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Radiometric Calibrations, Measurements, and Standards Development at NREL

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Radiometric Calibrations, Measurements, and Standards Development at NREL

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ABSTRACT

We describe proposed revisions to current reference standard spectral distributions used to evaluate photovoltaic device performance and durability of materials. Improvements in broadband outdoor radiometer calibrations reduce uncertainties in broadband radiometer calibrations. We report a method to quantify the rate of change of broadband radiometer responsivities as a function of integrated exposure to irradiance and thermal energy. The results of applying a vector of calibration factors or responsivities to field data to remove zenith-angle dependent errors in global solar radiation measurements are shown. We report on the relative sensitivity of radiometers to daily versus biweekly cleaning

1. Proposed Revisions to Spectral Irradiance Standards

We have compared existing consensus standard spectral irradiance distributions [1-3] with measured spectra, and prepared a critical review [4] of the results and the needs of the photovoltaic (PV) and materials-degradation community for updated reference spectral distributions.

A moderately complex spectral model, SMARTS2 [5], is being used along with the complex MODTRAN [6] spectral model to develop and validate proposed revised reference spectra. Working with the American Society of Testing and Materials (ASTM) subcommittee G03.09 on Radiometry, we proposed the preliminary direct, global, and ultraviolet spectra shown in Figures 1-3.

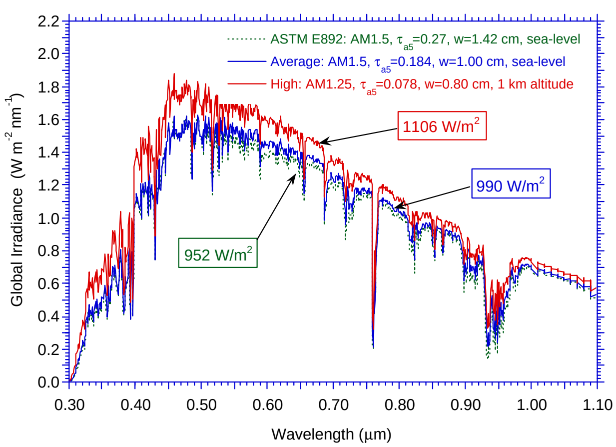

Fig. 1. Proposed typical, or "average," and clear sky ("high") global reference spectral distributions developed from SMARTS2 and MODTRAN spectral models.

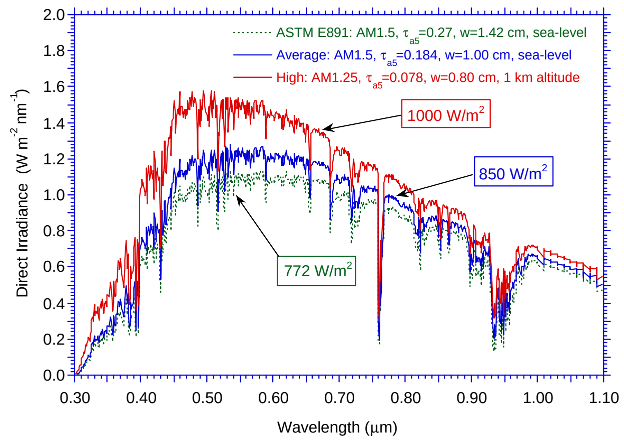

Fig. 2. Proposed typical, or "average," and clear sky ("high") direct normal reference spectral distributions derived from SMARTS2 and MODTRAN models.

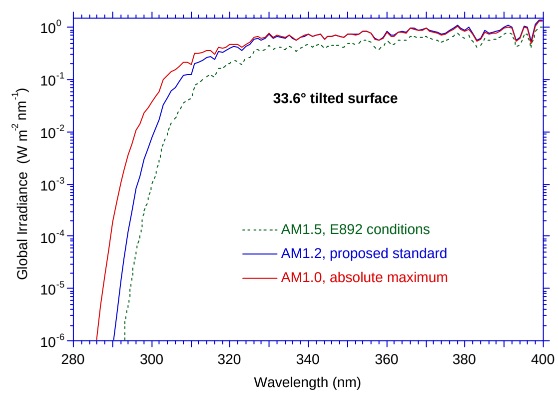

Fig. 3. Proposed typical, or "average," and absolute maximum ultraviolet global spectral distributions derived from SMARTS2 and MODTRAN models.

We intend to make the SMARTS2 model available as an adjunct standard to the revised spectral standards. This will allow users to (1) reproduce the spectra at will, and (2) produce test spectra for different atmospheric conditions for performance comparisons and analysis.

