Preface

Solar radiation data at ground level are important for a wide range of applications in meteorology, engineering, agricultural sciences (particularly for soil physics, agricultural hydrology, crop modeling and estimating crop evapo-transpiration), as well as in the health sector and in research in many fields of the natural sciences. A few examples showing the diversity of applications may include: architecture and building design (e.g. air conditioning and cooling systems); solar heating system design and use; solar power generation and solar powered car races; weather and climate prediction models; evaporation and irrigation; calculation of water requirements for crops; monitoring plant growth and disease control and skin cancer research.

The solar radiation reaching the Earth upper atmosphere is a quantity rather constant in time. But the radiation reaching some point on Earth surface is random in nature, due to the gases, clouds and dust within the atmosphere, which absorb and/or scatter radiation at different wavelengths. Obtaining reliable radiation data at ground level requires systematic measurements. However, in most countries the spatial density of actinometric stations is inadequate. For example, the ratio of weather stations collecting solar radiation data relative to those collecting temperature data in the USA is approximately 1:100 and worldwide the estimate is approximately 1:500. Even in the developed countries there is a dearth of measured long-term solar radiation and daylight data. This situation prompted the development of calculation procedures to provide radiation estimates for places where measurements are not carried out and for places where there are gaps in the measurement records. Also, the utility of existing weather data sets is greatly expanded by including information on solar radiation. Radiation estimates for historical weather can be obtained by predicting it using either a site-specific radiation model or a mechanistic prediction model. A site-specific model relies on empirical relationships of solar radiation with commonly recorded weather station variables. Although a site-specific equation requires a data set with actual solar radiation data for determining appropriate coefficients, this approach is frequently simpler to compute and may be more accurate than complicated mechanistic models. These simple, site-specific equations, therefore, may be very useful to those interested in sites near to where these models are developed.

The need for solar radiation data became more and more important mainly as a result of the increasing number of solar energy applications. A large number of solar radiation computation models were developed, ranging from very complicated computer codes to empirical relations. Choosing among these models usually takes into account two features: (1) the availability of meteorological and other kind of data used as input by the model and (2) the model accuracy. For most practical purposes and users the first criterion renders the sophisticated programs based on the solution of the radiative transfer equation unusable. As a consequence, the other models were widely tested.

The kind of solar radiation data required depends on application and user. For example, *monthly or daily averaged* data are required for climatologic studies or to conduct feasibility studies for solar energy systems. Data for *hourly* (or shorter) periods are needed to simulate the performance of solar devices or during collector testing and other activities. With the proliferation of cheap, high performance desktop computers, there is a growing need in various branches of science and engineering for detailed (*hourly or sub-hourly*) solar radiation data to be used for process simulation or design and optimum device sizing. As a best example, the past decade has seen a boom in the construction of energy efficient buildings which use solar architectural features to maximize the exploitation of daylight.

There is a need for a review of the existing "simple" methods of estimating solar radiation on horizontal and inclined surfaces. The goal of this book is to gather together a number of existing, as well as new models to compute solar radiation. Our objective is to classify various computing methods and models, to review statistical performance criteria and to recommend data sets suitable for validation. The book covers most aspects of solar radiation broadband computing models. Both statistical and deterministic methods are envisaged. Also, systematic information on the accuracy of each method is included. This information allows the user to choose the best available estimating model for his/her application when considering available data and demands for accuracy. The reader is implicitly provided with a solid understanding of the main mechanisms which determine the behavior of solar radiation on Earth surface and how solar radiation is estimated, measured and interpreted in an applied world.

