Evaluating the Sources of Uncertainties in the Measurements from Multiple Pyranometers and Pyrheliometers

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL is a national laboratory of the U. S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Aron Habte, Manajit Sengupta, Afshin Andreas, Mike Dooraghi, Ibrahim Reda, and Mark Kutchenreiter
National Renewable Energy Laboratory, Golden, Colorado

I. Abstract

Traceable radiometric data sets are essential for validating climate models, validating satellite-based models for estimating solar resources, and validating solar radiation forecasts; however, the uncertainty of current radiometers is 2%–5% and sometimes more [1].

The National Renewable Energy Laboratory (NREL) and the Atmospheric Radiation Measurement (ARM) Program are identifying uncertainties, improving measurement performance, and developing a consensus standard methodology for radiometric measurements.

This study analyzes the impact of differing parameters—such as cosine response, thermal offset, spectral response, and others—on the accuracy of data from several radiometers. The study provides insight on how to reduce the impact of some of the sources of uncertainties.

II. Method

We estimated measurement uncertainty following the International Organization for Standardization procedure for evaluating uncertainty, the *Guide to the Expression of Uncertainty in Measurement* (GUM) [2], as shown in Figure 1.

Sources of measurement uncertainty:

- *Calibration*
- *Spectral response*
- *Cosine angle response*
- *Maintenance—soiling*
- *Data logger uncertainty*
- *Temperature dependence*
- *Nonlinear response*
- *Thermal offset*
- *Instrument aging*

