

ENCYCLOPEDIA *of* REMOTE SENSING

Encyclopedia of Earth Sciences Series

ENCYCLOPEDIA OF REMOTE SENSING

Volume Editor

Eni G. Njoku is a Senior Research Scientist at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA. He has a B.A. from the University of Cambridge, and S.M. and Ph.D. from the Massachusetts Institute of Technology. His research focuses on spaceborne microwave sensing with application to land surface hydrology and the global water cycle. Amongst his awards are the NASA Exceptional Service Medal (1985) and Fellow of the Institute of Electrical and Electronics Engineers (1995).

Section Editors

Michael J. Abrams
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA

Vincent V. Salomonson
Department of Geography
University of Utah
Salt Lake City, UT 84112
USA

Ghassem R. Asrar
World Climate Research Programme
World Meteorological Organization
1211 Geneva
Switzerland

Vernon H. Singhroy
Canada Centre for Remote Sensing
Ottawa
Ontario K1A 0Y7
Canada

Frank S. Marzano
Department of Information Engineering
Sapienza University of Rome
00184 Rome, Italy
and Centre of Excellence CETEMPS
University of L'Aquila
67100 L'Aquila
Italy

F. Joseph Turk
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA

Peter J. Minnett
Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science
University of Miami
Miami, FL 33149
USA

Aims of the Series

The *Encyclopedia of Earth Sciences Series* provides comprehensive and authoritative coverage of all the main areas in the Earth Sciences. Each volume comprises a focused and carefully chosen collection of contributions from leading names in the subject, with copious illustrations and reference lists.

These books represent one of the world's leading resources for the Earth Sciences community. Previous volumes are being updated and new works published so that the volumes will continue to be essential reading for all professional earth scientists, geologists, geophysicists, climatologists, and oceanographers as well as for teachers and students. See the back of this volume for a current list of titles in the *Encyclopedia of Earth Sciences Series*. Go to <http://www.springerlink.com/reference-works/> and springerreference.com to visit the "Earth Sciences Series" on-line.

About the Series Editor

Professor Charles W. Finkl has edited and/or contributed to more than eight volumes in the Encyclopedia of Earth Sciences Series. For the past 25 years he has been the Executive Director of the Coastal Education & Research Foundation and Editor-in-Chief of the international *Journal of Coastal Research*. In addition to these duties, he is Professor at Florida Atlantic University in Boca Raton, Florida, USA. He is a graduate of the University of Western Australia (Perth) and previously worked for a wholly owned Australian subsidiary of the International Nickel Company of Canada (INCO). During his career, he acquired field experience in Australia; the Caribbean; South America; SW Pacific islands; southern Africa; Western Europe; and the Pacific Northwest, Midwest, and Southeast USA.

Founding Series Editor

Professor Rhodes W. Fairbridge (deceased) has edited more than 24 Encyclopedias in the Earth Sciences Series. During his career he has worked as a petroleum geologist in the Middle East, been a WW II intelligence officer in the SW Pacific and led expeditions to the Sahara, Arctic Canada, Arctic Scandinavia, Brazil and New Guinea. He was Emeritus Professor of Geology at Columbia University and was affiliated with the Goddard Institute for Space Studies.

ENCYCLOPEDIA OF EARTH SCIENCES SERIES

ENCYCLOPEDIA *of* REMOTE SENSING

edited by

ENI G. NJOKU

*Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
USA*

 **Springer** Reference

Library of Congress Control Number: 2013953424

ISBN 978-0-387-36698-2

This publication is available also as:

Electronic publication under ISBN 978-0-387-36699-9 and

Print and electronic bundle under ISBN 978-0-387-36700-2

Springer New York, Heidelberg, Dordrecht, London

Printed on acid-free paper

Cover photo: Cloud formations over the western Aleuthian Islands, taken by Landsat 7, 1 June 2000.
Credit: US Geological Survey, Earth Resources Observation and Science (EROS) Center.

Every effort has been made to contact the copyright holders of the figures and tables which have been reproduced from other sources. Anyone who has not been properly credited is requested to contact the publishers, so that due acknowledgment may be made in subsequent editions.

All rights reserved for the contributions *Aerosols; Air Pollution; Atmospheric General Circulation Models; Calibration and Validation; Calibration, Optical/Infrared Passive Sensors; Calibration, Synthetic Aperture Radars; Cloud Properties; Data Processing, SAR Sensors; Earth System Models; Emerging Technologies; Emerging Technologies, Free-Space Optical Communications; Emerging Technologies, Radar; Emerging Technologies, Radiometer; Geodesy; Geomorphology; Geophysical Retrieval, Forward Models in Remote Sensing; Geophysical Retrieval, Inverse Problems in Remote Sensing; Geophysical Retrieval, Overview; GPS, Occultation Systems; Ionospheric Effects on the Propagation of Electromagnetic Waves; Irrigation Management; Land Surface Roughness; Land-Atmosphere Interactions, Evapotranspiration; Lidar Systems; Limb Sounding, Atmospheric; Madden-Julian Oscillation (MJO); Mission Costs of Earth-Observing Satellite; Ocean Surface Topography; Ocean-Atmosphere Water Flux and Evaporation; Precision Agriculture; Reflected Solar Radiation Sensors, Multiangle Imaging; Reflected Solar Radiation Sensors, Polarimetric; Sea Level Rise; Sea Surface Wind/Stress Vector; Solid Earth Mass Transport; Stratospheric Ozone; Terrestrial Snow; Thermal Radiation Sensors (Emitted); Trace Gases, Stratosphere, and Mesosphere; Urban Environments, Beijing Case Study; Volcanism; Water Vapor*

© Springer Science+Business Media New York 2014

No part of this work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording or otherwise, without written permission from the Publisher, with the exception of any material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work.

