SOLAR SPECTRUM

NEWSLETTER OF THE RESOURCE ASSESSMENT DIVISION

Volume 12. Issue 2 – November 1999 **of the American Solar Energy Society®**

CURRENT ISSUES IN TERRESTRIAL SOLAR RADIATION INSTRUMENTATION FOR RENEWABLE ENERGY, CLIMATE, AND SPACE APPLICATIONS

An excerpt from a paper to be presented at the 7th International Conference on New Developments and Applications of Optical Radiometry, Oct 22-25,1999 Madrid, Spain. by *T. L. Stoffel, I. Reda, D.R. Myers, D. Renné, S.W. Wilcox, J. Treadwell.*

1. Introduction

Technical issues relating to climate change and renewable energy options require improved accuracy of solar broadband and spectral data at the Earth's surface. Effective deployment of renewable energy technologies such as photovoltaic and solar thermal conversion systems requires high temporal and spatial resolution and absolute accuracy.

The U.S. DOE National Renewable Energy Laboratory (NREL) has an active solar radiation measurement program with excellent capabilities. We report research results associated with broadband and solar irradiance measurements related to these renewable energy and climate change projects.

2. Broadband Shortwave Radiation

Shortwave solar radiation covers the spectral band from 285 nanometers (nm) to 2400 nm. Climate modeler's clear-sky models consistently overestimate shortwave radiation with respect to the best measurements available [1,2]. Attempts to resolve the discrepancies have led to improved knowledge of measurement-error sources.

Total (global horizontal) radiation, I_g, is the sum of the vertical component of the direct beam, I_d, and the diffuse-sky radiation, I_s, or

$$I_g = I_d \cos(z) + I_s, \qquad (1)$$

where z is the solar zenith angle.

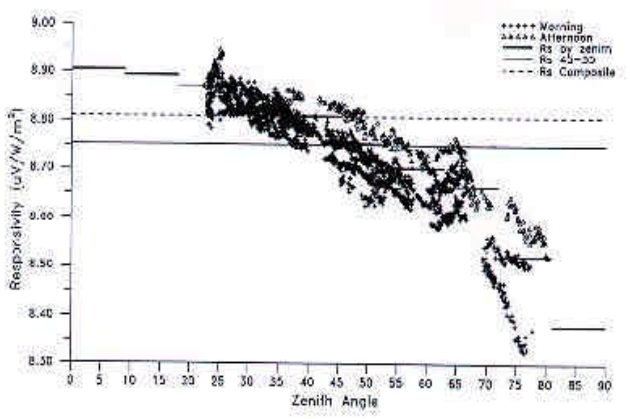

Fig. 1*. Cosine response of typical thermopile pyranometer.*

Pyranometers measure sky-diffuse and global shortwave radiation (180° field of view) and pyrheliometers measure the direct beam, (5° field of view). By shading a pyranometer sensor with a disk subtending the pyrheliometer field of view we obtain diffuse sky radiation. Thermopile sensing elements are protected under quartz domes or windows.

Thermopile signals are proportional to the temperature difference between the hot (absorbing) and cold thermopile junctions. Infrared (IR) exchange between domes and sensors can contribute errors to pyranometer data[3].

2.1 Radiometer Calibrations

Radiometers are calibrated with respect to the World Radiometric Reference (WRR), the mean of group of well-characterized absolute cavity pyrheliometers. Cavity radiometers are calibrated using the equivalence of electrical heating and solar radiation heating of thermopiles in thermal contact with cavity receivers [4,5]. WRR is

(Continued on page 4)

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 Bill Marion, Daryl Myers, David Renné, and Steve Wilcox for their contributions to this newsletter.

Deadline for contributions to the next newsletter is February 1, 2000.

Frank Vignola

Resource Assessment Division Officers & Board Members

Cecile Warner, Chair
Gary Vliet, Vice Chair
David Rennè, Secretary

Jim Augustyn	June 2000
Ray Bahm	June 2001
Bob Cable	June 2000
Dan Greenberg	June 2001
Bill Marion	June 2001
Rob Nelson	June 2001
Richard Perez	June 2000
Timothy Townsend	June 2000

UPCOMING EVENTS

June 12-16, 1999
Solar Powers Life
Share the Energy

SOLAR2000

Madison, Wisconsin
Information: ASES
2400 Central, G-1
Boulder, CO 80301
Tel 303-443-3130
Fax 303-443-3212
http://www.ases.org/conference/

September 17-22, 2000

Millennium Solar Forum 2000

Mexico City, Mexico
Information: c/o Centro de Investigación en Energía, U.N.A.M.
Apartado Postal #34, Temixco 62580
Morelos, México
Fax—52 (73) 250018
Tel—52 (73) 250052
Email ises2000gi@mazatl.cie.unam.mx

RAD DIVISION ELECTIONS

Elections ballots for the RAD Division officers and board member will be mailed along with other ASES general election ballots. Running for RAD Vice Chair is Bob Cable of Kramer Junction Operating Company. David Rennè of NREL is running for Secretary.

