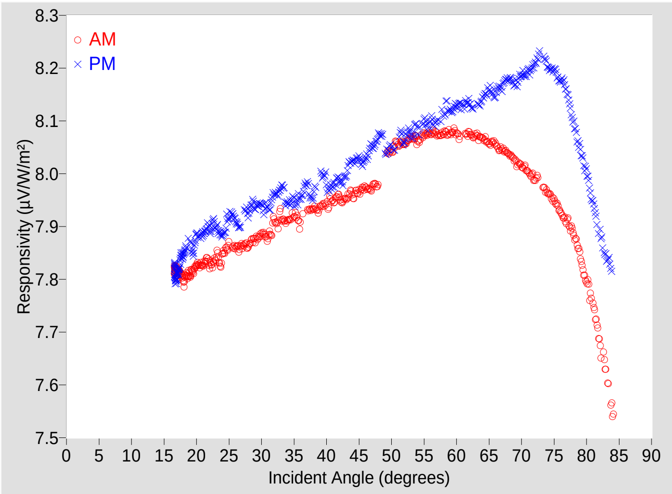

Figure 2. Responsivity vs Local Standard Time

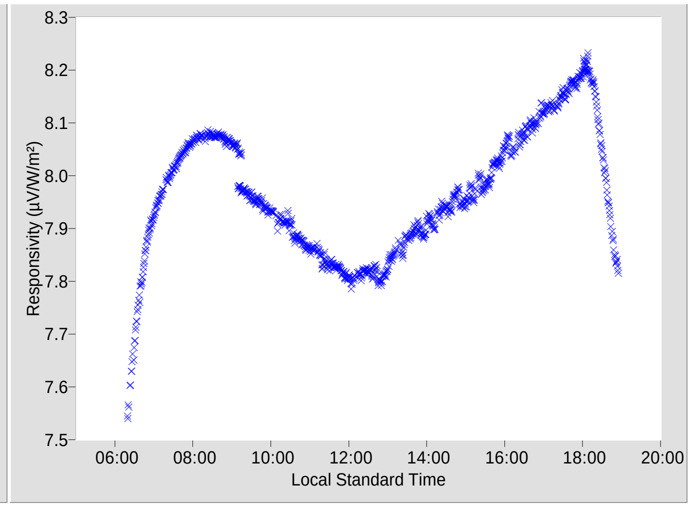

Table 2. Calibration Label Values

RS @ 45° (µV/W/m^2) ‡	U95 (%) †	Tilt / Azm
7.9971	+2.30 / -2.10	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m^2

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m^2)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m^2)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m^2)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m^2)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9731	0.54	97.14	8.0296	0.61	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9757	N/A	95.60	8.0704	0.59	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0418	0.63	101.88	8.0507	0.58	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0562	0.63	100.01	8.0625	0.61	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0623	0.66	98.22	8.0833	0.64	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0757	0.66	96.60	8.0996	0.63	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0773	0.69	94.96	8.1140	0.67	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0771	0.73	93.37	8.1286	0.66	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0758	0.75	91.85	8.1328	0.69	274.98
18	7.8018	0.51	155.56	7.8476	0.64	204.42	64	8.0670	0.80	90.32	8.1423	0.75	276.36
20	7.8260	0.50	142.83	7.8815	0.55	217.26	66	8.0562	0.85	88.82	8.1497	0.78	277.72
22	7.8305	0.49	134.54	7.8951	0.52	225.37	68	8.0376	0.91	87.39	8.1795	0.83	279.15
24	7.8426	0.56	128.39	7.8851	0.55	231.66	70	8.0141	0.99	85.88	8.1875	0.90	280.51
26	7.8615	0.48	123.38	7.9107	0.52	236.50	72	7.9912	1.07	84.48	8.2073	1.00	281.88
28	7.8626	0.49	119.35	7.9283	0.53	240.60	74	7.9644	1.19	83.04	8.2024	1.36	279.01
30	7.8855	0.50	115.75	7.9399	0.50	244.20	76	7.9271	1.39	81.60	8.1769	1.52	280.38
32	7.9103	0.58	112.61	7.9625	0.56	247.34	78	7.8859	1.65	80.17	8.0948	1.87	281.85
34	7.9109	0.50	109.82	7.9437	0.56	250.03	80	7.7984	2.02	78.74	8.0033	2.16	283.27
36	7.9050	0.54	107.47	7.9540	0.58	252.62	82	7.6817	2.64	77.26	7.8860	2.70	284.76
38	7.9342	0.50	105.02	7.9613	0.56	254.95	84	7.5532	3.45	75.80	7.8152	N/A	286.10
40	7.9411	0.54	102.85	7.9825	0.58	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9548	0.52	100.81	7.9876	0.55	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9583	0.54	98.92	8.0249	0.59	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

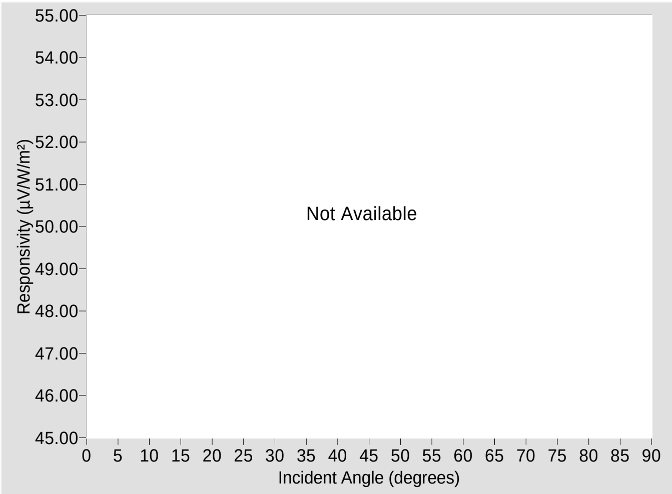


Figure 4. Responsivity vs Local Standard Time

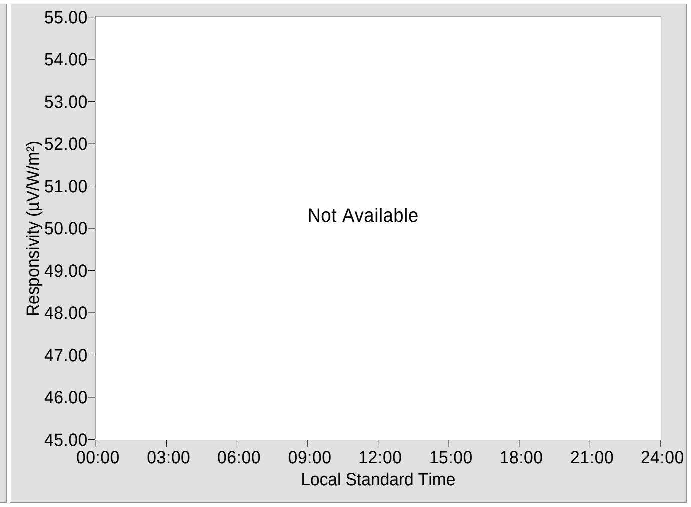


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

33262 Eppley 8-48

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

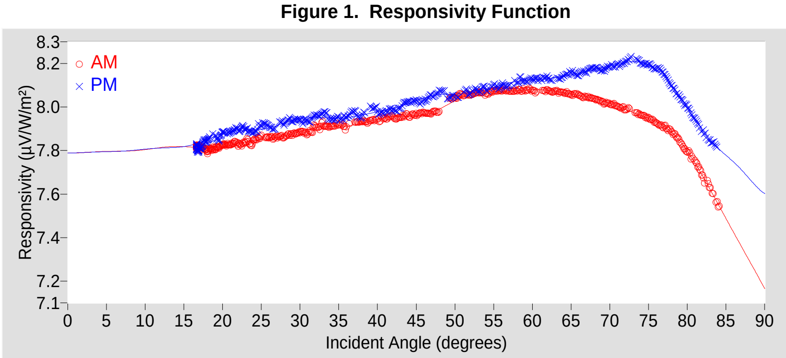
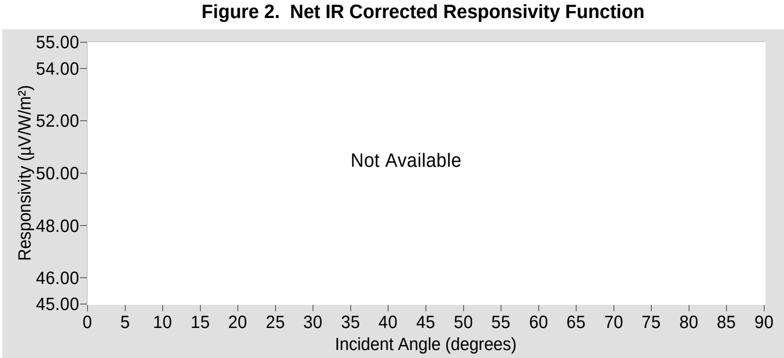


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.47	±1.47
R²	0.9999996	0.9999996
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	7.7941	*	7.7940	*	7.7941	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	7.8128	*	7.8166	*	7.8147	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	7.8339	±1.50	7.8865	±1.52	7.8602	±1.71	N/A	N/A	N/A	N/A	N/A	N/A
27-36	7.8933	±1.51	7.9438	±1.49	7.9185	±1.70	N/A	N/A	N/A	N/A	N/A	N/A
36-45	7.9413	±1.50	7.9823	±1.54	7.9618	±1.77	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.0140	±1.62	8.0557	±1.50	8.0349	±1.81	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.0749	±1.47	8.1134	±1.51	8.0941	±1.58	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.0408	±1.55	8.1675	±1.53	8.1041	±2.33	N/A	N/A	N/A	N/A	N/A	N/A
72-81	7.9095	±2.01	8.1348	±2.08	8.0221	±4.16	N/A	N/A	N/A	N/A	N/A	N/A
81-90	7.4562	*	7.7630	*	7.6096	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

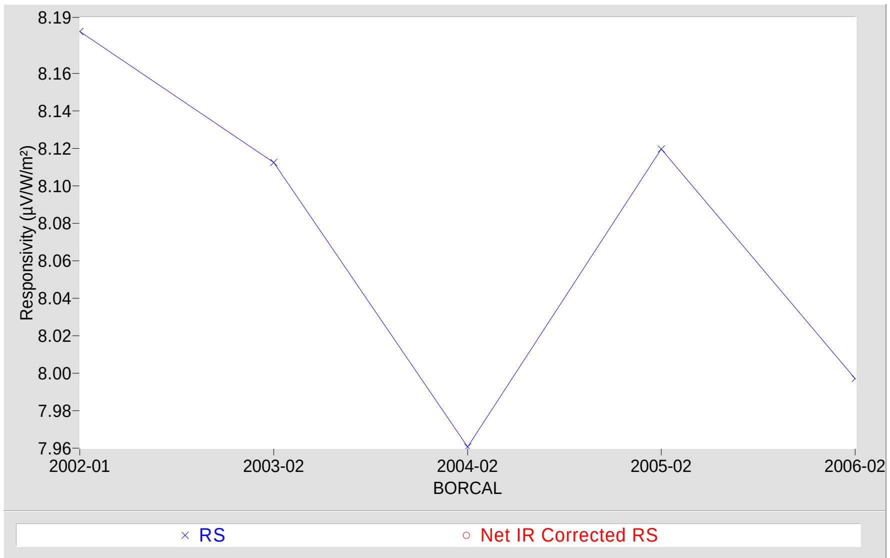
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.9971	+2.30 / -2.10
45° - 55°	8.0408	±1.68
Composite	7.9186	+3.95 / -4.84
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



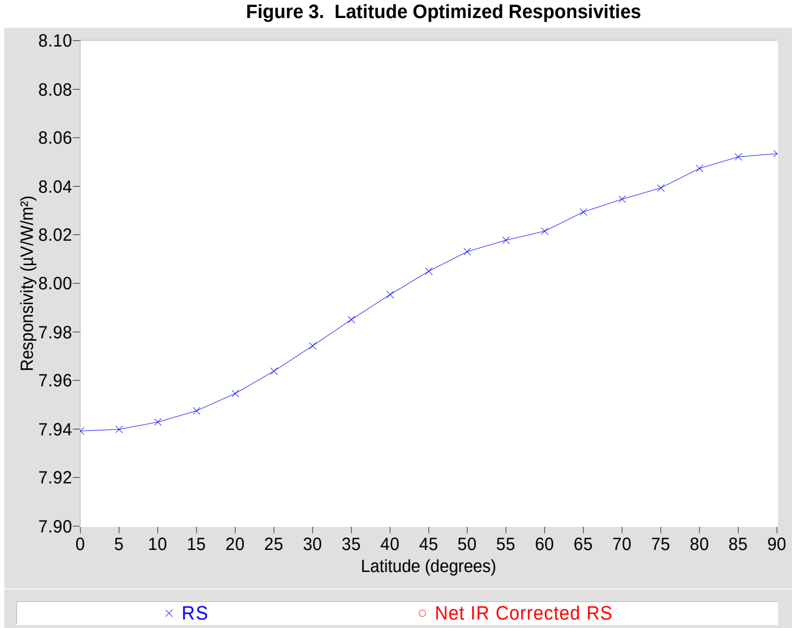
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.9392	+3.70 / -9.04	N/A	N/A
5	7.9399	+3.69 / -9.04	N/A	N/A
10	7.9428	+3.65 / -9.08	N/A	N/A
15	7.9475	+3.60 / -9.13	N/A	N/A
20	7.9546	+3.51 / -9.21	N/A	N/A
25	7.9638	+3.41 / -9.31	N/A	N/A
30	7.9743	+3.29 / -9.43	N/A	N/A
35	7.9850	+3.16 / -9.55	N/A	N/A
40	7.9954	+3.04 / -9.67	N/A	N/A
45	8.0050	+2.94 / -9.78	N/A	N/A
50	8.0130	+2.85 / -9.86	N/A	N/A
55	8.0178	+2.80 / -9.92	N/A	N/A
60	8.0215	+2.76 / -9.96	N/A	N/A
65	8.0294	+2.67 / -10.05	N/A	N/A
70	8.0347	+2.62 / -10.11	N/A	N/A
75	8.0393	+2.57 / -10.16	N/A	N/A
80	8.0474	+2.48 / -10.25	N/A	N/A
85	8.0521	+2.44 / -10.30	N/A	N/A
90	8.0535	+2.42 / -10.31	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

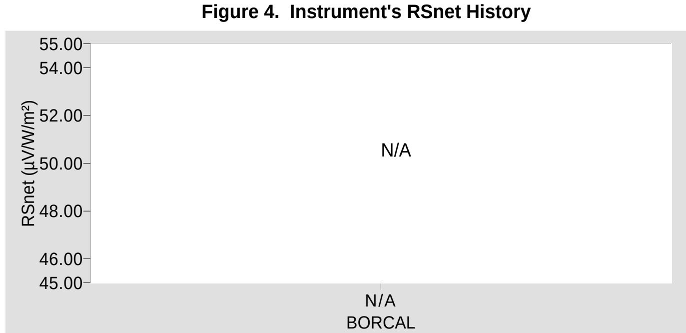
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33267

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

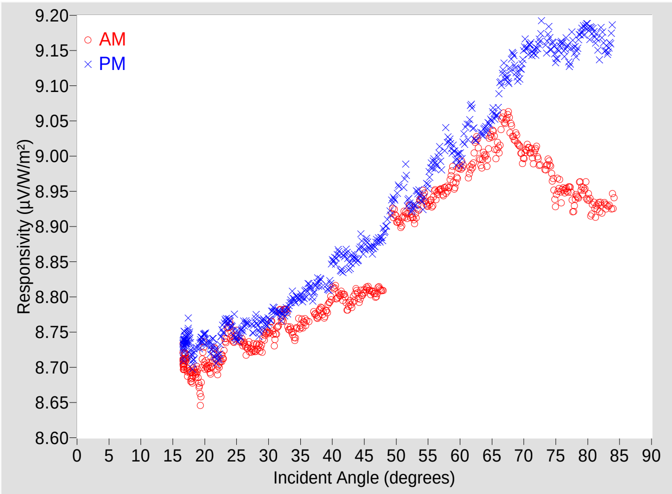

Figure 2. Responsivity vs Local Standard Time

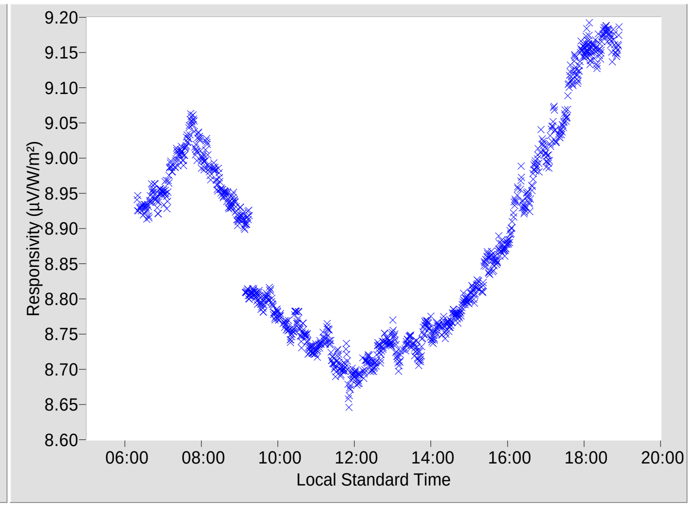

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8380	+2.82 / -1.75	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8076	0.54	97.14	8.8680	0.56	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8093	N/A	95.60	8.8893	0.58	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9137	0.62	101.88	8.9482	0.62	266.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9206	0.64	100.01	8.9340	0.69	267.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9428	0.67	98.22	8.9347	0.63	269.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9425	0.67	96.60	8.9899	0.65	270.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9526	0.71	94.96	9.0270	0.70	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9854	0.74	93.37	8.9967	0.72	273.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9894	0.81	91.85	9.0492	0.73	274.98
18	8.6875	0.51	155.56	8.7152	0.62	204.42	64	8.9970	0.82	90.32	9.0383	0.72	276.36
20	8.7131	0.69	142.83	8.7429	0.50	217.26	66	9.0123	0.91	88.82	9.0758	0.87	277.72
22	8.7021	0.52	134.54	8.7141	0.57	225.37	68	9.0411	0.91	87.39	9.1354	0.84	279.15
24	8.7541	0.52	128.39	8.7626	0.52	231.66	70	8.9995	0.98	85.88	9.1522	0.93	280.51
26	8.7350	0.49	123.38	8.7572	0.50	236.50	72	9.0058	1.06	84.48	9.1522	0.98	281.88
28	8.7271	0.48	119.35	8.7654	0.51	240.60	74	8.9906	1.22	83.04	9.1655	1.36	279.01
30	8.7506	0.54	115.75	8.7658	0.51	244.20	76	8.9483	1.36	81.60	9.1590	1.49	280.38
32	8.7723	0.52	112.61	8.7735	0.50	247.34	78	8.9337	1.58	80.17	9.1493	1.75	281.85
34	8.7439	0.51	109.82	8.7982	0.52	250.03	80	8.9451	1.91	78.74	9.1843	2.03	283.27
36	8.7649	0.50	107.47	8.8094	0.52	252.62	82	8.9278	2.44	77.26	9.1626	2.57	284.76
38	8.7782	0.50	105.02	8.8220	0.53	254.95	84	8.9345	3.27	75.80	9.1864	N/A	286.10
40	8.8055	0.55	102.85	8.8445	0.61	257.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7962	0.53	100.81	8.8617	0.56	259.11	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8013	0.54	98.92	8.8566	0.58	260.98	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

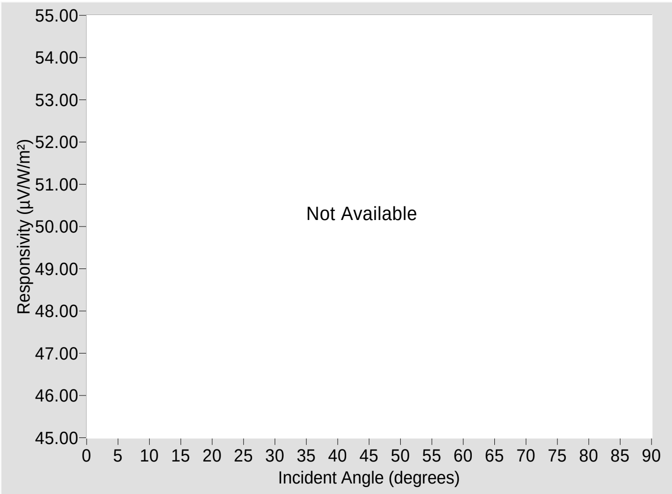

Figure 4. Responsivity vs Local Standard Time

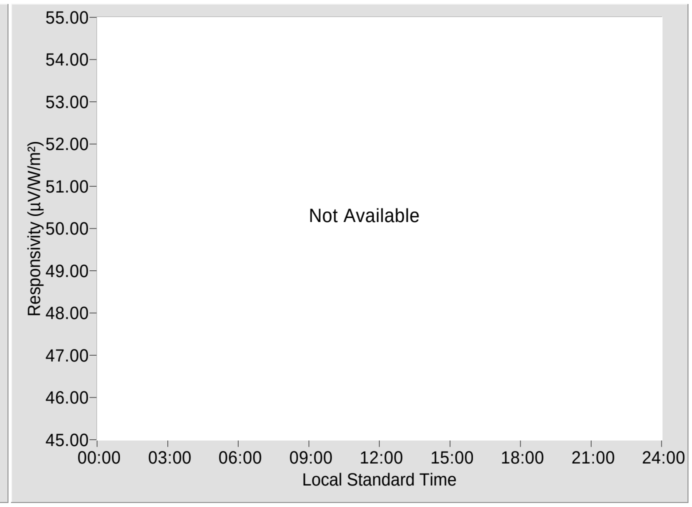

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

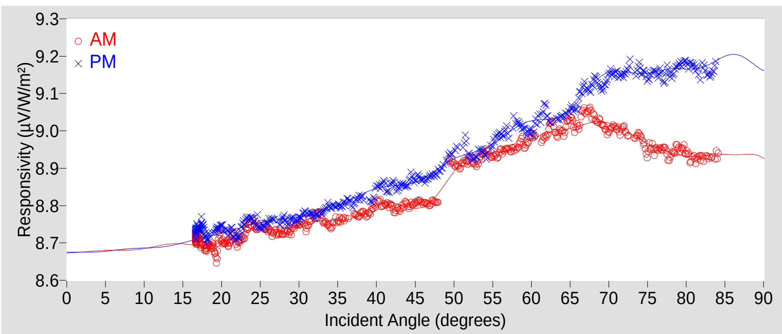
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I) \quad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

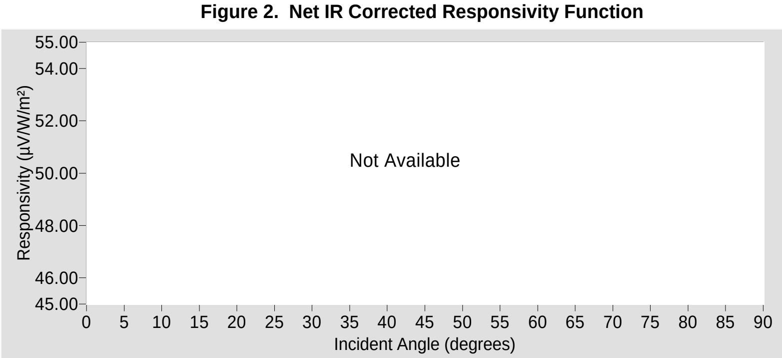


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.42	±1.42
R²	0.9999988	0.9999987
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.8°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.6781	*	8.6782	*	8.6781	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.6926	*	8.6955	*	8.6940	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.7196	±1.44	8.7390	±1.44	8.7293	±1.52	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.7513	±1.42	8.7771	±1.44	8.7642	±1.52	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.7906	±1.44	8.8411	±1.44	8.8159	±1.63	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.8676	±1.64	8.9113	±1.50	8.8895	±1.91	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.9628	±1.45	9.0031	±1.48	8.9830	±1.59	N/A	N/A	N/A	N/A	N/A	N/A
63-72	9.0136	±1.42	9.1045	±1.58	9.0590	±1.93	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.9590	±1.47	9.1605	±1.42	9.0597	±2.32	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.9352	*	9.1846	*	9.0599	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

See Note 1 below.

Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.8380	+2.82 / -1.75
45° - 55°	8.8981	±1.71
Composite	8.8040	+4.60 / -1.90
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:

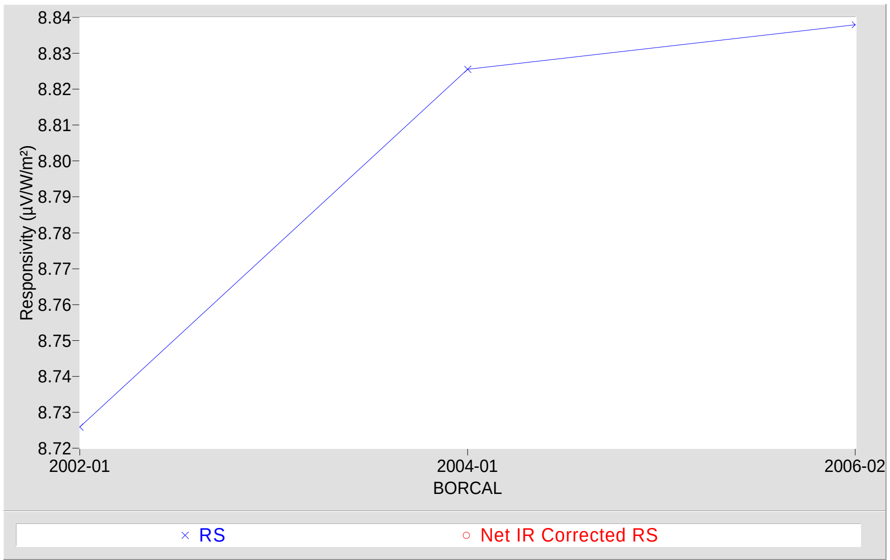
45°: 30.0° to 60.0°

45° - 55°: 45.0° to 55.0°

Composite: 16.6° to 83.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



5. Latitude Optimized Responsivity:

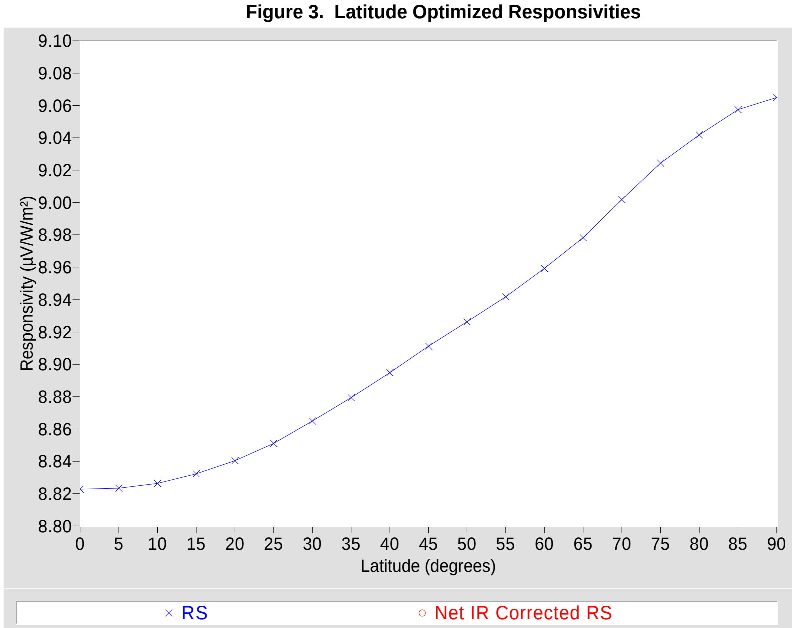
See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.8227	+4.56 / -2.21	N/A	N/A
5	8.8233	+4.55 / -2.21	N/A	N/A
10	8.8264	+4.51 / -2.24	N/A	N/A
15	8.8322	+4.45 / -2.29	N/A	N/A
20	8.8403	+4.36 / -2.36	N/A	N/A
25	8.8511	+4.24 / -2.45	N/A	N/A
30	8.8649	+4.09 / -2.52	N/A	N/A
35	8.8794	+3.93 / -2.59	N/A	N/A
40	8.8948	+3.76 / -2.67	N/A	N/A
45	8.9112	+3.59 / -2.64	N/A	N/A
50	8.9262	+3.43 / -2.55	N/A	N/A
55	8.9417	+3.26 / -2.53	N/A	N/A
60	8.9593	+3.08 / -2.63	N/A	N/A
65	8.9783	+2.89 / -2.51	N/A	N/A
70	9.0019	+2.66 / -2.68	N/A	N/A
75	9.0245	+2.45 / -1.86	N/A	N/A
80	9.0419	+2.29 / -1.87	N/A	N/A
85	9.0574	+2.16 / -1.98	N/A	N/A
90	9.0650	+2.09 / -2.04	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%

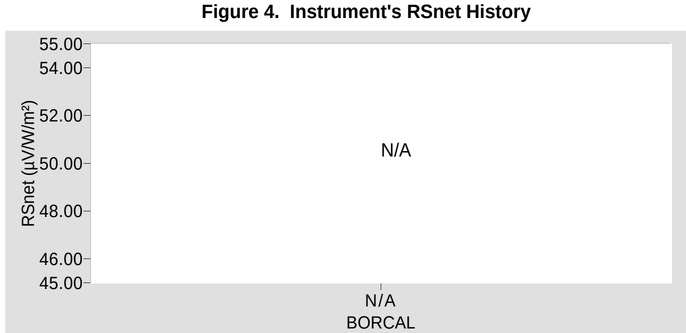
Instrument output voltage (V) = 0.00624 V (6240 µV)

Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33270

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

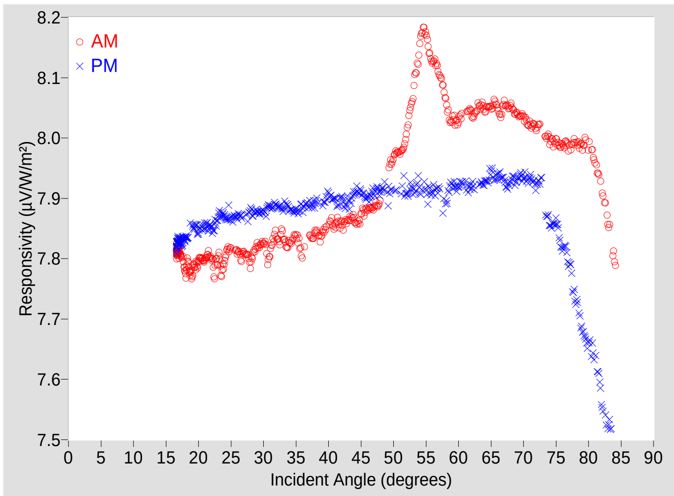

Figure 2. Responsivity vs Local Standard Time

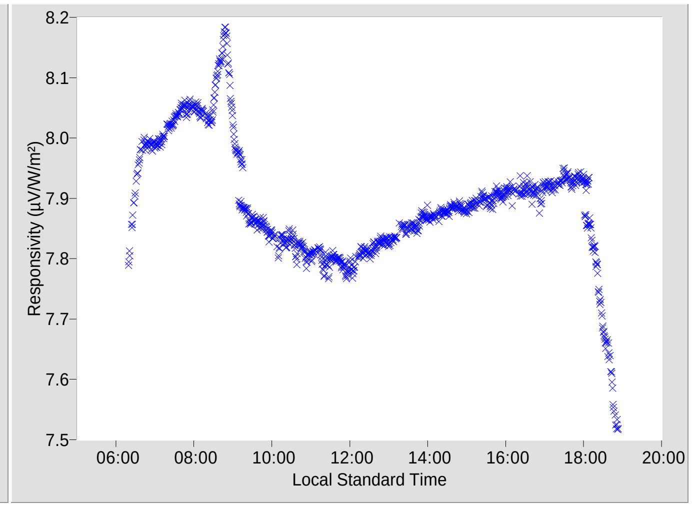

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
7.8905	+4.25 / -1.81	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8826	0.54	97.15	7.8998	0.57	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8911	N/A	95.61	7.9115	0.58	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9674	0.63	101.83	7.9120	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0067	0.81	100.02	7.9065	0.62	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1516	0.97	98.23	7.9178	0.63	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1276	0.76	96.60	7.9123	0.64	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0612	0.84	94.91	7.8944	0.71	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0301	0.72	93.37	7.9214	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0417	0.75	91.86	7.9207	0.70	274.99
18	7.7828	0.57	154.88	7.8334	0.53	204.45	64	8.0469	0.80	90.33	7.9262	0.74	276.36
20	7.7947	0.51	142.66	7.8481	0.48	217.28	66	8.0493	0.86	88.83	7.9367	0.78	277.72
22	7.7987	0.56	134.56	7.8507	0.50	225.39	68	8.0521	0.91	87.39	7.9288	0.83	279.15
24	7.7950	0.57	128.40	7.8707	0.50	231.41	70	8.0351	0.99	85.89	7.9345	0.89	280.51
26	7.8122	0.49	123.40	7.8705	0.49	236.52	72	8.0179	1.07	84.49	7.9227	0.98	281.88
28	7.7961	0.53	119.26	7.8788	0.50	240.72	74	7.9979	1.19	83.04	7.8593	1.36	278.98
30	7.8268	0.54	115.67	7.8782	0.50	244.21	76	7.9873	1.37	81.61	7.8179	1.58	280.39
32	7.8362	0.52	112.53	7.8879	0.50	247.35	78	7.9930	1.61	80.13	7.7326	1.91	281.85
34	7.8252	0.50	109.83	7.8836	0.51	250.04	80	7.9871	1.96	78.69	7.6599	2.11	283.28
36	7.8081	0.55	107.48	7.8843	0.52	252.63	82	7.9138	2.61	77.20	7.5680	2.75	284.71
38	7.8455	0.51	104.96	7.8935	0.52	254.89	84	7.8004	3.41	75.81	N/A	N/A	N/A
40	7.8575	0.54	102.81	7.9049	0.54	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8556	0.53	100.81	7.8998	0.55	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8652	0.54	98.93	7.9083	0.59	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

