SOLAR SPECTRUM

Newsletter of the Resource Assessment Division

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Progress toward an Updated National Solar Radiation Data Base (NSRDB)

Steve Wilcox—National Renewable Energy Laboratory

NSRDB Background

In 1992, the National Renewable Energy Laboratory (NREL) in conjunction with the National Climatic Data Center (NCDC) published the 1961-1990 National Solar Radiation Data Base (NSRDB). This 30-year data set contained data from 239 National Weather Service (NWS) stations across 50 states, Puerto Rico and Guam. The NSRDB provided serially complete sunup records of hourly modeled and measured solar radiation and meteorological observations.

NSRDB Update

In response to many inquiries, NREL began an investigation into an updated NSRDB that would expand the period of record through the year 2000. As early as 1995, NREL considered an updated product after users expressed the need for access to more recent data. But at that same time, a significant change was underway at the NWS with the deployment of the Automated Surface Observing System (ASOS). ASOS became a major obstacle for an updated NSRDB since it substituted ceilometers for the observer based cloud observations used in generating the NSRDB. Many stations had already been converted to ASOS, and the NWS had plans to convert most or all remaining stations within a few years.

Over 90% of the 1961-1990 NSRDB contained modeled solar data produced by the NREL-developed METSTAT (meteorological-statistical) solar radiation model [Reference: Maxwell E L, MESTAT—the solar radiation model used in the production of the national solar radiation data base (NSRDB). Solar Energy, 1998. **62**(4): p. 263-279]. The primary METSTAT input comes from NWS total and opaque cloud cover, two measurements that had been a mainstay of NWS manual observations for decades. Unfortunately, the ASOS ceilometer provides no directly comparable

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Map of the 239 stations in the NSRDB

Inside This Issue

Solar Spectrum is the newsletter from the Resource Assessment Division of the American Solar Energy Society and is published on a semi-annual basis. The purpose of this newsletter is to inform division members of events in the resource assessment field and activities of the division and its members.

Success of the newsletter depends on your contributions.

You are encouraged to send comments, letters, or short articles to the Editor:

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I would like to thank Steve Wilcox and Chris Gueymard for their contributions to this newsletter.

Deadline for contributions to the next newsletter is October 1, 2003.

Frank Vignola

Resource Assessment Division Officers & Board Members

Frank Vignola, Chair
Gary Vliet, Vice Chair
Gary Vliet, Secretary

Ray Bahm	June 2001
Mark Beaubien	June 2002
Doug Balcomb	June 2002
John Dunlop	June 2002
Dan Greenberg	June 2001
Bill Marion	June 2001
Rob Nelson	June 2001
Richard Perez	June 2002

Upcoming Events

America's Secure Energy June 21-26, 2003	Austin, Texas *Information*: ASES 2400 Central, G-1 Boulder, CO 80301 Tel 303-443-3130 Fax 303-443-3212 Email: ases@ases.org http://www.ases.org
ISES World Congress June 14-19, 2003	Göteborg, Sweden Dr. Jan-Olof Dalenbäck *Information*: ISES 2003 World Congress, c/o Building Services Engineering, Chalmers University of Technology Se-4129 Göteborg, Sweden Fax: +46 31 772 1152 Email: jod@vsect.cchalmers.se http://www.congrex.com/ises2003

RAD Division Officers and Board—In transition

The Resource Assessment Division of ASES in undergoing re-organization. The makeup of the division and its board will be at the next RAD division meeting at 2003.

At the last division meeting there was a discussion of the number of position on the division board and even if there should be a division board.

The division meeting has tentatively been scheduled for Monday, June 23, 2003 from 4:00-5:00 pm. This is a chance to help shape the future of the RAD division.

Currently the RAD division activities are mainly associated with the annual conference. In the past the division has put together forum or workshops, helped select reviews for the review of papers, and suggested members of the conference technical review committee. The division also helps in the nominations of the division member to the ASES board.

Email Addresses for Resource Assessment Division Members

In order to open communications between RAD division members, the following members circulated their Email address at the RAD division annual meeting. If you are not on this list and would like to add your name to the list, contact Solar Spectrum's editor and your Email address will be added to the list and published in the next newsletter.