The four RAD members running for the four vacant board positions are Doug Balcomb of the National Renewable Energy Laboratory, Mark Beaubien of Yankee Environmental Systems, John Dunlop consultant, and Richard Perez of ASRC-CESTM SUNY, Albany.

Thanks should be given to Roberta DiPasquale, Dave Kearney, and Dave Menicucci for their service on the RAD board for the past two years.

The change in officers will take place at the next annual RAD division meeting at SOLAR 2000.

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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Bill Berg	n/a at this time
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Gary Vliet	gvliet@mail.utexas.edu
Cecile Warner	cecile@nrel.nrel.gov

MINUTES RESOURCE ASSESSMENT DIVISION (RAD) MEETING 16 JUNE, 1999 PORTLAND, ME

by Dave Renné

1. Mike Sloan, outgoing Chair, turned the meeting over to Cecile Warner, incoming Chair.

2. Roberta diPasquale submitted her resignation; she is returning to school to study an MBA.

3. Dave Renné reported on the Wednesday morning Resource Assessment Technical Session. There were five papers, including one on wind resource assessment. Cecile noted that it is good to have the RAD meeting and the resource assessment technical sessions on the same day. There were complaints about the ready room not being large enough, and a printer not having a working cartridge. It was suggested that the front desk (annual conference) coordinators should advertise where the nearest Kinko's is located.

4. Jim Augustyn recommended that RAD meetings should be conducted around a conference table setting. All the RAD participants then moved to a conference table format.

5. Dave Renné, presenting the Program Committee, discussed the technical review process for the 2000 Conference. Three people are needed: 2 to review abstracts (but not to travel to the technical review meeting in January), one to read and possibly to travel to the technical review meeting the second week of January. As a Division, we need ideas to put forward for the technical program. We also need to consider a program structure beyond Madison (e.g., the Washington, DC meeting in 2001). Gary Vliet commented on the blind review process.

6. Nominating Committee (Jim Augustyn): The current board consists of Sloan (Chair), Warner (Vice Chair), Cable, DiPasquale, Kearney, Marion, Menicucci, Perez, and Townsend. New members elected to the Board are Ray Bahm, Dan Greenberg, Bill Marion, and Rob Nelson.

7. Newsletter (Frank Vignola): One of Gary Vliet's duties as the next Vice Chair is to get articles for the Solar Spectrum newsletter (including institutions like NREL, universities, industry like SEGS, and instrument companies like Eppley). Articles are due in early February (for the April edition) and early October (for the November edition). Frank will still assemble the newsletter.

8. New Business:

a. Need new reviewers and their biographies;

   1) Richard Perez — blind reviewer

   2) Jim Augustyn — blind reviewer

   3) Dave Renné — traveling reviewer

b. Modification of bylaws;

c. Select two names for the Fall ballot for ASES Board; RAD will have one member of the Board of ASES;

d. Upcoming conferences: Madison, Wisconsin; Washington, DC; Mexico City.

   1) A possible forum for Madison was discussed, which would involve getting data into the formats that people can used in the field. This would be targeted toward the PV industry, system sizes, solar water heating community, and hybrid systems developers. What are these stakeholders looking for in data? How can these data be integrated into GIS? What are the appropriate data capabilities, accuracies, and formats? What about wind, temperature, and other types of useful data?

   2) Frank Vignola will prepare a 1-2-page description of the proposed forum.

e. Need to replace Roberta DiPasquale on the RAD Board;

   1) Jim Augustyn was nominated and seconded to replace Roberta diPasquale on the RAD Board. This was passed.

   2) Dave Renné was nominated and seconded to serve as RAD Secretary. This was passed.

f. Need to elect 4 new RAD Board members and new officers (Chair and Vice Chair). The nominating committee will convene via e-mail to conduct this work. The nominating committee consists of Mike Sloan (Chairman), Jim Augustyn, Frank Vignola, Richard Perez, and Cecile Warner.

g. Jim Augustyn raised the issue of changing the Resource Assessment Division name and mission. What is RAD's function, and what does it provide of value to the organization? Richard Perez suggested changing the name to the Resources Division. Constantine Hadjilambrinos asked about financial resources for the Division.