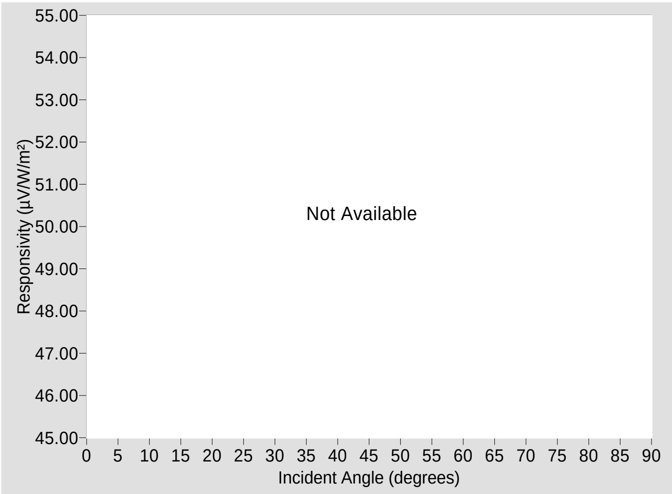

Figure 4. Responsivity vs Local Standard Time

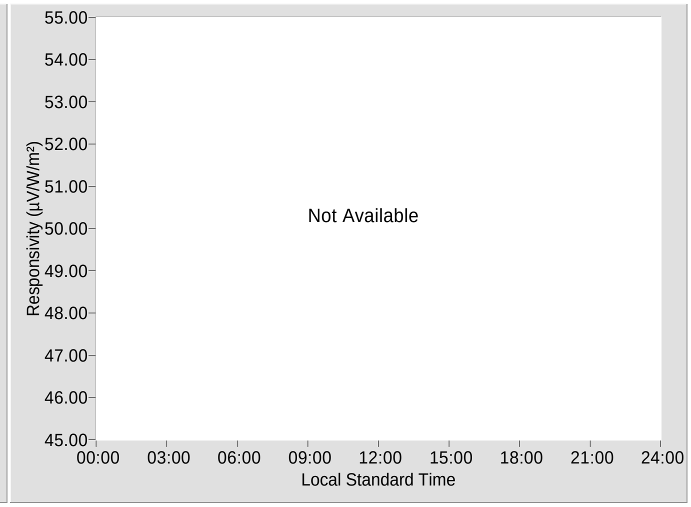

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

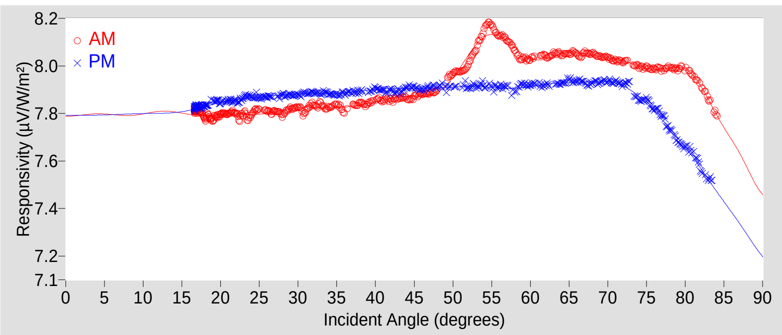
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

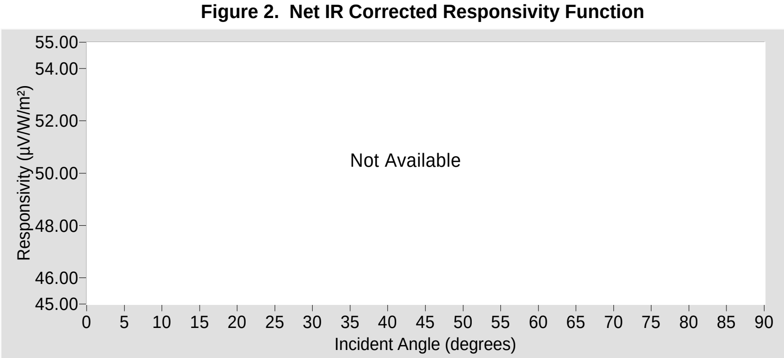


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.50	±1.50
R^2	0.9999984	0.9999996
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R^2	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	7.7935	*	7.7938	*	7.7936	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	7.8009	*	7.8057	*	7.8033	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	7.7965	±1.50	7.8558	±1.52	7.8261	±1.67	N/A	N/A	N/A	N/A	N/A	N/A
27-36	7.8215	±1.50	7.8819	±1.50	7.8517	±1.66	N/A	N/A	N/A	N/A	N/A	N/A
36-45	7.8504	±1.53	7.8990	±1.50	7.8747	±1.66	N/A	N/A	N/A	N/A	N/A	N/A
45-54	7.9533	±2.09	7.9093	±1.50	7.9313	±2.77	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.0750	±1.64	7.9118	±1.50	7.9934	±2.55	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.0445	±1.51	7.9310	±1.50	7.9877	±1.92	N/A	N/A	N/A	N/A	N/A	N/A
72-81	7.9950	±1.52	7.7920	±2.33	7.8935	±3.92	N/A	N/A	N/A	N/A	N/A	N/A
81-90	7.7136	*	7.4059	*	7.5597	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

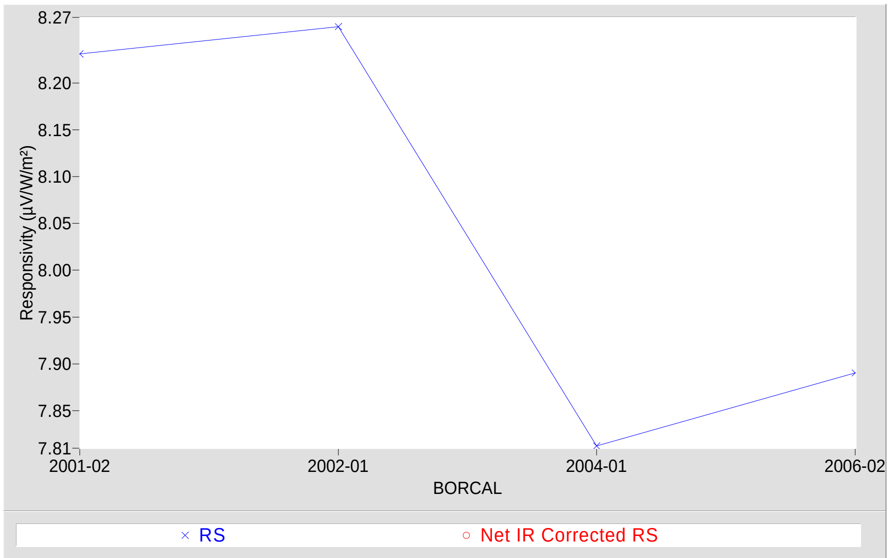
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	7.8905	+4.25 / -1.81
45° - 55°	7.9439	±2.21
Composite	7.8614	+3.77 / -5.15
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



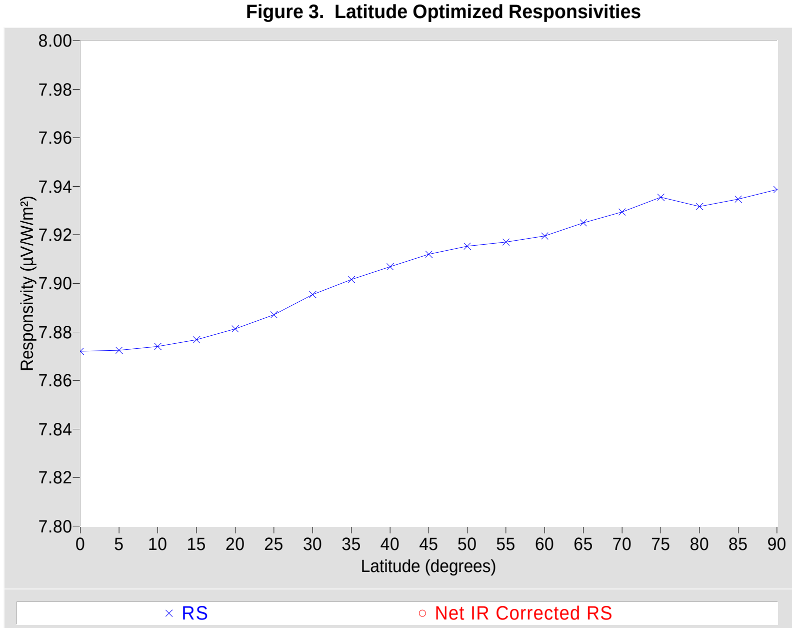
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	7.8721	+3.64 / -8.15	N/A	N/A
5	7.8724	+3.64 / -8.16	N/A	N/A
10	7.8740	+3.62 / -8.18	N/A	N/A
15	7.8768	+3.58 / -8.21	N/A	N/A
20	7.8813	+3.53 / -8.26	N/A	N/A
25	7.8871	+3.46 / -8.33	N/A	N/A
30	7.8954	+3.36 / -8.42	N/A	N/A
35	7.9016	+3.29 / -8.49	N/A	N/A
40	7.9068	+3.23 / -8.55	N/A	N/A
45	7.9120	+3.17 / -8.61	N/A	N/A
50	7.9153	+3.13 / -8.65	N/A	N/A
55	7.9170	+3.12 / -8.67	N/A	N/A
60	7.9195	+3.09 / -8.70	N/A	N/A
65	7.9249	+3.03 / -8.76	N/A	N/A
70	7.9295	+2.97 / -8.81	N/A	N/A
75	7.9355	+2.91 / -8.88	N/A	N/A
80	7.9317	+2.88 / -8.83	N/A	N/A
85	7.9347	+2.15 / -8.87	N/A	N/A
90	7.9387	+2.12 / -8.91	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

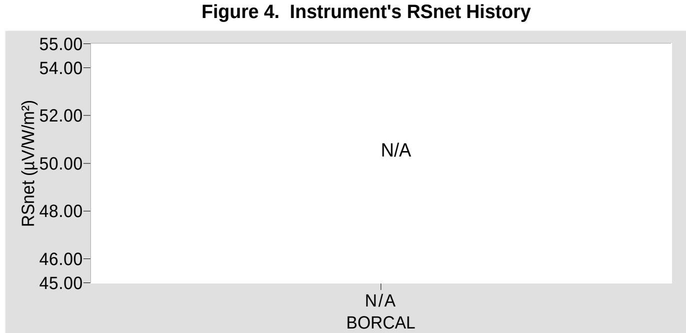
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33274

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: ___________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: ___________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

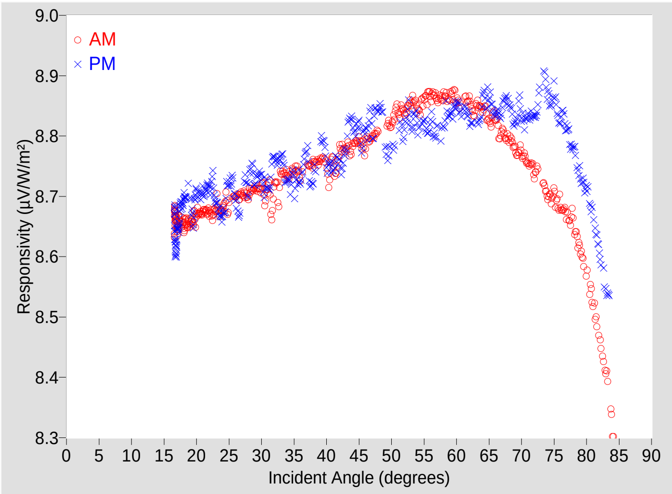

Figure 2. Responsivity vs Local Standard Time

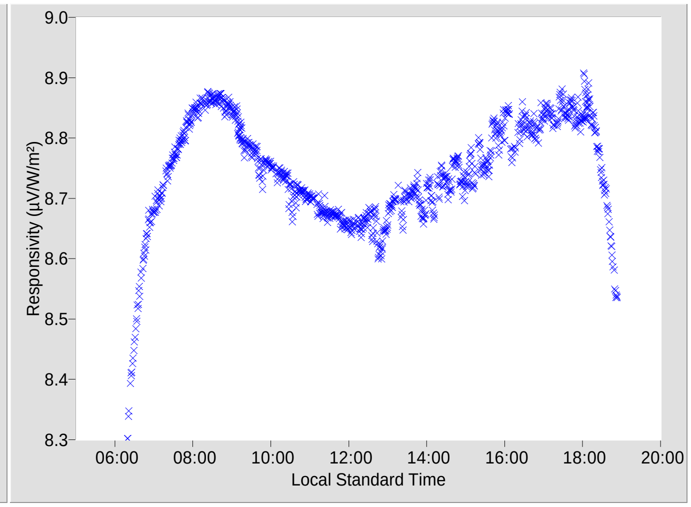

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.8020	+1.38 / -2.13	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7842	0.56	97.15	8.8066	0.69	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8097	N/A	95.61	8.8450	0.64	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8187	0.64	101.83	8.7861	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8400	0.65	100.02	8.8107	0.70	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8444	0.66	98.23	8.8197	0.63	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8679	0.67	96.60	8.8236	0.65	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8659	0.68	94.91	8.8173	0.73	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8617	0.73	93.37	8.8525	0.67	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8583	0.76	91.86	8.8264	0.70	274.99
18	8.6541	0.50	154.88	8.6930	0.66	204.45	64	8.8448	0.80	90.33	8.8594	0.79	276.36
20	8.6671	0.50	142.66	8.7037	0.61	217.28	66	8.8300	0.87	88.83	8.8367	0.80	277.72
22	8.6743	0.48	134.56	8.7131	0.56	225.39	68	8.7962	0.90	87.39	8.8528	0.85	279.15
24	8.6808	0.52	128.40	8.6686	0.61	231.41	70	8.7716	0.98	85.89	8.8343	0.93	280.51
26	8.7005	0.47	123.40	8.6953	0.62	236.52	72	8.7402	1.06	84.49	8.8327	1.00	281.88
28	8.7022	0.49	119.26	8.7212	0.57	240.61	74	8.7008	1.18	83.04	8.8715	1.38	278.98
30	8.7171	0.53	115.67	8.7253	0.54	244.21	76	8.6833	1.37	81.61	8.8276	1.52	280.39
32	8.7161	0.67	112.53	8.7637	0.58	247.35	78	8.6557	1.63	80.13	8.7783	1.81	281.85
34	8.7350	0.49	109.83	8.7263	0.63	250.04	80	8.5730	1.99	78.69	8.7136	2.07	283.28
36	8.7337	0.51	107.48	8.7273	0.67	252.63	82	8.4600	2.59	77.20	8.6059	2.64	284.71
38	8.7560	0.50	104.96	8.7325	0.64	254.89	84	8.3227	3.39	75.81	N/A	N/A	N/A
40	8.7488	0.59	102.81	8.7577	0.63	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7733	0.59	100.81	8.7516	0.58	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7820	0.55	98.93	8.8216	0.62	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

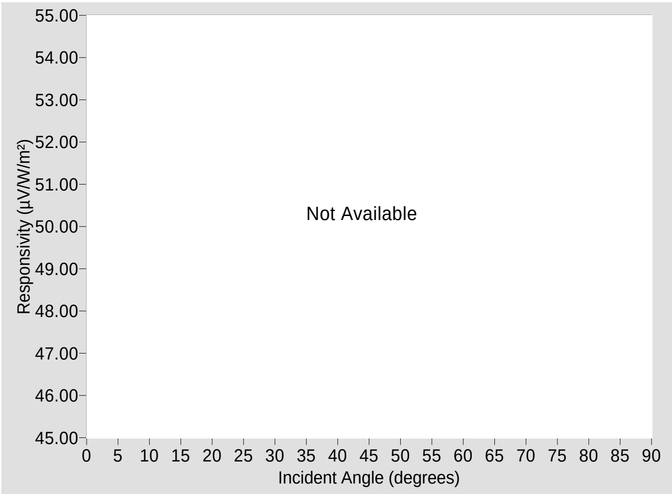

Figure 4. Responsivity vs Local Standard Time

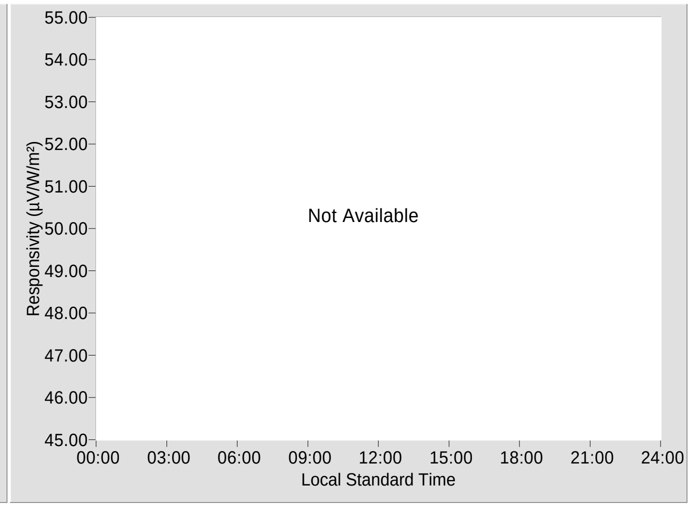

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \qquad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \qquad [2]$$

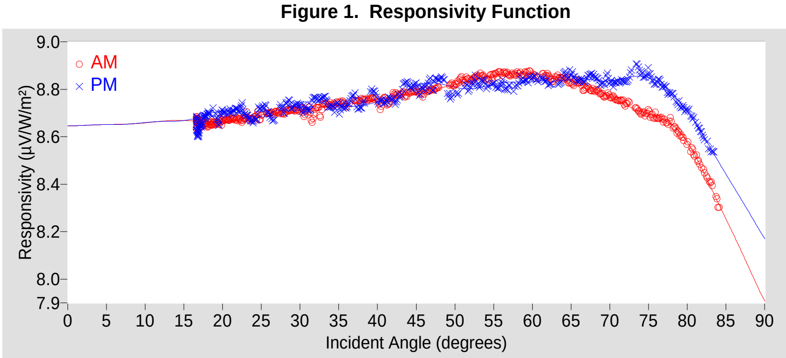
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

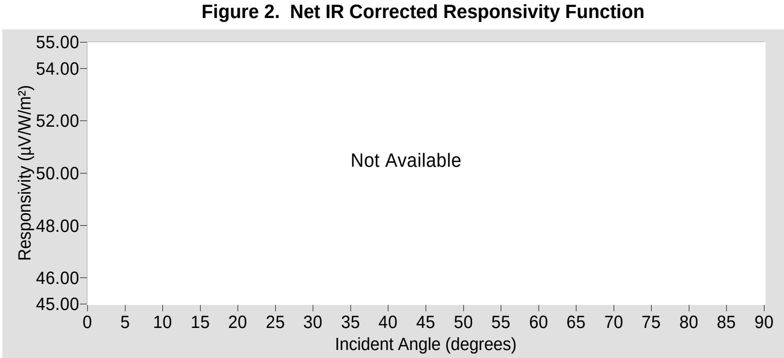


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.46	±1.46
R²	0.9999998	0.9999986
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	Responsivity AM U95 (%)	Responsivity PM RS (µV/W/m²)	Responsivity PM U95 (%)	Responsivity Combined RS (µV/W/m²)	Responsivity Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	Net IR Corr. Responsivity AM U95 (%)	Net IR Corr. Responsivity PM RSc (µV/W/m²)	Net IR Corr. Responsivity PM U95 (%)	Net IR Corr. Responsivity Combined RSc (µV/W/m²)	Net IR Corr. Responsivity Combined U95 (%)
0-9	8.6501	*	8.6499	*	8.6500	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.6643	*	8.6675	*	8.6659	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.6765	±1.47	8.6954	±1.47	8.6859	±1.51	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.7185	±1.47	8.7328	±1.48	8.7257	±1.51	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.7597	±1.48	8.7571	±1.53	8.7584	±1.61	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.8154	±1.50	8.8138	±1.46	8.8146	±1.54	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.8614	±1.46	8.8297	±1.47	8.8455	±1.52	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.8064	±1.58	8.8437	±1.46	8.8250	±1.75	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.6675	±1.80	8.8048	±1.75	8.7361	±2.90	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.2182	*	8.4164	*	8.3173	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

See Note 1 below.

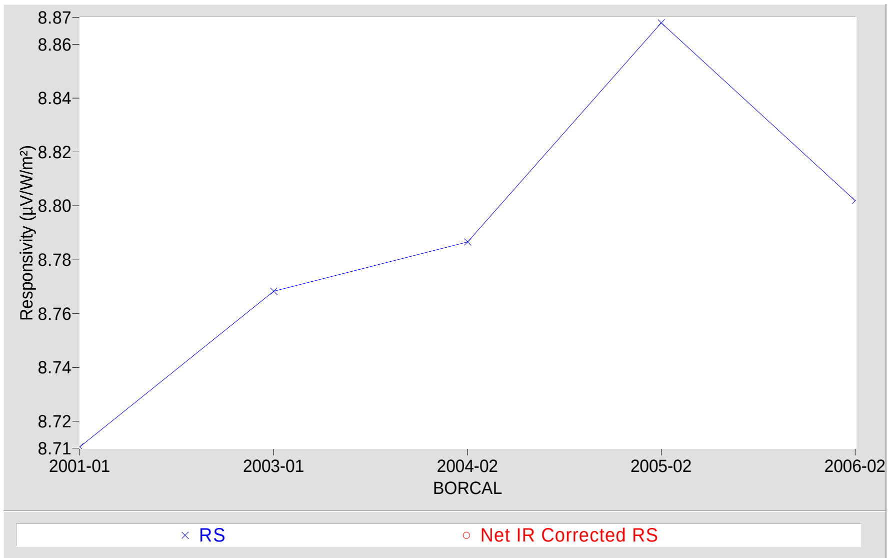
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.8020	+1.38 / -2.13
45° - 55°	8.8176	±1.51
Composite	8.7246	+2.18 / -4.85
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



5. Latitude Optimized Responsivity:

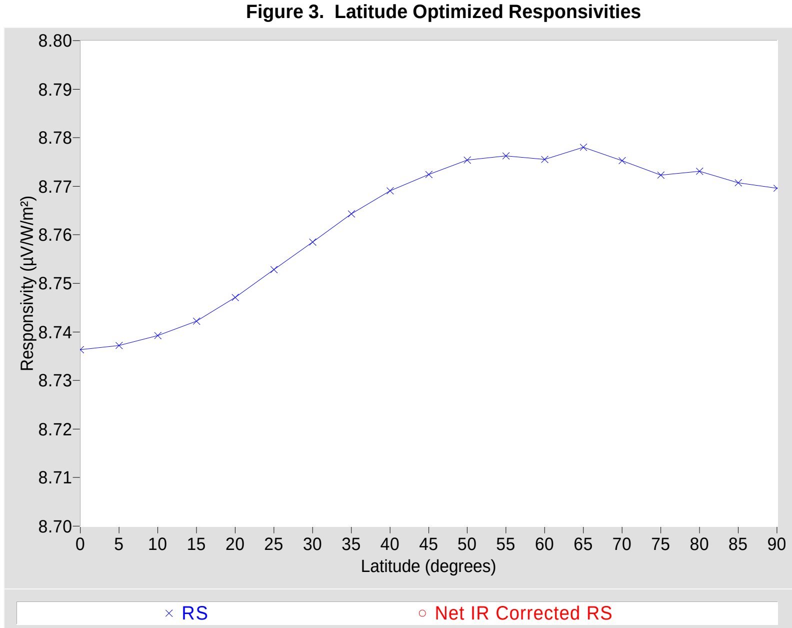
See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.7363	+2.08 / -8.84	N/A	N/A
5	8.7372	+2.08 / -8.85	N/A	N/A
10	8.7393	+2.06 / -8.87	N/A	N/A
15	8.7422	+2.03 / -8.90	N/A	N/A
20	8.7471	+2.00 / -8.95	N/A	N/A
25	8.7528	+1.95 / -9.01	N/A	N/A
30	8.7585	+1.91 / -9.06	N/A	N/A
35	8.7643	+1.87 / -9.12	N/A	N/A
40	8.7691	+1.83 / -9.17	N/A	N/A
45	8.7724	+1.81 / -9.21	N/A	N/A
50	8.7754	+1.79 / -9.24	N/A	N/A
55	8.7763	+1.78 / -9.25	N/A	N/A
60	8.7755	+1.79 / -9.24	N/A	N/A
65	8.7780	+1.77 / -9.26	N/A	N/A
70	8.7753	+1.79 / -9.24	N/A	N/A
75	8.7723	+1.81 / -9.21	N/A	N/A
80	8.7731	+1.80 / -9.21	N/A	N/A
85	8.7707	+1.79 / -9.19	N/A	N/A
90	8.7696	+1.75 / -9.18	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

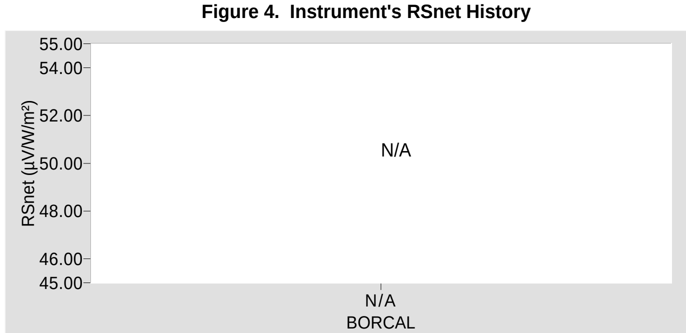
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33275

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

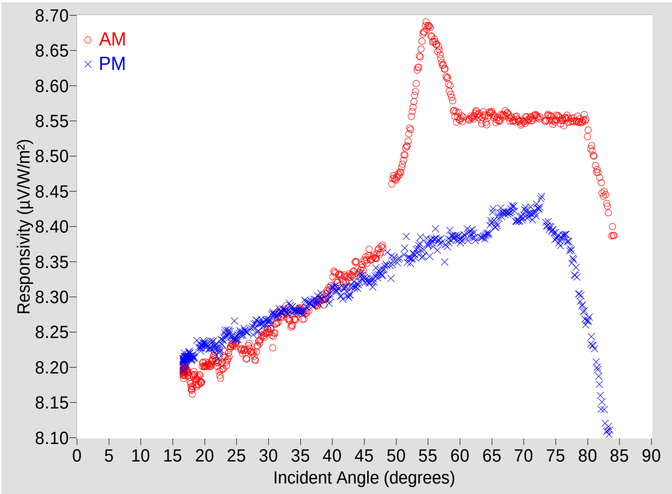

Figure 2. Responsivity vs Local Standard Time

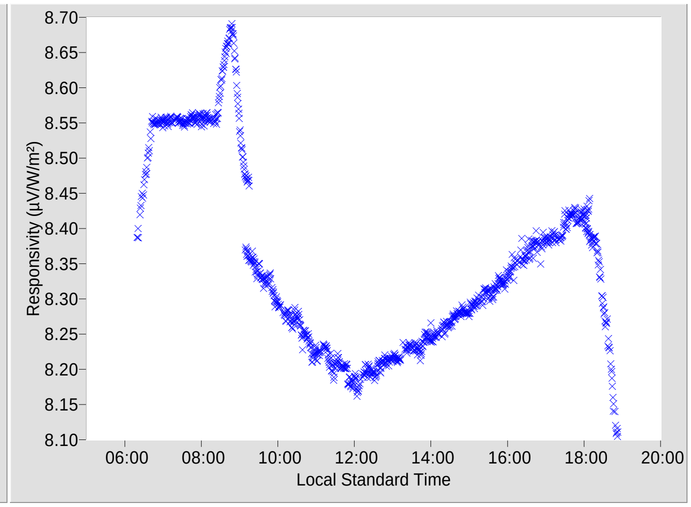

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3371	+4.78 / -1.84	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡		RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3573	0.54	97.15	8.3207	0.57	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3735	N/A	95.61	8.3365	0.60	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4684	0.63	101.83	8.3488	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5291	0.82	100.02	8.3538	0.62	267.71
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6613	0.86	98.23	8.3664	0.62	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6624	0.70	96.60	8.3832	0.65	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6061	0.81	94.91	8.3763	0.68	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5552	0.72	93.37	8.3823	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5553	0.75	91.86	8.3889	0.69	274.99
18	8.1760	0.54	154.88	8.2142	0.51	204.45	64	8.5520	0.79	90.33	8.3875	0.73	276.36
20	8.2031	0.50	142.66	8.2334	0.48	217.28	66	8.5515	0.84	88.83	8.4105	0.78	277.72
22	8.2052	0.52	134.56	8.2242	0.50	225.39	68	8.5528	0.89	87.39	8.4248	0.82	279.15
24	8.2256	0.51	128.40	8.2477	0.50	231.41	70	8.5503	0.97	85.89	8.4199	0.88	280.51
26	8.2240	0.49	123.40	8.2502	0.49	236.52	72	8.5572	1.06	84.49	8.4236	0.98	281.88
28	8.2199	0.52	119.26	8.2608	0.49	240.61	74	8.5562	1.17	83.04	8.4002	1.35	278.98
30	8.2527	0.51	115.67	8.2661	0.50	244.21	76	8.5487	1.35	81.61	8.3827	1.50	280.39
32	8.2749	0.50	112.53	8.2794	0.49	247.35	78	8.5506	1.59	80.13	8.3369	1.83	281.85
34	8.2682	0.51	109.83	8.2817	0.50	250.04	80	8.5391	1.93	78.77	8.2674	2.09	283.28
36	8.2781	0.50	107.48	8.2893	0.52	252.63	82	8.4600	2.52	77.20	8.1628	2.68	284.71
38	8.2952	0.50	104.96	8.2985	0.52	254.89	84	8.3903	3.33	75.81	N/A	N/A	N/A
40	8.3270	0.55	102.81	8.3104	0.54	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3233	0.52	100.81	8.3120	0.54	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3393	0.54	98.93	8.3169	0.55	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

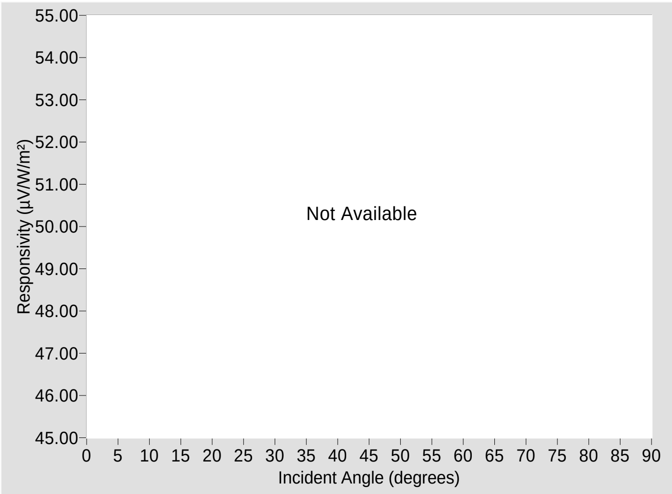

Figure 4. Responsivity vs Local Standard Time

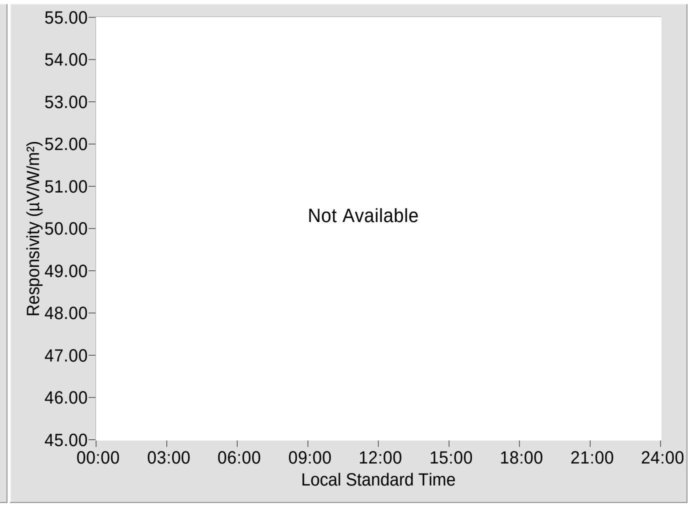

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

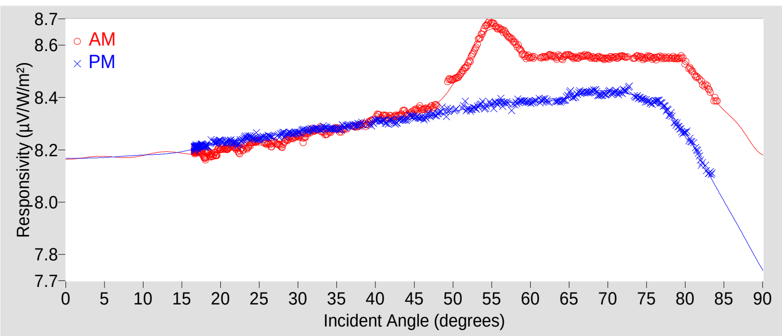
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

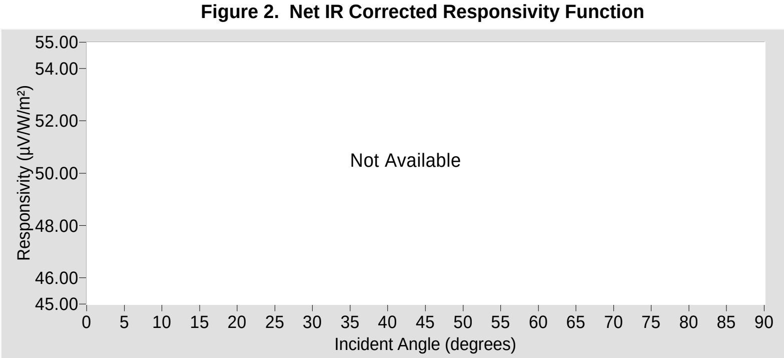


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.45	±1.45
R²	0.9999991	0.9999998
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.1705	*	8.1708	*	8.1707	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.1851	*	8.1890	*	8.1871	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.2085	±1.47	8.2347	±1.47	8.2216	±1.56	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.2564	±1.49	8.2728	±1.46	8.2646	±1.55	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.3157	±1.49	8.3066	±1.46	8.3111	±1.54	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.4487	±2.20	8.3419	±1.47	8.3953	±3.26	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.6037	±1.60	8.3795	±1.45	8.4916	±2.88	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.5526	±1.45	8.4122	±1.47	8.4824	±2.03	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.5494	±1.46	8.3593	±1.79	8.4544	±3.15	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.3381	*	7.9787	*	8.1584	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