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Resource Assessment, Modeling and Applications Talks at Solar 2003 in Austin

Wednesday at 10:30-12:00

From the ASES brochure, the talks for the Resource Assessment session on Modeling and Applications are as follows.

Solar Resource Assessment Methods for the United Nations Environment Programme's Solar and Wind Energy Resource Assessment (SWERA) project

D. Renné, National Renewable Energy Lab; R. Perez, ASRC, The University at Albany; C. Schillings, f. Trieb and R. Myer, German Aerospace Center (DLR) GERMANY; e. Pereira, Instituto Nacional de Pesquisas Espaciais, BRAZIL and M. Vipradas, Tata Energy, INDIA

Producing Satellite-Derived Irradiances in Complex Arid Terrain

R. Perez, ASRC, The University at Albany; P. Ineichen, U. Geneva; M. Kmiecik, ASRC; K. Moore, IED and D. Renné and R. George, NREL

Progress on Updating the 1961-1990 National Solar Radiation Database

D. Renné, S. Wilcox, B. Marion, R. George, D. Myers and T. Stoffel, National Renewable Energy Lab; R. Perez, ASRC the University at Albany and P. Stackhouse, Jr., NASA/Langley Research Center

Beam-Tilted Correlation

F. Vignola, University of Oregon

Solar Resource Assessment in the Foggiest City on Earth

J. Augustyn and T. Geer, Augustyn + Company and F. Schwartz and D. Appel, San Francisco Public Utilities Commission

The Effect of Aberrations in TMY2 Data on Simulation Results of Solar Systems

G. Vijayakumar, S. Klein and W. Beckman, University of Wisconsin, Madison

Solar monitoring equipment mounted on an automatic tracker at Twin Falls, Idaho.

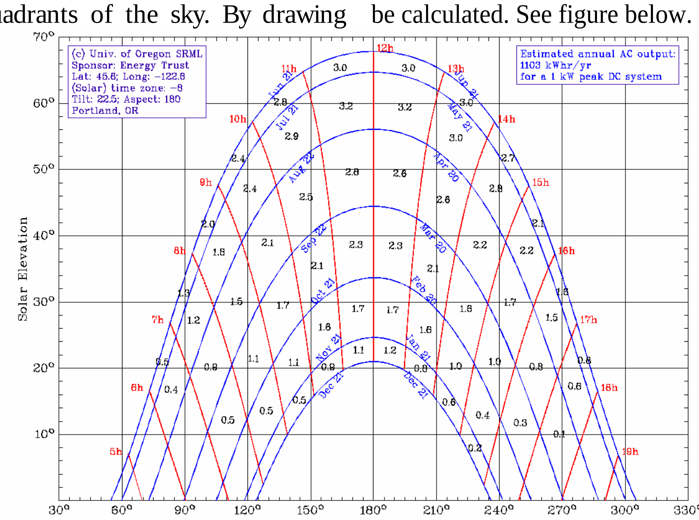
Enhancing the Value of Solar Radiation Data

by Frank Vignola

Solar radiation data are essential to evaluate, model, and operate solar energy systems. Many people are more interested in rules of thumb and information that can help them better orient their system or to estimate the typical performance of their systems without the use of sophisticated tools such as TRNSYS and DOEPAS.

Recently the University of Oregon Solar Radiation Monitoring Laboratory (UO SRML) was contracted by the Energy Trust of Oregon to develop a shade evaluation form that could be used by solar installers to estimate the lost from shading. The concept for this plot comes from the Eugene Water and Electric Board's Bright Way to heat water program.

Using an Excel add-in based on the PVWatts program, a sun path chart was produced showing the % solar radiation coming from different quadrants of the sky. By drawing the horizon line of objects that shade the system and adding the percentages in areas below the horizon line, the shading effect can be calculated. See figure below.



Recent Developments in Spectral Solar Radiation Standards and Modelling

by Chris A. Gueymard
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Many in the solar energy community have been using reference spectra for the rating or performance testing of PV systems, or for other solar energy applications involving spectral characteristics. These procedures have been usually designed around either one of two possible reference irradiance spectra that have been standardized by ASTM, ISO and IEC. These reference spectra are for direct normal irradiance at air mass 1.5 and for 37°-tilted global irradiance also at air mass 1.5, as originally published in ASTM standards E891 and E892, respectively.