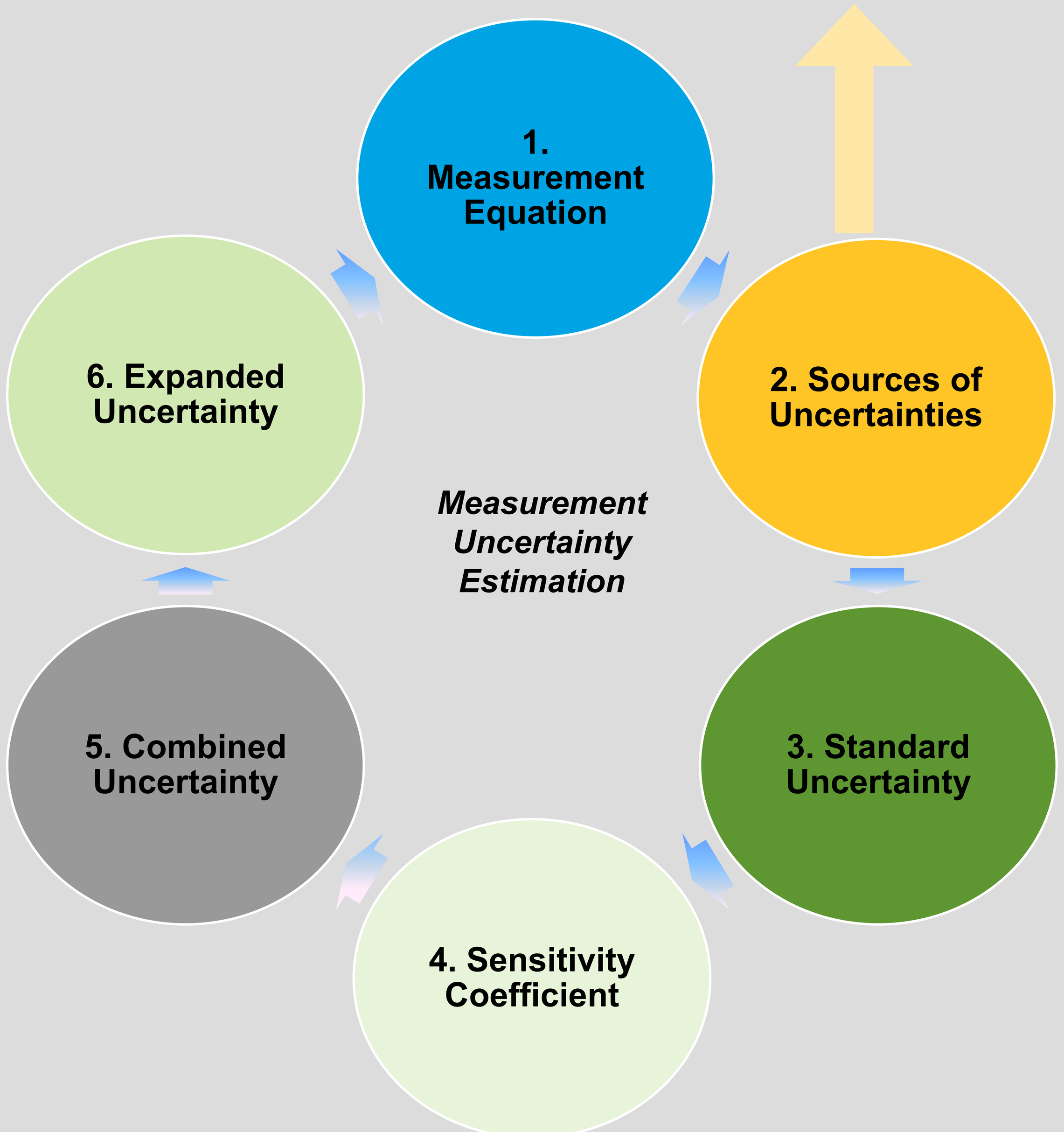

Figure 1. Measurement uncertainty estimation flowchart using the GUM method

III. Quantifying Sources of Uncertainties

A. Calibration, thermal offset, and cosine response errors

Figure 2 addresses the effect of different Broadband Outdoor Calibration methodologies and resulting differences [3]. These differences are attributed to the various sources of uncertainties, such as thermal offset and cosine response [4]. The result from the figure is used in the uncertainty estimation.

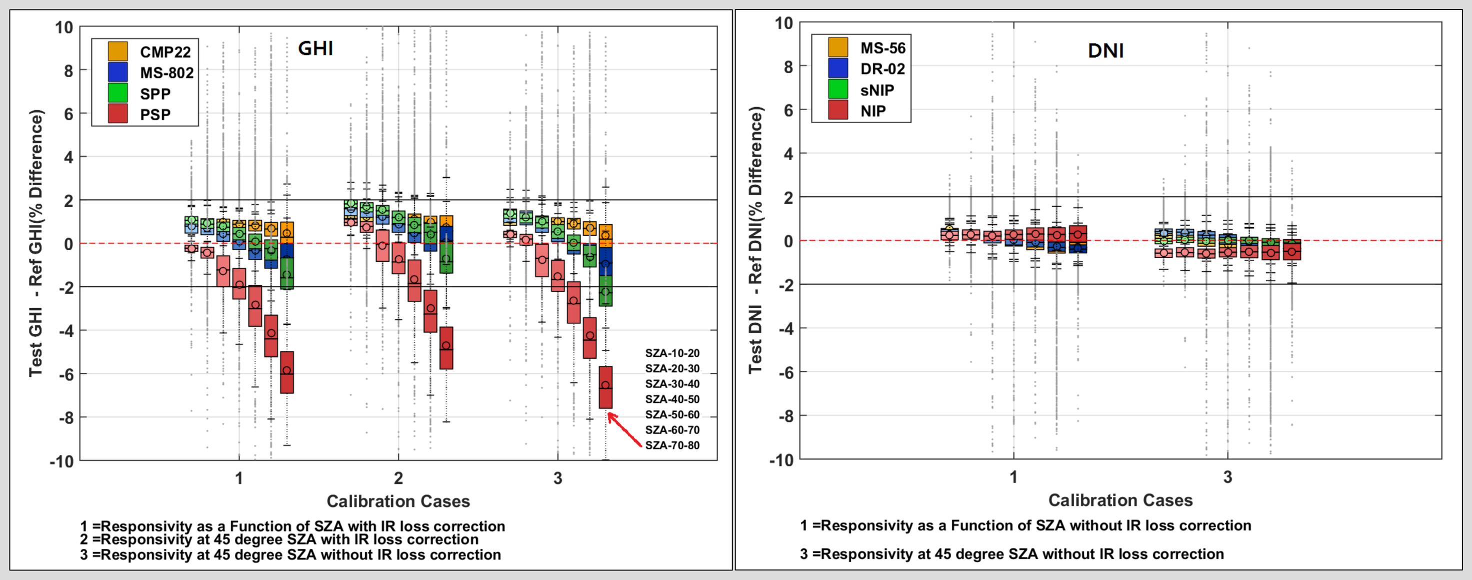

Figure 2. Comparison of NREL's calibration responsivity for clearness index (Kn) above 0.6. Differences are shown in percentage and W/m². Left: GHI; right: direct normal irradiance (DNI)