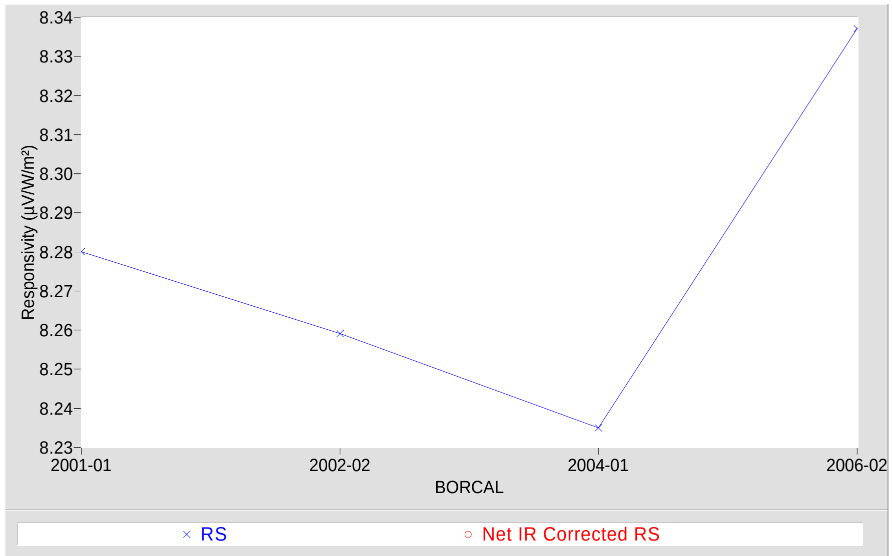
Table 3. Single Responsivities

Responsivity Characterization	RS (μV/W/m^2)	U95 † (%)
45°	8.3371	+4.78 / -1.84
45° - 55°	8.4120	±2.50
Composite	8.2891	+4.73 / -3.15
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



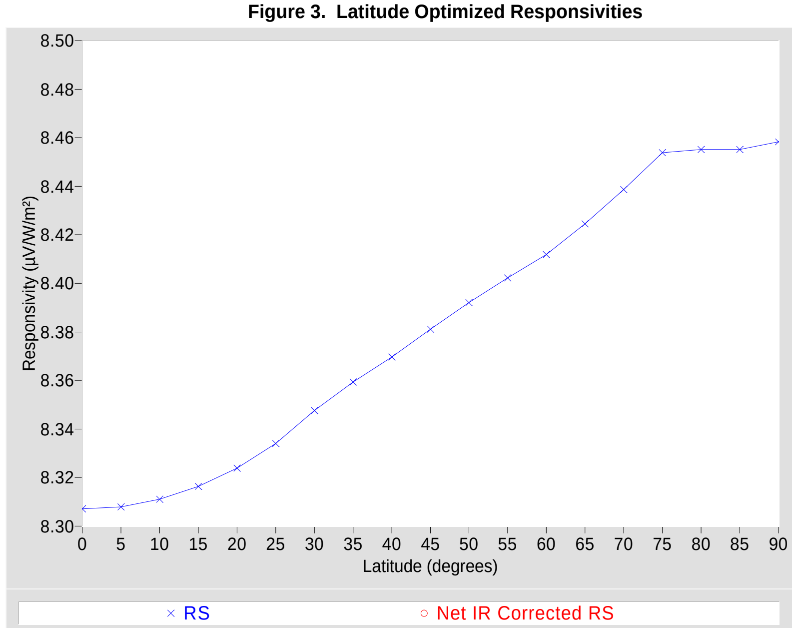
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (μV/W/m^2)	Error estimate* (%)	RSc (μV/W/m^2) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.3072	+4.51 / -6.36	N/A	N/A
5	8.3079	+4.50 / -6.37	N/A	N/A
10	8.3111	+4.46 / -6.40	N/A	N/A
15	8.3163	+4.40 / -6.46	N/A	N/A
20	8.3239	+4.31 / -6.54	N/A	N/A
25	8.3340	+4.19 / -6.65	N/A	N/A
30	8.3476	+4.03 / -6.80	N/A	N/A
35	8.3594	+3.89 / -6.93	N/A	N/A
40	8.3697	+3.78 / -7.04	N/A	N/A
45	8.3812	+3.65 / -7.17	N/A	N/A
50	8.3921	+3.52 / -7.28	N/A	N/A
55	8.4023	+3.41 / -7.39	N/A	N/A
60	8.4119	+3.30 / -7.50	N/A	N/A
65	8.4246	+3.16 / -7.64	N/A	N/A
70	8.4386	+3.01 / -7.79	N/A	N/A
75	8.4538	+2.85 / -7.95	N/A	N/A
80	8.4551	+2.81 / -7.96	N/A	N/A
85	8.4551	+1.88 / -7.96	N/A	N/A
90	8.4584	+1.86 / -8.00	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

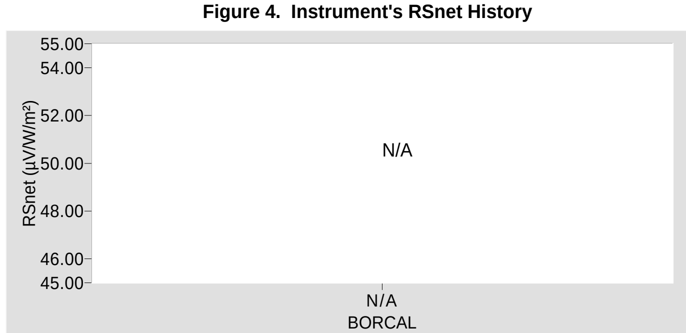
Example

Instrument responsivity (RS) = 7.34 μV/W/m^2 ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 μV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m^2 ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m^2

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33278

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

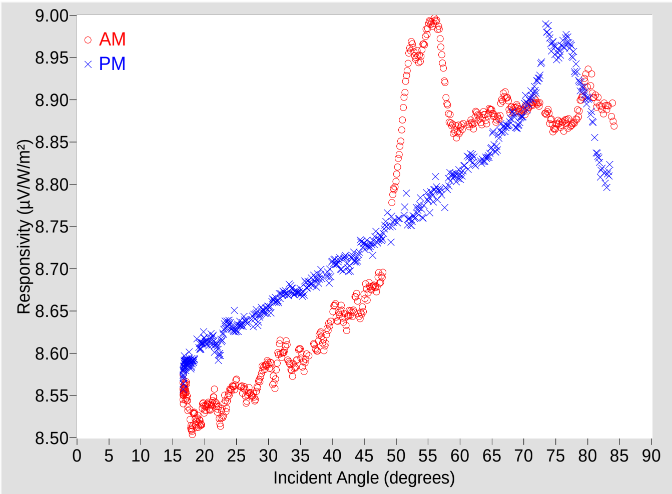

Figure 2. Responsivity vs Local Standard Time

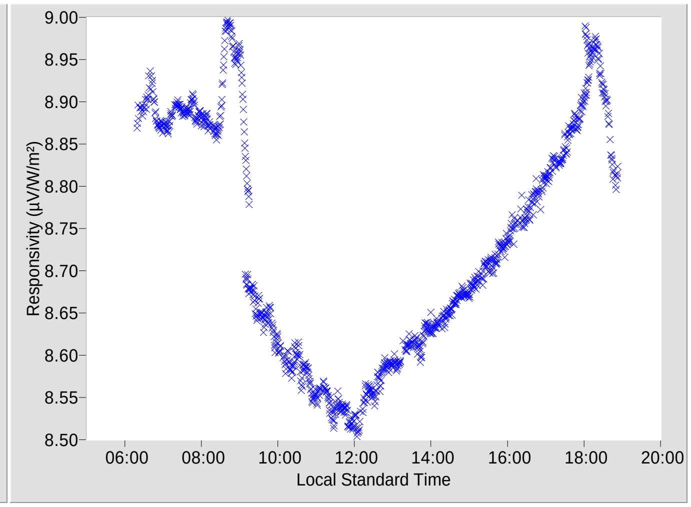

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6958	+4.00 / -2.11	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6787	0.54	97.15	8.7252	0.57	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6896	N/A	95.61	8.7418	0.59	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8083	0.82	101.83	8.7547	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9505	0.76	100.02	8.7574	0.62	267.71
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9577	0.68	98.23	8.7690	0.62	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9923	0.67	96.60	8.7946	0.65	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8899	0.89	94.91	8.7989	0.66	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8660	0.71	93.37	8.8121	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8714	0.75	91.86	8.8297	0.68	274.99
18	8.5158	0.59	154.88	8.5885	0.51	204.45	64	8.8781	0.79	90.33	8.8300	0.72	276.36
20	8.5356	0.49	142.66	8.6158	0.48	217.28	66	8.8787	0.86	88.83	8.8525	0.78	277.72
22	8.5343	0.53	134.56	8.6038	0.51	225.39	68	8.8887	0.90	87.39	8.8802	0.81	279.15
24	8.5551	0.52	128.40	8.6342	0.49	231.41	70	8.8878	0.97	85.89	8.8925	0.89	280.51
26	8.5585	0.48	123.40	8.6370	0.49	236.52	72	8.8967	1.05	84.49	8.9180	0.98	281.88
28	8.5518	0.51	119.26	8.6443	0.49	240.61	74	8.8803	1.17	83.04	8.9762	1.35	278.98
30	8.5878	0.51	115.67	8.6534	0.49	244.21	76	8.8695	1.34	81.61	8.9629	1.49	280.39
32	8.6023	0.55	112.53	8.6697	0.49	247.35	78	8.8749	1.58	80.13	8.9395	1.77	281.85
34	8.5819	0.52	109.83	8.6717	0.50	250.04	80	8.9274	1.89	78.77	8.9003	2.05	283.28
36	8.5936	0.51	107.48	8.6811	0.52	252.63	82	8.8913	2.47	77.20	8.8201	2.57	284.71
38	8.6213	0.51	104.96	8.6914	0.52	254.89	84	8.8800	3.27	75.81	N/A	N/A	N/A
40	8.6477	0.55	102.81	8.7048	0.54	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6371	0.54	100.81	8.7121	0.54	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6559	0.55	98.93	8.7134	0.55	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

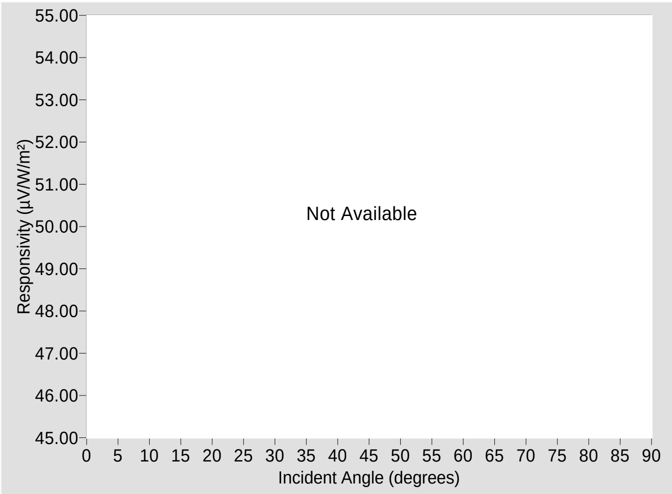

Figure 4. Responsivity vs Local Standard Time

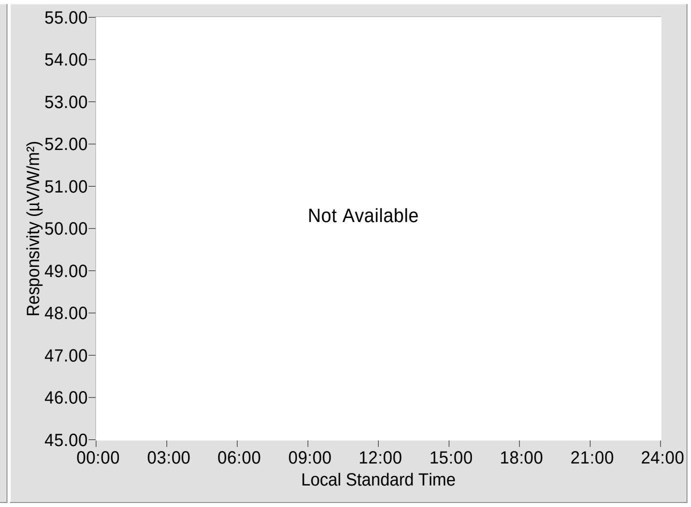

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function

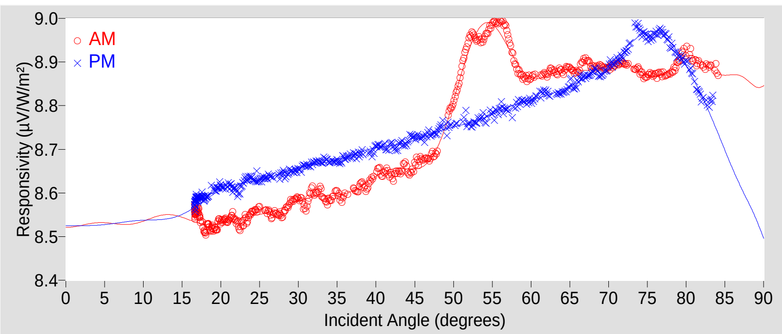
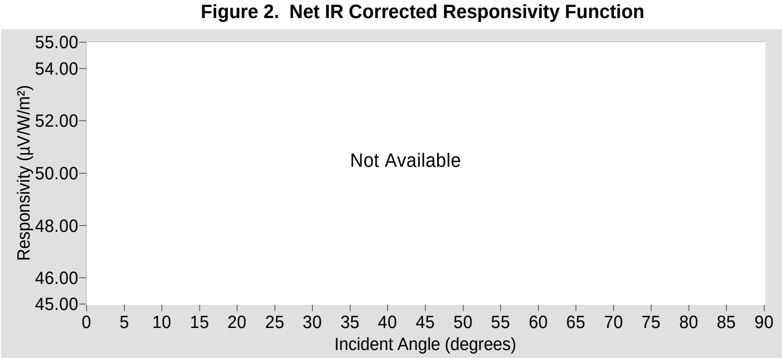


Figure 2. Net IR Corrected Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad [3]$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I)$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.42	±1.42
R²	0.9999986	0.9999996
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.5277	*	8.5280	*	8.5279	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.5409	*	8.5477	*	8.5443	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.5408	±1.43	8.6166	±1.46	8.5787	±1.69	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.5834	±1.44	8.6611	±1.44	8.6222	±1.72	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.6343	±1.46	8.7022	±1.44	8.6683	±1.73	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.7904	±2.34	8.7461	±1.45	8.7682	±3.10	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.9138	±1.59	8.8019	±1.46	8.8579	±2.28	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.8850	±1.43	8.8681	±1.51	8.8765	±1.59	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.8864	±1.45	8.9420	±1.52	8.9142	±1.65	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.8727	*	8.6797	*	8.7762	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

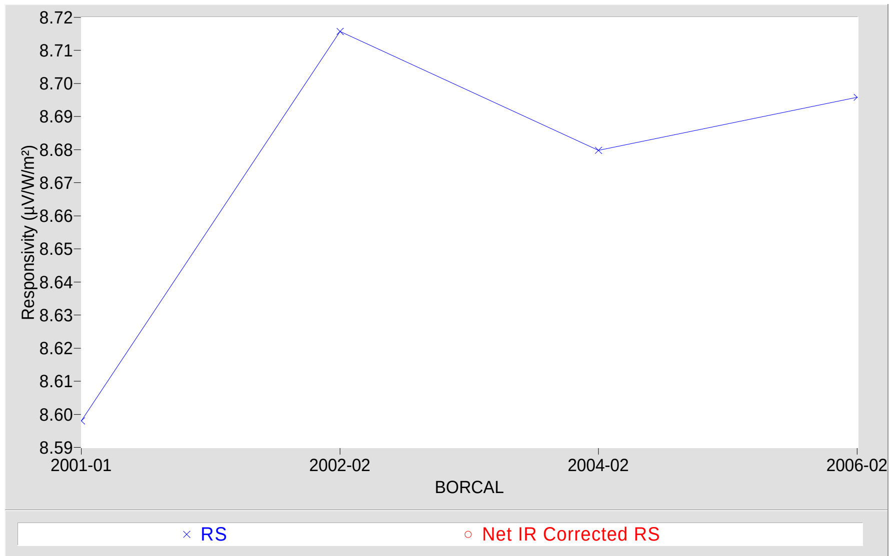
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6958	+4.00 / -2.11
45° - 55°	8.7845	±2.38
Composite	8.6574	+4.10 / -2.07
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



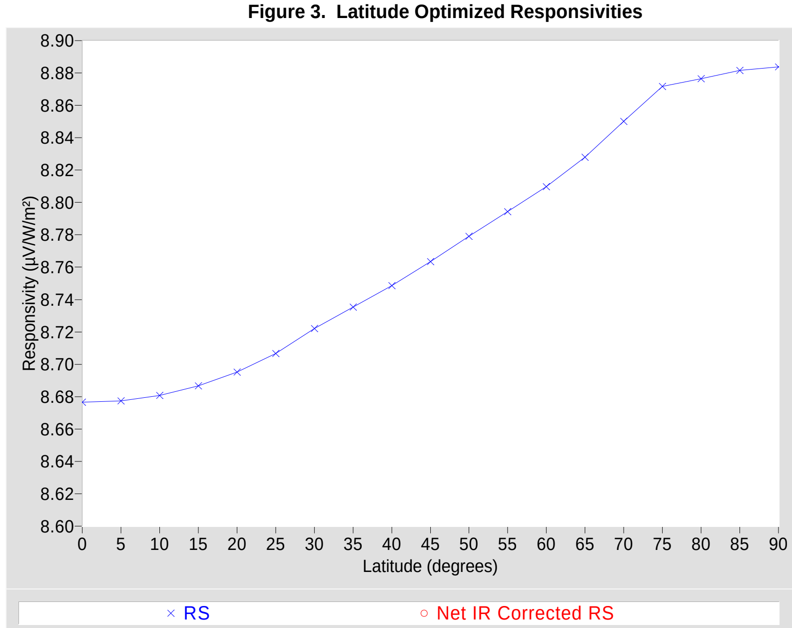
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.6766	+3.87 / -2.29	N/A	N/A
5	8.6774	+3.86 / -2.30	N/A	N/A
10	8.6808	+3.82 / -2.33	N/A	N/A
15	8.6866	+3.76 / -2.38	N/A	N/A
20	8.6951	+3.66 / -2.46	N/A	N/A
25	8.7067	+3.54 / -2.55	N/A	N/A
30	8.7222	+3.37 / -2.64	N/A	N/A
35	8.7353	+3.23 / -2.77	N/A	N/A
40	8.7486	+3.09 / -2.89	N/A	N/A
45	8.7635	+2.94 / -2.97	N/A	N/A
50	8.7791	+2.78 / -3.06	N/A	N/A
55	8.7942	+2.63 / -3.21	N/A	N/A
60	8.8098	+2.48 / -3.36	N/A	N/A
65	8.8280	+2.31 / -3.54	N/A	N/A
70	8.8501	+2.12 / -3.77	N/A	N/A
75	8.8718	+1.94 / -3.99	N/A	N/A
80	8.8764	+1.77 / -4.03	N/A	N/A
85	8.8816	+1.74 / -4.09	N/A	N/A
90	8.8838	+1.72 / -4.11	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

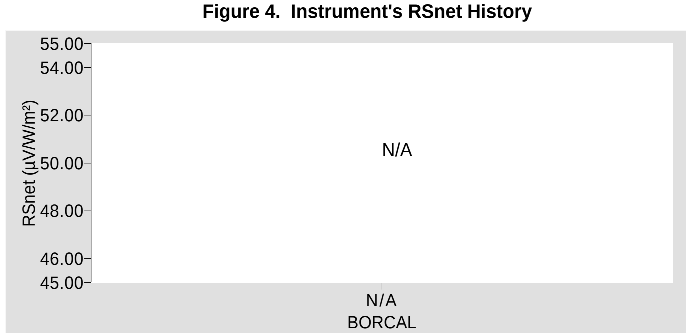
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33375

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: NSA

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

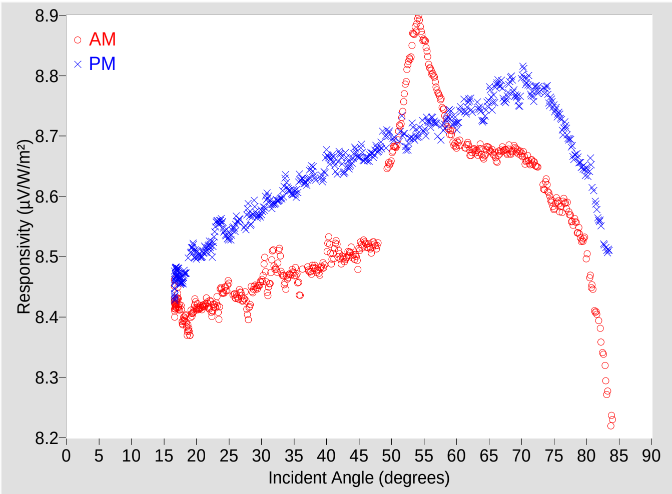

Figure 2. Responsivity vs Local Standard Time

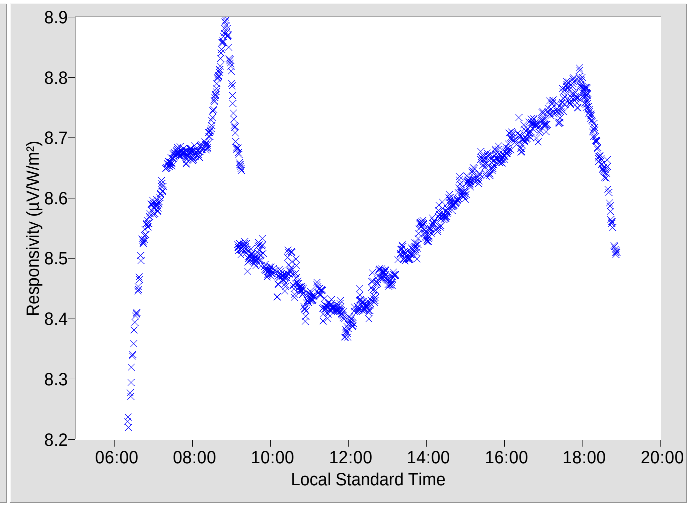

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5862	+4.19 / -2.29	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM			PM			Inc. Angle†	AM			PM		
	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡		RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5222	0.55	97.15	8.6612	0.57	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5187	N/A	95.61	8.6777	0.61	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6654	0.67	101.83	8.6958	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7688	0.93	100.02	8.6935	0.66	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8894	0.75	98.23	8.7030	0.62	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8109	0.79	96.60	8.7247	0.63	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7380	0.80	94.91	8.7149	0.69	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6862	0.73	93.37	8.7212	0.69	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6776	0.75	91.86	8.7565	0.69	274.99
18	8.3948	0.66	154.88	8.4657	0.53	204.45	64	8.6688	0.80	90.33	8.7283	0.74	276.36
20	8.4191	0.58	142.66	8.5035	0.49	217.28	66	8.6639	0.84	88.83	8.7755	0.81	277.72
22	8.4202	0.50	134.73	8.5182	0.56	225.39	68	8.6752	0.89	87.39	8.7825	0.84	279.15
24	8.4425	0.60	128.40	8.5540	0.52	231.41	70	8.6709	0.98	85.89	8.7947	0.95	280.51
26	8.4352	0.48	123.40	8.5539	0.53	236.52	72	8.6536	1.06	84.49	8.7742	0.98	281.88
28	8.4112	0.58	119.26	8.5716	0.55	240.61	74	8.6156	1.20	83.04	8.7724	1.35	278.98
30	8.4614	0.61	115.67	8.5741	0.54	244.21	76	8.5804	1.36	81.61	8.7284	1.51	280.39
32	8.4871	0.61	112.53	8.5894	0.50	247.35	78	8.5578	1.61	80.13	8.6697	1.77	281.85
34	8.4627	0.52	109.83	8.6194	0.55	250.04	80	8.5114	1.97	78.77	8.6393	2.07	283.28
36	8.4435	0.56	107.48	8.6299	0.55	252.63	82	8.3781	2.60	77.20	8.5589	2.60	284.71
38	8.4835	0.50	104.96	8.6414	0.53	254.89	84	8.2290	3.31	75.86	N/A	N/A	N/A
40	8.5058	0.60	102.81	8.6630	0.60	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4999	0.56	100.81	8.6675	0.57	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5050	0.57	98.93	8.6605	0.57	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

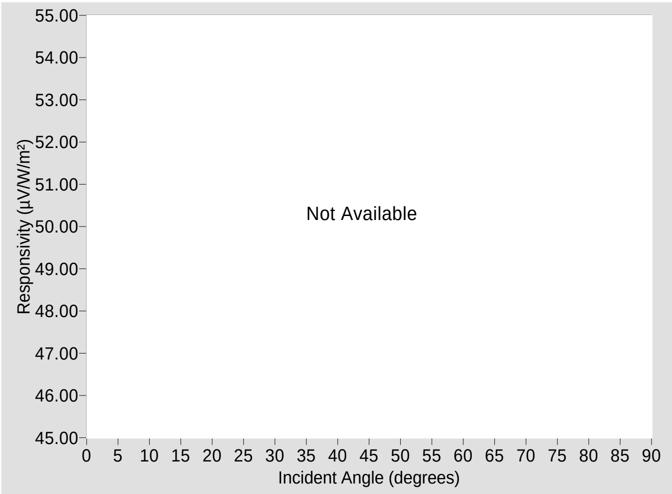

Figure 4. Responsivity vs Local Standard Time

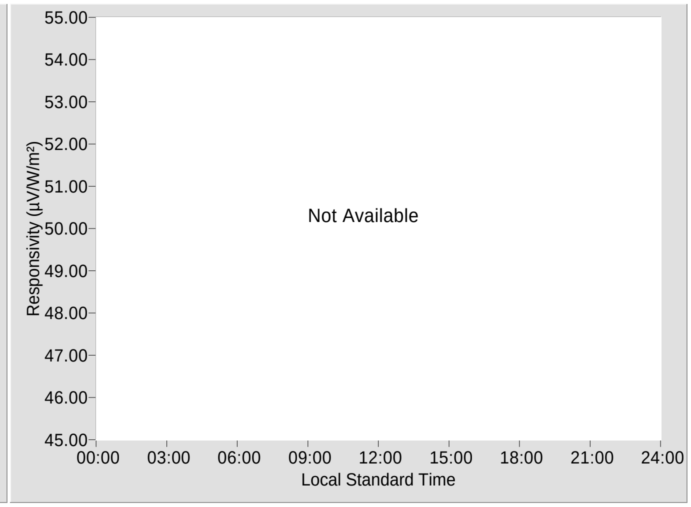

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

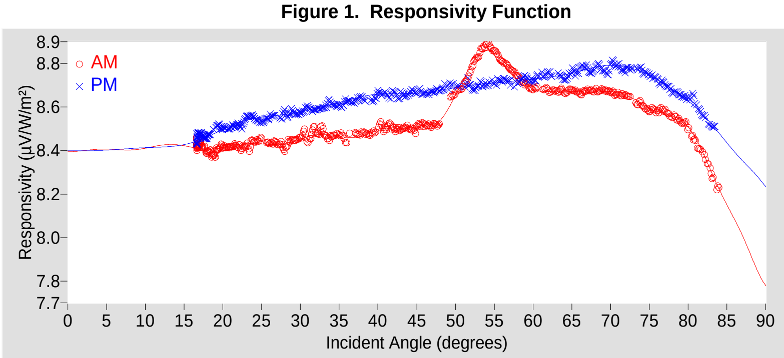
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

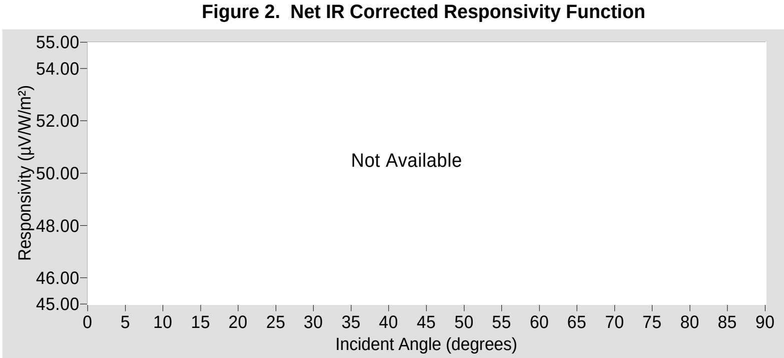


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.45	±1.45
R²	0.9999984	0.9999994
Valid incidence angle range	16.6° to 84.0°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.4022	*	8.4024	*	8.4023	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.4178	*	8.4243	*	8.4210	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.4232	±1.46	8.5229	±1.55	8.4731	±1.94	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.4570	±1.47	8.5897	±1.49	8.5233	±2.19	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.4923	±1.49	8.6548	±1.46	8.5736	±2.23	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.6365	±2.52	8.6840	±1.47	8.6603	±3.25	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.7502	±1.81	8.7223	±1.46	8.7362	±2.16	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.6698	±1.45	8.7726	±1.47	8.7212	±1.79	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.5794	±1.76	8.7135	±1.75	8.6464	±2.86	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.1159	*	8.4179	*	8.2669	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

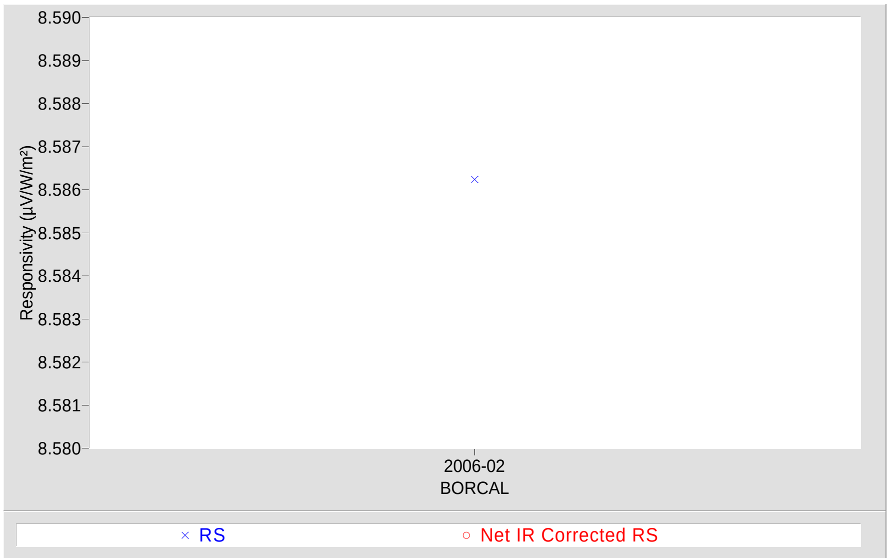
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.5862	+4.19 / -2.29
45° - 55°	8.6778	±2.54
Composite	8.5335	+4.08 / -3.50
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



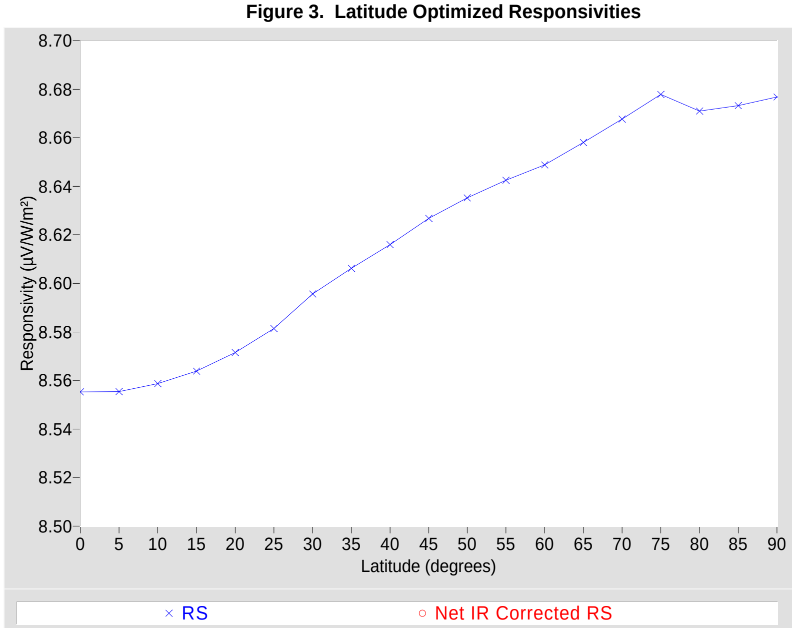
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5552	+3.84 / -8.44	N/A	N/A
5	8.5554	+3.83 / -8.44	N/A	N/A
10	8.5587	+3.80 / -8.48	N/A	N/A
15	8.5639	+3.74 / -8.53	N/A	N/A
20	8.5715	+3.66 / -8.61	N/A	N/A
25	8.5815	+3.55 / -8.72	N/A	N/A
30	8.5956	+3.39 / -8.87	N/A	N/A
35	8.6061	+3.28 / -8.98	N/A	N/A
40	8.6159	+3.17 / -9.08	N/A	N/A
45	8.6267	+3.06 / -9.19	N/A	N/A
50	8.6352	+2.97 / -9.28	N/A	N/A
55	8.6424	+2.90 / -9.35	N/A	N/A
60	8.6488	+2.83 / -9.42	N/A	N/A
65	8.6581	+2.74 / -9.52	N/A	N/A
70	8.6677	+2.64 / -9.62	N/A	N/A
75	8.6779	+2.54 / -9.72	N/A	N/A
80	8.6710	+2.29 / -9.65	N/A	N/A
85	8.6732	+1.99 / -9.67	N/A	N/A
90	8.6768	+1.96 / -9.71	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

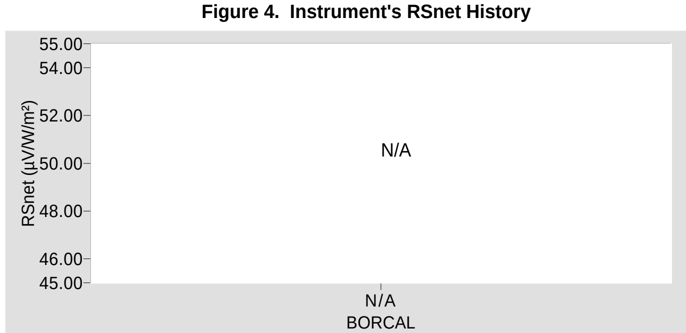
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33378

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: AMF

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results
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Figure 1. Responsivity vs Incident Angle