Contents

Contributors	xi	Calibration, Optical/Infrared Passive Sensors	47
Preface	xxiii	<i>Carol Bruegge</i>	
Acknowledgments	xxv	Calibration, Synthetic Aperture Radars	51
Acoustic Radiation	1	<i>Anthony Freeman</i>	
<i>Alain Weill</i>		Calibration, Scatterometers	54
Acoustic Tomography, Ocean	4	<i>David Long</i>	
<i>Brian Dushaw</i>		Climate Data Records	58
Acoustic Waves, Propagation	11	<i>Eric F. Wood</i>	
<i>Alain Weill</i>		Climate Monitoring and Prediction	58
Acoustic Waves, Scattering	13	<i>Mathew R. P. Sapiano</i>	
<i>Alain Weill</i>		Cloud Liquid Water	68
Aerosols	16	<i>Fuzhong Weng</i>	
<i>Ralph Kahn</i>		Cloud Properties	70
Agricultural Expansion and Abandonment	20	<i>Matthew Lebsock and Steve Cooper</i>	
<i>Jiaguo Qi</i>		Coastal Ecosystems	73
Agriculture and Remote Sensing	22	<i>Xiaojun Yang</i>	
<i>Jerry Hatfield and Susan Moran</i>		Commercial Remote Sensing	78
Air Pollution	32	<i>William Gail</i>	
<i>Annmarie Eldering</i>		Cosmic-Ray Hydrometeorology	83
Atmospheric General Circulation Models	35	<i>Darin Desilets and Marek Zreda</i>	
<i>Joao Teixeira, Mark Taylor, Anders Persson</i>		Cost Benefit Assessment	86
<i>and Georgios Matheou</i>		<i>Molly Macauley</i>	
Calibration and Validation	39	Crop Stress	88
<i>Andreas Colliander</i>		<i>Susan Moran</i>	
Calibration, Microwave Radiometers	46	Cryosphere and Polar Region Observing System	91
<i>Christopher Ruf</i>		<i>Mark Drinkwater</i>	

vi	CONTENTS	
Cryosphere, Climate Change Effects <i>Aixue Hu</i>	98	Emerging Technologies, Radiometer <i>Todd Gaier</i> 186
Cryosphere, Climate Change Feedbacks <i>Peter J. Minnett</i>	101	Emerging Technologies, Sensor Web <i>Mahta Moghaddam, Agnelo Silva and Mingyan Liu</i> 190
Cryosphere, Measurements and Applications <i>Roger Barry</i>	104	Environmental Treaties <i>Alexander de Sherbinin</i> 196
Data Access <i>Ron Weaver</i>	119	Fields and Radiation <i>Frank S. Marzano</i> 201
Data Archival and Distribution <i>Mark A. Parsons</i>	121	Fisheries <i>Cara Wilson</i> 202
Data Archives and Repositories <i>Ruth Duerr</i>	127	Forestry <i>Dar Roberts</i> 210
Data Assimilation <i>Dennis McLaughlin</i>	131	Gamma and X-Radiation <i>Enrico Costa and Fabio Muleri</i> 219
Data Policies <i>Ray Harris</i>	134	Geodesy <i>Calvin Klatt</i> 228
Data Processing, SAR Sensors <i>Jakob van Zyl</i>	136	Geological Mapping Using Earth's Magnetic Field <i>Vernon H. Singhroy and Mark Pilkington</i> 232
Decision Fusion, Classification of Multisource Data <i>Björn Waske and Jón Atli Benediktsson</i>	140	Geomorphology <i>David Pieri</i> 237
Earth Radiation Budget, Top-of-Atmosphere Radiation <i>Bing Lin</i>	145	Geophysical Retrieval, Forward Models in Remote Sensing <i>Eugene Ustinov</i> 241
Earth System Models <i>Andrea Donnellan</i>	146	Geophysical Retrieval, Inverse Problems in Remote Sensing <i>Eugene Ustinov</i> 247
Electromagnetic Theory and Wave Propagation <i>Yang Du</i>	150	Geophysical Retrieval, Overview <i>Eugene Ustinov</i> 251
Emerging Applications <i>William Gail</i>	159	Global Climate Observing System <i>Jean-Louis Fellous</i> 254
Emerging Technologies <i>Jason Hyon</i>	162	Global Earth Observation System of Systems (GEOSS) <i>Steffen Fritz</i> 257
Emerging Technologies, Free-Space Optical Communications <i>Hamid Hemmati</i>	163	Global Land Observing System <i>Johannes A. Dolman</i> 261
Emerging Technologies, Lidar <i>David M. Tratt</i>	177	Global Programs, Operational Systems <i>Mary Kicza</i> 263
Emerging Technologies, Radar <i>Alina Moussessian</i>	185	GPS, Occultation Systems <i>Chi O. Ao</i> 264

CONTENTS		vii
Ice Sheets and Ice Volume <i>Robert Thomas</i>	269	Microwave Dielectric Properties of Materials <i>Martti Hallikainen</i> 364
Icebergs <i>Donald L. Murphy</i>	281	Microwave Horn Antennas <i>Yahya Rahmat-Samii</i> 375
International Collaboration <i>Lisa Robock Shaffer</i>	284	Microwave Radiometers <i>Niels Skou</i> 382
Ionospheric Effects on the Propagation of Electromagnetic Waves <i>Attila Komjathy</i>	286	Microwave Radiometers, Conventional <i>Niels Skou</i> 386
Irrigation Management <i>Steven R. Evett, Paul D. Colaizzi, Susan A. O'Shaughnessy, Douglas J. Hunsaker and Robert G. Evans</i>	291	Microwave Radiometers, Correlation <i>Christopher Ruf</i> 389
		Microwave Radiometers, Interferometers <i>Manuel Martin-Neira</i> 390
Land Surface Emissivity <i>Alan Gillespie</i>	303	Microwave Radiometers, Polarimeters <i>David Kunkee</i> 395
Land Surface Roughness <i>Thomas Farr</i>	311	Microwave Subsurface Propagation and Scattering <i>Alexander Yarovoy</i> 398
Land Surface Temperature <i>Alan Gillespie</i>	314	Microwave Surface Scattering and Emission <i>David R. Lyzenga</i> 403
Land Surface Topography <i>G. Bryan Bailey</i>	320	Mission Costs of Earth-Observing Satellites <i>Randall Friedl and Stacey Boland</i> 405
Land-Atmosphere Interactions, Evapotranspiration <i>Joshua B. Fisher</i>	325	Mission Operations, Science Applications/Requirements <i>David L. Glackin</i> 407
Landslides <i>Vernon H. Singhroy</i>	328	Observational Platforms, Aircraft, and UAVs <i>Jeffrey Myers</i> 409
Law of Remote Sensing <i>Joanne Irene Gabrynowicz</i>	332	Observational Systems, Satellite <i>David L. Glackin</i> 412
Lidar Systems <i>Robert Menzies</i>	334	Ocean Applications of Interferometric SAR <i>Roland Romeiser</i> 426
Lightning <i>Rachel I. Albrecht, Daniel J. Cecil and Steven J. Goodman</i>	339	Ocean Data Telemetry <i>Michael R. Prior-Jones</i> 429
Limb Sounding, Atmospheric <i>Nathaniel Livesey</i>	344	Ocean Internal Waves <i>Werner Alpers</i> 433
Madden-Julian Oscillation (MJO) <i>Baijun Tian and Duane Waliser</i>	349	Ocean Measurements and Applications, Ocean Color <i>Samantha Lavender</i> 437
Magnetic Field <i>Nils Olsen</i>	358	Ocean Modeling and Data Assimilation <i>Detlef Stammer</i> 446
Media, Electromagnetic Characteristics <i>Yang Du</i>	362	Ocean Surface Topography <i>Lee-Lueng Fu</i> 455