Revised Reference Spectra

In the 20-year interval since the initial publication of these standards, many things have obviously changed, particularly in the fields of PV performance testing and solar radiation modelling. A first essential change has been the realization by many experimenters that the global reference spectrum (E892) was relatively satisfying for flat-plate PV systems, but that the direct spectrum (E891) could not reproduce the real conditions under which concentrating PV systems were deployed in many areas of the U.S. or other countries. In other words, E891 had become obsolete, and this could be traced back to the fact that this standard was originally designed for average aerosol conditions typical of the northeast U.S., whereas concentrating PV systems were mostly installed in much cleaner and dryer areas, such as the southwest U.S.

A second change was that the original radiative code (BRITE) that had been used to obtain the spectra in E891 and E892 had not been maintained and was not available anymore. In fact, many developments occurred in the field of spectrometry, radiometry, and solar radiation modelling, so that it became possible to predict spectral irradiance with greater flexibility, better resolution, and improved accuracy.

Conscious of the need for a revised spectrum, ASTM's Subcommittee G03.09 worked in close collaboration with NREL and Solar Consulting Services to develop a new standard. The rationale and scientific bases behind this move have been recently published in *Solar Energy*[1]. The new standard, G173-03[2], has been recently adopted and, as of this writing, was scheduled to be released in June 2003. The main differences with earlier standards E891 and E892 are as follows:

- The two reference spectra are obtained with the author's SMARTS code rather than BRITE;
- The resolution has been increased and spectral results are now provided at 2002 wavelengths from 280 to 4000 nm, rather than 120 wavelengths between 305 and 4045 nm;
- Whereas the old spectra had variable intervals, which resulted in spectral integration difficulties, the new spectra have three *fixed* intervals only: 0.5 nm in the UV (280–400 nm), 1 nm in the 400–1700 nm range, and 5 nm beyond;
- Three important modifications are considered for the atmospheric and environmental conditions: (i) the aerosol optical

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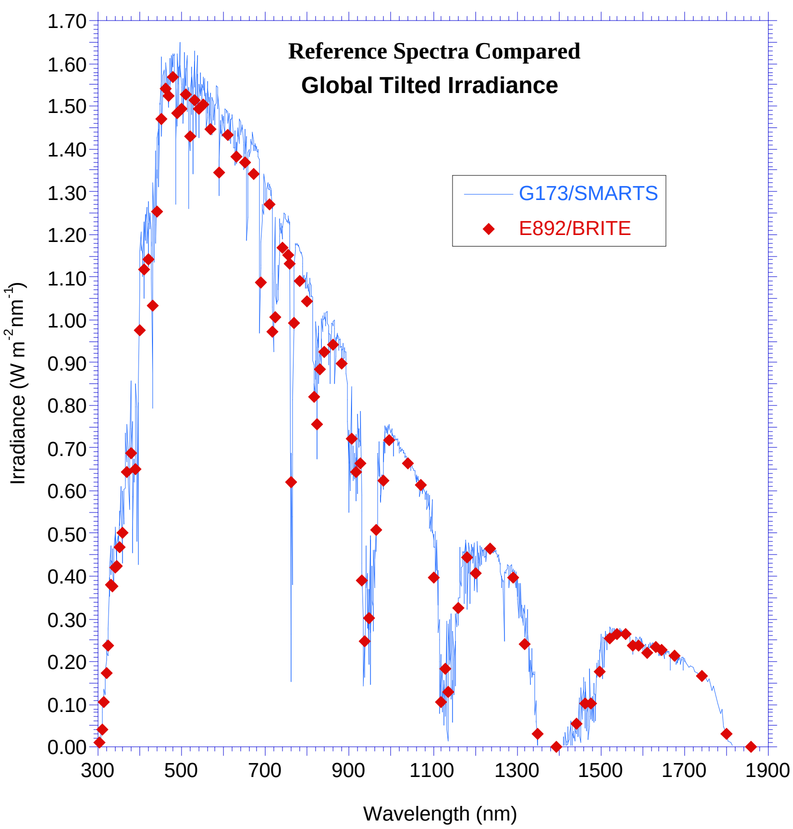

Fig. 1: The new (G173; continuous line) and old (E892; diamonds) reference spectra for global tilted irradiance.

