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Evaluating Radiometric Measurements Using a Fixed 45° Responsivity and Zenith Angle Dependent Responsivities

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Abstract

The Atmospheric Radiation Measurement (ARM) program provides high-quality radiometric data traceable to International System of Units (SI), through the World Radiometer Reference (WRR) and World Infrared Standard Group (WISG). The National Renewable Energy Laboratory (NREL) and ARM, through the Radiometer Calibration Facility (RCF) at the Southern Great Plains (SGP), provide calibration of broadband radiometers deployed in the SKYRAD, GNDRAD, and SIRS instrument platforms. Both NREL and ARM continue to improve radiometric calibration and measurement through the introduction of new methods and refinement of old methodologies. This poster seeks to demonstrate the importance and application of an existing but unused approach that ultimately reduces the uncertainty of radiometric measurements. Current radiometric data is based on a single responsivity value that introduces significant uncertainty to the data, however, through using responsivity as a function of solar zenith angle, the uncertainty could be decreased by 50%.

Method

Reference irradiance data created using:

A.Eppley NIP (direct) and 8-48 (diffuse)

B. Kipp and Zonen CH1 (direct) and CM22 (diffuse)

Table 1. Uncertainty of Reference Instruments

Instrument (DNI)	Uncertainty (U95%)* Solar Zenith Angle:30-60 degree	Instrument (DHI)	Uncertainty (U95%)* Solar Zenith Angle: 30-60 degree
CH1	+0.72/-0.66%	CM22	+1.23/-1.30%
NIP	+0.98/-1.22%	8-48	+3.31/-2.20%

* Obtained from NREL BORCAL Report http://www.nrel.gov/aim/borcal.html

Test Instrument

Eppley PSP (global) S/N: 28402F3

Three-Component Equation to Compute Reference Global

$$GHI = DNI * Cos(Z) + DHI$$

where, GHI = **global** horizontal irradiance in W/m^2, DNI = **direct** normal irradiance in W/m^2, DHI = **diffuse** horizontal irradiance in W/m^2, and Z = the solar zenith angle in degrees.

Thermal Offset Correction

The data from the test instrument (PSP) was corrected for thermal offset errors using a pyrgeometer, (an Eppley model PIR precision infrared radiometer).

Effective Net Infrared Correction (used in thermal offset correction and responsivity function to calculate test instrument irradiance)

$$V_c = V - W_{net} * R_{net}$$

where, V_c = corrected voltage in volts, V = uncorrected voltage in volts, W_{net} = effective net infrared (W/m²) (from the down-welling pyrgeometer), and R_{net} = instruments effective net infrared response (μV/W/m²) as determined during the Broadband Outdoor Radiometer CALibration (BORCAL).

Test Instrument Irradiance

$$G = V_c / R$$

Where, G is the calculated global solar irradiance for the test instrument in W/m^2)

R is the pyranometer's responsivity determined by calibration in μV/(W/m^2).