viii	CONTENTS	
Ocean Surface Velocity <i>Bertrand Chapron, Johnny Johannessen and Fabrice Collard</i>	461	Radiation (Natural) Within the Earth's Environment <i>Anthony England</i> 558
Ocean, Measurements and Applications <i>Ian Robinson</i>	469	Radiation Sources (Natural) and Characteristics <i>Anthony England</i> 574
Ocean-Atmosphere Water Flux and Evaporation <i>W. Timothy Liu and Xiaosu Xie</i>	480	Radiation, Electromagnetic <i>Frank S. Marzano</i> 576
Operational Transition <i>Richard Anthes</i>	489	Radiation, Galactic, and Cosmic Background <i>David M. Le Vine</i> 581
Optical/Infrared, Atmospheric Absorption/ Transmission, and Media Spectral Properties <i>Gian Luigi Liberti</i>	492	Radiation, Multiple Scattering <i>Frank S. Marzano</i> 585
Optical/Infrared, Radiative Transfer <i>Knut Stamnes</i>	495	Radiation, Polarization, and Coherence <i>Yang Du</i> 588
Optical/Infrared, Scattering by Aerosols and Hydrometeors <i>Gian Luigi Liberti</i>	498	Radiation, Solar and Lunar <i>David M. Le Vine</i> 591
Pattern Recognition and Classification <i>Björn Waske and Jón Atli Benediktsson</i>	503	Radiation, Volume Scattering <i>Leung Tsang and Kung-Hau Ding</i> 595
Polar Ice Dynamics <i>James Maslanik</i>	509	Radiative Transfer, Solution Techniques <i>Rodolfo Guzzi</i> 606
Polar Ocean Navigation <i>Lawson Brigham</i>	512	Radiative Transfer, Theory <i>Frank S. Marzano</i> 624
Policies and Economics <i>Roberta Balstad</i>	515	Radio-Frequency Interference (RFI) in Passive Microwave Sensing <i>David Kunke</i> 634
Precision Agriculture <i>Kelly Thorp</i>	515	Rainfall <i>Ralph Ferraro</i> 640
Processing Levels <i>Ron Weaver</i>	517	Rangelands and Grazing <i>Hunt E. Raymond, Jr.</i> 653
Public-Private Partnerships <i>William Gail</i>	520	Reflected Solar Radiation Sensors, Multiangle Imaging <i>David J. Diner</i> 658
Radar, Altimeters <i>Keith Raney</i>	525	Reflected Solar Radiation Sensors, Polarimetric <i>David J. Diner</i> 663
Radar, Scatterometers <i>David Long</i>	532	Reflector Antennas <i>Yahya Rahmat-Samii</i> 668
Radar, Synthetic Aperture <i>Keith Raney</i>	536	Remote Sensing and Geologic Structure <i>Vernon H. Singhroy and Paul Lowman</i> 681
Radars <i>Keith Raney</i>	547	Remote Sensing, Historical Perspective <i>Vincent V. Salomonson</i> 684

	CONTENTS	ix
Remote Sensing, Physics and Techniques <i>David L. Glackin</i>	691	Terrestrial Snow <i>Son V. Nghiem, Dorothy K. Hall, James L. Foster and Gregory Neumann</i> 821
Resource Exploration <i>Fred A. Kruse and Sandra L. Perry</i>	702	Thermal Radiation Sensors (Emitted) <i>Simon Hook</i> 830
SAR-Based Bathymetry <i>Han Wensink and Werner Alpers</i>	719	Trace Gases, Stratosphere, and Mesosphere <i>Nathaniel Livesey</i> 834
Sea Ice Albedo <i>Donald Perovich</i>	722	Trace Gases, Troposphere - Detection from Space <i>Pieter F. Levelt, J. P. Veefkind and K. F. Boersma</i> 838
Sea Ice Concentration and Extent <i>Josefino C. Comiso</i>	727	Trafficability of Desert Terrains <i>Charles Hibbitts</i> 846
Sea Level Rise <i>Josh Willis</i>	743	Tropospheric Winds <i>Chris Velden</i> 849
Sea Surface Salinity <i>Gary Lagerloef</i>	747	Ultraviolet Remote Sensing <i>Arlin Krueger</i> 853
Sea Surface Temperature <i>Peter J. Minnett</i>	754	Ultraviolet Sensors <i>Arlin Krueger</i> 860
Sea Surface Wind/Stress Vector <i>W. Timothy Liu and Xiaosu Xie</i>	759	Urban Environments, Beijing Case Study <i>Son V. Nghiem, Alessandro Sorichetta, Christopher D. Elvidge, Christopher Small, Deborah Balk, Uwe Deichmann and Gregory Neumann</i> 869
Severe Storms <i>Charles A. III Doswell</i>	767	Urban Heat Island <i>Lela Prashad</i> 878
Snowfall <i>Ralf Bennartz</i>	780	Vegetation Indices <i>Alfredo Huete</i> 883
Soil Moisture <i>Yann Kerr</i>	783	Vegetation Phenology <i>John Kimball</i> 886
Soil Properties <i>Alfredo Huete</i>	788	Volcanism <i>Michael J. Abrams</i> 890
Solid Earth Mass Transport <i>Erik Ivins</i>	791	Water and Energy Cycles <i>Taikan Oki and Pat J.-F. Yeh</i> 895
Stratospheric Ozone <i>Michelle Santee</i>	796	Water Resources <i>Taikan Oki and Pat J.-F. Yeh</i> 903
Subsidence <i>Stuart Marsh and Martin Culshaw</i>	800	Water Vapor <i>Eric Fetzer</i> 909
Surface Radiative Fluxes <i>Rachel T. Pinker</i>	806	Weather Prediction <i>Peter Bauer</i> 912
Surface Truth <i>Christopher Ruf</i>	815	Wetlands <i>John Melack</i> 921
Surface Water <i>Michael Durand</i>	816	Author Index 923
		Subject Index 925