B. Radiometer spectral change coating

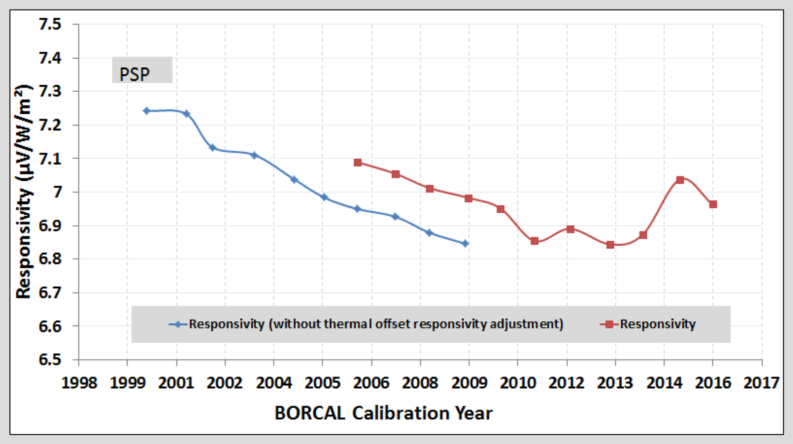

Figure 3. History of instrument at zenith angle = 45°

Radiometer response changes with time (Figure 3) because of changes in the optical transmittance of the glass dome and the reflectance of the black detector over time (Figure 4). Results from the figures are used in the uncertainty estimation.