The book is structured along logical lines of progressive thought. After an introductory Chapter 1 presenting the progress in solar radiation measurements, a group of two chapters (2 and 3) refer to fractal and statistical techniques used to quantify the properties of global irradiance. Chapter 4 is devoted to computation of solar radiation during clear days. The next four chapters present surveys of mature methods to compute solar radiation. The first three chapters in this series (5, 6 and 7) are related to correlations between solar irradiation and relative sunshine, cloud cover and air temperature, respectively. The series continues with Chapter 8, where the models to compute the diffuse solar fraction are presented. The methods of solar radiation estimation based on Artificial Neural Networks are discussed in Chapter 9. The next part of the book is oriented toward time-series procedures. In Chapter 10 the dynamic behavior of the solar radiation is discussed while chapter 11 shows how ARMA models are applied to solar radiation time series. Chapters 12 and 13 are devoted to new models used to generate series of actinometric data. The next chapters (14 and 15) present the details of MRM and METEONORM, respectively, which are very useful tools for solar radiation estimation. Chapters 16 and 17 refer to computation of UV solar radiation and sky diffuse radiance, respectively. These are important quantities used in the health sector and building design, respectively. Modern methods able to provide solar radiation information derived from Satellite Images are described in Chapters 18 and 19. A wide variety of techniques had been used during the years to describe model performance. This makes difficult comparison of models developed by different authors. Therefore, to meet the original objective would necessitate initially that validation method be classified, that models be catalogued uniformly, that statistical performance criteria are reviewed and that data sets suitable for validation be compiled. Chapter 20 deals with some of these aspects of model validation.

More details about the twenty chapters of the book are given below.

Chapter 1 by Christian Gueymard and Daryl Myers is designed to be an introduction to both solar radiation measurements and the concepts of solar radiation model validation. The authors discuss solar radiation fundamentals, components of solar radiation in the atmosphere, and instrumentation used to measure these components. Accuracy of solar measurements depends upon instrumentation performance, the reference scale and calibration techniques used. The physical principles of solar radiometer measurements, the World Radiometric Reference (WRR) reference scale, calibration and characterization techniques and the basic measurement uncertainty to be expected in measured data are described and commented. A brief discussion of measurement networks and data quality is presented. Very general and basic concepts behind solar radiation model types and their validation are outlined, leading to the detailed modeling and validation concepts that appear in the following chapters, especially chapter 20 which discusses model performance and validation in greater detail. The basic uncertainties in the *best* practical solar radiation data available today are on the order of 3% in direct beam, 5% in total global horizontal, $3\% +/-2$ Watt in diffuse horizontal irradiance (measured with a black and white or corrected all-black pyranometer), 15% to 20% in diffuse radiation measured with uncorrected all black pyranometers behind a shadow band, and perhaps 5% to 20% in sunshine duration, for digital (including pyrheliometer) and analog (burning) sunshine recorders, respectively.

Chapter 2 by Samia Harrouni deals with fractal classification of daily solar irradiances according to different weather classes. The aim of this new approach is to estimate the fractal dimensions in order to perform daily solar irradiances classification. Indeed, for daily solar irradiances, the fractal dimension (D) ranges from 1 to 2. D close to 1 describes a clear sky state without clouds while a value of D close to 2 reveals a perturbed sky state with clouds. In fact, a straight line has a fractal dimension of one, just like its Euclidean dimension, once the line shows curls, its fractal dimension increases. The curling line will fill the plane more and more, and once the plane is filled up, it has a fractal dimension of two. Thus, the fractal dimension of a temporal signal has a fractal dimension between 1 and 2. To measure the fractal dimension of time series, several methods and algorithms based on various coverings have been elaborated. In order to improve the complexity and the precision of the fractal dimension estimation of the discreet time series, the author developed a simple method called "Rectangular covering method" based on a multi-scale covering using the rectangle as a structuring element of covering. An optimization technique has been associated to this method in order to determine the optimal time interval through which the line log-log is fitted whose slope represents the fractal dimension. This optimization technique permitted to improve the precision and to decrease the computing time of the method. In order to measure the performance and the robustness of the proposed method, one applied it to fractal parametric signals whose theoretical fractal dimension is known, namely: the Weierstrass function and the fractional Brownian motion. Experimental results show that the proposed method presents a good precision since the estimation error averaged over 180 tests for the two types of signals is 3.7%. The "Rectangular covering method" is then applied to estimate the fractal dimension of solar irradiances of five sites of different climates: Boulder and Golden located at Colorado, Tahifet and Imehrou situated in the Algerian south and Palo Alto in California. Then the author proposed a classification method of irradiances using the estimated fractal dimension. The method which defines fractal dimensions thresholds leads to classify the days of the five sites into three classes: clear sky day, partially clouded sky day and clouded sky day. Annually and monthly analysis of the obtained classes demonstrate that this classification method may be used to construct three typical days from global solar irradiances, which allows to reduce a long time series of several variables into typical days.