Contributors

Michael J. Abrams
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
michael.j.abrams@jpl.nasa.gov

Rachel I. Albrecht
Divisão de Satélites e Sistemas Ambientais
(DSA/CPTEC), Instituto Nacional de Pesquisas
Espaciais (INPE)
12630-000 Cachoeira Paulista, SP
Brazil
rachel.albrecht@cptec.inpe.br

Werner Alpers
Institute of Oceanography
University of Hamburg
20146 Hamburg
Germany
alpers@ifm.uni-hamburg.de

Richard Anthes
University Corporation for Atmospheric Research
Boulder, CO 80301
USA
anthes@ucar.edu

Chi O. Ao
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
chi.o.ao@jpl.nasa.gov

G. Bryan Bailey
USGS Earth Resources Observation and Science Center
Sioux Falls, SD 57198
USA
gbbailey@mchsi.com

Deborah Balk
School of Public Affairs, Baruch College
City University of New York
New York, NY
USA
deborah.balk@baruch.cuny.edu

Roberta Balstad
CIESIN
Columbia University
Palisades, NY 10964
USA
roberta@ciesin.columbia.edu

Roger Barry
National Snow and Ice Data Center
NSIDC 449 UCB
University of Colorado
Boulder, CO 80309-0449
USA
rbarry@nsidc.org

Peter Bauer
European Centre for Medium-Range Weather Forecasts
(ECMWF)
Shinfield Park
Reading RG2 9AX
UK
peter.bauer@ecmwf.int

Jón Atli Benediktsson
Faculty of Electrical and Computer Engineering
University of Iceland
107 Reykjavik
Iceland
benedikt@hi.is

Ralf Bennartz
Atmospheric and Oceanic Sciences Department
University of Wisconsin-Madison
Madison, WI 53706-1481
USA
bennartz@aos.wisc.edu

K. F. Boersma
Koninklijk Nederlands Meteorologisch Instituut (KNMI)
3732 GK, De Bilt
The Netherlands
and
Technical University Eindhoven (TUE)
5612 AZ, Eindhoven
The Netherlands
k.j.boersma@tu.nl

Stacey Boland
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA

Lawson Brigham
University of Alaska
Fairbanks, AK 99775-5840
USA
lwb48@aol.com

Carol Bruegge
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
carol.j.bruegge@jpl.nasa.gov

Daniel J. Cecil
Marshall Space Flight Center (MSFC), National
Aeronautics and Space Administration (NASA)
Huntsville, AL 35805
USA
daniel.j.cecil@nasa.gov

Bertrand Chapron
Satellite Oceanography Laboratory, IFREMER
Plouzané 29280
France
bertrand.chapron@ifremer.fr

Paul D. Colaizzi
USDA-ARS Conservation and Production Research
Laboratory
Bushland, TX 79012
USA
paul.colaiizzi@ars.usda.gov

Fabrice Collard
CLS, Division Radar
Plouzané 29280
France
dr.fab@cls.fr

Andreas Colliander
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
andreas.colliander@jpl.nasa.gov

Josefino C. Comiso
Cryospheric Sciences Laboratory, Code 615
Earth Sciences Division, NASA Goddard Space
Flight Center
Greenbelt, MD 20771
USA
josefino.c.comiso@nasa.gov

Steve Cooper
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA

Enrico Costa
Istituto di Astrofisica e Planetologia Spaziali, INAF
00133 Rome
Italy
enrico.costa@iasf-roma.inaf.it

Martin Culshaw
Honorary Research Associate, British Geological Survey,
Keyworth
Nottingham NG12 1AE
UK
and
Honorary Visiting Professor, School of Civil Engineering,
University of Birmingham, Edgbaston
Birmingham B15 2TT
UK

Alexander de Sherbinin
Center for International Earth Science Information
Network (CIESIN)
Columbia University
Palisades, NY 10964
USA
adesherbinin@ciesin.columbia.edu

Uwe Deichmann
Development Research Group, The World Bank
Washington, DC
USA
udeichmann@worldbank.org

Darin Desilets
Hydroinnova LLC
Albuquerque, NM 87106
USA
darin@hydroinnova.com

David J. Diner
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
david.j.diner@jpl.nasa.gov

Kung-Hau Ding
Air Force Research Laboratory
Wright-Patterson AFB
Dayton, OH 45433
USA

Johannes A. Dolman
Department of Earth Sciences
VU University Amsterdam
1081 Amsterdam
The Netherlands
han.dolman@vu.nl

Andrea Donnellan
Science Division
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
andrea.donnellan@jpl.nasa.gov

Charles A. III Doswell
Doswell Scientific Consulting
Norman, OK 73071
USA
cdoswell@earthlink.net

Mark Drinkwater
Mission Science Division
European Space Agency, ESA/ESTEC
2201 AZ Noordwijk ZH
The Netherlands
mark.drinkwater@esa.int

Yang Du
Zhejiang University
310027 Hangzhou
People's Republic of China
zjydu03@zju.edu.cn

Ruth Duerr
National Snow and Ice Data Center, CIRES 449 UCB,
University of Colorado
Boulder, CO 80309
USA
rduerr@nsidc.org

Michael Durand
School of Earth Sciences
The Ohio State University
275 Mendenhall Laboratory
Columbus, OH 43210
USA
durand.8@osu.edu

Brian Dushaw
Applied Physics Laboratory
University of Washington
Seattle, WA 98105-6698
USA
dushaw@apl.washington.edu

Annmarie Eldering
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
annmarie.eldering@jpl.nasa.gov

Christopher D. Elvidge
Earth Observation Group, NOAA-NESDIS National
Geophysical Data Center E/GC2
Boulder, CO
USA
chris.elvidge@noaa.gov

Anthony England
College of Engineering
University of Michigan
Ann Arbor, MI 48109
USA
england@umich.edu