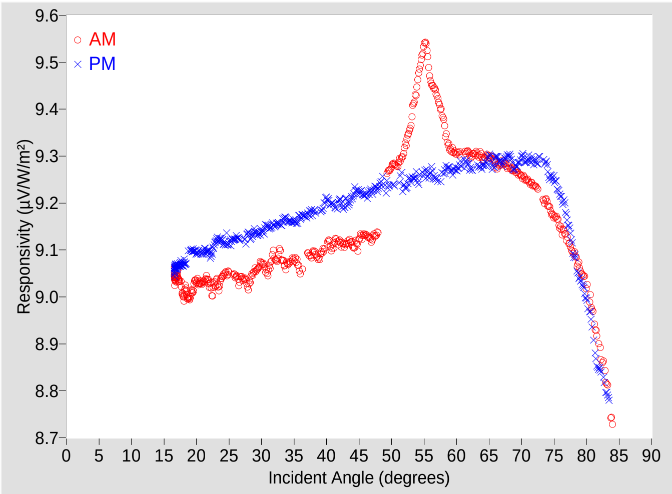

Figure 2. Responsivity vs Local Standard Time

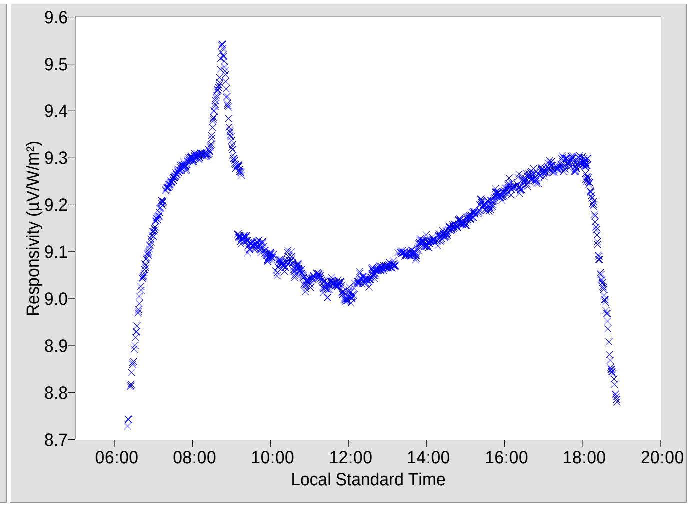

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.1708	+4.58 / -1.90	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1322	0.54	97.15	9.2162	0.55	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1385	N/A	95.61	9.2328	0.59	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2779	0.61	101.83	9.2392	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3143	0.74	100.02	9.2329	0.62	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4606	1.09	98.23	9.2505	0.61	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4654	0.87	96.60	9.2654	0.62	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3706	0.91	94.91	9.2653	0.65	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3073	0.71	93.37	9.2721	0.67	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3049	0.74	91.86	9.2773	0.69	274.99
18	9.0069	0.59	154.88	9.0710	0.51	204.45	64	9.2965	0.78	90.33	9.2781	0.72	276.36
20	9.0336	0.51	142.66	9.0948	0.47	217.28	66	9.2839	0.84	88.83	9.2916	0.77	277.72
22	9.0287	0.53	134.56	9.0930	0.51	225.39	68	9.2777	0.89	87.39	9.3015	0.82	279.15
24	9.0434	0.52	128.40	9.1192	0.49	231.41	70	9.2576	0.97	85.89	9.2999	0.88	280.51
26	9.0451	0.49	123.40	9.1252	0.49	236.52	72	9.2367	1.05	84.49	9.2886	0.95	281.88
28	9.0265	0.52	119.26	9.1335	0.51	240.61	74	9.1999	1.18	83.04	9.2729	1.35	278.98
30	9.0725	0.50	115.67	9.1392	0.50	244.21	76	9.1453	1.37	81.61	9.2152	1.53	280.39
32	9.0836	0.54	112.53	9.1532	0.49	247.35	78	9.0933	1.61	80.13	9.0929	1.87	281.85
34	9.0689	0.50	109.83	9.1634	0.51	250.04	80	9.0297	1.94	78.77	8.9906	2.11	283.28
36	9.0573	0.53	107.48	9.1708	0.51	252.63	82	8.8865	2.57	77.20	8.8456	2.62	284.71
38	9.0966	0.50	104.96	9.1822	0.51	254.89	84	8.7381	3.28	75.86	N/A	N/A	N/A
40	9.1107	0.53	102.81	9.2079	0.54	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1148	0.52	100.81	9.2049	0.54	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1118	0.54	98.93	9.2132	0.58	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

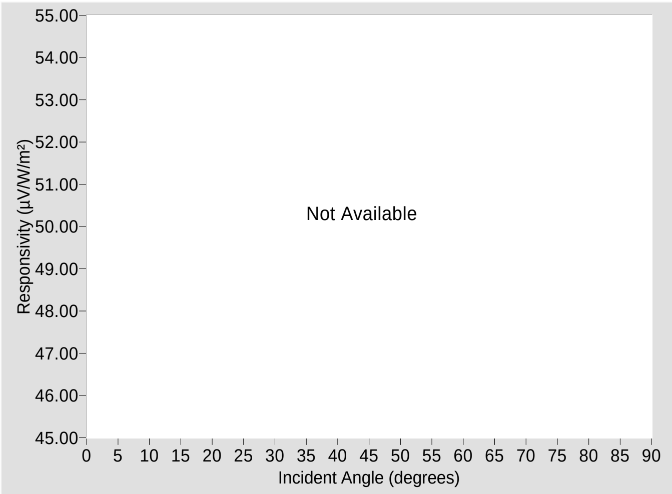

Figure 4. Responsivity vs Local Standard Time

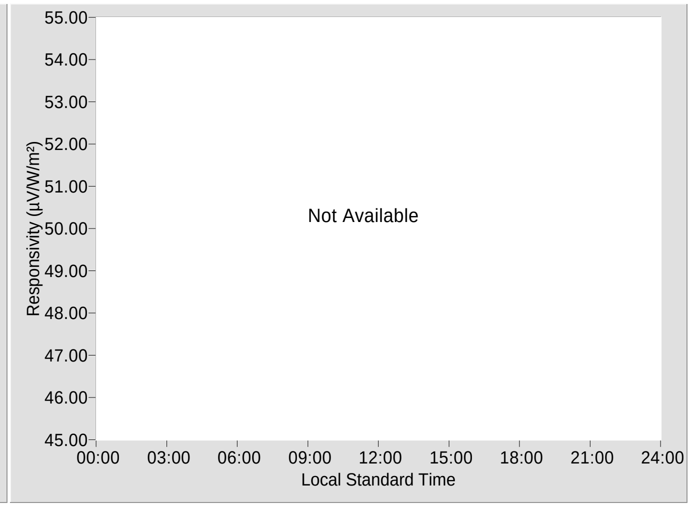

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

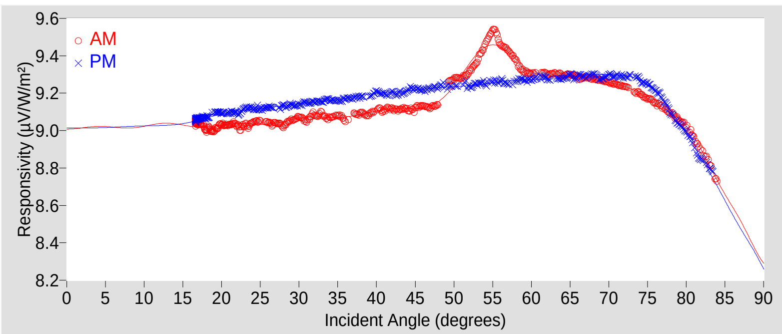
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

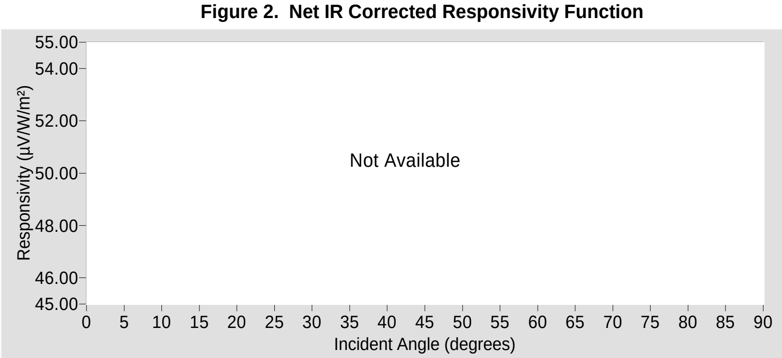


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.46	±1.46
R²	0.9999983	0.9999998
Valid incidence angle range	16.6° to 84.0°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	9.0161	*	9.0164	*	9.0163	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	9.0284	*	9.0345	*	9.0315	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	9.0321	±1.47	9.1018	±1.50	9.0670	±1.69	N/A	N/A	N/A	N/A	N/A	N/A
27-36	9.0641	±1.47	9.1483	±1.48	9.1062	±1.77	N/A	N/A	N/A	N/A	N/A	N/A
36-45	9.1024	±1.49	9.1979	±1.48	9.1502	±1.83	N/A	N/A	N/A	N/A	N/A	N/A
45-54	9.2343	±2.23	9.2321	±1.47	9.2332	±2.87	N/A	N/A	N/A	N/A	N/A	N/A
54-63	9.3749	±1.71	9.2664	±1.47	9.3207	±2.22	N/A	N/A	N/A	N/A	N/A	N/A
63-72	9.2769	±1.49	9.2927	±1.47	9.2848	±1.54	N/A	N/A	N/A	N/A	N/A	N/A
72-81	9.1351	±1.97	9.1672	±2.39	9.1511	±3.08	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.6263	*	8.5908	*	8.6086	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

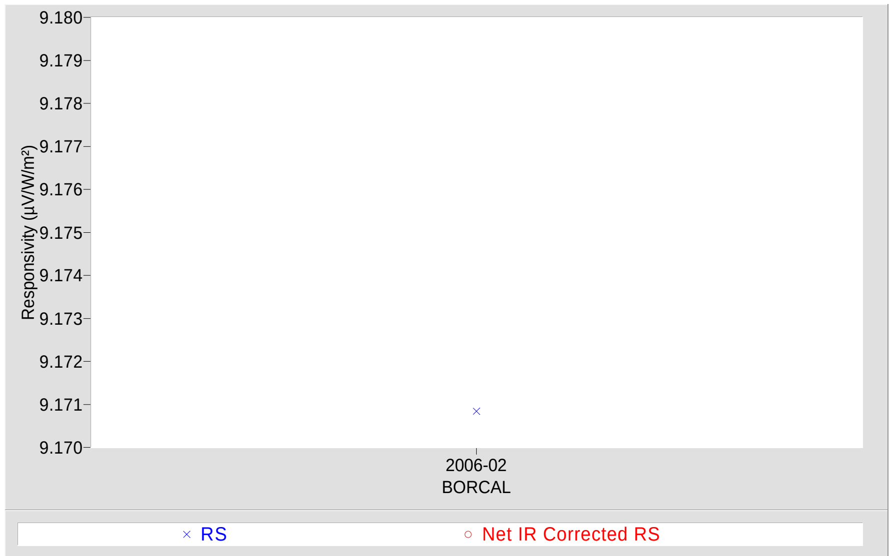
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.1708	+4.58 / -1.90
45° - 55°	9.2502	±2.35
Composite	9.1190	+4.00 / -4.40
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



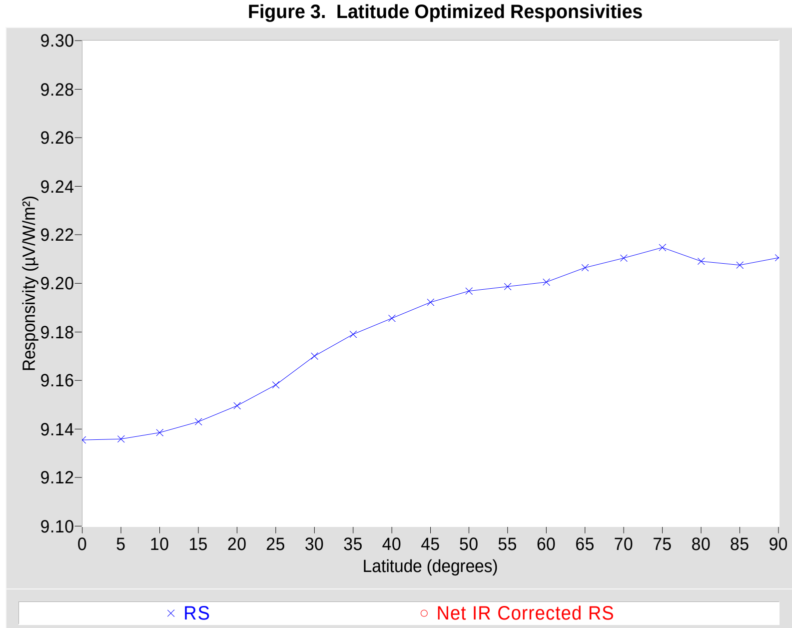
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.1354	+3.83 / -8.84	N/A	N/A
5	9.1359	+3.82 / -8.84	N/A	N/A
10	9.1385	+3.80 / -8.87	N/A	N/A
15	9.1430	+3.75 / -8.91	N/A	N/A
20	9.1496	+3.68 / -8.98	N/A	N/A
25	9.1582	+3.59 / -9.06	N/A	N/A
30	9.1701	+3.47 / -9.18	N/A	N/A
35	9.1790	+3.38 / -9.27	N/A	N/A
40	9.1856	+3.31 / -9.33	N/A	N/A
45	9.1923	+3.25 / -9.40	N/A	N/A
50	9.1969	+3.20 / -9.44	N/A	N/A
55	9.1987	+3.18 / -9.46	N/A	N/A
60	9.2006	+3.16 / -9.48	N/A	N/A
65	9.2064	+3.11 / -9.53	N/A	N/A
70	9.2104	+3.07 / -9.57	N/A	N/A
75	9.2148	+3.02 / -9.62	N/A	N/A
80	9.2091	+2.99 / -9.56	N/A	N/A
85	9.2075	+1.77 / -9.54	N/A	N/A
90	9.2105	+1.76 / -9.57	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

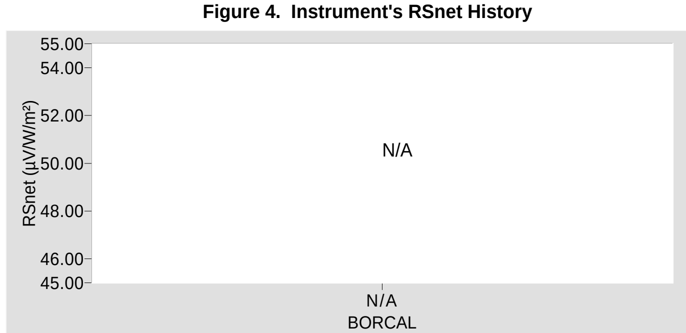
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33379

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: TWP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

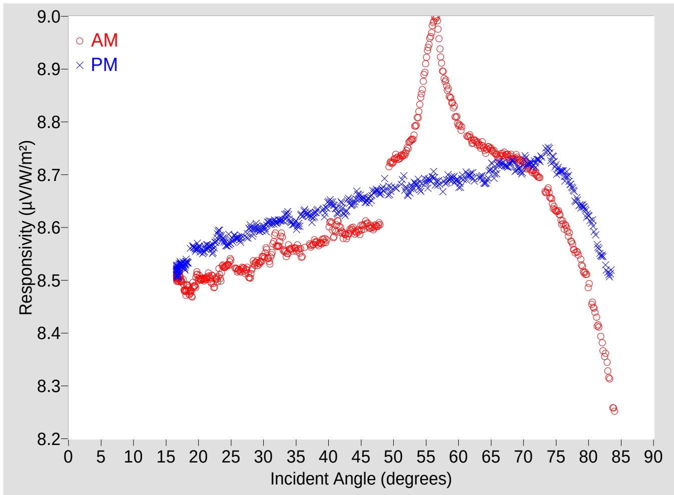

Figure 2. Responsivity vs Local Standard Time

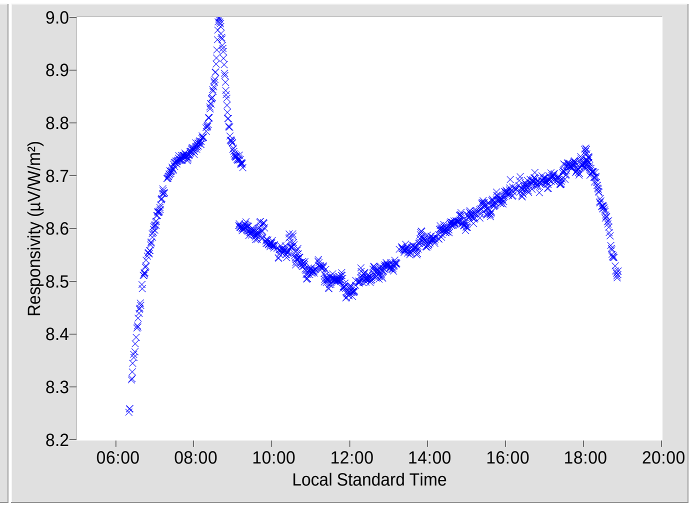

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.6267	+4.85 / -1.64	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6059	0.54	97.15	8.6513	0.56	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6090	N/A	95.61	8.6668	0.58	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7263	0.62	101.83	8.6762	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7451	0.65	100.02	8.6688	0.62	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8322	1.03	98.23	8.6770	0.61	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9785	0.78	96.60	8.6962	0.63	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8734	0.97	94.91	8.6867	0.65	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7977	0.77	93.37	8.6847	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7665	0.75	91.86	8.6987	0.68	274.99
18	8.4818	0.56	154.88	8.5295	0.52	204.45	64	8.7479	0.79	90.33	8.6851	0.73	276.36
20	8.5066	0.54	142.66	8.5614	0.48	217.28	66	8.7342	0.84	88.83	8.7146	0.78	277.72
22	8.5018	0.50	134.56	8.5597	0.52	225.39	68	8.7334	0.89	87.39	8.7238	0.82	279.15
24	8.5259	0.53	128.40	8.5743	0.50	231.41	70	8.7240	0.97	85.89	8.7216	0.90	280.51
26	8.5200	0.47	123.40	8.5805	0.48	236.52	72	8.6997	1.06	84.49	8.7248	0.96	281.88
28	8.5117	0.51	119.26	8.5974	0.50	240.61	74	8.6634	1.19	83.04	8.7424	1.35	278.98
30	8.5461	0.52	115.67	8.5994	0.50	244.21	76	8.6073	1.38	81.61	8.7050	1.50	280.39
32	8.5696	0.55	112.53	8.6105	0.49	247.35	78	8.5546	1.62	80.13	8.6553	1.77	281.85
34	8.5588	0.50	109.83	8.6183	0.52	250.04	80	8.4972	1.97	78.77	8.6205	2.07	283.28
36	8.5496	0.51	107.48	8.6250	0.55	252.63	82	8.3807	2.58	77.20	8.5471	2.59	284.71
38	8.5735	0.50	104.96	8.6274	0.53	254.89	84	8.2564	3.31	75.86	N/A	N/A	N/A
40	8.5957	0.56	102.81	8.6464	0.55	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5905	0.55	100.81	8.6396	0.56	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5930	0.53	98.93	8.6485	0.55	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

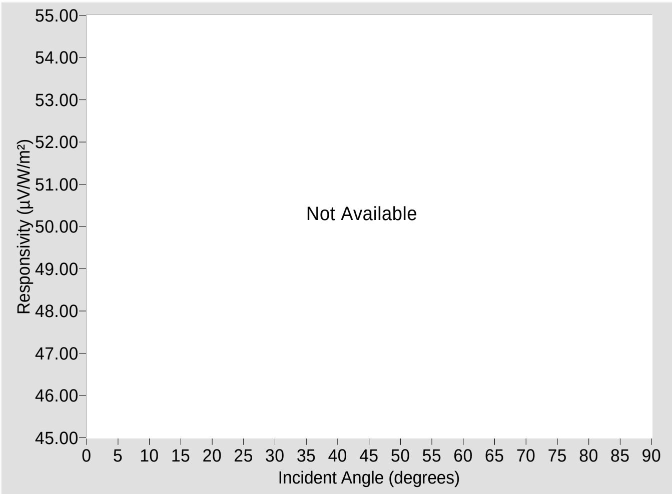


Figure 4. Responsivity vs Local Standard Time

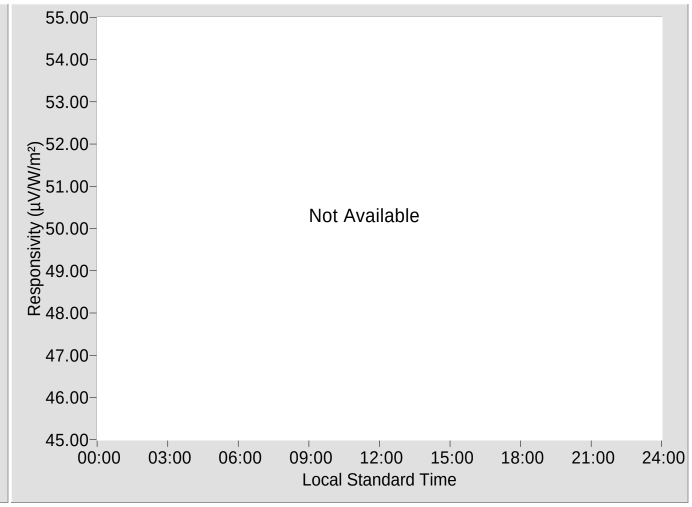


Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

33379 Eppley 8-48

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

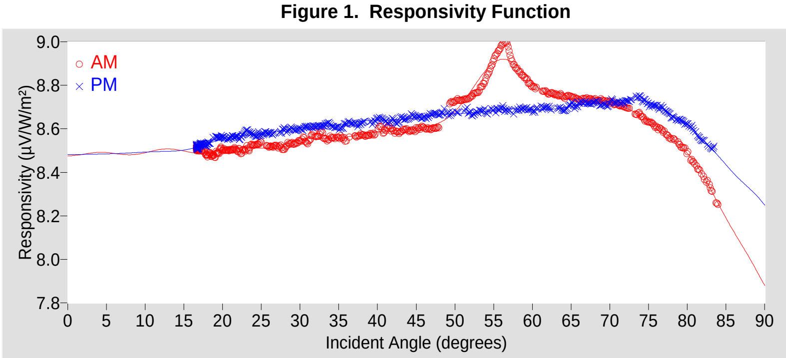
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

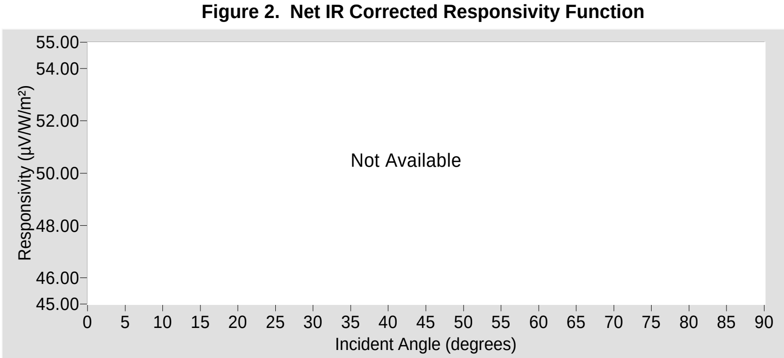


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.48	±1.48
R^2	0.9999970	0.9999996
Valid incidence angle range	16.6° to 84.0°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R^2	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.4844	*	8.4846	*	8.4845	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.4963	*	8.5010	*	8.4986	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.5081	±1.49	8.5633	±1.51	8.5357	±1.67	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.5474	±1.50	8.6064	±1.49	8.5769	±1.71	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.5834	±1.50	8.6383	±1.49	8.6108	±1.64	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.6840	±2.05	8.6669	±1.49	8.6755	±2.62	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.8535	±1.77	8.6879	±1.48	8.7707	±2.47	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.7324	±1.50	8.7137	±1.50	8.7230	±1.54	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.5981	±2.00	8.6878	±1.68	8.6430	±2.73	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.1634	*	8.4184	*	8.2909	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

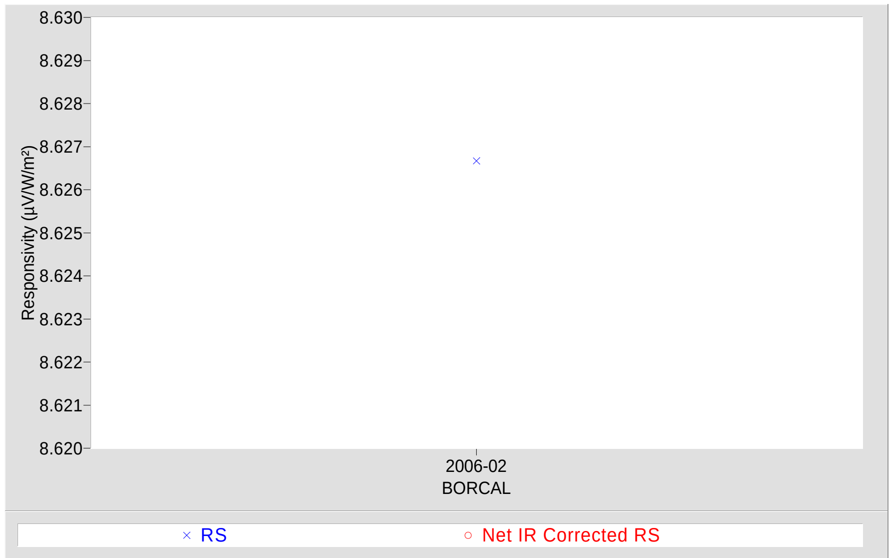
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.6267	+4.85 / -1.64
45° - 55°	8.6911	±2.29
Composite	8.5835	+4.18 / -3.72
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



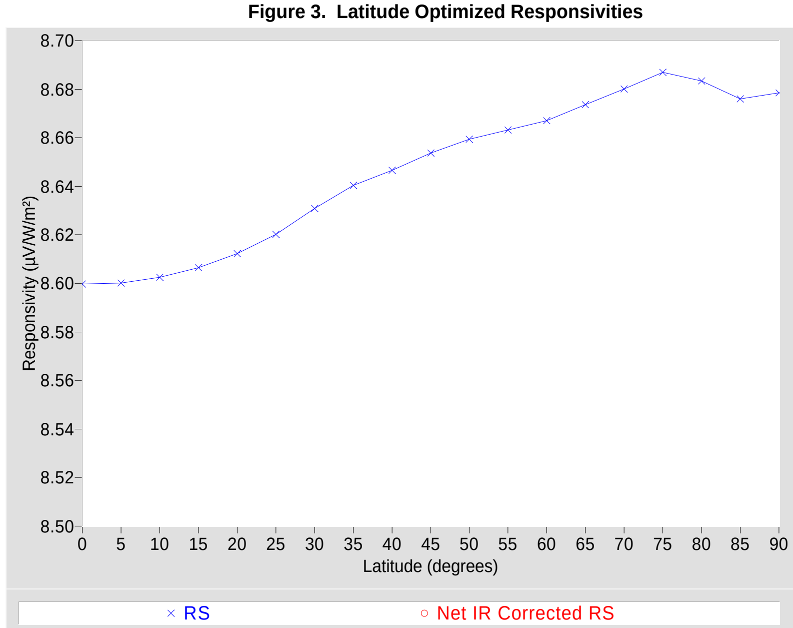
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5997	+4.00 / -7.75	N/A	N/A
5	8.6001	+4.00 / -7.76	N/A	N/A
10	8.6025	+3.97 / -7.78	N/A	N/A
15	8.6065	+3.92 / -7.83	N/A	N/A
20	8.6122	+3.86 / -7.89	N/A	N/A
25	8.6201	+3.77 / -7.97	N/A	N/A
30	8.6309	+3.65 / -8.08	N/A	N/A
35	8.6404	+3.55 / -8.18	N/A	N/A
40	8.6466	+3.48 / -8.25	N/A	N/A
45	8.6537	+3.41 / -8.32	N/A	N/A
50	8.6594	+3.35 / -8.38	N/A	N/A
55	8.6632	+3.30 / -8.42	N/A	N/A
60	8.6670	+3.27 / -8.46	N/A	N/A
65	8.6736	+3.20 / -8.53	N/A	N/A
70	8.6801	+3.13 / -8.60	N/A	N/A
75	8.6869	+3.06 / -8.67	N/A	N/A
80	8.6834	+3.09 / -8.63	N/A	N/A
85	8.6760	+1.92 / -8.55	N/A	N/A
90	8.6785	+1.65 / -8.58	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

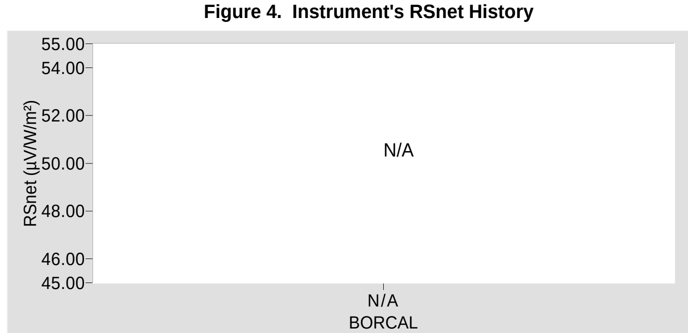
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33785
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:	**Quality Assured by:**
____	____
Ibrahim Reda	Thomas Stoffel
Title: Sr. Scientist II	Title: Group Manager II
Date: _________________	Date: _________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

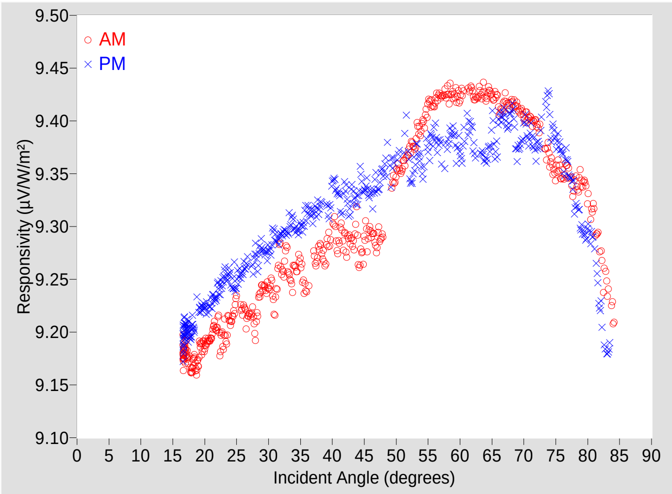

Figure 2. Responsivity vs Local Standard Time

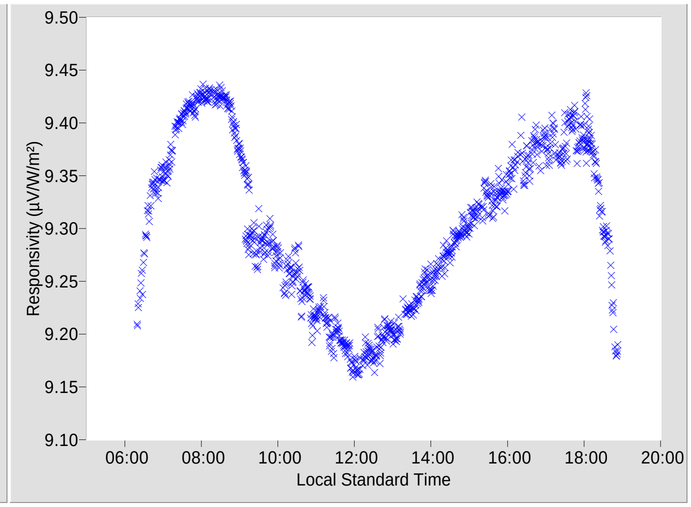

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
9.3097	+1.88 / -1.54	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2951	0.55	97.15	9.3283	0.57	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2931	N/A	95.61	9.3536	0.60	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3490	0.61	101.83	9.3632	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3710	0.63	100.02	9.3553	0.67	267.71
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3950	0.67	98.23	9.3552	0.62	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4159	0.66	96.60	9.3866	0.63	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4242	0.68	94.91	9.3783	0.65	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.4241	0.71	93.37	9.3721	0.67	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.4271	0.74	91.86	9.3818	0.71	274.99
18	9.1663	0.50	154.88	9.2023	0.52	204.45	64	9.4225	0.78	90.33	9.3626	0.73	276.36
20	9.1884	0.48	142.66	9.2238	0.47	217.28	66	9.4151	0.84	88.83	9.3905	0.80	277.72
22	9.2062	0.51	134.56	9.2390	0.50	225.39	68	9.4156	0.88	87.39	9.4102	0.85	279.15
24	9.2106	0.53	128.40	9.2523	0.49	231.41	70	9.4048	0.96	85.89	9.3964	0.88	280.51
26	9.2218	0.48	123.40	9.2590	0.49	236.52	72	9.3973	1.05	84.49	9.3737	0.97	281.88
28	9.2071	0.55	119.26	9.2715	0.51	240.61	74	9.3667	1.17	83.04	9.4110	1.35	278.98
30	9.2431	0.51	115.67	9.2769	0.51	244.21	76	9.3471	1.34	81.61	9.3669	1.49	280.39
32	9.2635	0.55	112.53	9.2924	0.49	247.35	78	9.3408	1.57	80.13	9.3227	1.75	281.85
34	9.2577	0.52	109.83	9.3014	0.51	250.04	80	9.3304	1.88	78.77	9.2961	2.03	283.28
36	9.2412	0.51	107.48	9.3143	0.52	252.63	82	9.2735	2.47	77.20	9.2209	2.58	284.71
38	9.2814	0.51	104.96	9.3192	0.52	254.89	84	9.2178	3.25	75.81	N/A	N/A	N/A
40	9.2974	0.54	102.81	9.3377	0.55	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2824	0.54	100.81	9.3345	0.56	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2840	0.61	98.93	9.3269	0.56	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