CURRENT ISSUES IN TERRESTRIAL SOLAR RADIATION INSTRUMENTATION FOR RENEWABLE ENERGY, CLIMATE, AND SPACE APPLICATIONS

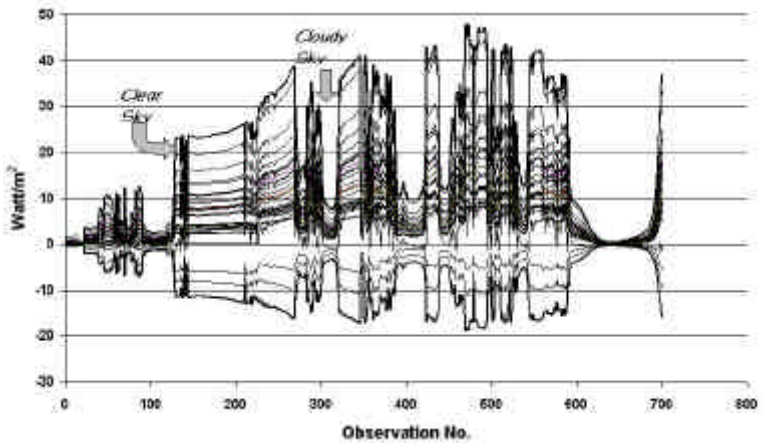

Fig. 2. *Difference between fluxes measured using a single versus "vector" zenith-angle-dependent responsivities for 30 thermopile radiometers.*

(Continued from page 1)

maintained to an estimated uncertainty of 0.3%, by the WMO World Radiation Center (WRC) at Davos, Switzerland. Romero et al. [5] showed equivalence between WRR and the International System of Units (SI) radiation scale realised with cryogenic absolute cavity radiometers to better than 0.05%.

The WRR is transferred to working reference absolute cavity radiometers every five years during International Pyrheliometer Comparisons (IPC) conducted at the WRC. Pyrheliometer responsivities are derived by direct comparisons with absolute cavity pyrheliometers.

Pyranometer responsivities are derived using equation 1 to generate a reference global irradiance from an absolute cavity radiometer beam measurement and shaded (diffuse) pyranometer measurement. The responsivity (RS) of the diffuse-measuring pyranometer is derived in a shade-unshade calibration from

$$RS = (Vu-Vs)/[I_d*\cos(z)], \quad (2)$$

where Vu and Vs are the voltages from unshaded and shaded sensors [6, 7].

2.2 Direct-Beam Radiation

Combining the uncertainties due to the uncertainty in the WRR (0.3%), the transfer of WRR to working reference cavity radiometers (0.2%), the changing thermal environment (1.0%), and the data acquisition uncertainty (0.2%), typical uncertainty in thermopile pyrheliometers is about 2.0%, or 20 Watt/m² at 1000 W/m².

2.3 Total Global-Horizontal Radiation

Absolute cavity pyrheliometer direct beam plus shaded pyranometer diffuse sky radiation give the most accurate value of total flux. Figure 1 shows that responsivities of pyranometers are not flat but are a function of zenith angle.

Pyranometer data can be improved by applying responsivities as a function of zenith angle, as shown in Figure 2, which shows the difference between shortwave flux computed using a single responsivity and a "vector" of responsivities that vary by 10 degree zenith angle increments.

Errors of up to 40 Watt/m² due to cosine response problems are corrected using the vectors.

Another approach is fitting of individual cosine responses, Rs, with functions of the form:

$$Rs = S\, a_i \cos^{\,i} z_i \quad (3)$$

for morning and afternoon zenith angles, z. Preliminary results show uncertainty reduced from ±1.8% to ±0.5% using 17 zenith angle bins (i=17) of 5° width [7].

NREL recently developed a modified shade-unshade calibration method that averages responsivity at equally spaced instrument azimuth orientations for 45° zenith angle. Uncertainty analysis for this method resulted in a factor of 3 (from ±6.4% to ±2.5%) reduction in clear-sky diffuse responsivities [6].