Robert G. Evans
USDA-ARS
Sidney, MT 59270
USA
robert.evans@ars.usda.gov

Steven R. Evett
USDA-ARS Conservation and Production Research
Laboratory
Bushland, TX 79012
USA
steve.evett@ars.usda.gov

Thomas Farr
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
thomas.g.farr@jpl.nasa.gov

Jean-Louis Fellous
Committee on Space Research (COSPAR) Secretariat
c/o CNES-2, place Maurice Quentin
75039 Paris
France
jean-louis.fellous@cosparhq.cnes.fr

Ralph Ferraro
NOAA/NESDIS, ESSIC/CICS
College Park, MD 20740
USA
ralph.r.ferraro@noaa.gov

Eric Fetzner
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
eric.j.fetzner@jpl.nasa.gov

Joshua B. Fisher
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
joshua.b.fisher@jpl.nasa.gov

James L. Foster
Hydrological Sciences Laboratory, Code 617
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD
USA
james.l.foster@nasa.gov

Anthony Freeman
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
anthony.freeman@jpl.nasa.gov

Randall Friedl
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
randall.r.friedl@jpl.nasa.gov

Steffen Fritz
International Institute for Applied Systems Analysis
2361 Laxenburg
Austria
fritz@iiasa.ac.at

Lee-Lueng Fu
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
llf@jpl.nasa.gov

Joanne Irene Gabrynowicz
National Center for Remote Sensing, Air, and Space Law
The University of Mississippi School of Law
Mississippi, MS 38677-1848
USA
jgabryno@olemiss.edu

Todd Gaier
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
todd.c.gaier@jpl.nasa.gov

William Gail
Global Weather Corporation
Boulder, CO 80303
USA
wb.gail@comcast.net

Alan Gillespie
Department of Earth and Space Sciences
University of Washington
Seattle, WA 98195
USA
gillespie@ess.washington.edu

David L. Glackin
Los Angeles, CA
USA

Steven J. Goodman
National Environmental Satellite, Data, and Information
Service (NESDIS), National Oceanic and Atmospheric
Administration (NOAA)
Silver Spring, MD 20910
USA
steven.j.goodman@noaa.gov

Rodolfo Guzzi
Agenzia Spaziale Italiana ASI
00133 Roma
Italy
rodolfoguzzi@yahoo.it

Dorothy K. Hall
Cryospheric Sciences Laboratory, Code 615
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
USA
dorothy.k.hall@nasa.gov

Martti Hallikainen
Aalto University
00076 Aalto Espoo
Finland
martti.hallikainen@aalto.fi

Ray Harris
Department of Geography
University College London
London WC1E 6BT
UK
ray.harris@ucl.ac.uk

Jerry Hatfield
National Laboratory for Agriculture and the Environment
Ames, IA 50011
USA
jerry.hatfield@ars.usda.gov

Hamid Hemmati
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
hamid.hemmati@jpl.nasa.gov

Charles Hibbitts
Applied Physics Laboratory
Laurel, MD 20723
USA
karl.hibbitts@jhuapl.edu

Simon Hook
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
simon.j.hook@jpl.nasa.gov

Aixue Hu
Climate and Global Dynamics Division
National Center for Atmospheric Research
Boulder, CO 80305
USA
ahu@ucar.edu

Alfredo Huete
Plant Functional Biology and Climate Change Cluster
Faculty of Science
University of Technology
2007 Sydney, NSW
Australia
alfredo.huete@uts.edu.au

Douglas J. Hunsaker
USDA-ARS
Maricopa, AZ 85138
USA
doug.hunsaker@ars.usda.gov

E. Raymond Hunt, Jr.
USDA-ARS Hydrology and Remote Sensing Laboratory
Beltsville, MD 20705
USA
raymond.hunt@ars.usda.gov

Jason Hyon
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
jason.j.hyon@jpl.nasa.gov

Erik Ivins
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 9109
USA
erik.r.ivins@jpl.nasa.gov

Johnny Johannessen
Nansen Environmental and Remote Sensing Center
5006 Bergen
Norway
johnny.johannessen@nersc.no

Ralph Kahn
NASA Goddard Space Flight Center
Greenbelt, MD 20771
USA
ralph.kahn@nasa.gov

Yann Kerr
CNES/CESBIO
31401 Toulouse
France
yann.kerr@cesbio.cnes.fr

Mary Kicza
National Oceanic and Atmospheric Administration
(NOAA)
Washington, DC 20230
USA
nina.jackson@noaa.gov

John Kimball
Flathead Lake Biological Station
University of Montana
Polson, MT 59860-6815
USA
johnk@ntsug.umt.edu

Calvin Klatt
Geodetic Survey Division
Natural Resources Canada
Ottawa, ON K1A 0E9
Canada
cklatt@nrcan.gc.ca

Attila Komjathy
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
attila.komjathy@jpl.nasa.gov

Arlin Krueger
Atmospheric Chemistry and Dynamics Laboratory
(Code 614)
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
USA
akrueger3@verizon.net

Fred A. Kruse
Physics Department and Remote Sensing Center
Naval Postgraduate School
Monterey, CA 93943
USA
fakruse@nps.edu

David Kunkee
The Aerospace Corporation
Los Angeles, CA 90009
USA
david.b.kunkee@aero.org

Gary Lagerloef
ESR
Seattle, WA 98121
USA
lager@esr.org

Samantha Lavender
Pixalytics Ltd
Plymouth, Devon PL6 8BX
UK
slavender@pixalytics.com

David M. Le Vine
Code 615, Cryospheric Sciences Branch
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
USA
david.m.levine@nasa.gov

Matthew Lebsack
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
matthew.d.lebsack@jpl.nasa.gov

Pieter F. Levelt
Koninklijk Nederlands Meteorologisch Instituut (KNMI)
3730 AE De Bilt
The Netherlands
and
Delft University of Technology
5612 AE Eindhoven
The Netherlands
pieter.f.levelt@knmi.nl

Gian Luigi Liberti
CNR/ISAC
00133 Rome
Italy
g.liberti@isac.cnr.it

Bing Lin
NASA Langley Research Center, MS 420
Hampton, VA 23681-2199
USA
bing.lin@nasa.gov

Mingyan Liu
Electrical and Computer Engineering
University of Michigan
Ann Arbor, MI 48109
USA