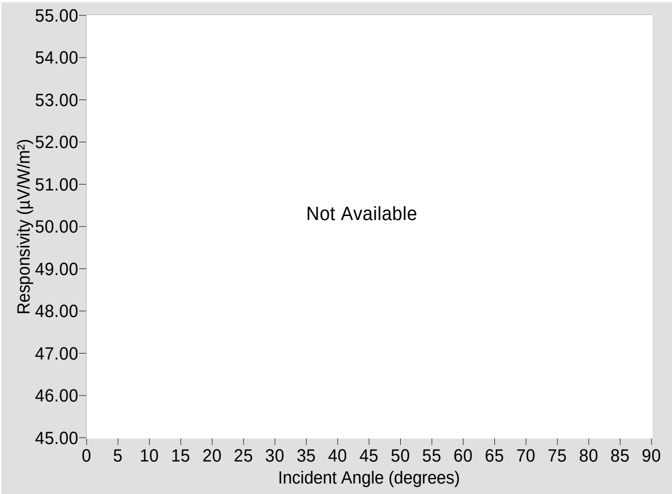

Figure 4. Responsivity vs Local Standard Time

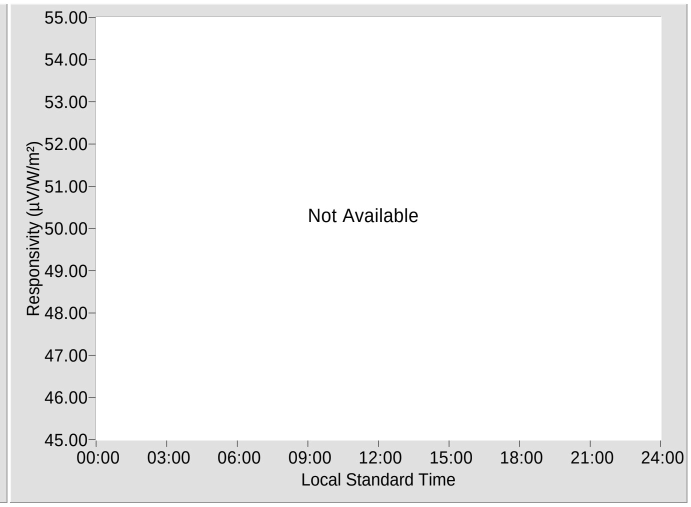

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

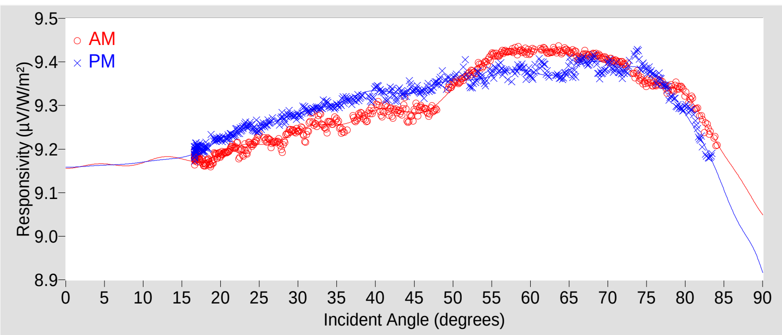
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

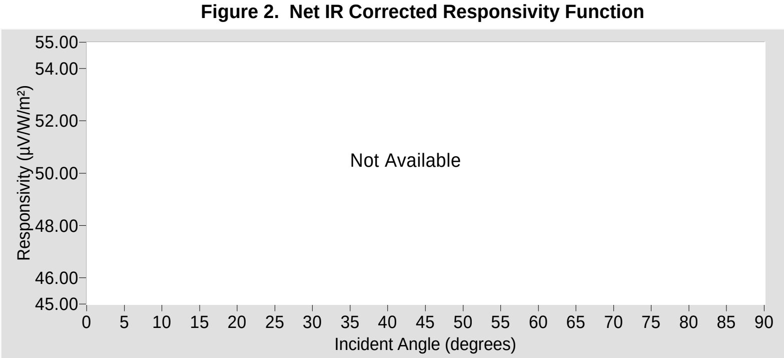


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.41	±1.41
R²	0.9999996	0.9999995
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	9.1620	*	9.1622	*	9.1621	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	9.1751	*	9.1785	*	9.1768	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	9.2000	±1.42	9.2376	±1.44	9.2188	±1.56	N/A	N/A	N/A	N/A	N/A	N/A
27-36	9.2436	±1.42	9.2865	±1.43	9.2650	±1.58	N/A	N/A	N/A	N/A	N/A	N/A
36-45	9.2813	±1.42	9.3277	±1.41	9.3045	±1.53	N/A	N/A	N/A	N/A	N/A	N/A
45-54	9.3304	±1.53	9.3507	±1.42	9.3405	±1.64	N/A	N/A	N/A	N/A	N/A	N/A
54-63	9.4192	±1.42	9.3748	±1.41	9.3970	±1.49	N/A	N/A	N/A	N/A	N/A	N/A
63-72	9.4139	±1.41	9.3902	±1.42	9.4021	±1.47	N/A	N/A	N/A	N/A	N/A	N/A
72-81	9.3525	±1.46	9.3529	±1.55	9.3527	±1.73	N/A	N/A	N/A	N/A	N/A	N/A
81-90	9.1763	*	9.0899	*	9.1331	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

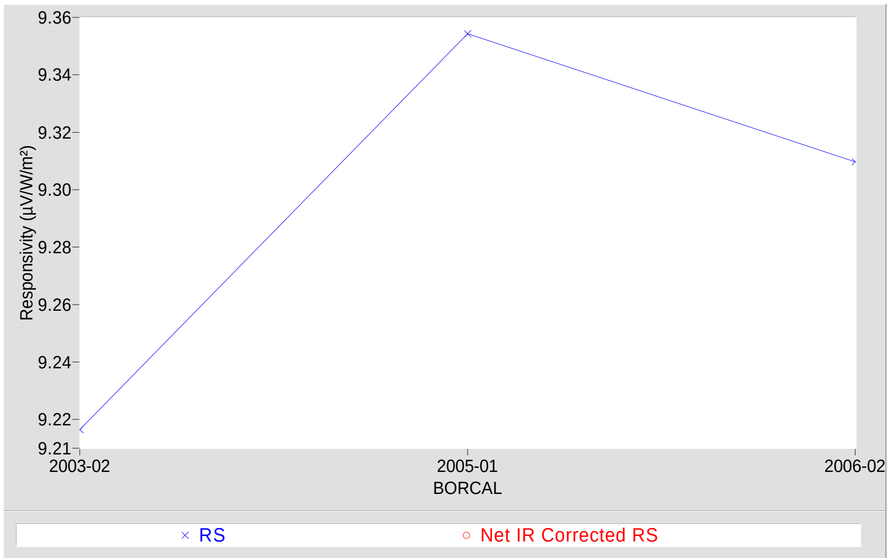
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	9.3097	+1.88 / -1.54
45° - 55°	9.3467	±1.55
Composite	9.2626	+2.28 / -1.85
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



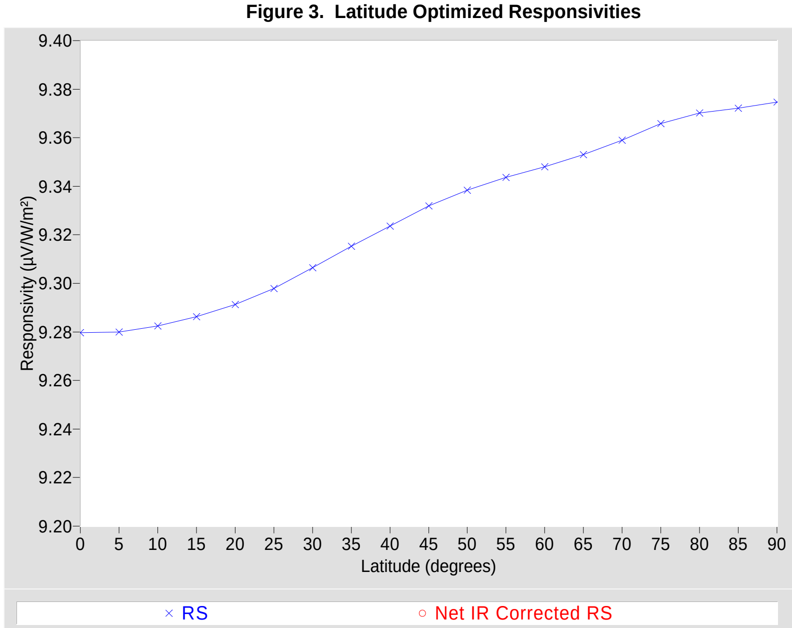
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	9.2797	+2.14 / -3.67	N/A	N/A
5	9.2800	+2.13 / -3.67	N/A	N/A
10	9.2824	+2.11 / -3.70	N/A	N/A
15	9.2862	+2.08 / -3.73	N/A	N/A
20	9.2913	+2.04 / -3.78	N/A	N/A
25	9.2979	+1.99 / -3.85	N/A	N/A
30	9.3064	+1.93 / -3.93	N/A	N/A
35	9.3153	+1.86 / -4.01	N/A	N/A
40	9.3236	+1.80 / -4.09	N/A	N/A
45	9.3320	+1.75 / -4.18	N/A	N/A
50	9.3384	+1.71 / -4.24	N/A	N/A
55	9.3437	+1.68 / -4.29	N/A	N/A
60	9.3480	+1.65 / -4.33	N/A	N/A
65	9.3530	+1.62 / -4.38	N/A	N/A
70	9.3590	+1.59 / -4.44	N/A	N/A
75	9.3658	+1.56 / -4.50	N/A	N/A
80	9.3702	+1.54 / -4.55	N/A	N/A
85	9.3722	+1.53 / -4.57	N/A	N/A
90	9.3746	+1.47 / -4.59	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

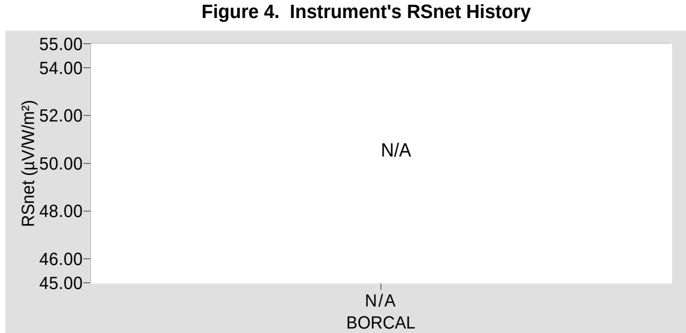
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 33787

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

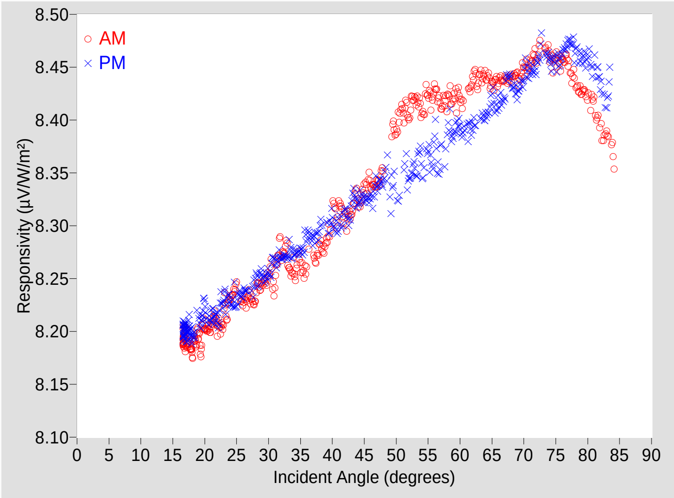

Figure 2. Responsivity vs Local Standard Time

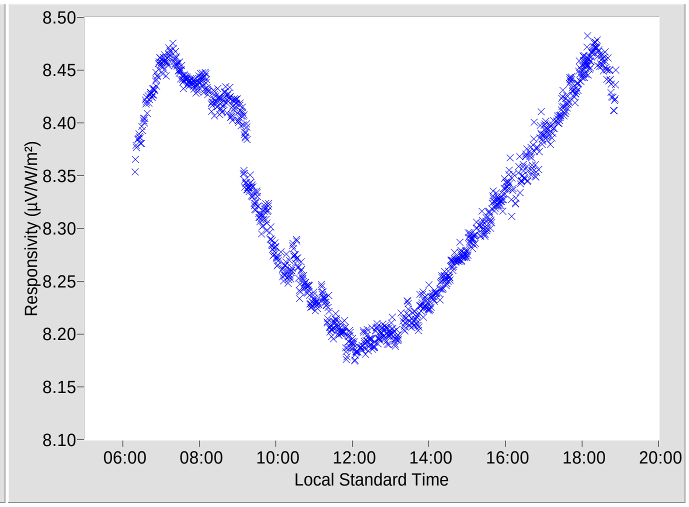

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.3300	+1.79 / -1.69	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3408	0.55	97.15	8.3243	0.58	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3548	N/A	95.61	8.3431	0.59	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3882	0.63	101.83	8.3240	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4039	0.64	100.02	8.3423	0.61	267.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4076	0.67	98.23	8.3560	0.62	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4273	0.68	96.60	8.3783	0.68	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4204	0.70	94.91	8.3867	0.70	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4220	0.72	93.37	8.3935	0.66	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4381	0.75	91.86	8.3943	0.69	274.99
18	8.1834	0.49	154.88	8.1963	0.50	204.45	64	8.4411	0.79	90.33	8.4029	0.73	276.36
20	8.2049	0.51	142.66	8.2217	0.50	217.28	66	8.4371	0.84	88.83	8.4152	0.77	277.72
22	8.2065	0.49	134.56	8.2104	0.52	225.39	68	8.4398	0.89	87.39	8.4356	0.82	279.15
24	8.2313	0.52	128.40	8.2300	0.51	231.41	70	8.4490	0.98	85.89	8.4441	0.90	280.51
26	8.2290	0.48	123.40	8.2359	0.49	236.52	72	8.4595	1.06	84.49	8.4519	0.98	281.88
28	8.2352	0.49	119.26	8.2489	0.50	240.61	74	8.4620	1.18	83.04	8.4579	1.35	278.98
30	8.2552	0.52	115.67	8.2545	0.50	244.21	76	8.4550	1.36	81.61	8.4611	1.51	280.39
32	8.2757	0.53	112.53	8.2697	0.50	247.35	78	8.4374	1.60	80.13	8.4664	1.76	281.85
34	8.2558	0.51	109.83	8.2734	0.51	250.04	80	8.4222	1.91	78.77	8.4614	2.06	283.28
36	8.2592	0.52	107.48	8.2898	0.52	252.63	82	8.3900	2.51	77.20	8.4343	2.58	284.71
38	8.2809	0.51	104.96	8.2960	0.53	254.89	84	8.3686	3.32	75.81	N/A	N/A	N/A
40	8.3137	0.56	102.81	8.3051	0.54	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3049	0.54	100.81	8.3133	0.55	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3256	0.55	98.93	8.3210	0.55	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

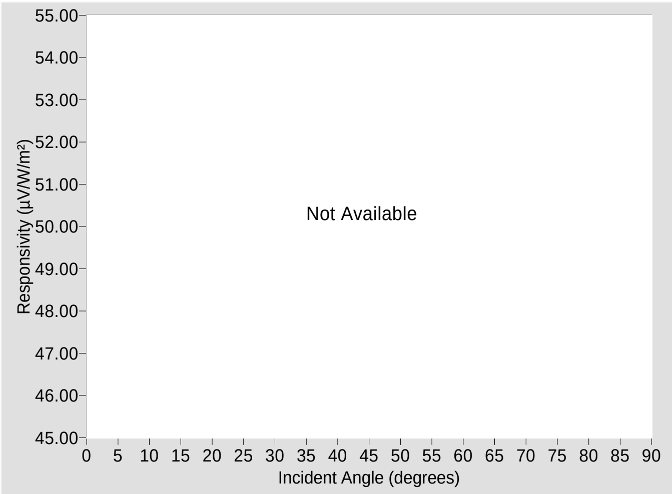

Figure 4. Responsivity vs Local Standard Time

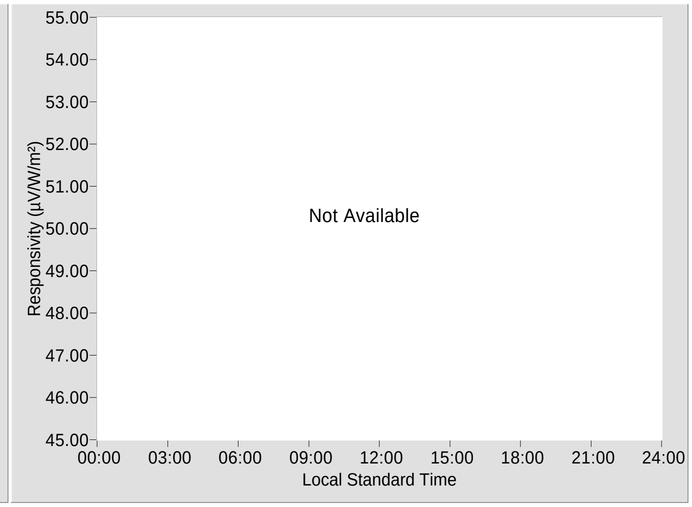

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

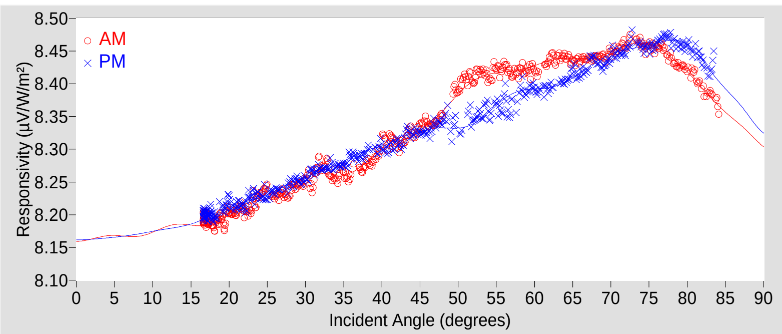
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

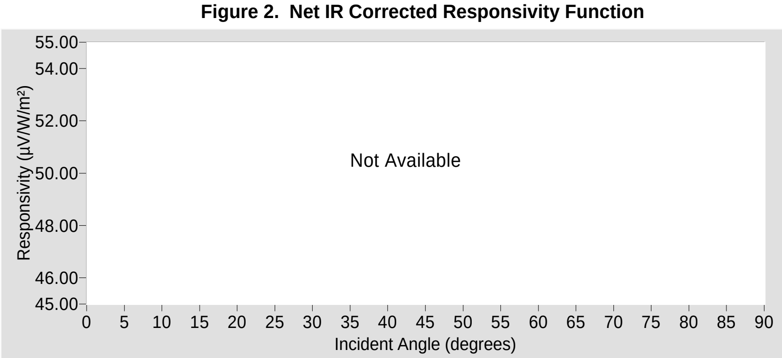


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.42	±1.42
R²	0.9999997	0.9999998
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity						Net IR Corr. Responsivity					
	AM		PM		Combined		AM		PM		Combined	
	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)	RSc (µV/W/m²)	U95 (%)
0-9	8.1653	*	8.1654	*	8.1654	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.1811	*	8.1827	*	8.1819	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.2125	±1.45	8.2201	±1.44	8.2163	±1.49	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.2559	±1.43	8.2632	±1.45	8.2595	±1.49	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.2997	±1.47	8.3058	±1.44	8.3027	±1.52	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.3733	±1.51	8.3349	±1.43	8.3541	±1.62	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.4239	±1.43	8.3839	±1.44	8.4039	±1.58	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.4429	±1.43	8.4259	±1.46	8.4344	±1.51	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.4468	±1.45	8.4602	±1.42	8.4535	±1.51	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.3530	*	8.3865	*	8.3697	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

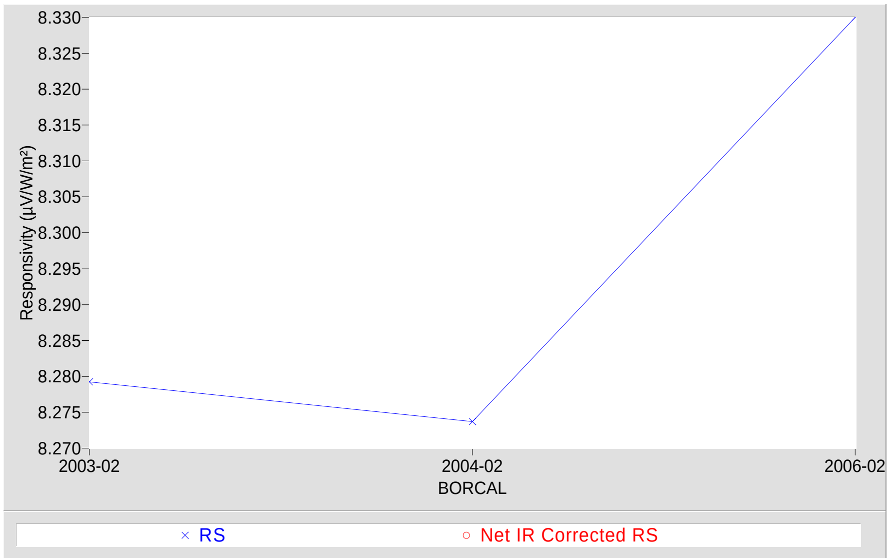
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.3300	+1.79 / -1.69
45° - 55°	8.3591	±1.52
Composite	8.2726	+2.74 / -1.78
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



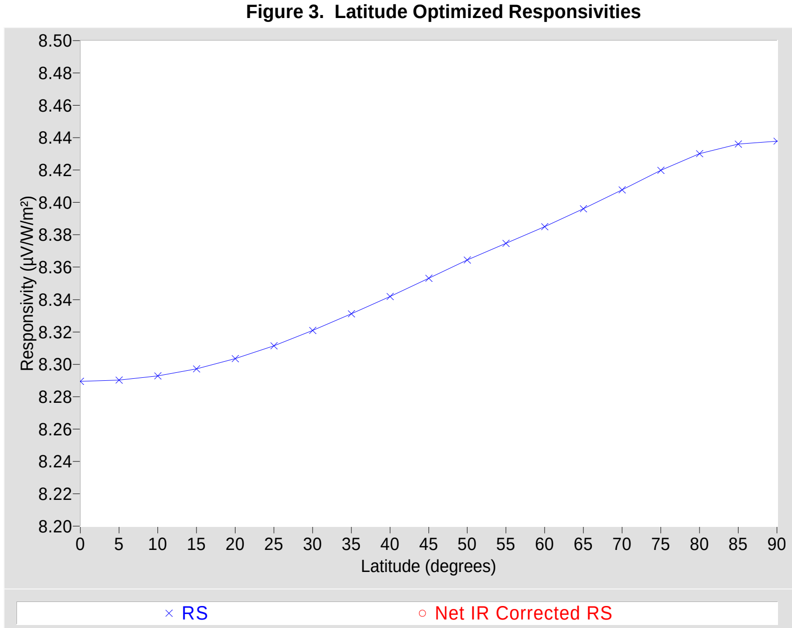
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.2895	+2.57 / -2.12	N/A	N/A
5	8.2902	+2.56 / -2.12	N/A	N/A
10	8.2928	+2.53 / -2.15	N/A	N/A
15	8.2972	+2.49 / -2.19	N/A	N/A
20	8.3036	+2.43 / -2.24	N/A	N/A
25	8.3115	+2.35 / -2.31	N/A	N/A
30	8.3209	+2.26 / -2.34	N/A	N/A
35	8.3312	+2.16 / -2.34	N/A	N/A
40	8.3419	+2.07 / -2.38	N/A	N/A
45	8.3532	+1.97 / -2.23	N/A	N/A
50	8.3644	+1.88 / -2.16	N/A	N/A
55	8.3747	+1.80 / -1.97	N/A	N/A
60	8.3849	+1.72 / -2.02	N/A	N/A
65	8.3960	+1.65 / -1.77	N/A	N/A
70	8.4077	+1.59 / -1.80	N/A	N/A
75	8.4199	+1.53 / -1.90	N/A	N/A
80	8.4301	+1.49 / -1.98	N/A	N/A
85	8.4361	+1.47 / -2.03	N/A	N/A
90	8.4379	+1.46 / -2.04	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

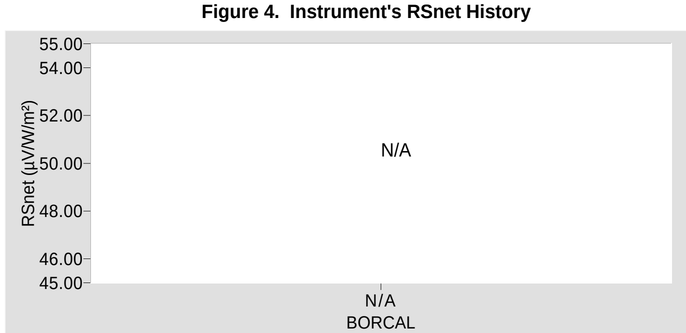
Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33788
Calibration Date:	8/12/2006	**Due Date:**	8/12/2007
Customer:	SGP	**Calibration Site Parameters:**	see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 4

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.
[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____
Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____
Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

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Figure 1. Responsivity vs Incident Angle

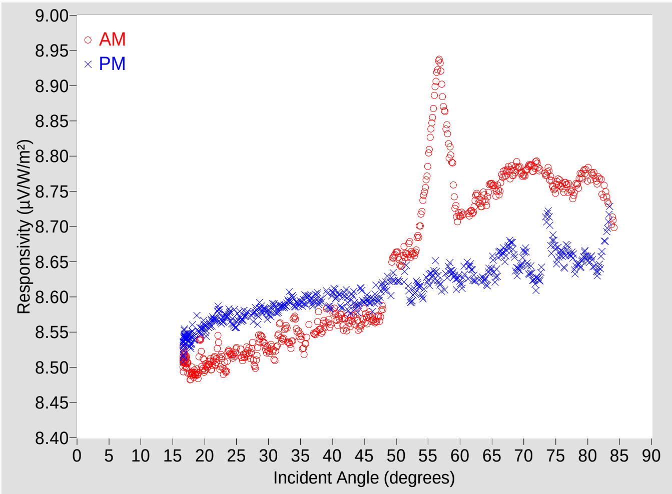

Figure 2. Responsivity vs Local Standard Time

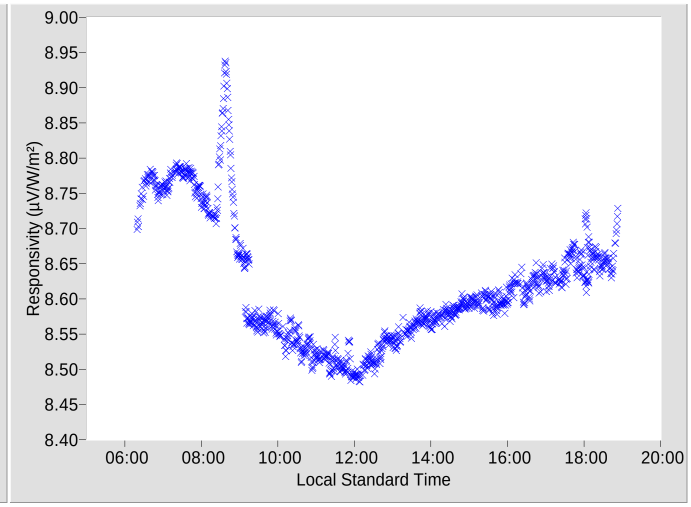

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.5827	+4.67 / -1.38	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration = -1.0000 W/m²

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (µV/W/m²)	AM U95 ± (%)	AM Azm. Angle‡	PM RS (µV/W/m²)	PM U95 ± (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5715	0.54	97.15	8.5908	0.59	262.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5878	N/A	95.61	8.6151	0.59	264.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6628	0.62	101.83	8.6219	N/A	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6655	0.64	100.02	8.6030	0.65	267.71
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7243	0.95	98.23	8.6040	0.62	269.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8829	1.00	96.60	8.6366	0.64	270.71
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8259	1.14	94.91	8.6351	0.66	272.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7170	0.74	93.37	8.6223	0.68	273.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7225	0.76	91.86	8.6307	0.70	274.99
18	8.4907	0.50	154.88	8.5418	0.54	204.45	64	8.7373	0.81	90.33	8.6214	0.73	276.36
20	8.5021	0.54	142.66	8.5563	0.49	217.28	66	8.7512	0.86	88.83	8.6506	0.81	277.72
22	8.5207	0.57	134.56	8.5775	0.50	225.39	68	8.7773	0.90	87.39	8.6760	0.86	279.15
24	8.5203	0.51	128.40	8.5736	0.50	231.41	70	8.7739	0.97	85.89	8.6638	0.90	280.51
26	8.5142	0.48	123.40	8.5711	0.48	236.52	72	8.7886	1.05	84.49	8.6215	0.98	281.88
28	8.5098	0.55	119.26	8.5764	0.51	240.61	74	8.7751	1.18	83.04	8.7028	1.38	278.98
30	8.5242	0.52	115.67	8.5755	0.50	244.21	76	8.7554	1.35	81.61	8.6579	1.50	280.39
32	8.5444	0.53	112.53	8.5864	0.50	247.35	78	8.7531	1.59	80.13	8.6449	1.76	281.85
34	8.5637	0.55	109.83	8.5921	0.51	250.04	80	8.7766	1.89	78.77	8.6530	2.05	283.28
36	8.5367	0.55	107.48	8.5982	0.51	252.63	82	8.7605	2.49	77.20	8.6501	2.58	284.71
38	8.5605	0.53	104.96	8.5959	0.52	254.89	84	8.7061	3.29	75.81	N/A	N/A	N/A
40	8.5726	0.53	102.81	8.6019	0.54	257.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5599	0.53	100.81	8.6034	0.56	259.12	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5656	0.56	98.93	8.5859	0.57	260.93	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Effective Net Infrared Corrected Calibration Results

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Figure 3. Responsivity vs Incident Angle

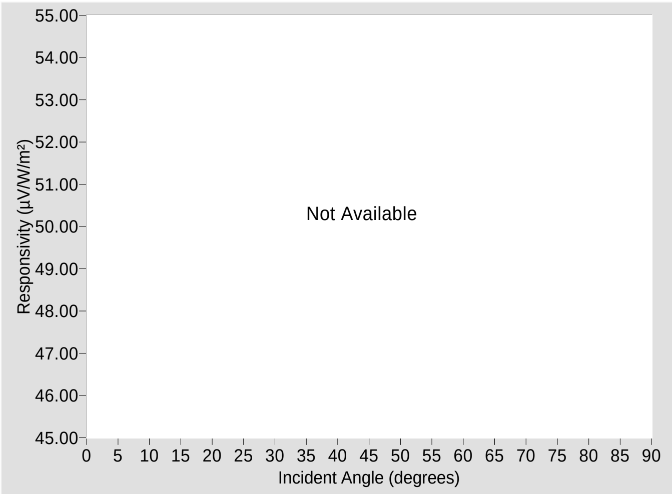

Figure 4. Responsivity vs Local Standard Time

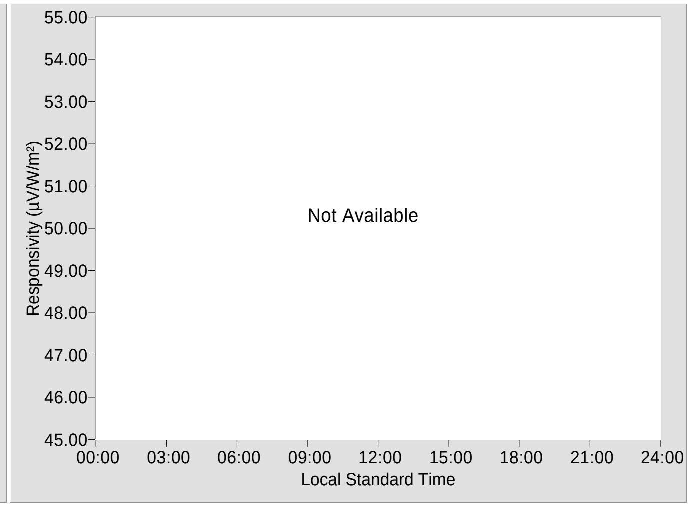

Table 4. Net IR Corrected Calibration Label Values

RSc @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
N/A	N/A	0.0° / 0.0°

† Valid incident angle range: N/A

‡ RSnet = N/A

Table 5. Net IR Corrected Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RSc (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	48	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	54	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	N/A	N/A	N/A	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	N/A	N/A	N/A	N/A	N/A	N/A
34	N/A	N/A	N/A	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	N/A	N/A	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	N/A	N/A	N/A	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox et al., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Computing the net infrared corrected solar irradiance is documented in "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error during Outdoor Calibration using the Component Sum Method," Reda et al., Journal of Atmospheric and Oceanic Technology V. 22 (10), pp. 1531-1540, October 2005.

In all cases, the solar irradiance is calculated from the instrument responsivity using one of these equations:

$$IRR = V / RS \quad [1]$$

$$IRR\ (corr.) = (V - Wnet * RSnet) / RSc \quad [2]$$

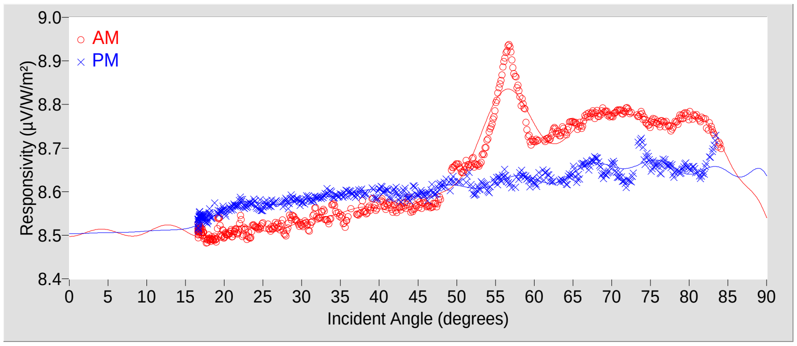
where,

IRR = solar irradiance (Watts per square meter),
V = radiometer output voltage (microvolts),
RS = responsivity of the radiometer (µV/W/m²),
IRR (corr.) = effective net infrared corrected solar irradiance (W/m²),
Wnet = effective net infrared measured by pyrgeometer (W/m²),
RSnet = pyranometer net infrared response (µV/W/m²), see Table 4,
RSc = effective net infrared corrected responsivity (µV/W/m²).

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3 or 5. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

Figure 1. Responsivity Function



$$RS\ (am) = \sum_{i=0}^{n} a_i \cdot \cos^i(I)$$

$$RS\ (pm) = \sum_{j=0}^{m} b_j \cdot \cos^j(I) \quad [3]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1 and 2.