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depth at 500 nm is decreased from 0.270 to 0.084, affecting the direct spectrum considerably but the global spectrum only marginally; (ii) an increased carbon dioxide concentration (370 ppm rather than 330 ppm) is used to reflect the current state of the atmosphere, but this has only minor influence on the spectra; and (iii) a more realistic spectral reflectance for a light sandy soil is now used, along with a non-Lambertian reflectance pattern (rather than the simplistic isotropic and fixed 0.2 albedo), affecting global irradiance significantly but not direct irradiance;

- The accuracy of the direct irradiance spectrum has been improved by about an order of magnitude, by comparison with benchmark calculations (using version 4 of the MODTRAN code);
- The new standard is dynamic rather than static, i.e., experimenters are given the possibility to use SMARTS and perform any number of simulations of their own, e.g., for parametric studies. The main benefit is considerable flexibility in evaluating the effect that non-standard atmospheric or environmental conditions might have on solar irradiance and any spectrally-selective device, while maintaining compatibility and consistency with the standard conditions of G173 for direct comparisons. In the case of PV systems, this opens the possibility to easily evaluate "spectral mismatch" functions.

Fig. 1 shows a comparison between the old and new global spectra. Their good agreement is obvious and will help many industries accomplish a smooth transition between the old and new standards. The new global spectrum integrates to 1000.37 W/m², or 3.8% more than the older spectrum. Moreover, the new integrated value is *directly* compatible (i.e., without any scaling) with the 1000 W/m² used in Standard Reporting Conditions for PV systems.

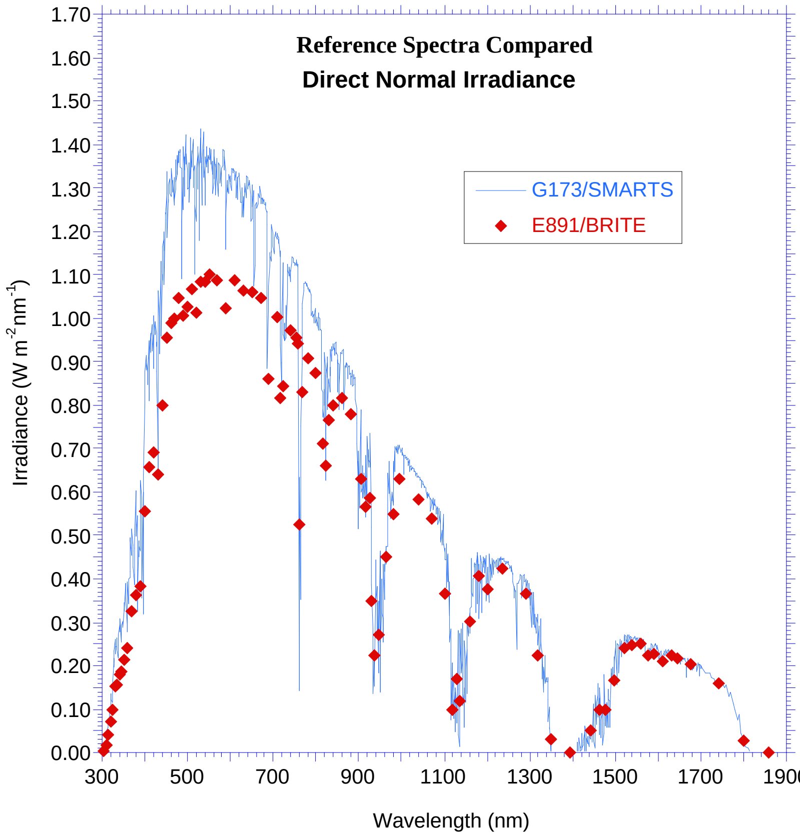

Fig. 2: The new (G173; continuous line) and old (E891; diamonds) reference spectra for direct normal irradiance.

Similarly, Fig. 2 provides a comparison between the old and new direct spectra. The latter integrates to 900.17 W/m², i.e., 17.2% more than with the older spectrum. This significant increase essentially results from the decrease in aerosol optical depth from 0.270 to 0.084 mentioned above. According to an NREL study, the latter value corresponds to the regional yearly average for 15 sites in Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah where the total annual direct irradiance is at least 6 kWh/m². A more subtle and qualitative consequence of this change in aerosol content of the atmosphere is that the new spectrum is slightly blue-shifted compared to the previous standard. This, in turn, may induce non-negligible changes in calculated PV cell performance or other devices, depending on their spectral sensitivity curve.