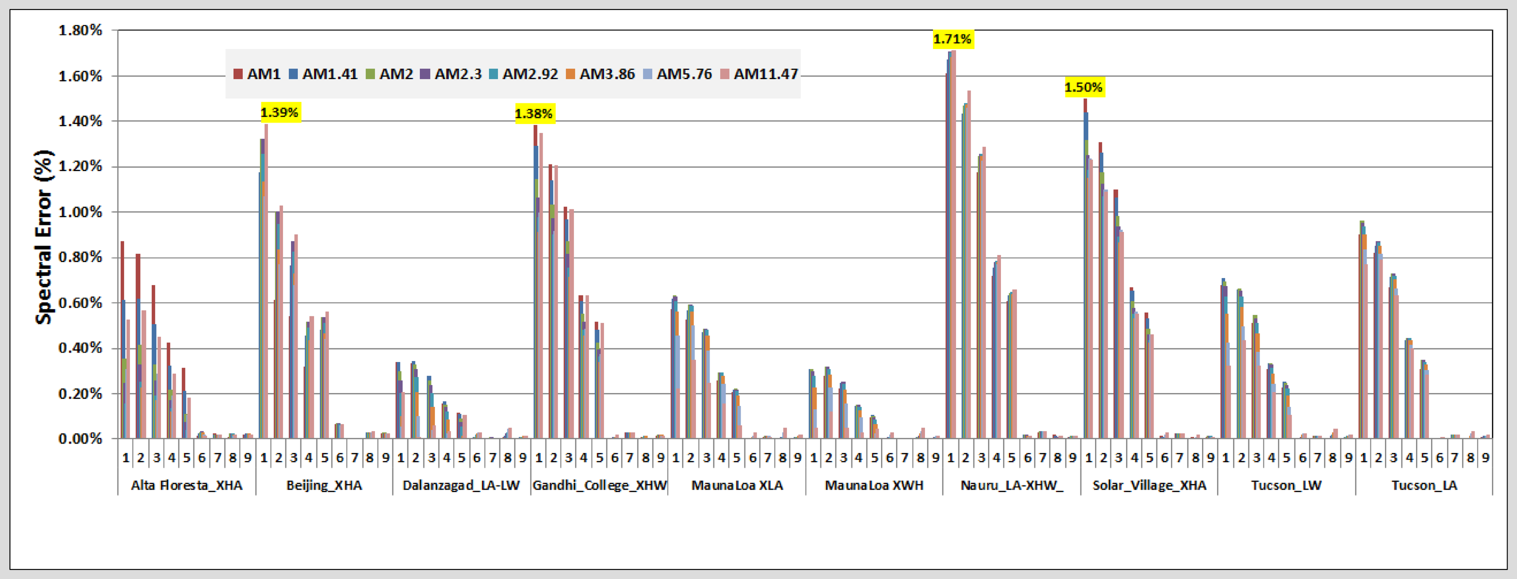

Figure 4. Results showing the spectral error of shortwave radiometers under different air masses (AM) and locations [5]. Note: Spectral irradiance simulation was performed using SMARTS model.

IV. Result: Uncertainty Estimation

NREL in collaboration with industry developed a guide to an uncertainty estimation international consensus standard through the American Society for Testing Materials. NREL has a spreadsheet that implements the standard [6]. The output plots from the spreadsheet assist in illustrating the overall uncertainty versus irradiance (Figure 5) and the main contributions to uncertainty (Figure 6). Uncertainty estimates shown in Table 1 were obtained using the spreadsheet in which both ARM radiometers, PSP and NIP, have higher uncertainty from the global horizontal irradiance (GHI) and direct normal irradiance (DNI) groups, respectively.

Table1. Uncertainty Estimated Using GUM

Type	Model	Manufacturer	Measurement Uncertainty (%)
GHI	CMP22	Kipp & Zonen	2.7
	SPP	Eppley Lab.	3.7
	MS-802	EKO Ins.	3
	PSP	Eppley Lab.	6.6
DNI	CHP-1	Kipp & Zonen	1.4
	NIP	Eppley Lab.	2.2
	sNIP	Eppley Lab.	1.7
	DR02	Hukseflux	2.1
	MS-56	EKO Ins.	1.8