Figure 2. Net IR Corrected Responsivity Function

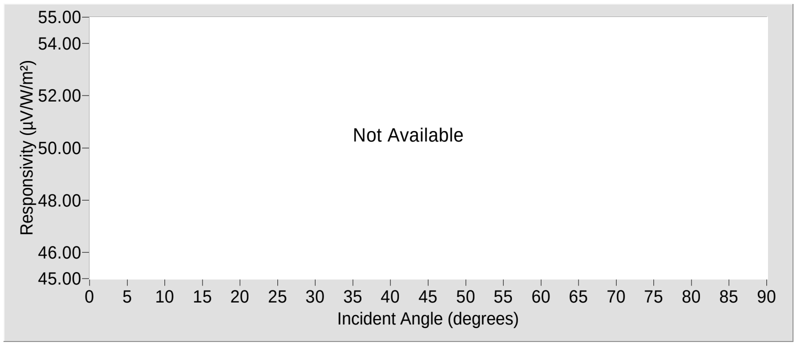


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.47	±1.47
R²	0.9999968	0.9999989
Valid incidence angle range	16.6° to 84.1°	16.6° to 83.4°
Net IR corr. uncert. U95 (%)	N/A	N/A
Net IR corrected R²	N/A	N/A
Corr. valid inc. angle range	N/A	N/A

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc. Angle	Responsivity AM RS (µV/W/m²)	AM U95 (%)	PM RS (µV/W/m²)	PM U95 (%)	Combined RS (µV/W/m²)	Combined U95 (%)	Net IR Corr. Responsivity AM RSc (µV/W/m²)	AM U95 (%)	PM RSc (µV/W/m²)	PM U95 (%)	Combined RSc (µV/W/m²)	Combined U95 (%)
0-9	8.5051	*	8.5054	*	8.5053	*	N/A	N/A	N/A	N/A	N/A	N/A
9-18	8.5097	*	8.5147	*	8.5122	*	N/A	N/A	N/A	N/A	N/A	N/A
18-27	8.5113	±1.48	8.5662	±1.49	8.5388	±1.62	N/A	N/A	N/A	N/A	N/A	N/A
27-36	8.5344	±1.49	8.5828	±1.47	8.5586	±1.62	N/A	N/A	N/A	N/A	N/A	N/A
36-45	8.5615	±1.47	8.5973	±1.47	8.5794	±1.52	N/A	N/A	N/A	N/A	N/A	N/A
45-54	8.6304	±1.78	8.6076	±1.47	8.6190	±2.16	N/A	N/A	N/A	N/A	N/A	N/A
54-63	8.7818	±1.63	8.6261	±1.48	8.7040	±2.36	N/A	N/A	N/A	N/A	N/A	N/A
63-72	8.7602	±1.52	8.6511	±1.49	8.7056	±1.97	N/A	N/A	N/A	N/A	N/A	N/A
72-81	8.7663	±1.47	8.6582	±1.48	8.7122	±1.85	N/A	N/A	N/A	N/A	N/A	N/A
81-90	8.6657	*	8.6464	*	8.6561	*	N/A	N/A	N/A	N/A	N/A	N/A

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities: See Note 1 below.

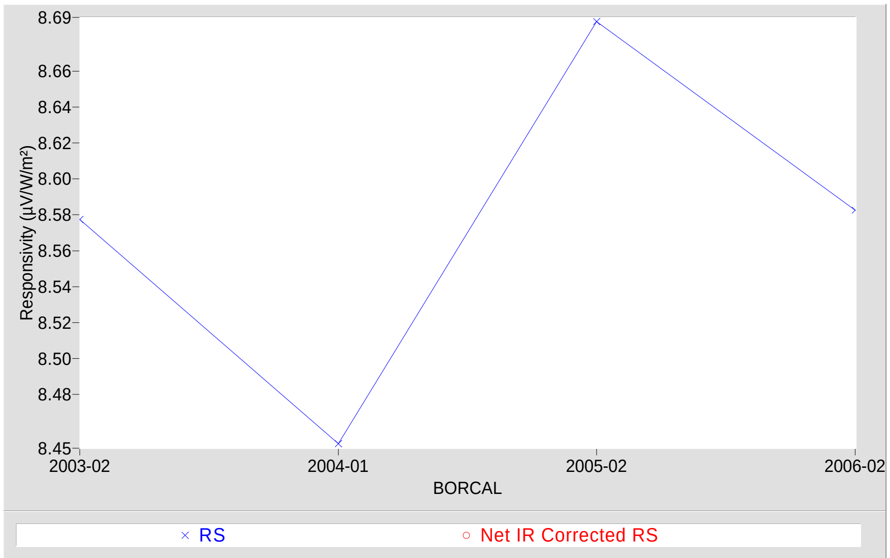
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 † (%)
45°	8.5827	+4.67 / -1.38
45° - 55°	8.6309	±2.00
Composite	8.5770	+3.35 / -1.76
45° (Net IR Corr.)	N/A	N/A
45° - 55° (Net IR Corr.)	N/A	N/A
Composite (Net IR Corr.)	N/A	N/A

† Valid incident angle ranges:
45°: 30.0° to 60.0°
45° - 55°: 45.0° to 55.0°
Composite: 16.6° to 83.4°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



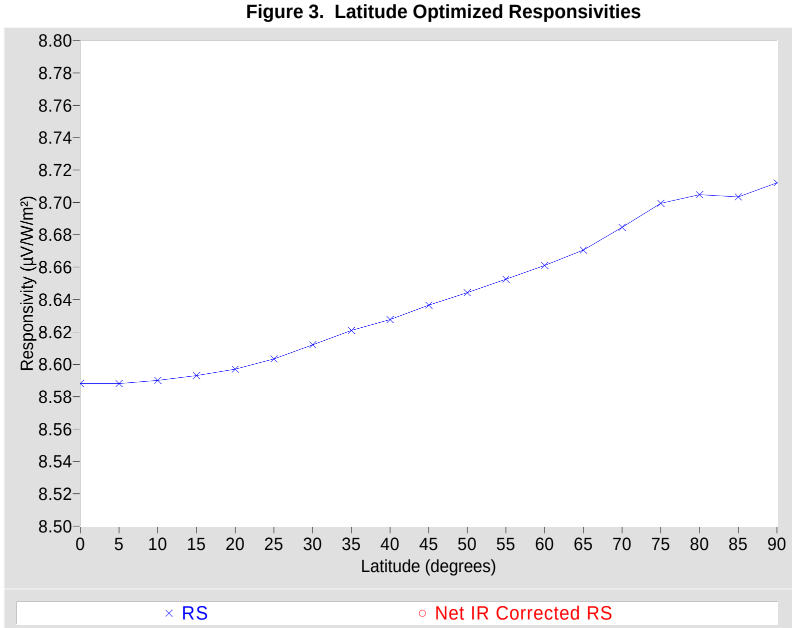
5. Latitude Optimized Responsivity: See Note 1 below.

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate* (%)	RSc (µV/W/m²) Net IR Corr.	Error estimate* (%) Net IR Corr.
0	8.5881	+3.22 / -1.83	N/A	N/A
5	8.5880	+3.22 / -1.83	N/A	N/A
10	8.5899	+3.20 / -1.84	N/A	N/A
15	8.5930	+3.17 / -1.86	N/A	N/A
20	8.5970	+3.13 / -1.89	N/A	N/A
25	8.6033	+3.06 / -1.94	N/A	N/A
30	8.6119	+2.97 / -2.01	N/A	N/A
35	8.6209	+2.88 / -2.08	N/A	N/A
40	8.6276	+2.81 / -2.13	N/A	N/A
45	8.6365	+2.72 / -2.09	N/A	N/A
50	8.6442	+2.64 / -2.15	N/A	N/A
55	8.6525	+2.56 / -1.99	N/A	N/A
60	8.6611	+2.48 / -1.90	N/A	N/A
65	8.6706	+2.39 / -1.97	N/A	N/A
70	8.6847	+2.26 / -1.91	N/A	N/A
75	8.6995	+2.13 / -2.02	N/A	N/A
80	8.7049	+2.09 / -2.06	N/A	N/A
85	8.7034	+1.73 / -2.05	N/A	N/A
90	8.7122	+1.68 / -2.12	N/A	N/A

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

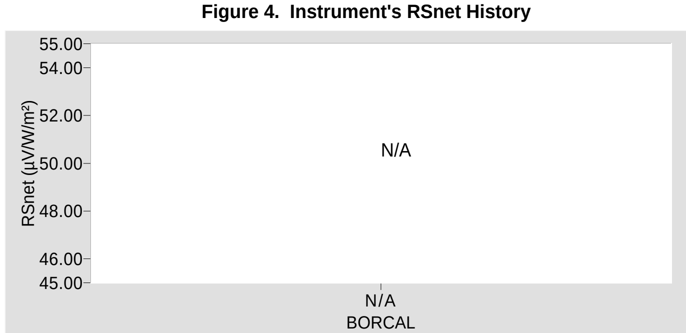
Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Instrument's Effective Net Infrared History (RSnet):

Figure 4. Instrument's RSnet History



Note 1:

All above methods, in conjunction with knowledge of the net infrared and sky irradiance distribution, may be used to determine the effective instrument responsivity with less uncertainties.

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 34507E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: SGP

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

34507E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

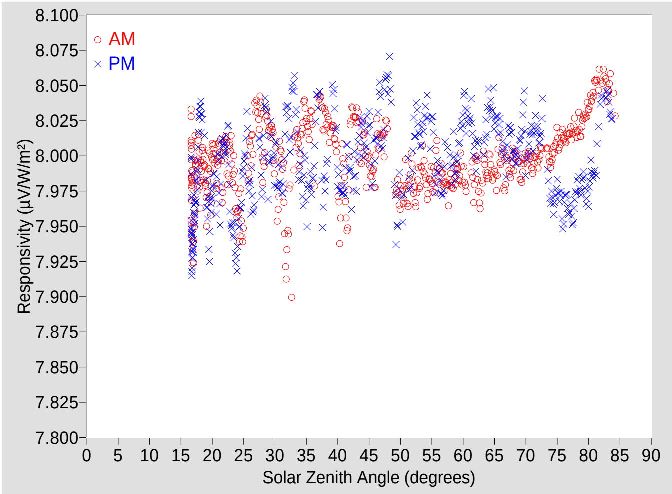


Figure 2. Responsivity vs Local Standard Time

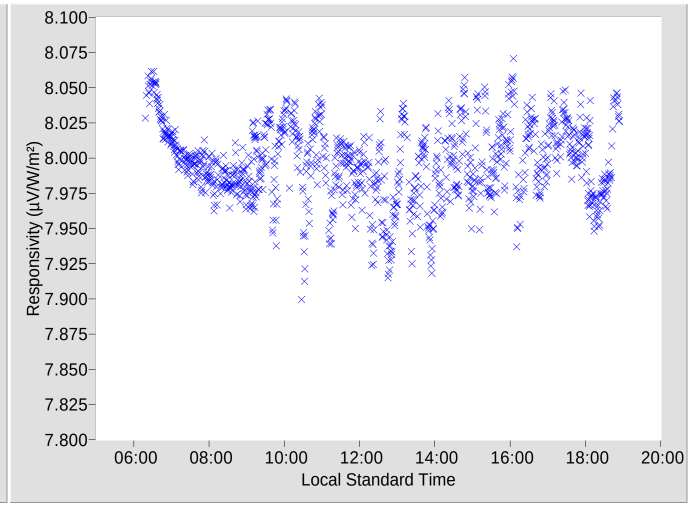


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.0058	+1.18 / -1.70	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9946	0.48	97.17	8.0083	0.60	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0247	N/A	95.63	8.0570	0.55	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9695	0.44	101.85	7.9794	0.49	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9861	0.45	100.05	8.0087	0.54	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9834	0.45	98.25	8.0335	0.44	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9913	0.44	96.57	7.9918	0.51	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9817	0.42	94.93	7.9917	0.44	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9854	0.42	93.39	8.0327	0.49	273.54
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9935	0.45	91.83	8.0012	0.50	274.96
18	7.9929	0.68	155.21	8.0238	0.66	204.54	64	7.9920	0.41	90.30	8.0328	0.48	276.38
20	7.9913	0.52	142.74	7.9738	0.60	217.16	66	8.0017	0.45	88.84	8.0156	0.47	277.74
22	8.0071	0.47	134.46	8.0071	0.58	225.29	68	7.9983	0.41	87.37	8.0012	0.42	279.13
24	7.9623	0.60	128.46	7.9350	0.59	231.46	70	7.9981	0.41	85.91	8.0094	0.54	280.48
26	7.9992	0.51	123.44	7.9781	0.59	236.44	72	7.9973	0.41	84.51	8.0141	0.45	281.90
28	8.0060	0.53	119.30	7.9971	0.58	240.65	74	7.9964	0.44	83.01	7.9704	0.46	278.99
30	7.9962	0.56	115.80	7.9957	0.47	244.25	76	8.0132	0.42	81.63	7.9590	0.46	280.40
32	7.9428	0.72	112.57	8.0290	0.61	247.30	78	8.0184	0.44	80.15	7.9749	0.50	281.82
34	8.0068	0.48	109.86	7.9905	0.69	250.07	80	8.0348	0.48	78.71	7.9738	0.53	283.25
36	8.0269	0.50	107.43	7.9822	0.69	252.59	82	8.0557	0.51	77.28	8.0402	0.67	284.72
38	8.0261	0.42	104.98	7.9804	0.71	254.92	84	8.0365	0.61	75.67	8.0263	N/A	286.03
40	7.9804	0.64	102.79	7.9905	0.61	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0114	0.66	100.84	7.9831	0.47	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0132	0.51	98.89	8.0151	0.42	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

34507E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

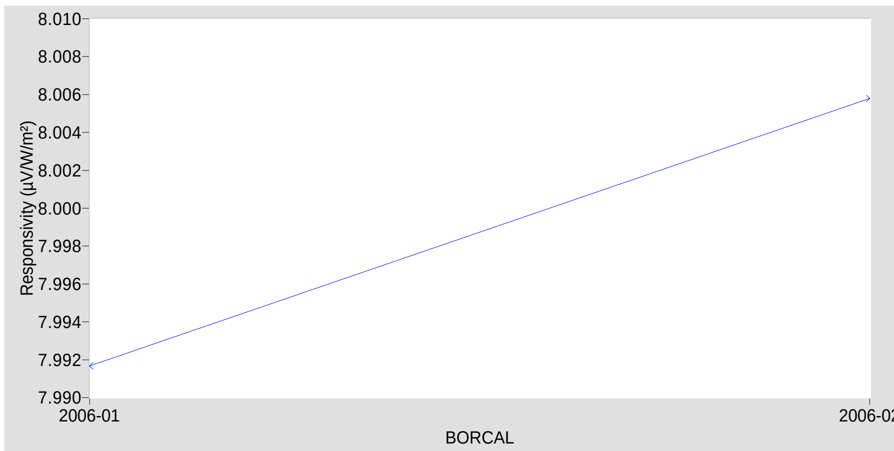
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0058	+1.18 / -1.70 †
Average	8.0003	+1.27 / -1.43 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 34546E6

Calibration Date: 8/12/2006

Due Date: 8/12/2007

Customer: AMF

Calibration Site Parameters: see Ancillary Data

Environmental Conditions: Outdoors, under natural sunlight (see Ancillary Data)

Data Acquisition Dates: 7/23, 8/6, 8/12

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	10/01/2004	10/01/2006
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	06/13/2005	06/13/2007
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	06/13/2005	06/13/2007
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/23/2006	03/23/2007

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure:

[1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME.

[2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb and Rod Soper

Certified by:

____

Ibrahim Reda

Title: Sr. Scientist II

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Group Manager II

Date: __________________

Calibration Results

34546E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

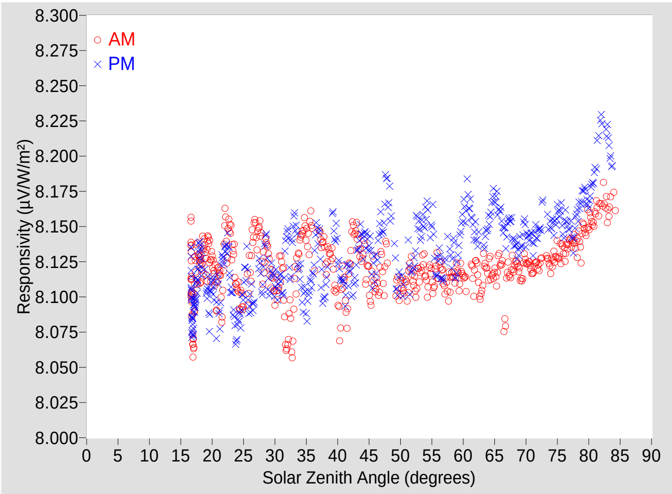


Figure 2. Responsivity vs Local Standard Time

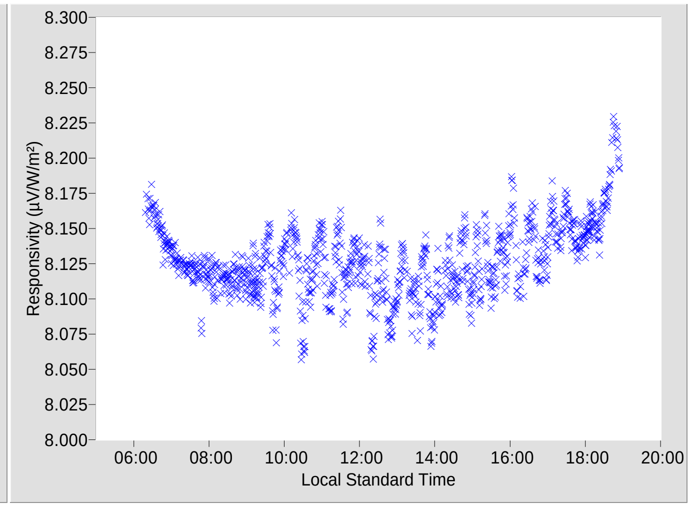


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²) ‡	U95 (%) †	Tilt / Azm
8.1238	+1.15 / -1.20	N/A

† Valid zenith angle range: 30.0° to 60.0°

‡ Estimated thermal offset error during calibration is unspecified.

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1087	0.44	97.17	8.1216	0.50	262.75
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1378	N/A	95.63	8.1754	0.45	264.46
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1043	0.39	101.85	8.1164	0.44	266.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1158	0.42	100.05	8.1220	0.51	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1144	0.42	98.25	8.1590	0.41	269.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1206	0.42	96.57	8.1262	0.50	270.68
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1134	0.41	94.93	8.1279	0.42	272.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1155	0.40	93.39	8.1596	0.52	273.54
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1236	0.42	91.83	8.1451	0.43	274.96
18	8.1250	0.61	155.21	8.1290	0.48	204.54	64	8.1212	0.41	90.30	8.1524	0.46	276.38
20	8.1235	0.49	142.74	8.1075	0.46	217.16	66	8.1251	0.51	88.84	8.1580	0.45	277.74
22	8.1444	0.62	134.46	8.1313	0.56	225.29	68	8.1222	0.40	87.37	8.1399	0.42	279.13
24	8.1073	0.52	128.46	8.0753	0.45	231.46	70	8.1257	0.41	85.91	8.1460	0.40	280.48
26	8.1140	0.53	123.44	8.0966	0.47	236.44	72	8.1219	0.40	84.51	8.1468	0.46	281.90
28	8.1287	0.46	119.30	8.1149	0.45	240.65	74	8.1228	0.42	83.01	8.1517	0.44	278.99
30	8.1043	0.43	115.70	8.1098	0.40	244.25	76	8.1329	0.42	81.63	8.1507	0.45	280.40
32	8.0698	0.56	112.57	8.1401	0.48	247.30	78	8.1365	0.45	80.15	8.1567	0.53	281.82
34	8.1377	0.54	109.86	8.1165	0.57	250.07	80	8.1548	0.46	78.71	8.1676	0.51	283.25
36	8.1497	0.45	107.43	8.1148	0.57	252.59	82	8.1657	0.52	77.28	8.2259	0.60	284.72
38	8.1294	0.42	104.98	8.1043	0.49	254.92	84	8.1678	0.59	75.67	8.1932	N/A	286.03
40	8.0977	0.55	102.79	8.1326	0.48	257.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1287	0.60	100.84	8.1149	0.41	259.08	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1322	0.46	98.89	8.1406	0.40	260.96	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

34546E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \quad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

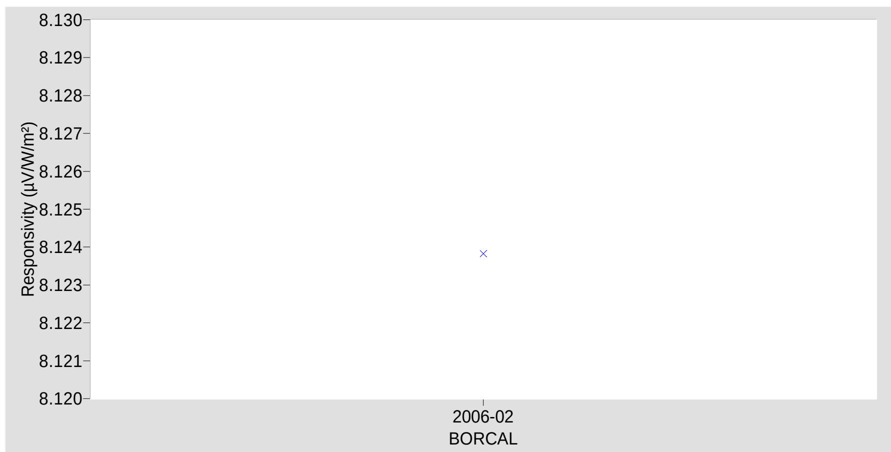
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1238	+1.15 / -1.20 †
Average	8.1311	+1.77 / -1.31 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 16.6° to 83.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

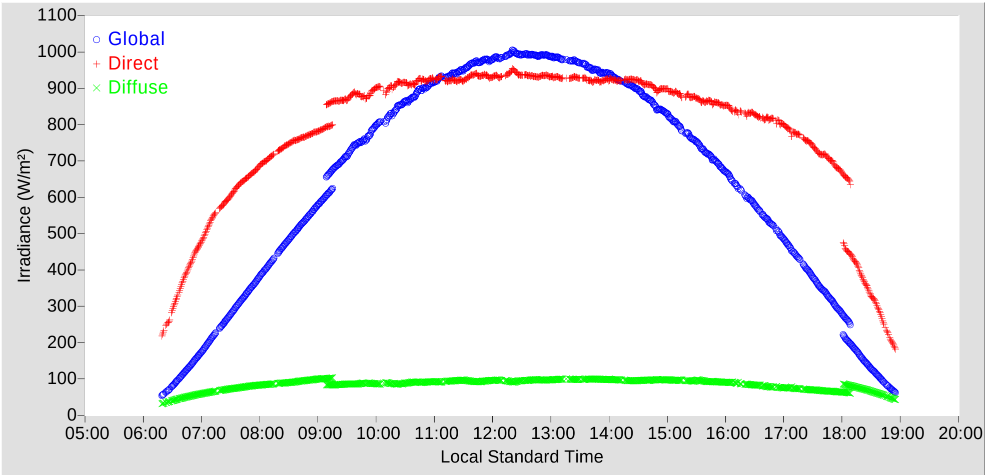
Ancillary Data for BORCAL 2006-02

Calibration Facility: Southern Great Plains

Latitude: 36.605°N | Longitude: 97.488°W | Elevation: 317.0 meters AMSL | Time Zone: -6.0

Reference Irradiance: 0.0° / 0.0° Tilt / Azm

Figure 1. Reference Irradiance



The reference global irradiance (G) is calculated using: G = B * Cos (I) + D, where I is the refraction-corrected solar incidence angle.

Meteorological Observations:

Figure 2. Temperature

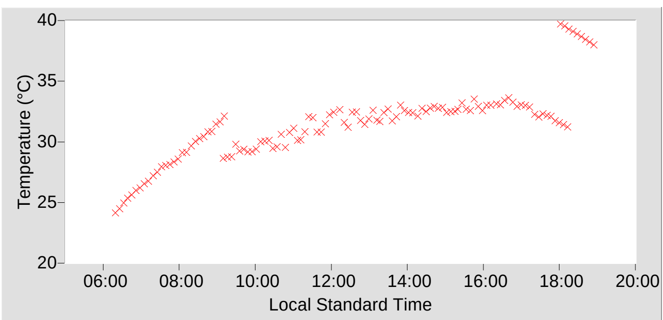


Figure 3. Humidity

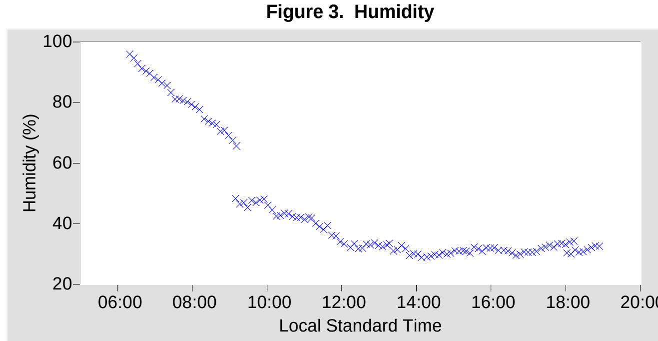


Figure 4. Pressure

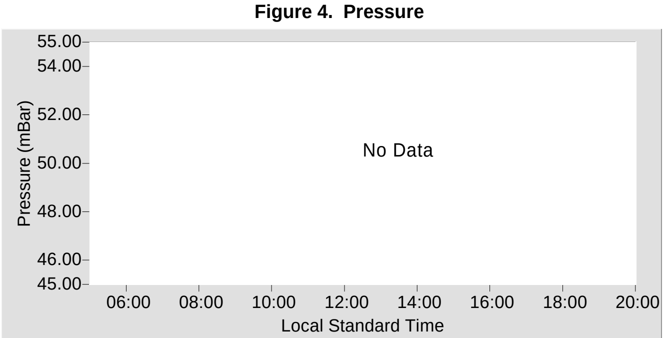


Figure 5. Effective Net Infrared

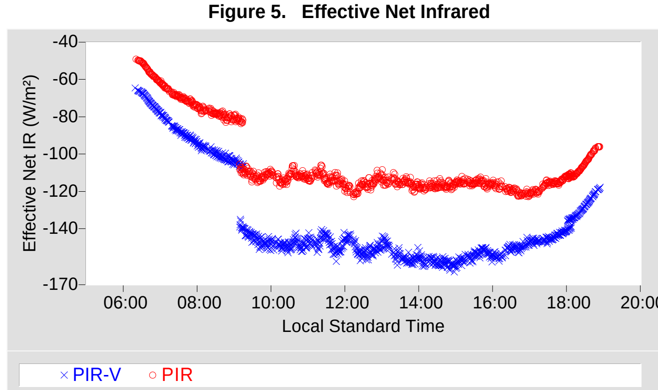


Figure 6. Estimated Broadband Aerosol Optical Depth

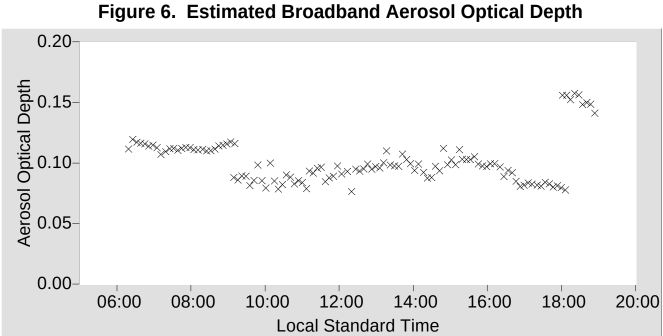


Table 1. Meteorological Observations

Observations	Mean
Temperature (°C)	31.47
Humidity (%)	45.13
Pressure (mBar)	N/A
Est. Aerosol Optical Depth (BB)	0.1012

For other information about the calibration facility visit: http://www.arm.gov/docs/sites/sgp/sgp.html

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

BORCAL: 2006-02
Comments:
Cavity 30495 was configured but not used in valid sessions for this BORCAL due to shutter problems. The problem was fixed at NREL August 2006 (loose wire in controller).

Facility: Southern Great Plains
Comments:
Avg. Station Pressure and Temperature is for Tulsa, OK, which is used for the Solar Position Algorithm (SPA).

29001E6 Eppley NIP
Comments:
Sent back to factor for repair July 2002. First BORCAL after repair was 2003-01
.Came back from Eppley with new factory calibration of 8.70

29578E6 Eppley NIP
Comments:
NEW FACTORY CAL AS OF 6/7/01. (First BORCAL after repair: 2001-01)

30585E6 Eppley NIP
Comments:
Sent back to Eppley for repair, old cal factor was 8.68uV/W/m^2 and the new cal factor is 8.32 uV/W/m^2.. First BORCAL after repair is 2001-02.

30891F3 Eppley PSP
Comments:
Cal factor was recorded as 8.46 instead of 8.49 as per cal sheet, dated Sept 7, 1995.

29926F3 Eppley PIR-V
Comments:
Ventilated PIR

30696F3 Eppley PIR
Comments:
Unventilated PIR

Appendix 3
Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL 2006-02 Session Configuration Audit Report

LOCATION

Facility	Facility Abbreviation	Contact	Latitude	Longitude	Elevation (m)	Avg press (mbr)	Avg temp (C)	Time zone
Southern Great Plains	SGP	Dan Nelson	36.605	-97.488	317.0	992.0	15.0	-6.0

SYSTEM

% Error Thresholds

Cav1 / Cav2	1.0
Dif1 / Dif2	5.0
Global Ctrl / Ref	5.0
Direct Ctrl / Ref	5.0
Global ASR / Ref	10.0
Direct ASR / Ref	10.0
Test(x) / Test(x-1)	0.5

Delta Thresholds

Temp(x) - Temp(x-1)	2.0
Hum(x) - Hum(x-1)	10.0
Bar(x) - Bar(x-1)	2.0
Thrm(x) - Thrm(x-1)	1.0
Thm (Dome-Case)	3.0
Case Thm (Inst-Pyrg)	5.0

Scan Rate (sec)

Radiometers	30
Meteorological	300

Clock

Reset Interval (m)	0
Warning Threshold (s)	3
Delta UT1	0.000

Cavity Stability

Delta Threshold (%)	0.20
Scan Rate (s)	1
Stability Readings (s)	3

Uncertainty

Zenith Angle (deg)	0.003
Decimal Precision	2
45° Offsets: -	-15.00
+	15.00

ASR Setup

Scan Rate (s)	1
Stability Readings (s)	60
Score Threshold 1	0.001
Score Threshold 2	0.002
Score Threshold 3	0.007
Weighting Dupes	5
Slope Weighting	2.00
Variability Weighting	1.00

PW: Slope	1.23	Intercept	1.00
Tilt: Zenith	0.00	Azimuth	0.00
W in: Min	150	Max	500

Cavity Calibration Interval (m)	60
Operator Log Interval (m)	20
SPA: Delta T	64.970
SPA: Atmos. Refraction	0.5667

ASR RADIOMETERS

	Channel	Junction Box	Cable	Location
ASR 1: 5042 Matrix MARK III	35			T-13
ASR 2: PY22692 Licor LI200	134			2

METEOROLOGICAL INSTRUMENTS

	Channel	Junction Box	Cable	Location
Temperature: 040502T Omega HX93T	157			36
Humidity: 040502H Omega HX93H	145			18
Pressure: None				

GPS TIME RECIEVER

GPS: None

Type	Port	Baud	Parity	Stop bits	Data bits
	0	0	0	0	0

DATALOGGER

	Logger/Relay	DMM
Unit 0	6294004 Fluke Helios 2287A	None
Unit 0	None	None
Unit 0	None	None
Unit 0	None	None

System Offsets

	Unit 0	Unit 0	Unit 0	Unit 0
Volts DC (µV)	0.00	0.00	0.00	0.00
2-Wire Res. (mOhms)	0.00	0.00	0.00	0.00
4-Wire Res. (mOhms)	0.00	0.00	0.00	0.00
Cal Date	03/23/2006			
Cal Due Date	03/23/2007			

Communications

	Unit	Type	Port	Baud	Parity	Stop	Data
Logger	0	RS232	1	19200	1	0	8
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0

CAVITIES, CONTROL UNITS, AND DIGITAL MULTI METERS

	Cavity 1	Cavity 2
Unwindowed WRR	1.000000	0.996633
Windowed WRR	1.059038	1.000000
Unwindowed Uncert (%)	0.00	0.34
Windowed Uncert (%)	0.35	0.00
Heater Resistance	153.90	154.40
Heater Lead Resistance	0.0660	0.0660
Mfg Calibration Factor	1.99980	1.99990
Default Sensitivity	0.01041	0.01050
Cal Date	10/01/2004	10/01/2004
Cal Due Date	10/01/2006	10/01/2006

Calibration Waits (Seconds)

	Cavity 1	Cavity 2
TP-solar	0	0
TP-heated	45	45
TP-zero	60	60
Dwell	0	0
Active	✔	
Window in Use	✔	

	Unit 1	Unit 2
Cavity Head	29222 Eppley HF	30495 Eppley HF
Control Unit	US37037985 NREL Reda	US37037994 NREL Reda
Digital Multi Meter	US37037985 Hewlett Packard 34970A	US37037994 Hewlett Packard 34970A
Cavity Location	T2A	T-5

	Control Unit 1	Control Unit 2
Current Shunt	1.000	1.000
Circuit Resist	3.700	2.200
Cal Date	10/01/2004	10/01/2004
Cal Due Date	10/01/2006	10/01/2006

Communications

	Type	Port	Bd.	Parity	Stop bits	Data bits
Control Unit 1	GPIB	10	0	0	0	0
DMM 1		0	0	0	0	0
Control Unit 2	GPIB	11	0	0	0	0
DMM 2		0	0	0	0	0

BORCAL 2006-02 Session Configuration Audit Report

DIFFUSE REFERENCE INSTRUMENTS

Responsivity	Cal Date	Cal Due Date	Shading Disk Diameter (cm)	Shading Disk Arm Length (cm)	Shading Disk Subtended Angle	Uncertainty Percent	Uncertainty Offset (W/m^2)	Channel	Junction Box	Cable	Location	Tilt	Active
Diffuse 1: 32872 Eppley 8-48													
9.470	06/13/2005	06/13/2007	6.2	70.0	5.1	2.04	1.0	40		T3	T-3	☐	☑
Diffuse 1: Case Thermistor								n/a	n/a	n/a			
Diffuse 1: Dome Thermistor								n/a	n/a	n/a			
Diffuse 2: 32873 Eppley 8-48													
8.590	06/13/2005	06/13/2007	6.2	70.0	5.1	1.62	1.0	41		T4	T-4	☐	☑
Diffuse 2: Case Thermistor								n/a	n/a	n/a			
Diffuse 2: Dome Thermistor								n/a	n/a	n/a			