Chapter 3 by Joaquin Tovar-Pescador starts with fundamental ideas about statistical research techniques and their applications to solar radiation. An exhaustive revision of the research for modelling the statistic behaviour of solar radiation, from first works by Ångström until now, by means of normalised indices k_t, k_b and k_d, and in several temporal intervals (daily, hourly and instantaneous distributions), is made. Finally, the work is focused on the analysis of instantaneous distributions of global, direct and diffuse components of solar radiation, for different values of optical mass and different intervals of temporal integration (conditional distributions). The author proposes a method to model this behaviour by using a special type of functions, based on Boltzmann statistics, whose parameters are related to sky conditions.

Chapter 4 by Amiran Ianetz and Avraham Kudish starts with the common observation that the terrestrial solar irradiation is a function of solar altitude, site altitude, albedo, atmospheric transparency and cloudiness. The atmospheric transparency is a function of aerosol concentration, water vapor as well as other factors. The solar global radiation on a clear day is a function of all the abovementioned parameters with the exception of the degree of cloudiness. The analysis of the relative magnitudes of the measured solar global irradiation and the solar global irradiation on a clear day, as determined by a suitable model, provides a platform for studying the influence of cloudiness on solar global irradiation. Also, the magnitude of the solar global irradiation on clear day provides an estimate of the maximum solar energy available for conversion on a particular day. This chapter deals with the classification of the clear days and investigates a number of models for determining the solar global irradiation on clear sky, recommending the most suitable model. A clear day global index is defined and argued to be a better indicator of the degree of cloudiness than the widely reported clearness index. A clear day horizontal diffuse index and horizontal beam index are also defined and the correlation between them is studied. In addition, the analysis of frequency distribution types with regard to solar irradiation are discussed and defined on the basis of the skewness and kurtosis of the database. The preferred types of frequency distribution, viz., most suitable for solar energy conversion systems, are ranked and the reasoning behind the order of preference of the distribution types is explained. The average solar irradiation at a site, either global and/or beam, is of the utmost importance when designing a solar conversion system but the frequency distribution of the irradiation intensity is also a critical parameter.

Chapter 5 by Bulent Akinoglu shows that the relation between bright sunshine hours and solar radiation has quite a long history, which started at the beginning of the last century. Angström (1924) proposed a linear relation and since then many other different forms appeared in the literature. In this chapter, the physical base of this relation is explained and basic approaches of modeling are summarized. Among these approaches, two recent models are chosen and described in details. One of them is a hybrid model which uses wide band spectral information but also preserves a simple form. In this approach some wide band spectral data is used to calculate the ratio of actual global solar radiation to the clear sky value and this ratio is latter on correlated with the fractional bright sunshine. The second type of correlation discussed is the quadratic type expressions. In this modeling, a quadratic relation between bright sunshine hours and the global solar radiation has emerged within a physical formalism in which the ground reflected radiation is included. Also, the relation between the two Angström coefficients is discussed, which indicates that a quadratic relation should exits between the ratio of global solar radiation to the extraterrestrial radiation and fractional bright sunshine hours. A method is described to obtain a quadratic correlation using the relation between the Angström coefficients. The reasons why these models give relatively better estimates are discussed. A conclusion and some future prospects are also given in the chapter.