2. Broadband Radiometer Calibration Improvements

We have updated the radiometer calibration and characterization (RCC) software used for broadband radiometer calibrations at NREL [7]. Improvements include a new graphical user interface and integrated calibration history database and reporting functionality. The new RCC processes responsivity data based on more accurate diffuse reference irradiance measurements and zenith-angle information. The resulting uncertainty in the new RCC responsivity results are about half of the older version, as seen in Figure 4.

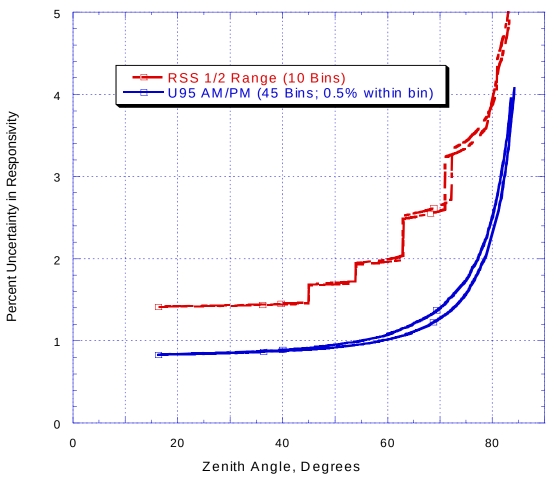

Fig. 4. Comparison of percent total uncertainty in NREL RCC responsivities versus zenith angle for older (top curve) and new (bottom curve) radiometer calibration procedures.

3. Pyranometer Degradation and Cosine Corrections

We modeled the degradation of pyranometer responsivities as a function of cumulative irradiance and thermal exposure [8] with multilinear regressions of cumulative changes in responsivity versus cumulative irradiance (megaJoules) and temperature (cumulative degree-days, base 0°C). Four years of radiometer calibrations for pyranometers in the Kingdom of Saudi Arabia 12-station solar monitoring network were used. Figure 5 shows the correlation between predicted and measured responsivity degradation is better than 0.92.

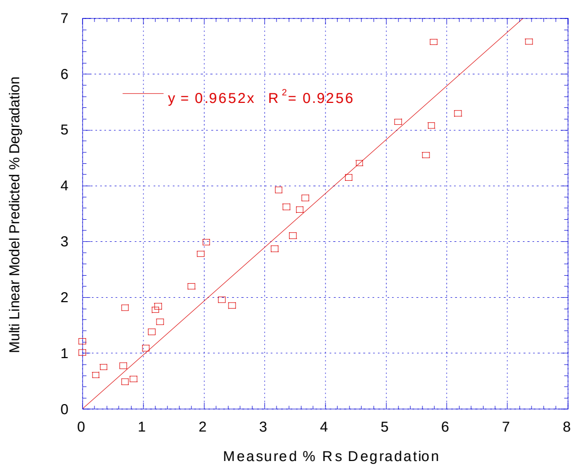

Fig. 5. Model versus measured pyranometer responsivity degradation with cumulative irradiance and temperature.

RCC-generated pyranometer responsivity functions for the Saudi monitoring network station at the Solar Village, just outside Riyadh, were used to correct global solar radiation data for zenith-angle errors in the individual radiometers[9]. Table 1 shows 2% errors at high zenith angles, and 1% errors at small zenith angles accounted for.

Using a single pyranometer responsivity for zenith-angle 45° produces a 0.1% error in annual total solar radiation.

TABLE 1: EFFECTS OF ZENITH-ANGLE CORRECTIONS ON GLOBAL IRRADIANCE

Zenith angle bin	Average Irradiance (W/m^2)		% change
	Original	Corrected	
0-9	1006	996	-1.0
9-18	962	954	-0.8
18-27	900	894	-0.7
27-36	816	814	-0.2
36-45	702	702	0.0
45-54	585	589	0.7
54-63	436	441	1.1
63-72	284	288	1.4
72-81	141	144	2.1
81-90	54	55	1.9
Total (kWh)	3089606	3092756	0.1

4. Pyranometer-Cleaning Study

Pyranometers and pyrheliometers are cleaned every 2 weeks at 25 sites in the Atmospheric Radiation Measurement (ARM) program. A control site is cleaned every day. The mean change in irradiance before and after cleaning for two years of one-minute global and direct irradiance data are shown in Table 2. We also show mean and standard deviation of the time rate of change for clear sky irradiances; i.e., maximum rates of change.

TABLE 2. MEAN GLOBAL AND DIRECT IRRADIANCE CHANGES DUE TO CLEANING

	25 Pyran	Ctrl Pyran	25 NIP	Ctrl NIP
Mean Delta W/m^2	0.94	0.34	4.5	3.0
Mean dI/dT $W/m^2/min$	0.65 ± 4.5		2.30 ± 11.9	

Radiometers cleaned on a biweekly and daily basis show irradiance differences slightly greater than the mean rate of change of irradiance for one-minute clear sky data.

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