W. Timothy Liu
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
w.t.liu@jpl.nasa.gov

Nathaniel Livesey
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
nathaniel.j.livesey@jpl.nasa.gov

David Long
Department of Electrical and Computer Engineering
BYU Center for Remote Sensing
Brigham Young University
Provo, UT 84602
USA
long@byu.edu

Paul Lowman
NASA Goddard, Code 698.0
Greenbelt, MD 20771
USA
paul.d.lowman@nasa.gov

David R. Lyzenga
College of Engineering, Naval Architecture and Marine
Engineering
University of Michigan
Ann Arbor, MI 48109-2145
USA
lyzenga@umich.edu

Molly Macauley
Resources for the Future
Washington, DC 202-328-5043
USA
macauley@rff.org

Stuart Marsh
Nottingham Geospatial Institute
The University of Nottingham
Nottingham Geospatial Building, Triumph Road
Nottingham NG7 2TU
UK
ngi@nottingham.ac.uk

Manuel Martin-Neira
European Space Agency (ESA-ESTEC)
Keplerlaan 1
2200 Noordwijk
The Netherlands
manuel.martin-neira@esa.int

Frank S. Marzano
Department of Information Engineering
Sapienza University of Rome
00184 Rome
Italy
and
Centre of Excellence CETEMPS
University of L'Aquila
67100 L'Aquila
Italy
frank.marzano@uniroma1.it

James Maslanik
Department of Aerospace Engineering Sciences
University of Colorado, CCAR
Boulder, CO 80309
USA
jimm@colorado.edu

Georgios Matheou
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
georgios.matheou@jpl.nasa.gov

Dennis McLaughlin
Department of Civil and Environmental Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139
USA
dennism@mit.edu

John Melack
Department of Ecology, Evolution and Marine Biology
University of California
Santa Barbara, CA 93106
USA
melack@lifesci.ucsb.edu

Robert Menzies
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
robert.t.menzies@jpl.nasa.gov

Peter J. Minnett
Rosenstiel School of Marine and Atmospheric Science
University of Miami
Miami, FL 33149
USA
pminnett@rsmas.miami.edu

Mahta Moghaddam
Electrical Engineering – Electrophysics
University of Southern California
Los Angeles, CA 0089
USA
mahta@usc.edu

Susan Moran
USDA ARS Southwest Watershed Research Center
Tuscon, AZ 85719
USA
susan.moran@ars.usda.gov

Alina Moussessian
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
alina.moussessian@jpl.nasa.gov

Fabio Muleri
Istituto di Astrofisica e Planetologia Spaziali, INAF
00133 Rome
Italy
fabio.muleri@lasf-roma.inaf.it

Donald L. Murphy
International Ice Patrol, US Coast Guard
New London, CT 06320
USA
iipcomms@uscg.mil

Jeffrey Myers
NASA/Ames Research Center, Airborne Science and
Technology Laboratory
University of California, Santa Cruz
MS244-15
Moffett Field, CA 94035
USA
jmyers@mail.arc.nasa.gov

Gregory Neumann
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
gregory.neumann@jpl.nasa.gov

Son V. Nghiem
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
son.v.nghiem@jpl.nasa.gov

Taikan Oki
Institute of Industrial Science, University of Tokyo
153-8505 Tokyo
Japan
taikan@iis.u-tokyo.ac.jp

Nils Olsen
DTU Space
Technical University of Denmark
2800 Kgs. Lyngby
Denmark
nio@space.dtu.dk

Susan A. O'Shaughnessy
USDA-ARS Conservation and Production Research
Laboratory
Bushland, TX 79012
USA
susan.oshaughnessy@ars.usda.gov

Mark A. Parsons
Center for a Digital Society
Rensselaer Polytechnic Institute
Troy, NY 12180
USA
parsonsm@nsidc.org

Donald Perovich
USACE Cold Regions Research and Engineering
Laboratory
Hanover, NH 03755-1250
USA
donald.k.perovich@erdc.usace.army.mil

Sandra L. Perry
Perry Remote Sensing, LLC
Denver, CO 80231
USA
sandyp@rm.incc.net

Anders Persson
United Kingdom Meteorological Office
Exeter
Devon, EX1 3PB
UK

David Pieri
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
dave.pieri@jpl.nasa.gov

Mark Pilkington
Geological Survey of Canada
Ottawa, ON K1A 0E9
Canada
mark.pilkington@nrcan-rncan.gc.ca

Rachel T. Pinker
Department of Atmospheric and Oceanic Science
University of Maryland
College Park, MD 20742
USA
pinker@atmos.umd.edu

Lela Prashad
School of Earth and Space Exploration, 100 Cities Project
Arizona State University
Tempe, AZ 85287-1404
USA
lprashad@asu.edu

Christopher Ruf
Department of Atmospheric, Oceanic and Space Sciences
University of Michigan
Ann Arbor, MI 48109
USA
cruf@umich.edu

Michael R. Prior-Jones
British Antarctic Survey
Cambridge CB3 0ET
UK
michael@randominformation.co.uk

Vincent V. Salomonson
Department of Geography, University of Utah
South Jordan, UT 84095
USA
vincent.v.salomonson@nasa.gov

Jianguo Qi
Department of Geography/CGCEO
Michigan State University
East Lansing, MI 48823
USA
qi@msu.edu

Michelle Santee
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
michelle.l.santee@jpl.nasa.gov

Yahya Rahmat-Samii
Department of Electrical Engineering
University of California at Los Angeles
Los Angeles, CA 90095
USA
rahmat@ee.ucla.edu

Mathew R. P. Sapiano
University of Maryland - College Park
College Park, MD 20742
USA
msapiano@atmos.colostate.edu

Keith Raney
Applied Physics Laboratory
Johns Hopkins University
Laurel, MD 20723
USA
keith.raney@jhuapl.edu

Lisa Robock Shaffer
MC 0553 Rady School of Management
University of California, San Diego
La Jolla, CA 92093-0553
USA
lshaffer@ucsd.edu

Dar Roberts
Department of Geography
University of California
Santa Barbara, CA 93106
USA
dar@geog.ucsb.edu

Agnelo Silva
Electrical Engineering – Electrophysics
University of Southern California
Los Angeles, CA 0089
USA

Ian Robinson
Ocean and Earth Science
University of Southampton, at National Oceanography
Centre
Southampton SO14 3ZH
UK
isr@noc.soton.ac.uk