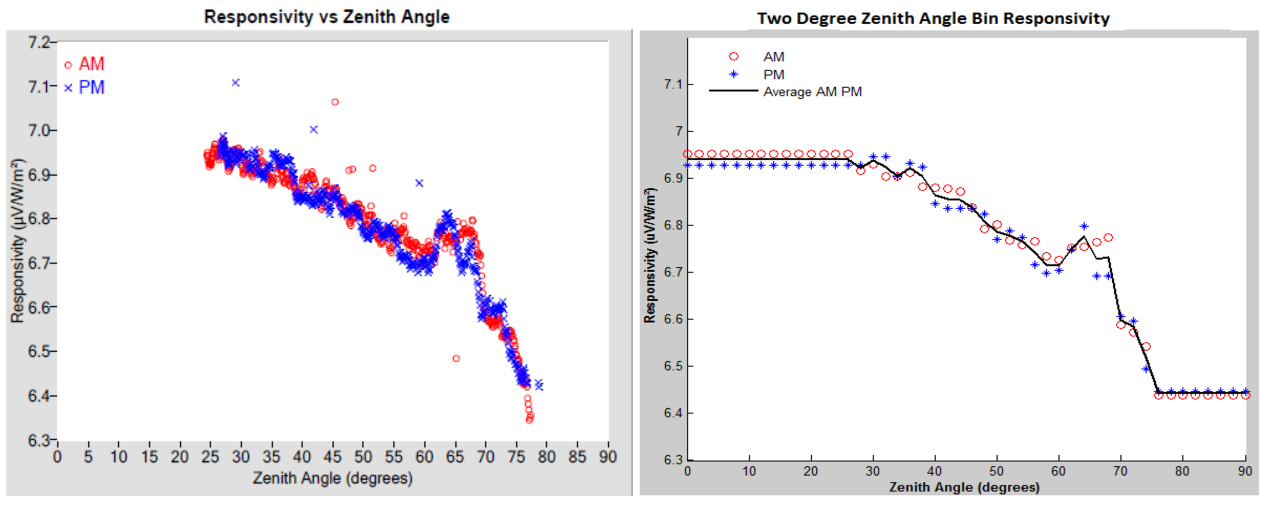

Figure 1. Left figure shows AM and PM responsivity and solar-zenith angle as measured on May 5, 2011. Right figure shows measured responsivity, grouped into AM and PM 2-degree solar-zenith angle bins. These bins were averaged and linearly interpolated to produce a responsivity function by which any discrete responsivity can be calculated.

Obtained from BORCAL report : http://www.nrel.gov/aim/Calibrations/BORCAL/SRRL/report/2011-02_NREL-SRRL-BMS.pdf

Results

Table 2 demonstrates the differences between the 45-degree solar-zenith angle responsivity and the solar-zenith angle function responsivity. Overall, the latter shows an approximate 50% reduction in Mean Bias Error (MBE). Similar reduction rates of uncertainty were described in previous studies, such as [1,2,3].

Solar Zenith Angle Bins	Responsivity at Zenith Function		Responsivity at 45 degree Zenith		Solar Zenith Angle Bins	Responsivity at Zenith Function		Responsivity at 45 degree Zenith	
	MBE%	MBE in W/m^2	MBE%	MBE in W/m^2		MBE%	MBE in W/m^2	MBE%	MBE in W/m^2
10-20	-0.36	-2.77	3.01	22.12	10-20	-0.91	-6.64	2.45	18.60
20-30	-1.55	-4.62	1.77	19.61	20-30	-1.57	-9.00	1.76	15.32
30-40	-1.40	-5.04	1.93	17.47	30-40	-1.86	-9.93	1.46	12.72
40-50	-1.10	-4.15	2.25	16.04	40-50	-1.67	-8.69	1.66	11.55
50-60	-0.77	-2.74	2.58	13.13	50-60	-1.47	-7.10	1.85	8.87
60-70	-0.83	-2.99	2.52	8.60	60-70	-1.85	-6.89	1.45	4.71
70-80	3.03	3.68	6.48	9.97	70-80	1.47	0.82	4.86	7.10

Table 2. MBE for the NREL EPPLEY PSP (28402F3) using CH1 and CM22 as a reference (left) and using NIP and 8-48 (right)