Chapter 6 by Ahmet Duran Şahin and Zekai Şen presents several new methods applied to the Angström equation and proposes a new alternative methodology to describe the dynamic behavior of this equation and solar irradiation variables. A dynamic model estimation procedure (denoted SSM) is proposed, which leads to a sequence of parameters. This makes possible to look at the frequency distribution function (probability distribution function) of model parameters. This allows deciding whether the arithmetic average of the parameters or the mode (the most frequently occurring parameter value) should be used in further solar irradiation estimations. In addition, it is easy and practical to do statistical analysis of Angström equation parameters and variables with SSM. Apart from the dynamic model parameter estimation procedure, an unrestricted solar irradiation parameter estimation procedure (UM) is presented, which considers only the conservation of the arithmetic mean and standard deviation of model's input and output variables, without the use of least squares technique. Around the average values, solar irradiation and sunshine duration values are close to each other for Angström and UM models, however, the UM approach alleviates these biased-estimation situations. Lastly, an alternative formulation to Angström equation is proposed for sunshine duration and solar irradiation variables estimation. This formulation and Angström equation procedure are compared and it is proven that there are some physical problems with the classical Angström approach.

Chapter 7 by Marius Paulescu refers to simple formulae that can be used to calculate daily global solar irradiation from air temperature data. These models either using air temperature as additional parameter to cloudiness or using only air temperature, are equally viable alternatives to the classical equations based on sunshine duration. Consequently, these models may be useful in many locations where sunshine duration measurements are missing but air temperature measurements are available in many-year database. A distinct case is the model built inside fuzzy logic, which may exhibit the flexibility needed in solar energy forecast. A C program included on the CD-ROM, which enable fuzzy calculation for daily global solar irradiation is presented. The arguments itemized are leading to the conclusion that air temperature, an all-important parameter worldwide recorded, can be used with success in the estimation of the available solar energy.

Chapter 8 by John Boland and Barbara Ridley refers to models of diffuse solar fraction. The authors previously developed a validated model for Australian conditions, using a logistic function instead of piecewise linear or simple nonlinear functions. Recently, it was proved that this model performs well for locations in Cyprus and that the form of the proposed relationship corresponds well to a logistic function. In this chapter the authors made significant advances in both the physically based and mathematical justification of the use of the logistic function. The theoretical development of the model utilises advanced non-parametric statistical methods. One has also constructed a method of identifying values that are likely to be erroneous. Using quadratic programming, one can eliminate outliers in diffuse radiation values, the data most prone to errors in measurement. Additionally, this is a first step in identifying the means for developing a generic model for estimating diffuse from global radiation values and other predictors. The more recent investigations focus on examining the effects of adding extra explanatory variables to enhance the predictability of the model. Examples for Australian and other locations are presented.

Chapter 9 by Filippos Tymvios, Silas Michaelides and Chara Skouteli discusses the applicability of Artificial Neural Networks (ANN) as a modern tool for the retrieval of surface solar radiation. It also comprises a survey of published research in this field, focusing on the neural methodology that was adopted, the database that was employed and the validation that was subsequently performed. Overall, this chapter aims at assisting the reader to obtain a good understanding of the capabilities and the applicability of the use of ANN in estimating solar radiation, to provide the basic theoretical background material for the issues discussed and to present some software tools that may offer the reader the assistance to build these models. Hopefully, the information presented in this chapter will trigger further research in more diverse areas related to solar radiation and renewable energy issues.

Chapter 10 by Teolan Tomson, Viivi Russak and Ain Kallis shows that solar radiation on the infinitely (in practice – sufficiently) long time axis is a stationary ergodic process that includes both periodical and stochastic components. Still, solar radiation could be a non-stationary process during some shorter time interval, intended for practical problem-solving. Different approaches have to be used for the analysis of the dynamical behavior of solar radiation. These approaches are explained in the chapter as well the technology of the analysis. The chapter is addressed mainly to engineers working on utilization of solar energy converted from the global radiation. Authors expect that the reader is acquainted with fundamentals and terminology of solar engineering.