Zero offsets of -5 to -20 W/m² due to thermal imbalances in the instruments contribute to uncertainty in

(Continued on page 5)

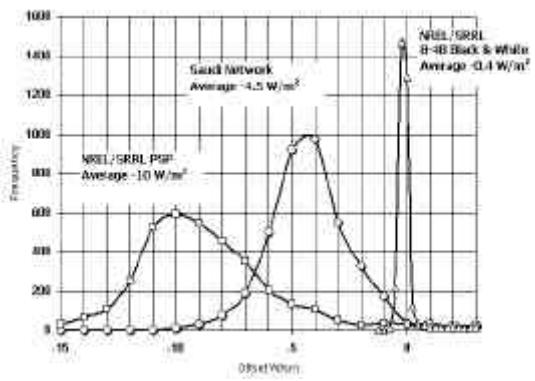

Fig. 3. *Distributions of dark offsets for NREL black-and-white (mean -0.4 W/m²) and all-black diffuse pyranometers (mean offset -10 W/m²), and Saudi Arabia all-black pyranometers (12-station network mean -4.5 W/m²)*

CURRENT ISSUES IN TERRESTRIAL SOLAR RADIATION INSTRUMENTATION FOR RENEWABLE ENERGY, CLIMATE, AND SPACE APPLICATIONS

(Continued from page 4)

diffuse pyranometer measurements [8,9]. Figure 3 shows the distributions of dark (night-time) offsets for all black sensor (model PSP, an instrument widely deployed in this application) in a U.S. continental climate (at NREL) and in a desert site in Saudi Arabia. The offset for a black-and-white (model 8-48) detector, insensitive to such offsets, is shown for comparison.

Correction algorithms based on the observed correlation of night-time offsets, O, with net longwave IR radiation and estimates of sky and radiometer temperatures based on Stefan-Boltzmann (sT^4) estimates [9] such as:

$$O=a+bW_{net}+cW_{inc}+d(T_{sky}-T_{amb})+eT_{amb} \quad (4)$$

where W_{net} is net IR, W_{inc} is downwelling IR, T_{sky} is $(W_{inc}/s)^{1/4}$, and T_{amb} is ambient temperature in Kelvin. Figure 4 shows reductions in zero offset errors in diffuse data from -20 W/m² to -2 W/m² at NREL

4. Conclusion

Accurate measurements of terrestrial solar radiation can enhance the deployment of solar energy conversion systems, confirm or deny long term climate change, and validate remote sensing estimates of solar energy flux and the Earth's radiation budget. Non-lambertian radiometer responses, zero offsets, and lack of high accuracy references for diffuse-sky and longwave radiometer calibrations contribute to discrepancies up to 40 W/m² between model and measured shortwave radiation. Characterisation of these effects identifies and removes errors on the order of magnitude of the discrepancies observed. Diffuse-sky measurement accuracy could be increased if high accuracy references for this components could be developed.

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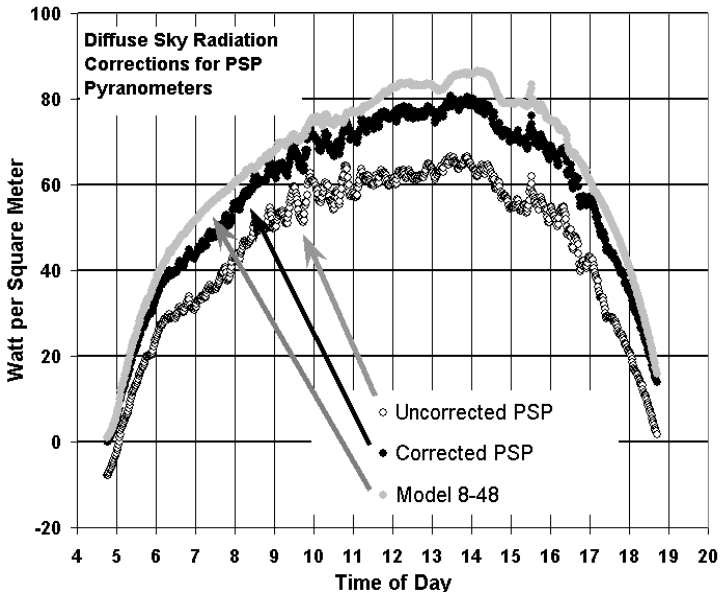

Fig. 4. *Zero offset corrections reduced from 20 W/m² to less than 2 W/m² for model PSP diffuse.*

1999 PYRHELIOMETER COMPARISON AT NREL

by Tom Stoffel and Steve Wilcox

Mr. Herizal of the Indonesian Meteorological and Geophysical Agency sets up for the 1999 NREL Pyrheliometer Comparison.

Twenty scientists from five countries gathered in Golden, Colorado to participate in the NREL Pyrheliometer Comparisons (NPC-99) from October 4-15, 1999. This tenth annual comparison of reference standard radiometers provides calibration traceability to the World Radiometric Reference (WRR) maintained by the World Meteorological Organization at the World Radiation Center in Davos, Switzerland.