The SMARTS Code

The development of the *Spectral Model of the Atmospheric Radiative Transfer of Sunshine* (SMARTS) started about 10 years ago while this author was at the Florida Solar Energy Center. Early accounts of this development were duly presented at the Annual Conferences of ASES (in 1993 and 1994). Since then, the model underwent considerable transformation. Originally developed to investigate the effect of varying atmospheric conditions on the performance of spectrally-

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Progress toward an Updated National Solar Radiation Data Base (NSRDB)

Meeting at NREL on updating the NSRDB. Attendees: generally from Left to Right: Bill Marion (NREL), Marc Plantico (NCDC), Mark Mehos (NREL), Bill Beckman (U of Wisconsin), Frank Vignola (U of Oregon), Charlie Whitlock (SAIC) (partially hidden), Chris Gueymard (SCS), Tom Stoffel (NREL) (in back), Daryl Myers (NREL), Ray George (NREL), Dave Renne' (NREL), Richard Perez (SUNYA). Not pictured: Roland Hulstrom (NREL), Carol Riordan (NREL), Steve Wilcox (NREL). Photo by Steve Wilcox

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measurements. Instead of total and opaque cloud observations, ASOS reports an estimated total cloud cover only to an upper limit of about 3700 meters. Missing from the ASOS records are a measurement of opaque cloud cover as well as *any* cloud measurements above 3700 meters. Thus, our 1995 feasibility investigation for updating the NSRDB concluded that it would not be easy task to produce a simple five-year update by running existing software on newer data.

Meeting of Experts

However, interest in an updated NSRDB persisted. With the passing of the year 2000, a ten-year update became even more attractive, and justification for the update grew stronger. Although the question of modeling solar radiation data from ASOS observations had not been resolved, significant progress occurred since 1995 in modeling solar radiation from satellite images. To help determine the feasibility of producing an updated NSRDB and establish a likely method, NREL convened a meeting of experts in April 2003 to study the obstacles and issues. The panel included NREL staff, other experts using the NSRDB for varied technologies in recent years, and those at the forefront of emerging technologies:

-Bill Beckman, University of Wisconsin

-Chris Gueymard, Solar Consulting Services

-Richard Perez, State University of New York, Albany

-Marc Plantico, National Climatic Data Center

-Frank Vignola, University of Oregon.

-Charlie Whitlock, SAIC (representing NASA)

During the day and a half meeting, these goals guided the group:

- Find an approach for updating the NSRDB
- Develop a timeline for an update project
- Formulate a vision for the NSRDB that anticipates the needs of future solar resource assessment.

The panel determined that a hybrid method would be necessary to produce solar radiation data that spans the 1990s. The hybrid approach might necessitate the use of two or three solar models, depending on the data available. However, input data for no model is continuous throughout the period:

- Manual observations ceased at most NWS stations at some point during the nineties, and a changeover means the end of METSTAT modeling as METSTAT now exists. Further, an ASOS-based model cannot be used prior to a station's switchover to ASOS.
- Historical satellite images (back to the 80s or even 70s) may be prohibitively expensive, unavailable, or incompatible with current satellite solar

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models. Thus it is not likely that a switch to satellite-based modeling would yield a single, consistent method for a thirty-year period (for example, 1971-2000).

While a hybrid approach paves the way to modeling all years, it likely also reduces comparability of the more recent data with that from the original NSRDB. In addition, very few high quality measurement sites in the United States persisted through the decade of the nineties, adding to the difficulty of validating new methods and establishing comparability with older data.

The meeting ended with a management summary session that outlined these long-term goals:

- Produce a gridded satellite-derived high spatial (10km) and temporal (hourly) resolution solar database overlaying an enhanced U.S. Solar Database product for 239-800+ surface meteorological stations
- Continually reduce uncertainties
- Enhance accessibility of data
- Ultimately 30 years (i.e.1971-2000, 1976-2005)
- More frequent and less costly updates (for example, yearly)
- Nowcasting and forecasting capability
- Continue to improve satellite methods toward future capabilities.