PYRGEOMETER INSTRUMENTS

Cal Date	Cal Due Date	K0	K1	K2	K3	Kr	Uncert. (W/m^2)	Channel	Junction Box	Cable	Location	Active
Pyrgeometer 1: 29926F3 Eppley PIR-V												
02/24/2006	02/24/2007	-6.00000	0.26500	1.01670	-3.18000	7.04400E-4	2.60	128		83	Position 83	☑
Pyrgeometer 1: Case Thermistor								108		83		
Pyrgeometer 1: Dome Thermistor								109		56		
Pyrgeometer 2: 30696F3 Eppley PIR												
02/24/2006	02/24/2007	-12.40000	0.23800	1.03200	-3.09000	7.04400E-4	2.90	54		30	Position 30	☑
Pyrgeometer 2: Case Thermistor								74		30		
Pyrgeometer 2: Dome Thermistor								75		12		

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INSTRUMENT GROUPS

Group Number	Calibration Type	Instrument Type	Pyrgeometer Type	Instrument Count
1	Global	Eppley 8-48	none	10
2	Global	Eppley 8-48	none	10
3	Direct	Eppley NIP	none	10
4	Direct	Eppley NIP	none	10
5	Direct	Eppley NIP	none	6
6	Global	Eppley PSP	Eppley PIR-V	10
7	Global	Eppley PSP	Eppley PIR-V	10
8	Global	Eppley PSP	Eppley PIR-V	10
9	Global	Eppley PSP	Eppley PIR-V	2
10	Global	Eppley PSP	Eppley PIR	10
11	Global	Eppley PSP	Eppley PIR	10
12	Global	Eppley PSP	Eppley PIR	5
Total				103

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INSTRUMENTS

Serial Number	Customer	Grp	Idx	Ch	Box	Cbl	TcCh	TcBox	TcCbl	TdCh	TdBox	TdCbl	Location	Due
14862F3 ©	SGP	6	1	182			n/a	n/a	n/a	n/a	n/a	n/a	69	12
29001E6	SGP	3	1	36			n/a	n/a	n/a	n/a	n/a	n/a	T-17	12
29009E6	SGP	3	2	92			n/a	n/a	n/a	n/a	n/a	n/a	T-26	12
29010E6	SGP	3	3	39			n/a	n/a	n/a	n/a	n/a	n/a	T-20	12
29279F3 ©	SGP	6	2	167			n/a	n/a	n/a	n/a	n/a	n/a	48	12
29554E6	SGP	3	4	96			n/a	n/a	n/a	n/a	n/a	n/a	T-33	12
29556E6	SGP	3	5	91			n/a	n/a	n/a	n/a	n/a	n/a	T-25	12
29578E6	SGP	3	6	43			n/a	n/a	n/a	n/a	n/a	n/a	T-13	12
29610F3 ©	SGP	6	3	160			n/a	n/a	n/a	n/a	n/a	n/a	40	12
29615F3 ©	SGP	6	4	180			n/a	n/a	n/a	n/a	n/a	n/a	67	12
29742E6	SGP	3	7	80			n/a	n/a	n/a	n/a	n/a	n/a	T-7	12
29743E6	SGP	3	8	38			n/a	n/a	n/a	n/a	n/a	n/a	T-19	12
29848E6	SGP	3	9	97			n/a	n/a	n/a	n/a	n/a	n/a	T-34	12
29850E6	SGP	3	10	90			n/a	n/a	n/a	n/a	n/a	n/a	T-24	12
29852E6	SGP	4	1	33			n/a	n/a	n/a	n/a	n/a	n/a	T-14	12
29853E6	SGP	4	2	37			n/a	n/a	n/a	n/a	n/a	n/a	T-18	12
29912F3 ©	SGP	6	5	169			n/a	n/a	n/a	n/a	n/a	n/a	50	12
29915F3 ©	TWP	6	6	174			n/a	n/a	n/a	n/a	n/a	n/a	59	12
29934E6	TWP	4	3	94			n/a	n/a	n/a	n/a	n/a	n/a	T-30	12
29935E6	SGP	4	4	34			n/a	n/a	n/a	n/a	n/a	n/a	T-15	12
30585E6	SGP	4	5	88			n/a	n/a	n/a	n/a	n/a	n/a	T-21	12
30614F3 ©	SGP	10	1	149			n/a	n/a	n/a	n/a	n/a	n/a	23	12
30620F3 ©	SGP	10	2	57			n/a	n/a	n/a	n/a	n/a	n/a	14	12
30652F3 ©	SGP	10	3	150			n/a	n/a	n/a	n/a	n/a	n/a	24	12
30664F3 ©	SGP	10	4	137			n/a	n/a	n/a	n/a	n/a	n/a	5	12
30665F3 ©	SGP	6	7	186			n/a	n/a	n/a	n/a	n/a	n/a	75	12
30666F3 ©	SGP	6	8	126			n/a	n/a	n/a	n/a	n/a	n/a	65	12
30709F3 ©	SGP	6	9	181			n/a	n/a	n/a	n/a	n/a	n/a	68	12
30775F3 ©	SGP	10	5	147			n/a	n/a	n/a	n/a	n/a	n/a	21	12
30778F3 ©	SGP	10	6	146			n/a	n/a	n/a	n/a	n/a	n/a	20	12
30812F3 ©	SGP	6	10	168			n/a	n/a	n/a	n/a	n/a	n/a	49	12
30823F3 ©	SGP	7	1	187			n/a	n/a	n/a	n/a	n/a	n/a	76	12
30888F3 ©	SGP	10	7	148			n/a	n/a	n/a	n/a	n/a	n/a	22	12
30890F3 ©	SGP	7	2	179			n/a	n/a	n/a	n/a	n/a	n/a	66	12
30891F3 ©	SGP	7	3	166			n/a	n/a	n/a	n/a	n/a	n/a	47	12
30894F3 ©	SGP	7	4	162			n/a	n/a	n/a	n/a	n/a	n/a	42	12
30902F3 ©	SGP	10	8	56			n/a	n/a	n/a	n/a	n/a	n/a	13	12
30929F3 ©	SGP	7	5	159			n/a	n/a	n/a	n/a	n/a	n/a	39	12
30933F3 ©	SGP	7	6	127			n/a	n/a	n/a	n/a	n/a	n/a	74	12
30940F3 ©	SGP	7	7	161			n/a	n/a	n/a	n/a	n/a	n/a	41	12
30945F3 ©	SGP	10	9	59			n/a	n/a	n/a	n/a	n/a	n/a	32	12
30949F3 ©	SGP	10	10	138			n/a	n/a	n/a	n/a	n/a	n/a	6	12
30951F3 ©	SGP	11	1	141			n/a	n/a	n/a	n/a	n/a	n/a	9	12
30954F3 ©	SGP	11	2	135			n/a	n/a	n/a	n/a	n/a	n/a	3	12
30955F3 ©	SGP	11	3	153			n/a	n/a	n/a	n/a	n/a	n/a	27	12
30958F3 ©	SGP	11	4	136			n/a	n/a	n/a	n/a	n/a	n/a	4	12
30961F3 ©	SGP	11	5	58			n/a	n/a	n/a	n/a	n/a	n/a	31	12
31099F3 ‡©	Calibration System	7	8	123			103			n/a	n/a	n/a	64	12
31100F3 ‡©	Calibration System	7	9	124			104			n/a	n/a	n/a	73	12
31101F3 ‡©	Calibration System	7	10	125			105			n/a	n/a	n/a	82	12

‡ Control Instrument © Effective Net IR Corrected Instrument

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INSTRUMENTS

Serial Number	Customer	Grp	Idx	Ch	Box	Cbl	TcCh	TcBox	TcCbl	TdCh	TdBox	TdCbl	Location	Due
31120E6 ‡	Calibration System	4	6	42			n/a	n/a	n/a	n/a	n/a	n/a	T12	12
31122E6 ‡	Calibration System	4	7	44			n/a	n/a	n/a	n/a	n/a	n/a	T-22	12
31149F3 ‡©	Calibration System	8	1	120			100			n/a	n/a	n/a	37	12
31150F3 ‡©	Calibration System	8	2	121			101			n/a	n/a	n/a	46	12
31151F3 ‡©	Calibration System	8	3	122			102			n/a	n/a	n/a	55	12
31152F3 ‡©	Calibration System	11	6	51			71			n/a	n/a	n/a	19	12
31153F3 ‡©	Calibration System	11	7	52			72			n/a	n/a	n/a	28	12
31154F3 ‡©	Calibration System	11	8	53			73			n/a	n/a	n/a	29	12
31158F3 ‡©	Calibration System	11	9	48			68			n/a	n/a	n/a	1	12
31159F3 ‡©	Calibration System	11	10	49			69			n/a	n/a	n/a	10	12
31160F3 ‡©	Calibration System	12	1	50			n/a	n/a	n/a	n/a	n/a	n/a	11	12
31274F3 ©	TWP	8	4	133			n/a	n/a	n/a	n/a	n/a	n/a	85	12
31276F3 ©	TWP	8	5	131			n/a	n/a	n/a	n/a	n/a	n/a	58	12
31279F3 ©	TWP	8	6	193			n/a	n/a	n/a	n/a	n/a	n/a	86	12
31285F3 ©	TWP	12	2	139			n/a	n/a	n/a	n/a	n/a	n/a	7	12
31289F3 ©	TWP	12	3	140			n/a	n/a	n/a	n/a	n/a	n/a	8	12
31290F3 ©	TWP	12	4	151			n/a	n/a	n/a	n/a	n/a	n/a	25	12
31295F3 ©	TWP	12	5	152			n/a	n/a	n/a	n/a	n/a	n/a	26	12
31344E6	NSA	4	8	47			n/a	n/a	n/a	n/a	n/a	n/a	T-32	12
31345E6	TWP	4	9	93			n/a	n/a	n/a	n/a	n/a	n/a	T-29	12
31361E6	TWP	4	10	45			n/a	n/a	n/a	n/a	n/a	n/a	T-27	12
31386E6	SGP	5	1	99			n/a	n/a	n/a	n/a	n/a	n/a	T-36	12
31387E6	SGP	5	2	98			n/a	n/a	n/a	n/a	n/a	n/a	T-35	12
31388E6	SGP	5	3	89			n/a	n/a	n/a	n/a	n/a	n/a	T-23	12
31633F3 ©	SGP	8	7	158			n/a	n/a	n/a	n/a	n/a	n/a	38	12
31762E6	NSA	5	4	46			n/a	n/a	n/a	n/a	n/a	n/a	T-28	12
32012F3 ©	NSA	8	8	188			n/a	n/a	n/a	n/a	n/a	n/a	77	12
32016F3 ©	NSA	8	9	170			n/a	n/a	n/a	n/a	n/a	n/a	51	12
32018F3 ©	NSA	8	10	189			n/a	n/a	n/a	n/a	n/a	n/a	78	12
32026F3 ©	NSA	9	1	130			n/a	n/a	n/a	n/a	n/a	n/a	57	12
32039F3 ©	NSA	9	2	132			n/a	n/a	n/a	n/a	n/a	n/a	84	12
32330	SGP	1	1	176			n/a	n/a	n/a	n/a	n/a	n/a	61	12
32972	SGP	1	2	173			n/a	n/a	n/a	n/a	n/a	n/a	54	12
33236	SGP	1	3	192			n/a	n/a	n/a	n/a	n/a	n/a	81	12
33239	SGP	1	4	175			n/a	n/a	n/a	n/a	n/a	n/a	60	12
33247	SGP	1	5	196			n/a	n/a	n/a	n/a	n/a	n/a	89	12
33252	SGP	1	6	194			n/a	n/a	n/a	n/a	n/a	n/a	87	12
33256	SGP	1	7	163			n/a	n/a	n/a	n/a	n/a	n/a	43	12
33261	SGP	1	8	164			n/a	n/a	n/a	n/a	n/a	n/a	44	12
33262	SGP	1	9	178			n/a	n/a	n/a	n/a	n/a	n/a	63	12
33267	SGP	1	10	165			n/a	n/a	n/a	n/a	n/a	n/a	45	12
33270	SGP	2	1	183			n/a	n/a	n/a	n/a	n/a	n/a	70	12
33274	SGP	2	2	177			n/a	n/a	n/a	n/a	n/a	n/a	62	12
33275	SGP	2	3	184			n/a	n/a	n/a	n/a	n/a	n/a	71	12
33278	SGP	2	4	185			n/a	n/a	n/a	n/a	n/a	n/a	72	12
33375	NSA	2	5	197			n/a	n/a	n/a	n/a	n/a	n/a	90	12
33378	AMF	2	6	191			n/a	n/a	n/a	n/a	n/a	n/a	80	12
33379	TWP	2	7	195			n/a	n/a	n/a	n/a	n/a	n/a	88	12
33785	SGP	2	8	171			n/a	n/a	n/a	n/a	n/a	n/a	52	12
33787	SGP	2	9	172			n/a	n/a	n/a	n/a	n/a	n/a	53	12

‡ Control Instrument © Effective Net IR Corrected Instrument

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INSTRUMENTS

Serial Number	Customer	Grp	Idx	Ch	Box	Cbl	TcCh	TcBox	TcCbl	TdCh	TdBox	TdCbl	Location	Due
33788	SGP	2	10	190			n/a	n/a	n/a	n/a	n/a	n/a	79	12
34507E6	SGP	5	5	81			n/a	n/a	n/a	n/a	n/a	n/a	T-8	12
34546E6	AMF	5	6	95			n/a	n/a	n/a	n/a	n/a	n/a	T-31	12

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Effective Net IR Corrected Instruments

Instrument	Correcting Pyrgeometer	Inst. RSnet	RSnet uncert.	RSnet Date
14862F3 Eppley PSP	29926F3 Eppley PIR-V	0.7454	10.0000	06/08/2006
29279F3 Eppley PSP	29926F3 Eppley PIR-V	0.6272	10.0000	06/08/2006
29610F3 Eppley PSP	29926F3 Eppley PIR-V	0.6688	10.0000	06/07/2006
29615F3 Eppley PSP	29926F3 Eppley PIR-V	0.6438	10.0000	06/07/2006
29912F3 Eppley PSP	29926F3 Eppley PIR-V	0.6056	10.0000	06/13/2006
29915F3 Eppley PSP	29926F3 Eppley PIR-V	0.6327	10.0000	06/09/2006
30614F3 Eppley PSP	30696F3 Eppley PIR	0.6312	10.0000	06/06/2006
30620F3 Eppley PSP	30696F3 Eppley PIR	0.6691	10.0000	07/10/2006
30652F3 Eppley PSP	30696F3 Eppley PIR	0.6610	10.0000	06/07/2006
30664F3 Eppley PSP	30696F3 Eppley PIR	0.6245	10.0000	06/06/2006
30665F3 Eppley PSP	29926F3 Eppley PIR-V	0.6879	10.0000	06/09/2006
30666F3 Eppley PSP	29926F3 Eppley PIR-V	0.6919	10.0000	06/07/2006
30709F3 Eppley PSP	29926F3 Eppley PIR-V	0.6150	10.0000	06/07/2006
30775F3 Eppley PSP	30696F3 Eppley PIR	0.6069	10.0000	06/06/2006
30778F3 Eppley PSP	30696F3 Eppley PIR	0.6431	10.0000	06/06/2006
30812F3 Eppley PSP	29926F3 Eppley PIR-V	0.6661	10.0000	06/09/2006
30823F3 Eppley PSP	29926F3 Eppley PIR-V	0.6346	10.0000	06/08/2006
30888F3 Eppley PSP	30696F3 Eppley PIR	0.6365	10.0000	06/06/2006
30890F3 Eppley PSP	29926F3 Eppley PIR-V	0.5945	10.0000	06/07/2006
30891F3 Eppley PSP	29926F3 Eppley PIR-V	0.5755	10.0000	06/08/2006
30894F3 Eppley PSP	29926F3 Eppley PIR-V	0.6467	10.0000	06/07/2006
30902F3 Eppley PSP	30696F3 Eppley PIR	0.5504	10.0000	07/10/2006
30929F3 Eppley PSP	29926F3 Eppley PIR-V	0.6304	10.0000	06/07/2006
30933F3 Eppley PSP	29926F3 Eppley PIR-V	0.5869	10.0000	06/09/2006
30940F3 Eppley PSP	29926F3 Eppley PIR-V	0.6187	10.0000	06/07/2006
30945F3 Eppley PSP	30696F3 Eppley PIR	0.5340	10.0000	07/10/2006
30949F3 Eppley PSP	30696F3 Eppley PIR	0.5885	10.0000	06/07/2006
30951F3 Eppley PSP	30696F3 Eppley PIR	0.6427	10.0000	07/06/2006
30954F3 Eppley PSP	30696F3 Eppley PIR	0.6333	10.0000	06/06/2006
30955F3 Eppley PSP	30696F3 Eppley PIR	0.6150	10.0000	07/06/2006
30958F3 Eppley PSP	30696F3 Eppley PIR	0.6154	10.0000	06/06/2006
30961F3 Eppley PSP	30696F3 Eppley PIR	0.5806	10.0000	07/10/2006
31099F3 Eppley PSP	29926F3 Eppley PIR-V	0.5787	10.0000	05/08/2006
31100F3 Eppley PSP	29926F3 Eppley PIR-V	0.6473	10.0000	05/09/2006
31101F3 Eppley PSP	29926F3 Eppley PIR-V	0.6483	10.0000	05/09/2006
31149F3 Eppley PSP	29926F3 Eppley PIR-V	0.5490	10.0000	03/30/2006
31150F3 Eppley PSP	29926F3 Eppley PIR-V	0.5510	10.0000	03/30/2006
31151F3 Eppley PSP	29926F3 Eppley PIR-V	0.5330	10.0000	03/30/2006
31152F3 Eppley PSP	30696F3 Eppley PIR	0.6339	10.0000	05/09/2006
31153F3 Eppley PSP	30696F3 Eppley PIR	0.6429	10.0000	05/09/2006
31154F3 Eppley PSP	30696F3 Eppley PIR	0.5616	10.0000	05/09/2006
31158F3 Eppley PSP	30696F3 Eppley PIR	0.5240	10.0000	03/30/2006
31159F3 Eppley PSP	30696F3 Eppley PIR	0.5320	10.0000	03/30/2006
31160F3 Eppley PSP	30696F3 Eppley PIR	0.4900	10.0000	03/30/2006
31274F3 Eppley PSP	29926F3 Eppley PIR-V	0.6323	10.0000	06/13/2006
31276F3 Eppley PSP	29926F3 Eppley PIR-V	0.5694	10.0000	06/09/2006
31279F3 Eppley PSP	29926F3 Eppley PIR-V	0.4835	10.0000	06/09/2006
31285F3 Eppley PSP	30696F3 Eppley PIR	0.5813	10.0000	06/09/2006
31289F3 Eppley PSP	30696F3 Eppley PIR	0.6097	10.0000	06/09/2006
31290F3 Eppley PSP	30696F3 Eppley PIR	0.5990	10.0000	06/09/2006

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Effective Net IR Corrected Instruments

Instrument	Correcting Pyrgeometer	Inst. RSnet	RSnet uncert.	RSnet Date
31295F3 Eppley PSP	30696F3 Eppley PIR	0.5465	10.0000	06/13/2006
31633F3 Eppley PSP	29926F3 Eppley PIR-V	0.6546	10.0000	06/07/2006
32012F3 Eppley PSP	29926F3 Eppley PIR-V	0.6597	10.0000	06/13/2006
32016F3 Eppley PSP	29926F3 Eppley PIR-V	0.6405	10.0000	06/13/2006
32018F3 Eppley PSP	29926F3 Eppley PIR-V	0.6055	10.0000	06/13/2006
32026F3 Eppley PSP	29926F3 Eppley PIR-V	0.6242	10.0000	06/13/2006
32039F3 Eppley PSP	29926F3 Eppley PIR-V	0.6577	10.0000	06/13/2006

Appendix 4
Operator Session Logs

Operator session logs for the BORCAL

BORCAL 2006-02 Operator Session Log

Session: 1

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	08:45:31	08:48:29	29222	08:25	966.5	966.5
			30495	08:25	951.6	951.6

Observations: [None]

Session: 2

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	08:56:50	09:12:12	29222	08:25	966.0	965.6
			30495	08:25	1016.7	812.9

Observations: [None]

Session: 3

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	09:12:12	09:26:50	29222	08:25	965.6	965.5
			30495	08:25	812.9	668.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:16:57	45.38	Green	490.3	24.3	Craig Webb

Comments:
test session working on cavity 30495 problem.

Session: 4

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	09:26:50	09:27:20	29222	08:25	965.5	965.5
			30495	08:25	668.5	668.5

Observations: [None]

Session: 5

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	09:34:16	09:38:01	29222	08:25	955.4	955.4
			30495	08:25	637.3	637.3

Observations: [None]

Session: 6

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	09:58:50	10:02:27	29222	08:25	965.4	965.1
			30495	08:25	956.7	956.0

Observations: [None]

Session: 7

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	10:02:27	10:07:40	29222	08:25	965.1	965.2
			30495	08:25	956.0	955.8

Observations: [None]

Session: 8

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-14-2006	10:07:40	10:10:56	29222	08:25	965.2	965.1
			30495	08:25	955.8	950.8

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```
Observations: [None]
==========================================================================================
Session: 9
------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-14-2006    10:10:56      10:11:12      29222         08:25           965.1         965.1
                                          30495         08:25           950.8         950.8
------------------------------------------------------------------------------------------
Observations: [None]
==========================================================================================
Session: 10
------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-14-2006    11:44:45      11:47:30      29222         08:25           963.4         963.8
                                          30495         08:25           954.3         954.6
------------------------------------------------------------------------------------------
Observations: [None]
==========================================================================================
Session: 11
------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-14-2006    11:47:30      11:52:41      29222         08:25           963.8         963.8
                                          30495         08:25           954.6         954.6
------------------------------------------------------------------------------------------
Observations: [None]
==========================================================================================
Session: 12
------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-14-2006    12:50:36      12:54:52      29222         08:25           963.0         963.0
                                          30495         08:25           955.1         955.1
------------------------------------------------------------------------------------------
Observations: [None]
==========================================================================================
Session: 13
------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-17-2006    06:14:01      07:12:04      29222         05:40           966.8         966.0
------------------------------------------------------------------------------------------
Observations:
----------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
06:34:07       77.88        Green          480.6             34.2     Craig Webb
                                                                      Rod Soper
----------------------------------------------------------------------------------
Comments:
clear with haze on horzin and clouds to the west and north.  Temp-29C, hum-42%, hpa-977, wnd dir-210 @ 6
mph.
----------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
07:02:51       72.35        Green          590.3             27.0     Craig Webb
                                                                      Rod Soper
----------------------------------------------------------------------------------
Comments:
small cirrus to the south and west, temp-29C, hum-56, hpa-978, wnd dir-205 @ 10 mph.  Afew reference
alarms but everything seems to be going just fine.
==========================================================================================
Session: 14
------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-17-2006    07:12:04      08:12:06      29222         05:40           966.0         964.9
------------------------------------------------------------------------------------------
Observations:
----------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
07:25:10       67.99        Green          653.4             23.3     Craig Webb
                                                                      Rod Soper
----------------------------------------------------------------------------------
```

Comments:
small cirrus form and moving in on the ares from the south. temp-30C, hum-53%, hpa-978, wnd dir-210 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:45:46	63.92	Green	703.4	20.7	Craig Webb Rod Soper

Comments:
no change in sky conditions. temp-31C, hum-50%, hpoa-978, wnd dir-200 @ 14 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:05:56	59.90	Green	737.5	18.9	Craig Webb Rod Soper

Comments:
clouds getting closer, temp-33C, hum-47%, hpa-978, wnd dir-210 @ 10 mph. had a dew alarms on the nipd a group of floating cob webs had to be cleaned of them.

Session: 15

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-17-2006	08:12:06	09:12:07	29222	05:40	964.9	963.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:40:04	53.06	Green	771.6	17.2	Craig Webb Rod Soper

Comments:
clear with clouds to the south and west. temp-34C, hum-43%, hpa-978, wnd dir-220 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:00:15	49.02	Green	792.2	16.5	Craig Webb Rod Soper

Comments:
no change, temp-25C, hum-41%, hpa-978, wnd dir-230 @ 10 mph.

Session: 16

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-17-2006	09:12:07	10:12:09	29222	05:40	963.9	962.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:20:40	44.94	Green	814.7	15.4	Craig Webb Rod Soper

Comments:
clear with a few clouds to the south and west, temp-35C, hum-41%, hoa-978 ,wind dir-210c @ 11 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:40:59	40.91	Green	830.9	14.7	Craig Webb Rod Soper

Comments:
no change in sky cnditions, temp-37C, hum-39%, hpa-977, wnd dir-200 @ 15 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:01:25	36.90	Green	832.5	14.8	Craig Webb Rod Soper

Comments:
Clear with clouds towards S.W. temp.37C., RH 36%, hpa 977, wind speed 20 mph. at 190.

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Session: 17

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-17-2006	10:12:09	11:09:12	29222	05:40	962.9	962.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:22:26	32.87	Green	846.9	14.1	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-28C, hum-35%, hpa-977, wnd dir-210 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:53:48	27.07	Green	862.7	13.2	Craig Webb Rod Soper

Comments:
a few clouds to the south and west, temp-39C, hum-33%, hpa-977, wnd dir-210 @ 15 mph.

Session: 18

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-17-2006	11:09:12	12:09:12	29222	05:40	962.3	961.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:14:06	23.60	Green	869.4	12.9	Craig Webb Rod Soper

Comments:
Clear sky with clouds towards S.W. Temp. 39C., RH 31%, hpa 977, wind speed 13 mph. at 210.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:34:17	20.50	Green	870.7	12.7	Craig Webb Rod Soper

Comments:
Clear sky with clouds towards S.W. Temp. 40C., RH 31%,hpa 977, wind speed 9 mph. at 210.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:54:57	17.88	Green	888.2	12.1	Craig Webb Rod Soper

Comments:
Clear sky with clouds forming toards S.W. Temp. 40C., RH 30%, hpa 977, wind speed 16 mph. at 180.

Session: 19

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-17-2006	12:09:12	13:00:56	29222	05:40	961.6	961.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:18:27	15.95	Green	874.6	14.8	Craig Webb Rod Soper

Comments:
Clear sky with clouds forming towards S.W. Temp 40C., RH 29%, hpa 977, wind speed 17 mph at 200.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:38:36	15.49	Green	884.7	15.2	Craig Webb Rod Soper

Comments:
Clouds forming east and SW. Temp. 40C., RH 29%, hpa 976, wind speed 16 mph. at 190.

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Session: 20
----------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-18-2006     06:13:14       07:12:16       29222          05:30            967.0          966.1
----------------------------------------------------------------------------------------------------
Observations:
----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
06:33:42        78.07         Green           306.2              52.0      Craig Webb
                                                                           Rod Soper
----------------------------------------------------------------------------------------
Comments:
haze on the horzin and a fer small cirrus to the east.  Temp-26C, hum-77, hpa-978, wnd dir-130 @ 1 mph.
----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
06:54:38        74.05         Green           402.6              43.7      Craig Webb
                                                                           Rod Soper
----------------------------------------------------------------------------------------
Comments:
sky seems to be clearing a little. temp-28C, hum-70%, hpa-978, wnd dir-120 @ 1 mph.
----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
07:01:37        72.70         Green           428.9              41.5      Craig Webb
                                                                           Rod Soper
----------------------------------------------------------------------------------------
Comments: [None]
==========================================================================================================
Session: 21
----------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-18-2006     07:12:16       08:12:17       29222          05:30            966.1          964.9
----------------------------------------------------------------------------------------------------
Observations:
----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
07:22:01        68.71         Green           493.1              37.1      Craig Webb
                                                                           Rod Soper
----------------------------------------------------------------------------------------
Comments:
Clear sky, Temp. 29C., RH 63%, hpa 978, wind speed 4 mph. ,at 190.
----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
07:38:33        65.45         Green           531.1              34.7      Craig Webb
                                                                           Rod Soper
----------------------------------------------------------------------------------------
Comments:
There is a lot of diffuse  toward the horzin.
----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
07:59:16        61.33         Brown           577.0              31.8      Craig Webb
                                                                           Rod Soper
----------------------------------------------------------------------------------------
Comments:
several arlarm due to sky haze. temp-31C, hum-57%, hpa-979, wnd dir-180 @ 6 mph.
==========================================================================================================
Session: 22
----------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-18-2006     08:12:17       08:27:52       29222          05:30            964.9          964.7
----------------------------------------------------------------------------------------------------
Observations:
----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
08:25:00        56.19         Brown           620.1              29.3      Craig Webb
                                                                           Rod Soper
----------------------------------------------------------------------------------------
Comments:
unstable conditions quitting for now.
==========================================================================================================
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Session: 23

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-18-2006	13:23:55	13:28:13	29222	05:30	961.1	961.4
			30495	13:00	959.8	959.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:25:38	18.99	Red	-0.2	100.1	Craig Webb

Comments:
test session.

Session: 24

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-18-2006	13:28:13	13:31:58	29222	05:30	961.4	961.4
			30495	13:00	959.1	958.4

Observations: [None]

Session: 25

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-19-2006	06:04:49	07:02:50	29222	05:30	966.8	966.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:25:51	79.68	Green	273.5	54.9	Craig Webb Rod Soper

Comments:
Lots of haze on horzin but sky seems fairly clear compared to yesterday, ttemp-25C, hum-77%, hpa-977, wnd dir-130 @ 4 mpg. Severs; reference alaarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:48:35	75.33	Green	377.6	45.7	Craig Webb Rod Soper

Comments:
a few contrails to the east of the RCF, clear with a very light haze, temp-27C, hum-70%, hpa-977, wnd dir-185 @ 7 mph.

Session: 26

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-19-2006	07:02:50	08:02:52	29222	05:30	966.2	965.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:10:18	71.11	Green	456.1	39.7	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-27C, hum-62%, hpa-977, wnd dir-190 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:34:29	66.37	Green	518.7	35.5	Craig Webb Rod Soper

Comments:
clear with haze on horzin, temp-31C, hum-54%, hpa-978, wnd dir-200 @ 12 mph.

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Session: 27

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-19-2006	08:02:52	08:23:45	29222	05:30	965.2	964.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:03:45	61.16	4	577.2	32.5	Craig Webb Rod Soper

Comments:
cirrus starting to from to the southeast and moving this way, temp-33C, hum-47, hpa-978, wnd dir-210 @ 11 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:20:48	57.14	Brown	607.3	31.7	Craig Webb Rod Soper

Comments:
closing due to clouds moving in.

Session: 28

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-19-2006	09:49:55	09:53:09	29222	05:30	963.0	963.0

Observations: [None]

Session: 29

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-20-2006	07:17:37	08:20:38	29222	07:00	966.0	964.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:38:20	65.72	Green	557.6	32.9	Craig Webb Rod Soper

Comments:
hevy haze on horzin, didn't start till sun was past haze. tep-30C, hum-49, hpa-977, wnd dir-250 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:08:00	59.81	Green	625.5	28.8	Craig Webb Rod Soper

Comments:
getting hotter, temp-33C, hum-42%, hpa-979, wnd dir-250 @ 10 mph.

Session: 30

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-20-2006	08:20:38	09:13:42	29222	07:00	964.6	963.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:32:19	54.93	Green	668.5	26.3	Craig Webb Rod Soper

Comments:
no change in sky conditions., temp-34C, hum-39%, hpa-979, wnd dir-250 @ 17 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:52:53	50.81	Green	707.6	24.2	Craig Webb Rod Soper

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Comments:
hot and a very light haze is starting to for to the waet and south, temp-35C, hum-37%, hpa-979, wnd dir-260 @ 15 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:13:07	47.09	Green	725.9	23.3	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-37C, hum-36%

Session: 31

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-20-2006	09:13:42	10:13:43	29222	07:00	963.3	962.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:13:43	47.09	Green	725.9	23.3	Craig Webb Rod Soper

Comments: [None]

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:33:54	42.63	Green	738.0	22.8	Craig Webb Rod Soper

Comments:
34507E6 alarmed but couldn't find anything wrong. temp-37C, hum-34%, hpa-979, wnd dir-250 @ 11 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:54:39	38.56	Green	752.8	22.2	Craig Webb Rod Soper

Comments:
haze moving in from the south and getting closer. temp-38C, hum-32%, hpa-979, wnd dir-270 @ 10 mph.
30951F3 had a spider on it.

Session: 32

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-20-2006	10:13:43	11:10:45	29222	07:00	962.3	961.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:15:01	34.62	Green	766.0	21.2	Craig Webb Rod Soper

Comments:
no change i sky conditions, temp-39C, hum-30%, hpa-979, wnd dir-260 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:50:30	28.05	Green	772.1	21.4	Craig Webb Rod Soper

Comments:
hot and dry, temp-39C, hum-29%, hpa-979, wnd dir-210 @ 9 mph.

Session: 33

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-20-2006	11:10:45	12:10:47	29222	07:00	961.5	961.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:12:36	24.27	Green	778.8	21.4	Craig Webb Rod Soper

Comments:
hot and windy, temp-40C, hum-27%, hpa-979, wnd dir-190 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:33:42	21.04	Green	780.7	21.7	Craig Webb Rod Soper

Comments:
no change in sky cinditions, temp-40C, hum-27%, hpa-979, wnd dir-210 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:58:19	18.03	Green	780.4	21.5	Craig Webb Rod Soper

Comments:
hot and some haze in sky, temp-40C, hum-26%, hpa-979, wnd dir-230 @ 12 mph.

Session: 34

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-20-2006	12:10:47	13:08:49	29222	07:00	961.0	960.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:18:36	16.48	Green	803.1	20.5	Craig Webb Rod Soper

Comments:
some light haze in sky, temp-40C, hum-26, hpa-978, wnd dir-240 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:39:07	16.03	Green	777.2	21.5	Craig Webb Rod Soper

Comments:
haze seems to be getting thicker, temp-42C, hum-24%, hpa-978, wnd dir-210 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:59:24	16.79	Green	792.1	21.7	Craig Webb Rod Soper

Comments:
Clear sky, Temp. 41C., RH 24%, hpa 978, wind speed 6 mph. at 240.

Session: 35

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-20-2006	13:08:49	13:38:24	29222	07:00	960.5	960.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:19:32	18.58	Brown	774.9	22.4	Craig Webb Rod Soper

Comments:
Clear sky with small cirrus starting to form.. Temp. 42C., RH 24 %, hpa 978, wind speed 4 mph. at 210.

Session: 36

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	09:07:40	10:06:41	29222	08:40	966.6	965.5

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:28:15	44.10	Green	870.9	12.1	Craig Webb Rod Soper

Comments:
clear, temp-26C,m hum-47%, hpa-981, wnd dir-060 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:48:58	40.02	Green	869.7	11.7	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-26C, hum-44%, hpa-981, wnd dir-04 @ 7 mph.

Session: 37

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	10:06:41	11:09:44	29222	08:40	965.5	965.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:09:04	36.13	Brown	881.1	11.1	Craig Webb Rod Soper

Comments:
small cirrus starting to form through the sky. temp-28C, hum-46%, hpa-981, wnd dir-150 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:29:15	32.32	Green	917.2	10.3	Craig Webb Rod Soper

Comments:
no change, temp-30C, hum-39%, hpa-981, wnd dir-090 @8 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:50:12	28.51	Green	920.2	10.1	Craig Webb Rod Soper

Comments:
no change , temp-36C, hum-39C, hpa-981, wnd dir-360 @ 3 mph.

Session: 38

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	11:09:44	12:11:45	29222	08:40	965.0	964.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:10:18	25.54	4	933.3	9.8	Craig Webb Rod Soper

Comments:
a few small cirrus through out the sky and a cloud bank to the east, temp-31C, hum-36%, hpa-980, wnd dir-120 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:30:33	21.98	Green	922.2	10.2	Craig Webb Rod Soper

Comments:
no change in sky conditions. temp-31C hum-37%, hpa-980, wnd dir-060 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:50:54	19.36	Green	937.6	9.6	Craig Webb Rod Soper

Comments:
no change, temp-31C, hum-34%, hpa-980, wnd dir-040 @ 4 mph.

Session: 39

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	12:11:45	13:14:46	29222	08:40	964.2	964.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:13:46	17.34	Green	935.8	9.6	Craig Webb Rod Soper

Comments:
A few small cirrus to the north and a bank of clouds to the east, temp-32C, hum-34%, hpa-979, wnd dir-060 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:34:03	16.62	Green	937.1	9.7	Craig Webb Rod Soper

Comments:
no change, temp-33C, hum-29%, hpa-979, wnd dir-090 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:54:25	17.07	Green	936.3	9.8	Craig Webb Rod Soper

Comments:
no change, temp-33C, hum-27%, hpa-979, wnd dir-080 @ 3 mph.

Session: 40

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	13:14:46	14:14:48	29222	08:40	964.1	963.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:15:07	18.40	4	930.6	10.1	Craig Webb Rod Soper

Comments:
some small cirrus through the sky and a cloud bank to the southeast, temp-34C, hum-27%, hpa-979, wnd dir-070 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:35:33	21.04	Green	928.2	10.3	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-34C, hum-27%, hpa-978, wnd dir-090 @ 14 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:56:17	24.08	Green	924.7	10.5	Craig Webb Rod Soper

Comments:
no change, temp-34C, hum-27%, hpa-978, wnd dir-120 @ 5 mph.

Session: 41

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	14:14:48	15:17:49	29222	08:40	963.8	963.7

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```
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:17:12        27.56         Green           925.5              10.5      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
no change in sky conditions, temp-34C, hum-24%, hpa-979, wnd dir-100 @ 1 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:37:18        31.15         Green           911.1              11.1      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
checked nip allignment adjusted some for afternoon sun angle. temp-35C, hum-26%, hpa-978, wnd dir-100 @ 2
mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:58:31        35.13         Green           898.6              11.7      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
a few small cirrus in the area, temp-35C, hum-25%, hpa-977, wnd dir-080 @ 11mph
==========================================================================================================
Session: 42
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-23-2006     15:17:49       16:18:52       29222          08:40            963.7          963.8
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
15:29:24        41.10         Green           874.3              12.7      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
clear with a few small cirrus in the ares, temp-35C, hum-27%, hpa-977, wnd dir-130 @ 2 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
15:50:48        45.34         Green           862.1              13.2      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
starting to get a few reference alarms, temp-35C, hum-26, hpa-977, wnd dir-070 @ 8 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
16:10:57        49.36         Green           837.0              14.0      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
no change in sky conditions, temp-35C, hum-26%, hpa-977, wnd dir-120 @ 6 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
16:13:14        49.82         Green           826.0              14.6      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments: [None]
==========================================================================================================
Session: 43
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-23-2006     16:18:52       17:18:54       29222          08:40            963.8          963.5
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
16:33:25        53.86         Green           819.7              14.7      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
```