Vernon H. Singhroy
Applications Development Section
Natural Resources Canada
Canada Centre for Remote Sensing
Ottawa, ON K1A 0Y7
Canada
vern.singhroy@nrcan-rncan.gc.ca

Roland Romeiser
Rosenstiel School of Marine and Atmospheric Science
University of Miami
Miami, FL 33149-1031
USA
rromeiser@rsmas.miami.edu

Niels Skou
National Space Institute
Technical University of Denmark
2800 Lyngby
Denmark
ns@space.dtu.dk

Christopher Small
Lamont Doherty Earth Observatory
Marine Geology and Geophysics
Columbia University
Palisades, NY
USA
cs184@columbia.edu

Alessandro Sorichetta
Dipartimento di Scienze della Terra “A. Desio”
Universita’ degli Studi di Milano
20122 Milan
Italy
alessandro.sorichetta@unimi.it

Detlef Stammer
Institut für Meereskunde, Zentrum für Marine und
Atmosphärische Wissenschaften
Universität Hamburg
20146 Hamburg
Germany
detlef.stammer@zmaw.de

Knut Stamnes
Stevens Institute of Technology, Castle Point on Hudson
Hoboken, NJ 07030-5991
USA
kstamnes@stevens.edu

Mark Taylor
Sandia National Laboratory
Albuquerque, New Mexico 91109
USA
mataylor@sandia.gov

Joao Teixeira
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
teixeira@jpl.nasa.gov

Robert Thomas
Sigma Space
66-400 Gorzow Wlkp
Poland
robert_thomas@hotmail.com

Kelly Thorp
USDA-ARS U.S. Arid-Land Agricultural Research
Center
Maricopa, AZ 85138
USA
kelly.thorp@ars.usda.gov

Baijun Tian
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
baijun.tian@jpl.nasa.gov

David M. Tratt
The Aerospace Corporation
Los Angeles, CA 90009-2957
USA
dtratt@aero.org

Leung Tsang
Paul Allen Center
Department of Electrical Engineering
University of Washington
Seattle, WA 98195-2500
USA
leung@ee.washington.edu

Eugene Ustinov
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
eugene.a.ustinov@jpl.nasa.gov

Jakob van Zyl
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
jakob.j.vanzyl@jpl.nasa.gov

J. P. Veefkind
Koninklijk Nederlands Meteorologisch Instituut (KNMI)
3732 GK, De Bilt
The Netherlands
and
Eindhoven University of Technology
5612 AE Eindhoven
The Netherlands
veefkind@knmi.nl

Chris Velden
University of Wisconsin, CIMSS
Madison, WI 53706
USA
chrisv@ssec.wisc.edu

Duane Waliser
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 9109
USA
duane.e.waliser@jpl.nasa.gov

Björn Waske
Institute of Geodesy and Geoinformation
University of Bonn
53115 Bonn
Germany
wf@ipb.uni-bonn.de

Ron Weaver
National Snow and Ice Data Center, Cooperative Institute
for Research in Environmental Sciences
University of Colorado
Boulder, CO 80309-0449
USA
weaverr@kryos.colorado.edu

Alain Weill
Bur. Jussieu
LATMOS, Laboratoire Atmosphere Milieux
Observations Spatiales
75005 Paris
France
alain.weill@latmos.ipsl.fr

Fuzhong Weng
Center for Satellite Applications and Research (STAR)
National Oceanic and Atmospheric Administration
College Park, MD 20740
USA
fuzhong.weng@noaa.gov

Han Wensink
ARGOSS BV
8325ZH Vollenhove
The Netherlands
wensink@argoss.nl

Josh Willis
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
joshua.k.willis@jpl.nasa.gov

Cara Wilson
Southwest Fisheries Science Center
NOAA/NMFS, Environmental Research Division
Pacific Grove, CA 93950-2097
USA
cara.wilson@noaa.gov

Eric F. Wood
Department of Civil and Environmental Engineering
Princeton University
Princeton, NJ 08544
USA
efwood@princeton.edu

Xiaosu Xie
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
USA
xiaosu.xie@jpl.nasa.gov

Xiaojun Yang
Department of Geography
Florida State University
Tallahassee, FL 32306-2190
USA
xyang@fsu.edu

Alexander Yarovoy
Delft University of Technology
2628 CN Delft
The Netherlands
a.yarovoy@tudelft.nl

Pat J.-F. Yeh
Department of Civil and Environmental Engineering
National University of Singapore
117576 Singapore
Singapore
ceeyehj@nus.edu.sg

Marek Zreda
Department of Hydrology and Water Resources
University of Arizona
Tucson, AZ 85721
USA
marek@hwr.arizona.edu

Preface

During the past few decades, the emergence of remote sensing as a discipline – its science, instruments, missions, and applications – has inspired new and comprehensive studies of the Earth. Detailed observations of Earth's land, ocean and atmospheric processes, and measurements of hitherto unexplored geophysical phenomena have been made possible by remote sensing instruments on ground-based, airborne, and spaceborne platforms. In particular, the unique vantage point of space provides spatially extensive and global perspectives of Earth. Frequent measurements, made hourly, daily, or weekly, over extended periods of years to decades, depending on the observing system and its configuration, have enabled comprehensive studies of Earth's global system. Remote sensing has thus profoundly altered our understanding of the world in which we live, and has revolutionized the approaches we use to study our environment. Each year the growing number of Earth observing satellites, and the increasingly huge amounts of data and information provided, yield new knowledge and greater appreciation of the changes occurring on our planet, with important implications for future generations of Earth inhabitants. This encyclopedia is a comprehensive reference work on Earth remote sensing that presents the foundations, principles, and state of the art of remote sensing and describes the diverse applications it serves. It covers the concepts, techniques, instrumentation, data analysis, interpretation, and applications of remote sensing. This volume is part of the Encyclopedia of Earth Science series and is organized in the same style as other volumes in the series. The scientific disciplines covered by the series have all benefited in one way or another from the new understanding and discoveries afforded by remote sensing. It is thus timely for publication of an encyclopedia that can link these disciplines and the remote sensing techniques relevant to them in an integrated framework.