Chapter 11 by John Boland starts by reminding that measurements of the components of solar radiation - global, diffuse and direct – traditionally have been made at only a limited number of sites. In recent times, for various reasons including the increased use of satellite images, this coverage has decreased further. To use simulation models to predict output from systems under the influence of solar radiation, hourly data values are usually needed. There are various approaches to generating synthetic sequences of solar radiation, using alternatively Markov models, state space models, neural networks or Box and Jenkins methods. The author uses the latter, which he also denotes as classical time series modeling structures. There is a specific reason for choosing this methodology. It is the approach that gives the most knowledge of the underlying physical nature of the phenomenon. The author describes the behaviour of global solar radiation on both daily and hourly time scales. In so doing, one identifies the various components inherent in the time series, seasonality, autoregressive structure, and the statistical properties of the white noise. Subsequently, procedures for generating synthetic sequences are presented, as well as procedures for generating sequences on a sub-diurnal time scale when only daily values (or inferred daily values) are available.

Chapter 12 by Llanos Mora-Lopez presents a model to generate synthetic series of hourly exposure of global radiation. This model has been constructed using a machine learning approach. The model is based on a subclass of probabilistic finite automata which can be used for variable order Markov processes. This model allows to describing the different relationships and the representative information observed in the hourly series of global radiation; the variable order Markov process can be used as a natural way to represent different types of days, and to take into account the "variable memory" of cloudiness. A method to generate new series of hourly global radiation, which incorporates the randomness observed in recorded series, has been also proposed. This method only uses, as input data, the mean monthly value of the daily solar global radiation and the probabilistic finite automata constructed.

Chapter 13 by Viorel Badescu proposes a new kind of solar radiation computing model. The novelty is that the approach uses two parameters to describe the state of the sky. The parameters are the common total cloud amount and a new two-value parameter - the sunshine number - stating whether the sun is covered or uncovered by clouds. Regression formulas to compute instantaneous cloudy sky global and diffuse irradiance on a horizontal surface are proposed. Fitting these relationships to Romanian data shows low bias errors for global radiation and larger errors for diffuse radiation. The physical meaning of the regression coefficients is explained. The model's accuracy is significantly higher than that based on total cloud amount alone. The model is applied to synthesize time-series solar radiation data. A first approximation relationship neglecting auto-correlation of the sunshine number is used in computations. Visual inspection as well as a statistical analysis shows a reasonably good similarity between the sequential features of measured and synthetic data. When the time interval is in the range of a few minutes, the sequential features of the generated time-series change significantly.

Chapter 14 by Harry Kambezidis and Basil Psiloglou describes the history of the various versions of the Meteorological Radiation Model (MRM), a computer code which estimates (broadband) solar irradiance values on a horizontal surface, using as input information only widely available meteorological parameters, viz. air temperature, relative humidity, barometric pressure and sunshine duration. Description of the various versions of MRM is given in detail together with their drawbacks, which triggered the development of the next version. Now MRM is at its version 5, especially developed by the Atmospheric Research Team (ART) at the National Observatory of Athens (NOA) for the purpose of this book. The performance of the recent MRM code is examined by comparing its results against solar radiation data from different locations in the Mediterranean area. Though MRM seems to work very well on cloudless days, an algorithm for calculating the solar radiation components on cloudy days has been added. This part of the code is based on the detailed sunshine duration information provided. If this consists of hourly values, the accuracy of the MRM is better than having just the daily sunshine duration instead. Nevertheless, the MRM results are on the same time steps as the input data, i.e. instant, half-hourly, hourly or daily values.