Preliminary Work

The panel concluded that additional study is required before selecting a method for producing a national solar database. A preliminary work plan under development will establish a test case based on a one year time period and will be designed to exercise and evaluate the various models under consideration:

- METSTAT
- METSTAT modified for an NCDC cloud product using ASOS and GOES satellite data
- An NRCC/ ASHRAE/ ASOS model current under development (Northeast Regional Climate Center)
- The SUNY/ Albany satellite model (Richard Perez)

For this preliminary effort the panel also plans to investigate and determine improved methods of estimating aerosols. A test year as described would have the additional benefit of making available a prototype product for wider review.

Initial work is currently planned to identify a test year that yields an optimal mix of input data for the models and provides high quality ground measurements for validation. Once the test year is identified, a thorough study of the models will determine their suitability for meeting the needs of NSRDB users and how their output compares with the historical NSRDB data set. Drawing on the one-year test analysis, a more comprehensive work plan can be developed and presented to the Department of Energy and NREL management for consideration of funding what will probably be a significant two year NSRDB update project.

Conclusion

We hope these efforts produce a plan that satisfies the needs of current NSRDB users. But we also envision a long-term data base scheme using satellite modeling that meets future needs with high-resolution solar data sets. Such data sets hold the greatest potential for increased value as satellite remote sensing technology improves and satellite solar models advance.

NREL will present a paper on this work at the 2003 Conference of the American Solar Energy Society [*Progress on Updating the 1961-1990 National Solar Radiation Database*, Dave Renné, et. al) with hopes of generating additional discussions about the project.

Please contact the author at stephen_wilcox@nrel.gov for additional information.

Workshop on the Use of Solar Radiation Data

by Frank Vignola

The University of Oregon Solar Radiation Monitoring Laboratory is planning to hold a one day workshop on the use of solar radiation data on October 16, 2003 at Sun River, Oregon. The workshop will feature the satellite derived solar radiation database for the Pacific Northwest on a 0.1° grid created by Richard Perez as part of DOE contract DE-FC26-00NT41011.

The satellite derived solar radiation database will be discuss and demonstrated along with tools developed to facilitate the use of the database.

This workshop will be part of a larger meeting put together by the Northwest Solar Alliance (a partnership of regional Million Solar Roofs groups). The target audience will be utility personnel and decision makers.

As the program is developed, information on the meeting and workshop will be available at http://solardata.uoregon.edu.

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selective glazings, the model evolved into a versatile radiative transfer code adaptable to a variety of applications. Most of these applications are engineering-related, particularly in the field of solar energy, but other possible applications include:

- obtaining UV reference spectra for weathering studies and material degradation testing;
- calculating the erythemal irradiance or the UV Index for public health and skin cancer prevention;
- evaluating the columnar abundance of atmospheric constituents such as aerosols, water vapor, ozone, or nitrogen dioxide;
- evaluating the performance of spectroradiometers, pyrheliometers or pyranometers;
- simulating filtered pyrheliometers or pyranometers;
- evaluating the uncertainty in silicon-based broadband radiometers induced by their spectral limitations;
- determining the fraction of circumsolar radiation received by pyrheliometers or concentrating solar collectors;
- predicting the clear-sky illuminance and luminous efficacy for daylighting studies;
- predicting the photosynthetically-active radiation (PAR) for plant growth;
- assessing the performance of broadband solar radiation models;
- mesoscale mapping of radiative fluxes in different spectral bands.

In recent years, the development of the latest versions of the code (including 2.9.2, which served to define the ASTM standard described above) was partially supported by NREL. A joint effort between Solar Consulting Services and NREL also permitted the development of a graphical user interface, which is particularly appealing to new users. Furthermore, NREL offered to host a SMARTS webpage, which is now live at http://rredc.nrel.gov/solar/models/SMARTS/ and can be also accessed by doing a search for 'SMARTS' from NREL's homepage, http://www.nrel.gov. The code and its documentation can be freely downloaded from this webpage, but a preliminary registration and acceptance of its terms and conditions are required. In order to better maintain the code, and propose useful improvements or new features in the future, this author welcomes feedback from users.

References

1. C. A. Gueymard, D. Myers and K. Emery, Proposed reference irradiance spectra for solar energy systems testing. *Solar Energy*, **73**, 443-467 (2002).
2. ASTM, "Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface". Standard G173-03, http://www.astm.org (2003).