The focus of the encyclopedia is on remote sensing of Earth – its atmosphere, oceans, cryosphere, and land

surface and subsurface. Some of the techniques described in this volume have their origins in the disciplines of astronomy and astrophysics, and the study of the stars and planets for which, until recently, remote sensing was the only means of obtaining observational scientific data. When applied to Earth, these techniques have blossomed into a remarkably diverse and increasingly sophisticated set of scientific, technological, and computational approaches that all fall under the umbrella of remote sensing. The rapid growth of remote sensing as a discipline is evidenced by the large number of scientific journals now devoted to this field, and the number of courses and degree programs offered at universities around the world. The measurement and interpretation of radiation scattered and emitted by Earth's atmosphere, surface, and subsurface is what we generally mean when we speak of Earth remote sensing. These measurements are obtained by instruments on remote platforms that include satellites, aircraft, balloons, drones, trucks, and stationary towers. Remote sensing instruments take many forms and are designed to measure electromagnetic radiation in specific wavelength regions of the broad electromagnetic spectrum; some instruments use other forms of radiation such as acoustic radiation. Measurements from the wide array of instruments, operating on the variety of available platforms available, can be processed and analyzed to extract characteristic information about Earth and its constituent biological, chemical, and physical structures, at resolutions from centimeters to thousands of kilometers. This remotely sensed information can be used on its own or combined with direct or 'in situ' measurements and geophysical models to give a more comprehensive understanding of the diversity of Earth science phenomena, some of which would be very limited without the unique perspective brought by remote sensing.

It is clear that an attempt to fully cover the breadth and depth of topics in remote sensing is a daunting task. Nevertheless, the need for a compendium that can be used as a reference work for this field, as a living document that

can be updated periodically to capture new advances, is a pressing one. It is with this aim in mind that the Springer *Encyclopedia of Remote Sensing* was conceived. Both this print version of the encyclopedia, which can be updated with revisions once every several years, and an online version, which can be updated on a more frequent basis by authors of individual entries, are provided. The online version can accommodate introduction of new entries as the need for new topics or treatments emerges. The encyclopedia entries cover topics that include broad introductory surveys as well as more in-depth treatment of some subjects. The entries treat topics of the physical principles of remote sensing in different wavelength regimes, propagation and scattering of radiation, geophysical models, remote sensing instrumentation, retrieval methods, remote sensing platforms and observational configurations. The models and retrieval methods are described with reference to specific applications in atmosphere, ocean, cryosphere, land, and solid earth geophysics. These applications include human impacts of climate change, and the enabling interdisciplinary science, as well as applications of direct societal benefit such as human health, food security, and prediction and mitigation of natural hazards. Earth remote sensing from space has flourished in the past few decades, and has become a truly global enterprise through development of international collaborations and partnerships, with investments from an increasing number of countries in building and operating satellite observational systems. Several entries in this volume have been devoted to describing these programs, and associated international policies and principles.

This encyclopedia is designed to support the needs of students, teachers, and professionals across a broad

spectrum of science, technology, and societal applications related to Earth remote sensing. The intended audience includes those with observational interests in the fields of oceanography, atmospheric sciences, meteorology, climate, cryospheric studies, hydrology, geology, solid earth geophysics, ecology, agronomy, forestry, environmental pollution, geography, land use and social studies, among others. The target audience also includes those with interests in remote sensing theory and practice, electromagnetic propagation, radiative transfer modeling, remote sensing instruments, spacecraft systems and orbits, environmental policy and decision-making, resource planning, and monitoring and forecasting of extreme events and natural hazards. In the commercial sector, economists, legal and insurance companies, and commercial and industrial concerns relying on the production, marketing and availability of value-added remote sensing products will also find the encyclopedia a valuable resource. The entries are presented in alphabetical order with titles that are designed to aid searches for specific topics. Cross-referencing using keywords to related entries is also provided to support efficient searches for information of interest to readers. The entries provide bibliographies for further in-depth reading. In summary, though it cannot be claimed that this encyclopedia represents an exhaustive treatment or complete coverage of the field of Earth remote sensing, it is hoped that the volume will serve as a comprehensive and dynamic introduction, and initial entry point, to inspire further reading and study of this exciting and rapidly developing field.

September 2013

Eni G. Njoku

Acknowledgments

A work the size of this encyclopedia inevitably relies on the help and cooperation of a large number of people, only some of whom can be individually identified and thanked here. My particular thanks go to the Board of Section Editors, a group of diverse and highly respected remote sensing scientists. To Mike Abrams, Ghassem Asrar, Frank Marzano, Peter Minnett, Vince Salomonson, Vern Singhroy, and Joe Turk, thank you for keeping this project on course by helping to choose the topics that form the entries, suggesting high-quality authors, reviewing the initial manuscripts, and finally checking proofs with your selected groups of authors as well as writing important contributions yourselves. I also wish to acknowledge the great help of Roberta Balstad, Farouk El-Baz, Moustafa Chahine, Jean-Marie Dubois, A.J. Chen, Robert Gurney, Jim Smith, and Guido Visconti who contributed to the early selection of topics and authors for the encyclopedia. My thanks are due also to Tom Farr who assisted me with the editorial duties during a critical stage in the project.

This leads to the largest group I wish to acknowledge, the authors of the 170 entries that range in size from several hundred words up to major contributions of several thousand words. Many authors took on more than one entry within their specialty area. Due to the length of time required to produce a volume of this type many

authors who submitted entries early had to wait a considerable amount of time before their entries were finally published. To these authors I especially wish to express my thanks for their patience and dedication to the completion of the project, and I hope they find the final volume worth the wait.

At the production end of the project has been the staff of Springer. Their help, understanding, and cooperation, especially when problems needed to be overcome, is something that cannot be appreciated enough. Their patient discussions and exchanges with the authors and board members did much to maintain the smooth progress of the project. Special acknowledgment should go to Petra van Steenberg and Sylvia Blago who provided me with encouragement through many difficult periods, and to Simone Giesler, all of who were involved with the encyclopedia from start to finish. I must also acknowledge the rewarding environment of my host institution and colleagues, all of whom provided a rich source of motivation and ideas in the field of remote sensing to inspire a publication of this type. My final appreciation goes to my wife Mary whose patience and support over the years has been a major factor in my ability to undertake this task, and to my son Eni Jr. who reminds me constantly of the power of positive thinking.

Encyclopedia of Remote Sensing

Njoku, E.G. (Ed.)

2014, XXV, 939 p. 370 illus., 223 illus. in color.,

Hardcover

ISBN: 978-0-387-36698-2