Chapter 15 by Jan Remund describes the formulation of a chain of algorithms for computing shortwave radiation used in Meteonorm Version 6 (Edition 2007). The basic inputs into the chain are monthly mean values of the Linke turbidity factor and global radiation. The outputs of the chain are time series of hourly values of global shortwave radiation on inclined planes. They correspond to typical years. This is achieved via stochastic generation of daily and hourly values of global radiation, splitting the global into beam and diffuse radiation and finally calculating the radiation on inclined planes. The short validation shows that the quality is good for the focused user group. The root mean square error of yearly means of computed beam radiation comes to 7%, that of the computed radiation on inclined plane is 6%.

Chapter 16 by John Davies and Jacqueline Binyamin refers to a climatological model for calculating spectral solar irradiances in the ultra-violet B waveband. The model is described and evaluated with Brewer spectrophotometer measurements at Resolute, Churchill, Winnipeg and Toronto in Canada. The model linearly combines cloudless and overcast irradiance components calculated with either the delta-Eddington or the discrete ordinates methods. It uses daily measurements of atmospheric ozone depth from the Brewer instrument, hourly observations of total cloud amount and standard climatological vertical profiles of temperature, pressure, humidity, ozone and aerosol properties for midlatitude and subarctic conditions. Cloud optical depth was calculated by iteration using single scattering albedo and asymmetry factor calculated by the Mie theory. Surface albedo varies linearly from 0.05 for snow-free ground to 0.75 for a complete snow cover.

Chapter 17 by José Luis Torres and Luis Miguel Torres carries on a revision of different models proposed for determining the angular distribution of diffuse radiance in the sky vault. Among all the models which can be found in literature, the ones that claim to be valid for all kinds of sky have been selected. Moreover, in many cases, given the similar origin of radiance and luminance, the models can be used for determining both quantities by means of the right set of coefficients. Although most of the models are empirical, as they are widely used, both a semiempirical model and another model that takes into consideration the stochastic nature of radiance in the sky vault are considered. In order to explain the procedure that is to be followed, an example of application of one of the newer empirical models is included. This model requires starting data usually available in conventional meteorological stations and uses an easy procedure for selecting the kind of sky. Knowledge of the angular distribution of diffuse radiance in the sky vault allows for a more precise calculation of the incident irradiance on a sloped surface. In this way, some of the simplifications used in many current models can be overcome. This new approach is especially interesting in urban environments and in terrains of complex orography where the incidence of obstacles can be very important. Finally, a section is devoted to show some of the measure equipments of radiance/luminance in the sky vault. Data registered by them has allowed for the elaboration of the empirical models and the evaluation of the different proposals. As these equipments became more widely used, they will be able to calibrate the models in places different from the ones where they were obtained. Among these equipments are considered both those in which the sensor that measures radiance/luminance moves sweeping different areas of the sky vault and those where the radiance/luminance is measured simultaneously in every area.

Chapter 18 by Jesús Polo, Luis Zarzalejo and Lourdes Ramírez deals with methods to derive solar radiation from satellite images. This approach has become an increasingly important and effective way of developing site-time specific solar resource assessments over large areas. Geostationary satellites observe the earth-atmosphere system from a fixed point offering continuous information for very large areas at temporal resolution of up to 15 minutes and spatial resolution of up to 1 km. Several methods and models have been developed during the last twenty years for estimating the solar radiation from satellite images. Most of them rely on transforming the radiance (the physical magnitude actually measured by the satellite sensor) into the cloud index, which is a relative measure of the cloud cover. Finally, the cloud index is related with the solar irradiation at the earth surface. A review of the most currently used models is made throughout this chapter, after describing the fundamentals concerning meteorological satellites observing the earth-atmosphere system and the cloud index concept. Finally, the degree of maturity in this technology has resulted in a number of web services that provide solar radiation data from satellite information. The different web services are briefly described at the end of this chapter.