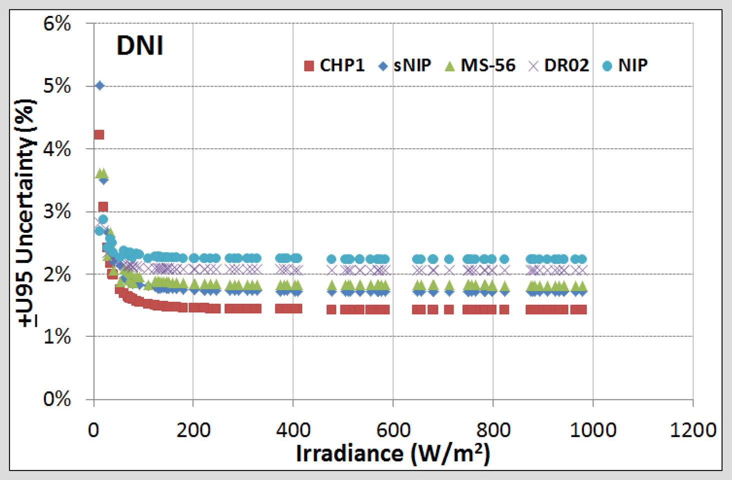

Figure 5. Overall uncertainty for DNI radiometers

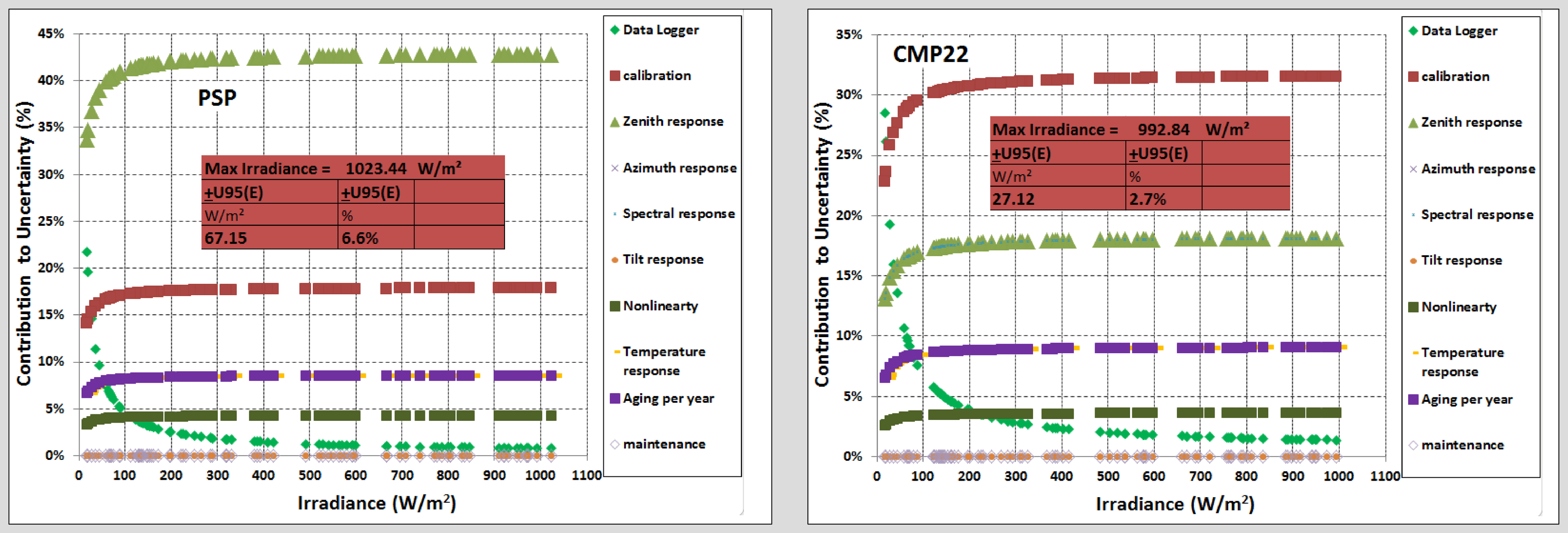

Figure 6. Contribution of sources of uncertainties to the overall uncertainty estimation of pyranometers. Left: PSP; right: CMP22

V. Potential Benefit of Lower Uncertainty Radiometers for the ARM Program

Pros:

- Reduces uncertainty in predicting the solar resource, which in turn assists in accurately validating climate and radiative transfer models.
- Reduces time spent in quality analysis/quality check of measured radiometric data.
- Increases reliability of measurement, and provides more defensible solar resource data.

Cons:

- Expensive to replace existing radiometers with new ones.
- Causes a disruption in the historical consistency of the data due to the use of a different radiometer.

VI. Conclusions

- The radiometers presented in this poster are a cross section of the commercially available radiometers.
- Some sources of uncertainties that may affect radiometric measurements still need to be considered, such as soiling, effects of ventilation, extreme climates, and high-latitude locations.

References and More Information

1. A. Habte, M. Sengupta, A. Andreas, S. Wilcox, and T. Stoffel, "Intercomparison of 51 Radiometers for Determining Global Horizontal Irradiance and Direct Normal Irradiance Measurements," *Solar Energy* 133 (2016): 372–393.
2. Joint Committee for Guides in Metrology, *ISO/IEC JCGM 100: 2008 GUM 1995—With Minor Corrections: Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement*.
3. A. Habte, M. Sengupta, A. Andreas, and I. Reda, "Radiometer Calibration Methods and Resulting Irradiance Differences," *Progress in Photovoltaics: Research and Applications* (2016), http://dx.doi.org/10.1002/pip.2812.
4. I. Reda, *Method to Calculate Uncertainty Estimate of Measuring Shortwave Solar Irradiance Using Thermopile and Semiconductor Solar Radiometers* (Technical Report NREL/TP-3B10-52194) (Golden, CO: National Renewable Energy Laboratory: 2011).
5. A. Habte and M. Sengupta, "Exploring Sources of Uncertainties in Solar Resource Measurements" (NREL/PR-5D00-67320) (presented at the PV Performance and Monitoring Workshop, Freiburg, Germany, October 24–25, 2016.)
6. "Solar Resource Models and Tools," NREL, https://github.com/NREL/SolarResourceModelsandTools/tree/master/RadiometerGUM.

Support for NREL is provided by Argonne National Laboratory MPO No.2T-30084. Additional support is provided by the U.S Department of Energy, Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office.

Atmospheric System Research Science Team Meeting
Vienna, Virginia
March 13–17, 2017
NREL/PO-5D00-68065