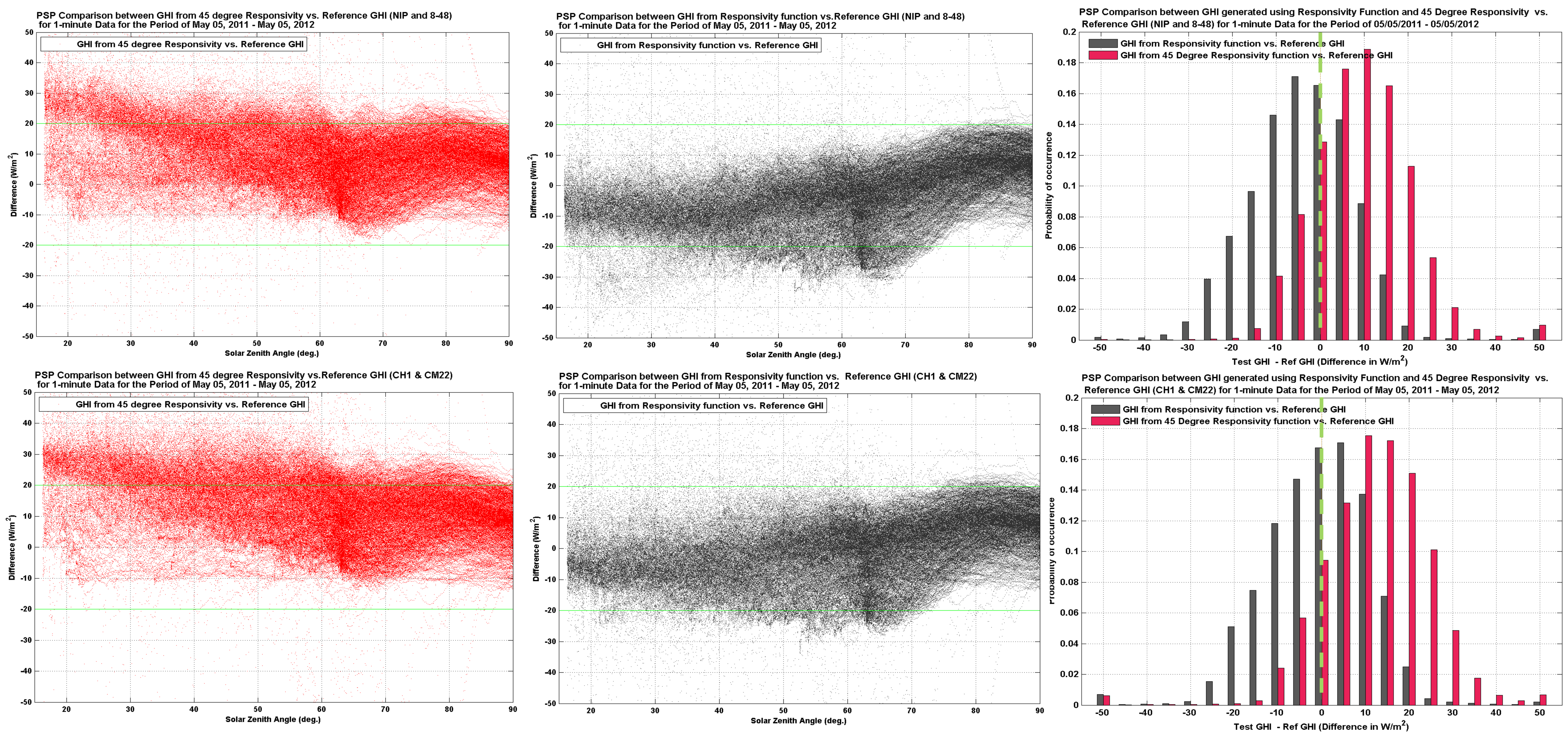

Figure 2. Top figures are Eppley PSP comparison relative to the reference GHI calculated using Eppley NIP (DNI) and 8-48 (DHI) and bottom figures are the same comparison, but the reference is calculated using Kipp and Zonen CH1 (DNI) and CM22 (DHI).

Summary

- **Each instrument responds differently under various climatic/weather conditions; thus, these results are limited to the location where the above instruments are located.**
- **As stated above using the responsivity function, the irradiance MBE decreased by more than 50%. This reduction is mostly attributed to the uncertainty reduction of the instrument's responsivity. References 2 and 3 below show that the responsivity function reduces the uncertainty by 50%.**
- **We strongly recommend that the responsivity function be applied to the ARM radiometric data for the individual pyranometer or pyrheliometer deployed to provide high quality radiometric data and reduce the overall uncertainty.**

References

[1] D. R. Myers, "Solar radiation modeling and measurements for renewable energy applications: Data and model quality," in Energy: Special Edition—Proceedings from the First International Conference on Measurement and Modelling of Solar Radiation and Daylight, Edinburgh, Scotland, September 15-16, 2003, vol. 30, no. 9, 2005; pp. 1,517-1,531; NREL Preprint, NREL/JA-560-37892.

[2] I. Reda, "Method to calculate uncertainty estimate of measuring shortwave solar irradiance using thermopile and semiconductor solar radiometers," National Renewable Energy Laboratory, Golden, CO, Tech. Rep., NREL/TP-3B10-52194, 2011, 20 pp.

[3] I. Reda, D. Myers, and T. Stoffel, "Uncertainty estimate for the outdoor calibration of solar pyranometers: A metrologist perspective," Measure (NCSLI Journal of Measurement Science), vol. 3, no. 4, pp. 58-66, Dec. 2008; NREL Preprint, NREL/JA-581-41370.

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