Chapter 19 by Serm Janjai refers to the usage of satellite data to generate solar radiation at ground level. Solar radiation maps of Lao People's Democratic Republic (Lao PDR) have been generated by using 12-year period (1995–2006) of geostationary satellite data. To generate the maps, a physical model relating incident solar radiation on the ground with satellite-derived reflectivity and scattering and absorption due to various atmospheric constituents was developed. The satellite data provided cloud information for the model. The absorption of solar radiation due to water vapour was computed from precipitable water obtained from ambient relative humidity and temperature at 17 meteorological stations. The ozone data from the TOMS/EP satellite were used to compute the solar radiation absorption by ozone. The depletion of radiation due to aerosols was estimated from visibility data and the 5S radiative transfer model. Pyranometer stations were established in 5 locations in Lao PDR: Vientiane, Luangprabang, Xamnua, Thakhak and Pakxe. Global radiation measured at these stations was used to validate the model. The validation was also performed by using existing solar radiation collected at 3 stations in Thailand: Nongkhai, Nakhon Panom and Ubon Ratchathani. The solar radiation calculated from the model was in good agreement with that obtained from the measurements, with a root mean square difference of 7.2%. After the validation, the model was used to calculate the monthly average daily global solar radiation for the entire country. The results were displayed as monthly radiation maps and a yearly map. The monthly maps revealed the seasonal variation of solar radiation affected by the monsoons and local geography and solar radiation is highest in April for most parts of the country. From the yearly map, it was observed that the western parts of the country received high solar radiation with the values of 17–18 $\mathrm{MJ/m^2}$-day. The areas which receive the highest solar radiation are in the south with the values of 18–19 $\mathrm{MJ/m^2}$-day. The yearly average of solar radiation for the entire country was found to be 15.8 $\mathrm{MJ/m^2}$-day. This solar radiation data revealed that Lao PDR has relatively high solar energy potentials which can be utilized for various solar energy applications.

Chapter 20 by Christian Gueymard and Daryl Myers refers to different types of models which have been developed to provide the community with predictions of solar radiation when or where it is not measured appropriately or at all. An accepted typology of solar radiation models does not currently exist. Thus technical approaches to the evaluation and validation of solar radiation models vary widely. This chapter discusses classification of models by methodology, input criteria, spatial, temporal and spectral resolution, and discusses issues regarding the testing and validation of solar radiation models in general. The importance, and examples of, establishing sensitivity to model input data errors are described. Methods and examples of qualitative and quantitative quality assessment of input data, validation data, and model output data are discussed. The methods discussed include the need for totally independent validation data sets, evaluation of scatter plots, various statistical tests, and the principle of radiative closure. Performance assessment results, including comparison of model performance, for fifteen popular models are presented. Several approaches to evaluating the relative ranking of collections of models are presented, and relative ranking of the 15 example models using the various techniques are shown. This chapter emphasizes to the newcomer as well as the experienced solar radiation model developer, tester, and user, the nuances of model validation and performance evaluation. Section 2 addressed seven criteria describing typical solar radiation model approaches or types. Sections 3 and 4 described the principles of model validation and uncertainty analysis required for both measured validation data and uncertainties in model estimates. Sections 5.1 and 5.2 addressed qualitative and quantitative measured data quality and model performance. Section 5.3 emphasized seven constituent elements of model validation that must be addressed in any evaluation, including validation and input data quality, independence, and uncertainty to consistency of temporal and spatial extent, and validation limits. Section 6 discussed evolution and validation of model component parts (Sect. 6.1), the importance of, and difficulties associated with, interpreting independent model validation (Sect. 6.2), as well as demonstrated the practice (and difficulties) of comparing the performance of many models (Sect. 6.3).

The book facilitates the calculation of solar radiation required by engineers, designers and scientists and, as a result, increases the access to needed solar radiation data. To help the user of solar radiation computing models, a CD-ROM with computer programs and other useful information is attached to the book.

The Editor

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