Toward this end, five absolute cavity radiometers with direct WRR traceability formed the reference group to provide the standard reference irradiance. These reference instruments serve as calibration standards for the US Department of Energy, US Department of Commerce, radiometer manufacturers, European Union photovoltaic test facilities, and the Saudi Arabian solar resource measurement network. Direct traceability for these radiometers is established by participation in the most recent International Pyrheliometer Comparison (IPC) in 1995. The IPCs are held every five years at the WRC.

Several thousand simultaneous measurements were taken by the 21 cavities participating in the two week event at NREL's Solar Radiation Research Lab (SRRL), providing a representative sample of data under a variety of clear-sky conditions.

The results of NPC-99 will be used to improve the accuracy of solar radiation measurements and increase the value of solar resource measurements to industry.

Meanwhile, NREL's new Solar Radiation Research Laboratory is well out of the ground and slated for completion by December. This new facility provides consolidated space for NREL metrology functions, optics lab, and offices, and will continue to support the baseline measurement system for solar and wind resource assessment. The new SRRL, which is being

Cavity radiometers from five countries participate in the 1999 NREL Pyrheliometer Comparison.

1999 PYRHELIOMETER COMPARISON AT NREL

NREL's Tom Stoffel under the instrumentation deck during construction of the Solar Radiation Research Facility.

constructed adjacent to the present facility atop South Table Mountain in Golden, Colorado, will have 300% more deck space for instrumentation, calibration, and other research projects.

UPDATING THE NATIONAL SOLAR RADIATON DATA BASE

WHAT ARE YOUR OPINIONS, SUGGESTIONS, & CONCERNS?

Every 10 years, climatologists update the meteorological data bases. This gives a current idea of the mean temperature, rain fall, and other measures of interest over the past 30 years.

Since solar radiation has similar variability as the meteorological data bases, there is talk about updating the National Solar Radiation Data Base (NSRDB) from the 1961-1990 time period to 1971-2000.

There is at least one major problem with updating the NSRDB. Cloud cover observations used in the model to generate most of the solar radiation values are no longer made. Satellite measurements can also be used to estimate cloud cover, but they do not go back 30 years and they are not really the same type of measurement. It is possible to mix the two types of measurements and obtain a continuous estimate of solar radiation.

Now is a chance for RAD division members to voice their opinions. This is a call for letters to the editor expressing your opinion on:

- Should the NSRDB be updated?
- How best to update the NSRDB?
- What problems would be of concern?
- Who should update the NSRDB?

With climate change and the growing value of solar radiation data, does the solar community have a Y2K problem if it doesn't update the NSRDB?

This is a call for letters to the editor to express your opinions on updating the NSRDB!

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In This Issue... *Current Issues in Terrestrial Solar Radiation Instrumentation for Renewable Energy, Pyrheliometer Comparison*

PV WATTS — A PERFORMANCE CALCULATOR FOR GRID CONNECTED PV SYSTEMS

by Bill Marion and Mary Anderberg

Mary Anderberg and Bill Marion have added a feature to NREL's website called PVWATTS. PVWATTS is an internet-accessible model that calculates the performance of grid-connected PV systems. Based on subroutines from Sandia's PVFORM, PVWATTS reads Typical Meteorological Year (TMY2) data and performs an hour-by-hour simulation for a one year period. Users may select any of the 239 TMY2 stations from a clickable station map, and may select default PV system parameters, or specify their own. Parameters that may be specified include: PV system size, fixed or tracking PV array, PV array tilt angle, PV array azimuth angle, and local electric cost. PVWATTS outputs a table of monthly and annual energy production in AC kWh and energy value in dollars.

PVWATTS' internet accessibility and ease of use permits both experts and non-experts to quickly obtain performance estimates for grid-connected PV systems located in the United States and its territories. The website address for PVWATTS is http://rredc.nrel.gov/solar/codes_algs/PVWATTS/.

[*A sample output is given on the right for a 1 kW peak AC system in Eugene, Oregon tilted at latitude. The price of electricity was chosen to be 5 cents/kWh. ED.*]

Energy Production

Month	Energy (kWh)	Energy Value $
1	54	2.70
2	67	3.35
3	113	5.65
4	125	6.35
5	150	7.50
6	145	7.25
7	170	8.50
8	169	8.45
9	146	7.30
10	111	5.55
11	52	2.60
12	46	2.30
Year	1348	67.40