Comments:
clear temp-35C, hum-25%, hpa977, wnd dir-110 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:53:30	57.88	Green	812.4	15.2	Craig Webb Rod Soper

Comments:
light haze on the horzin and a few small cirrus in area, temp-34C, hum-25%, hpa-977, wnd dir-140 @ 8 mph.
getting a few reference alarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:07:16	60.65	Brown	780.7	16.5	Craig Webb Rod Soper

Comments: [None]

Session: 44

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	17:18:54	18:19:56	29222	08:40	963.5	963.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:27:50	64.75	Green	749.4	18.0	Craig Webb Rod Soper

Comments:
some light cirrus and haze on the horzin, temp-34C, hum-26%, hpa-976, wnd dir-110 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:00:13	71.15	Green	666.6	22.8	Craig Webb Rod Soper

Comments:
clear with a haze on the horzin, temp-33C, hum-28%, hpa-976, wnd dir-090 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:12:17	73.52	Red	172.6	52.6	Craig Webb Rod Soper

Comments:
cloud moved in and blocked the sun,

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:17:37	74.53	Red	277.5	40.6	Craig Webb Rod Soper

Comments:
going to closefor today because the haze and cloud bank are shutting borcal down.

Session: 45

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2006	18:19:56	18:21:22	29222	08:40	963.9	963.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:20:23	74.58	4	206.0	47.7	Craig Webb Rod Soper

Comments: [None]

Session: 46

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-30-2006	08:35:41	09:37:44	29222	08:15	966.5	965.2

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:55:53	51.37	Green	827.2	13.9	Craig Webb Rod Soper

Comments:
Clear with haze on the horzin to the east and southeast. some contrails, temp-31C, hum-55%, hpa-975, wnd dir-190 @ 22 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:15:57	47.38	Green	844.3	13.1	Craig Webb Rod Soper

Comments:
clouds starting to form to the north west, most of the haze has dissappeared at this time. temp-32C, hum-51%, hpa-975, wnd dir-200 @ 19 mph. Birs tring to nest under the north west table.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:37:26	43.51	Green	860.8	12.6	Craig Webb Rod Soper

Comments:
clouds to the northwest getting closer, temp-

Session: 47

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-30-2006	09:37:44	10:40:46	29222	08:15	965.2	964.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:57:32	39.24	Green	868.2	12.2	Craig Webb Rod Soper

Comments:
clouds to the north east moving a little closer, temp-33C, hum-46%, hpa-974, wnd dir-210 @ 24 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:17:36	35.43	Blue	876.0	12.1	Craig Webb Rod Soper

Comments:
clear with some clouds to the north, windy, temp-33C, hum-49%, hpa-974, wnd dir-210 @ 17 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:37:57	31.72	Blue	883.9	11.7	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-34C, hum-45%, hpa-974, wnd dir-210 @ 18

Session: 48

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-30-2006	10:40:46	11:36:49	29222	08:15	964.3	963.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:58:34	28.14	Green	890.1	11.5	Craig Webb Rod Soper

Comments:
clear with a few thin cirrus to the north, temp-34C, hum-43%, hpa0974, wnd dir-200 @ 21 mph.

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Time	Zenith	ASR	Direct	% Diffuse	Operator
11:19:31	24.82	Green	897.9	11.7	Craig Webb Rod Soper

Comments:
Clouds are closing in on the RCF will be shutting down in about 45 minutes to 1 hour. temp-35C, hum-41% ,hpa-974, wnd dir-210 @ 20 mph. some alrams dur to light cirrus forming.

Session: 49

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-30-2006	11:36:49	11:39:29	29222	08:15	963.5	963.5

Observations: [None]

Session: 50

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	05:59:59	07:00:02	29222	05:30	967.0	966.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:06:29	84.84	Green	260.6	53.4	Craig Webb Rod Soper

Comments:
Clear with a light haze on horzin and several contrails to the south, temp-26C, hum-68%, hpa-971, wnd dir-180 @ 7 mph. several alrams

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:26:41	81.04	Green	392.6	39.8	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-27C, hum-66%, hpa-971, wnd dir-170 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:46:52	77.14	Green	507.0	31.4	Craig Webb Rod Soper

Comments:
Clear with soome contrails to the south and east. temp-28C, hum-63%, hpa-971, wnd dir-180 @ 10 mph. alarms

Session: 51

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	07:00:02	08:00:05	29222	05:30	966.3	965.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:07:26	73.13	Green	596.3	26.0	Craig Webb Rod Soper

Comments:
contrail about to come between sun and cavity, temp-28C, hum-62%, hpa-972, wnd dir-190 @ 19 mph. alarms STD, REF, TST.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:31:43	68.33	Green	671.1	21.7	Craig Webb Rod Soper

Comments:
clear with some contrails to the south, temp-29C, hum-61%, hpa-972, wnd dir-190 @ 22 mph.

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Time	Zenith	ASR	Direct	% Diffuse	Operator
07:51:52	64.31	Green	715.3	19.4	Craig Webb Rod Soper

Comments:
windy and hot, clear, temp-30C, hum-60%, hpa-972, wnd dir-190 @ 18 mph.

Session: 52

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	08:00:05	09:00:06	29222	05:30	965.8	965.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:12:13	60.24	Green	752.6	17.6	Craig Webb Rod Soper

Comments:
contrail just caused a red ASR alarm, temp-30C, hum-58%, hpa-972, wnd dir-200 @ 28 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:32:28	56.19	Green	787.5	15.8	Craig Webb Rod Soper

Comments:
getting a few ref alarms, temp-31C, hum-56, hpa-972, wnd dir-190 @ 22 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:55:28	51.57	Green	809.0	14.8	Craig Webb Rod Soper

Comments:
a few contrails through the sky, temp-31C, hum-55%, hpa-972, wnd dir-190 @ 26 mph.

Session: 53

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	09:00:06	10:00:07	29222	05:30	965.1	964.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:15:59	47.50	Green	829.9	14.0	Craig Webb Rod Soper

Comments:
hot and windy, clear and some contrails, temp-32C, hum-54%, hpa-972, wnd dir-200 @ 16 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:36:27	43.47	Green	845.9	13.3	Craig Webb Rod Soper

Comments:
somr cirrus forming south of RCF, a few small contrails in area, temp-33C, hum-51%, hpa-972, wnd dir-190 @ 20 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:48:19	41.15	Green	855.0	12.9	Craig Webb Rod Soper

Comments: [None]

Session: 54

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	10:00:07	10:57:08	29222	05:30	964.3	963.7

```
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
10:08:29        37.29         Green           870.4              12.2      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
some small contrails and light cirrus to the south, temp-34C, hum-47%, hpa-972, wnd dir-200 @ 20 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
10:39:31        31.59         Green           889.1              11.4      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
looks like light cirrus forming to the south, and there is a few contrails floating the the sky, temp-35C,
hum-44%, hpa-971, wnd dir-180 @ 24 mph.  some alarms due to contrails.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
10:48:40        30.00         Green           889.4              11.4      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments: [None]
==========================================================================================================
Session: 55
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-31-2006     10:57:08       11:57:10       29222          05:30            963.7          963.3
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
11:09:12        26.59         Green           891.5              11.5      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
several contrails, windy, temp-35C, hum-43%, hpa-972, wnd dir-180 @ 20 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
11:29:33        23.58         Green           886.2              11.8      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
contrails with some cirrus forming to the southeast, temp-36C, hum-40%, hpa-971, wnd dir-210 @ 23 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
11:49:54        21.08         Green           871.9              12.8      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
several Brown ASR alarms, temp-36C, hum-40%, hps-971 win dir- 180 @ 18 mph.
==========================================================================================================
Session: 56
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-31-2006     11:57:10       12:57:11       29222          05:30            963.3          962.9
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
12:11:14        19.25         Green           906.8              10.7      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
Comments:
contrails with some cirrus to the south and east.,,temp-36C, hum-41%, hpa-971, wnd dir-170 @ 13 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
12:32:37        18.46         Green           909.1              10.3      Craig Webb
                                                                           Rod Soper
------------------------------------------------------------------------------------------
```

Comments:
contrails and light cirrus to the south and east, temp-37C, hum-38%, hpa-971, wnd dir-170 @ 19 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:52:52	18.80	Green	921.1	10.0	Craig Webb Rod Soper

Comments:
no change on sky conditions. temp-37C, hum-38%, hpa-971, wnd dir-190 @ 16 mph.

Session: 57

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	12:57:11	13:57:12	29222	05:30	962.9	962.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:07:16	19.66	Green	910.4	10.2	Craig Webb Rod Soper

Comments:
small cirrus starting to pop up through the sky, temp-37C, hum-35%, hpa-971, wnd dir-180 @ 21 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:12:42	20.10	Green	922.5	9.9	Craig Webb Rod Soper

Comments: [None]

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:32:48	22.24	Green	918.4	10.2	Craig Webb Rod Soper

Comments:
clouds still forming will run till brown and red ASR values. temp-38C, hum-34%, hpa-970, wnd dir-190 @ 20 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:52:51	24.97	Green	906.1	10.8	Craig Webb Rod Soper

Comments:
clouds seem to be incearsing, temp-38C, hum-34%, hpa-970, wnd dir-200 @ 16 mph. getting a lot more brown conditions.

Session: 58

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	13:57:12	14:53:15	29222	05:30	962.7	962.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:13:46	28.27	Green	910.6	11.2	Craig Webb Rod Soper

Comments:
two referance alarms in 20 minutes, clouds forming and moving in on RCF. temp-38C, hum-33%, hpa-970

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:34:02	31.76	Green	894.8	12.4	Craig Webb Rod Soper

Comments:
no change, temp-38C, hum-33%, hpa-970, wnd dir-180 @ 21 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:37:43	32.42	Green	882.7	12.7	Craig Webb Rod Soper

Comments: [None]

Session: 59

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2006	14:53:15	15:08:44	29222	05:30	962.4	962.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:59:01	36.34	Green	852.1	14.4	Craig Webb Rod Soper

Comments:
clouds getting thicker will have to stop during this sesssion due to clouds. temp-39C, hum-33%, hpa-970, wnd dir-190 @ 18 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:08:16	38.09	Red	817.5	15.4	Craig Webb Rod Soper

Comments:
clouds shut down borcal

Session: 60

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-05-2006	09:05:19	10:05:20	29222	08:30	966.6	964.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:26:07	46.15	Green	766.0	20.2	Craig Webb Rod Soper

Comments:
light haze on horzin with some llight cirrus to the north, temp-33C, hum-46%, hpa-976, wnd dir-210 @ 16 mph. Started late due to clouds and junk on horzin had to wait till it cleared.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:47:03	42.08	Green	804.8	17.7	Craig Webb Rod Soper

Comments:
no change in sky condition, temp-34C, hum-44%, hpa-976, wnd dir-210 15 mph. bug on 31151F3.

Session: 61

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-05-2006	10:05:20	11:02:21	29222	08:30	964.8	963.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:08:23	38.04	Green	822.1	16.6	Craig Webb Rod Soper

Comments:
clear with some light cirrus to the north, temp-35C, hum-41%, hpa-976, wnd dir-210 @ 16 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:28:43	34.31	Green	839.4	15.7	Craig Webb Rod Soper

Comments:
no chang in skky conditions, temp-35C, hum-40%, hpa-976, wnd dir-190 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:48:54	30.79	Green	857.7	14.6	Craig Webb Rod Soper

Comments:
clear temp-36C, hum-38%, hpa-976, wnd dir-220 @ 9 mph.

Session: 62

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-05-2006	11:02:21	12:02:23	29222	08:30	963.7	963.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:09:09	27.52	Green	866.1	14.0	Craig Webb Rod Soper

Comments:
31120E6 went into alarm signal went high everything checked good don't know why. clear, temp-36C, hum-36%, hpa-976, wnd dir-220 @ 8 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:29:28	24.60	Green	877.7	13.4	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-37C, hum-34%, hpa-976, wnd dir-210 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:49:59	22.20	Brown	880.8	13.1	Craig Webb Rod Soper

Comments:
light cirrus stating to for to the south, temp-37C, hum-32%, hpa-976, wnd dir-240 @ 7 mph.

Session: 63

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-05-2006	12:02:23	12:25:02	29222	08:30	963.1	962.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:11:29	20.47	Green	882.4	13.5	Craig Webb Rod Soper

Comments:
Clear sky with clouds starting to form in all quads. Temp. 38C., RH 32%, hpa 976, wind 5 mph. at 180.

Session: 64

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	06:02:47	07:02:48	29222	04:50	968.4	967.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:22:50	82.59	Green	179.4	66.1	Rod Soper

Comments:
Clear sky with light haze towards east. Temp. 24C., RH 77%, hpa 977, wind dir. 130 at 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:42:54	78.71	Green	306.2	51.8	Rod Soper

Comments:
Clear sky with light haze towards east. Temp. 25 C., RH 74%, hpa 977, wind dir. 160 at 1 mph.

Session: 65

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	07:02:48	08:02:50	29222	04:50	967.7	966.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:03:06	75.25	4	397.5	44.2	Rod Soper

Comments:
Clear sky with light haze towards east. Temp. 27C., RH 62%, hpa 977, wind dir. 160 at 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:23:15	70.77	Green	482.8	38.9	Rod Soper

Comments:
Clear sky, Temp. 28C., RH 56%, hpa 977, wind dir. 190 at 8 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:43:20	66.77	Red	323.5	53.6	Rod Soper

Comments:
Clear sky with light cirrus towards east. Temp. 29C., RH 53%, hpa 977, wind dir 190 at 8 mph.

Session: 66

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	08:02:50	09:02:51	29222	04:50	966.5	965.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:03:25	63.31	4	589.6	32.8	Rod Soper

Comments:
Clear sky with light cirrus towards east. Temp. 30C., RH 48%, hpa 978, wind dir. 210 at 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:23:30	58.74	Red	610.4	29.5	Rod Soper

Comments:
Clear sky with light cirrus towards east. Temp. 31C., RH 46%, hpa 978, wind dir. 200 at 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:45:00	54.43	Green	685.0	25.4	Rod Soper

Comments:
Clear sky with light cirrus towards north. Temp. 32C., RH 44%, hpa 978, wind dir. 200 at 13 mph.

Session: 67

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	09:02:51	10:03:52	29222	04:50	965.2	964.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:07:35	49.94	Green	724.3	23.0	Rod Soper

Comments:
Clear sky with light cirrus towards north. Temp. 33C., RH 43%, hpa 978, wind dir. 210 at 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:27:47	45.96	Green	743.1	22.1	Rod Soper

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Comments:
Clear sky with light cirrus towards north. Temp. 34C., RH 42%, hpa 978, wind dir. 230 at 11 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:47:59	42.05	Green	763.5	21.0	Rod Soper

Comments:
Clear sky ,Temp. 35C., RH 40%, hpa 978, wind dir. 190 at 15 mph.

Session: 68

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	10:03:52	11:03:55	29222	04:50	964.1	963.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:08:06	38.24	Green	778.9	20.1	Rod Soper

Comments:
Clear sky, Temp. 36C., RH 38%, hpa 978, wind dir. 200 at 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:28:14	34.56	Green	788.1	19.6	Rod Soper

Comments:
Clear sky, Temp. 36C., RH 37%, hpa 978, wind dir 210 at 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:48:22	31.06	Green	801.5	18.9	Rod Soper

Comments:
Clear sky, Temp. 37C., RH 33%, hpa 978, wiind dir. 210 at12 mph.

Session: 69

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	11:03:55	12:03:56	29222	04:50	963.2	962.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:08:33	27.80	Green	811.3	18.5	Rod Soper

Comments:
Clear sky , Temp. 38C .,RH 31%, hpa 978, wind dir. 180 at 9 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:29:02	24.87	Green	815.2	18.2	Rod Soper

Comments:
Clear sky with light cirrus sarting to form towards north. Temp. 39C., RH 30%, hpa 977, wind dir. 190 at 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:50:22	22.40	Red	812.5	18.5	Rod Soper

Comments:
Clear sky withclouds starting to form in all quads. Temp. 39C., RH 29%, hpa 977, wind dir. 170 at 6 mph.

Session: 70

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	12:03:56	13:03:59	29222	04:50	962.5	962.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:10:28	20.79	Green	830.5	17.7	Rod Soper

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Comments:
Cirrus forming in all quads. Temp. 39C., RH 29%, hpa 977, wind dir. 210 at 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:30:41	20.05	Green	843.7	19.6	Rod Soper

Comments:
clouds starting to form and move in on the RCF, temp-39C, hum-29%, hpa-977, wnd dir-180 @ 9 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:50:48	20.29	Red	49.0	80.7	Rod Soper

Comments:
clouds everywhere, temp-38C, hum-30%, hpa-977, wnd dir-190 @ 3 mph.

Session: 71

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	13:03:59	14:02:01	29222	04:50	962.2	961.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:13:26	21.69	Red	822.8	24.9	Rod Soper

Comments:
Running to see if clouds clear out so we can get the late afternoon. temp-39C, hum-29%, hpa-977, wnd dir-170 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:33:29	23.75	Green	827.7	20.9	Rod Soper

Comments:
no change in sky conditions, temp-40C, hum-26%, hpa-977, wnd dir-150 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:44:40	25.16	Green	827.7	20.6	Rod Soper

Comments: [None]

Session: 72

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	14:02:01	15:00:03	29222	04:50	961.8	961.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:04:57	28.11	Green	821.3	19.4	Rod Soper

Comments:
clouds temp--41C, hum-26, hpa-976, wnd dir-180 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:25:17	31.41	Green	816.7	18.8	Rod Soper

Comments:
cloudy and hot, temp-40C, hum-26%, hpa-976, wnd dir-220 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:48:07	35.42	Green	803.3	19.3	Rod Soper

Comments:
no change in sky conditions, temp-41C, hum-25%, hpa-976, wnd dir-160 @ 3 mph.

Session: 73

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	15:00:03	16:00:05	29222	04:50	961.4	961.4

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:08:11	39.13	Green	816.8	20.1	Rod Soper

Comments:
taking data through the clouds, temp-40C, hum-25%, hpa-975, wnd dir-190 @ 9 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:28:53	43.08	Green	784.0	22.2	Rod Soper

Comments:
no change in sky conditions, temp-40C, hum-25%, hpa-975, wnd dir-220 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:50:45	47.34	Green	759.4	22.8	Rod Soper

Comments:
taking data through the clouds, temp-41C, hum-24%, hpa-975, wnd dir-200 @ 12 mph.

Session: 74

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	16:00:05	17:00:07	29222	04:50	961.4	961.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:10:57	51.33	Green	741.5	22.1	Rod Soper

Comments:
Still running through the clouds, temp-41C, hum-24%, hpa-975, wnd dir-170 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:31:05	55.34	Green	710.6	23.6	Rod Soper

Comments:
no change in sky conditions, temp-41C, hum-25%, hpa-975, wnd dir 210 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:51:34	59.45	Green	684.6	25.2	Rod Soper

Comments:
no change, temp-40C, hum-25%, hpa-975, wnd dir-210 @ 13 mph.

Session: 75

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	17:00:07	18:00:08	29222	04:50	961.0	961.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:12:04	63.57	Green	617.9	28.9	Rod Soper

Comments:
still runn with clouds through the sky, temp-41C, hum-24%, hpa-975, wnd dir-150 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:32:14	67.60	Blue	574.5	31.8	Rod Soper

Comments:
no change in sky conditions, temp-40C, hum-25%, hpa-975, wnd dir-200 @ 11 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:52:28	71.64	Green	503.1	36.7	Rod Soper

Comments:
starting to get alarms due to the haze on the horzin, temp-40C, hum-25%, hpa-975, wnd dir-210 @ 6 mph.

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Session: 76

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2006	18:00:08	18:57:15	29222	04:50	961.3	962.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:12:32	75.61	Green	425.2	42.7	Rod Soper

Comments:
no change in sky conditiond, temp-40C, huym-26%, hpa-975, wnd dir-15 @ 4 mph. getting a few alarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:33:22	79.68	Green	319.0	52.6	Rod Soper

Comments:
no change, temp-39C, hum-27%, hpa=975, wnd dir-150 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:53:55	83.63	Green	187.9	67.9	Rod Soper

Comments:
qutting for the day constant alarms, temp-38C, hum-29%, hpa-975, wnd dir-130 @ 5 mph.

Session: 77

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-07-2006	11:53:39	12:53:41	29222	11:25	965.7	963.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:14:00	20.86	Green	761.2	21.8	Craig Webb Rod Soper

Comments:
some very light cirrus in the area, temp-38C, hum-37%, hpa-981, wnd dir-150 @ 3 mph. running to try to get solar noon and the first part of the afternoon to replace yesterdays data.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:35:25	20.30	Green	778.9	21.2	Craig Webb Rod Soper

Comments:
some oight cirrus through the sky, temp-37C, hum-37%, hpa-980, wnd dir-170 @ 6 mph.

Session: 78

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-07-2006	12:53:41	13:46:14	29222	11:25	963.8	963.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:58:33	20.92	Green	770.5	21.8	Craig Webb Rod Soper

Comments:
somr light cirrus through the sky temp-38C, hum-35%, hpa-980, wnd dir-190 @ 9 mph. somr alarms dur to the haze

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:21:01	22.65	Green	758.2	23.4	Craig Webb Rod Soper

Comments:
no change in sky condition, temp-39C, hum-33%, hpa-980, wnd dir-140 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:41:36	25.00	Green	753.8	25.3	Craig Webb Rod Soper

Comments:
clouds moving in on RCF, will be shuting down, temp-39C, hum-32%, hpa-980, wnd dir-150 @ 30mph.

Session: 79

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-08-2006	07:40:51	08:42:52	29222	06:55	967.1	966.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:01:04	63.48	Green	643.7	24.9	Craig Webb Rod Soper

Comments:
didn't get an early start due to haze, dirt and clouds on the horzin. temp-28C, hum-75%, hpa-981, wnd dir-180 @ 6 mph. get several ref. alarms and some TST alarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:21:46	59.33	Green	686.9	22.6	Craig Webb Rod Soper

Comments:
getting several alarms due to sky conditions. Temp-28C, hum-73%, hpa-981, wnd dir-210 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:42:46	55.56	Green	710.5	21.8	Craig Webb Rod Soper

Comments: [None]

Session: 80

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-08-2006	08:42:52	09:43:54	29222	06:55	966.3	965.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:04:06	50.89	Green	733.9	20.6	Craig Webb Rod Soper

Comments:
fon the edge of an unstable sky, temp-29C, hum-96%, hpa-981, wnd dir-210 @ 8 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:24:47	46.83	Brown	758.1	19.3	Craig Webb Rod Soper

Comments:
closing at the end of this session due to shy condition. temp-30C, hum-65% hoa-981, wnd dir-200 @ 5 mph.

Session: 81

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-08-2006	09:43:54	09:47:16	29222	06:55	965.4	966.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:45:31	43.54	Green	781.7	18.2	Craig Webb Rod Soper

Comments:
quiting for the day too many alarms and light haze.

Session: 82

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-12-2006	06:17:13	07:17:15	29222	05:50	968.4	967.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:40:39	79.99	Green	367.9	43.0	Craig Webb

Comments:
light haze on horzin, temp-25C,hum-87%, hpa-974, wnd dir-130 @ 3 mph getting lots of alarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:00:52	76.01	Green	482.6	34.0	Craig Webb

Comments:
no change in sky cindition, temp-26C, hum-83%, hpa-974, wnd dir-130 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:06:13	74.95	Green	515.8	31.9	Craig Webb

Comments: [None]

Session: 83

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-12-2006	07:17:15	08:17:16	29222	05:50	967.5	966.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:26:25	70.93	Green	592.2	27.0	Craig Webb

Comments:
clrar with some light cirrus to the west, temp-27C, hum-76%, hpa-974, wnd dir-140 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:46:39	66.90	Green	653.2	23.7	Craig Webb

Comments:
no change in sky condition, temp-28C, hum-73%, hpa-974, wmd dir-130 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:07:29	62.72	Green	702.9	20.9	Craig Webb

Comments:
clear temp-29C, hum-70 hpa-974, wnd dir-130 @ 8 mph. bug on one instrument.

Session: 84

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-12-2006	08:17:16	09:17:19	29222	05:50	966.6	966.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:29:19	58.35	Green	746.7	18.7	Craig Webb

Comments:
clear witjh light cirrus to the west, ttemp--30, hum-70, hpa-974, wnd dir-120 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:50:14	54.20	Green	771.1	17.7	Craig Webb

Comments:
no change, temp-31C, hum-64%, hpa-974, wnd dir-120 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:11:27	49.99	Green	795.9	16.6	Craig Webb

Comments:
no change, temp-32C, hum-59%, hpa-974, Wni dir-130 @ 11 mph.

Session: 85

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-12-2006	09:17:19	10:18:21	29222	05:50	966.1	965.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:32:04	45.98	Green	804.5	16.4	Craig Webb

Comments:
clear with light cirrus to the west, temp-33C, hum-55%, hpa-974, win dir-100 @ 9 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:52:13	42.15	Green	823.7	15.6	Craig Webb

Comments:
no change in sky conditions, temp-24C, hum-54%, hpa-974, wnd dir-100 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:12:36	38.37	Green	834.0	15.0	Craig Webb

Comments:
clear with cirrus starting to form to the south and west, temp35C, hum-50%, hpa-974, wnd dir-120 @ 6 mph.

Session: 86

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-12-2006	10:18:21	11:20:24	29222	05:50	965.0	964.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:32:53	34.77	Green	845.7	14.3	Craig Webb

Comments:
clear with growing cirrus to the southweat, temp-36C, hum-48%, hpa-974, wnd dir-150 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:53:07	31.40	Green	838.6	14.5	Craig Webb

Comments:
no change in sky condition, temp-36C, hum-47%, hpa-974, wnd dir-120 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:13:22	28.34	Green	856.5	14.3	Craig Webb

Comments:
no change, temp-36C, hum-46%, hpa-974, wnd dir-160 @ 12 mph.

Session: 87

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-12-2006	11:20:24	12:11:26	29222	05:50	964.4	963.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:33:31	25.69	Green	861.6	16.0	Craig Webb

Comments:
clouds moving in from the southwest and causing some alarms, temp-36C, hum-44%, hpa-974, wnd dir-130 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:53:45	23.61	Brown	845.5	16.4	Craig Webb

Comments:
clouds seem to be growing will run to see they move out with the hour. temp-37C, hum-42%, hpa-974, wnd dir-130 @ 5 mph.

Session: 88

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-12-2006	12:11:26	13:02:40	29222	05:50	963.8	963.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:14:14	22.24	Brown	842.4	17.3	Craig Webb

Comments:
clouds are here, temo-
0, hum-41%, hpa-974, wnd dir-130 @5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:34:27	21.76	Green	859.6	18.3	Craig Webb

Comments:
will run to see if cluds move out, temp-38C, hum-39%, hpa-974, wnd dir-180 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:54:37	22.20	Red	831.0	20.4	Craig Webb

Comments:
no change, temp-38C hum-39%, hpa-974, wnd dir-140 @ 4 mph. several alarms due to clouds.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:59:45	22.45	Red	867.3	22.2	Craig Webb

Comments:
shutting down due to clouds being too thick,

Session: 89

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-13-2006	11:23:14	12:08:02	29222	11:00	966.1	964.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:43:56	24.80	Green	848.7	15.1	Craig Webb

Comments:
clear with some cirrus to the northwest, temp-37C, hum-38%, hpa-974, wnd dir-210 @ 19 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:04:03	23.10	Green	851.2	14.9	Craig Webb

Comments:
light haze in sky and clouds to the northwest, temp-37C, hum-38%, hpa-974, wnd dir-210 @ 17 mph. going to recalibrate early or it will do it at solar noon.

Session: 90

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-13-2006	12:08:02	12:39:34	29222	11:00	964.2	964.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:24:08	22.19	Brown	838.4	19.2	Craig Webb

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Comments:
clouds form through the sky going to close at end of session. temp-38C, hum-36%, hpa-974, wnd dir-210 @ 13 mph.

Session: 91

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2006	07:51:17	08:17:14	29222	07:27	967.9	967.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:11:52	63.37	Green	614.6	32.4	Craig Webb

Comments:
This is a test session after a rogram change to the RCC data base.

Session: 92

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2006	08:20:38	08:24:04	29222	07:27	967.7	967.7

Observations: [None]

Session: 93

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-30-2006	06:21:06	07:21:08	29222	05:51	970.0	971.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:42:07	82.28	Green	432.2	37.4	Craig Webb Rod Soper

Comments:
clear with haze on the horzin, some clouds to the southwest, temp-15C, hum-99%, hpa-981, wnd dir-270 @ 4 mph. Condensation on domes of the unvented PSP. lots of alarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:02:12	78.31	Green	558.6	29.1	Craig Webb Rod Soper

Comments:
no change in sky condition, temp-16C, hum-99%, hpa-981, wnd dir-270 @ 3 mph STD alarms and a few Ref.

Session: 94

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-30-2006	07:21:08	08:21:10	29222	05:51	971.2	970.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:22:17	74.96	Green	614.1	27.1	Craig Webb Rod Soper

Comments:
a small band of clouds seem to be move/forming above the RCF at this time. temp-17C, hum-99%, hpa-981, wnd dir-250 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:42:28	70.26	Green	673.6	22.9	Craig Webb Rod Soper

Comments:
some lite cirrus in area temp-18C, hum-99%, hpa-981, wnd dir-300 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:02:50	66.20	Green	710.4	22.0	Craig Webb Rod Soper

Comments:
no change in sky conditions, temp-19C, hum-91%, hpa0981, wnd dir-260 @ 4 mph.

Session: 95

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-30-2006	08:21:10	08:35:39	29222	05:51	970.9	970.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:22:55	62.22	Green	742.7	21.5	Craig Webb Rod Soper

Comments:
clouds forming to the south and west and seem to be moving this way, temp-20C, hum-84%, hpa-981, wnd dir-260 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:32:15	60.38	Red	728.3	25.3	Craig Webb Rod Soper

Comments:
shutting down due to clouds converging on the RCF.