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Evaluation of Sources of Uncertainties in Solar Resource Measurement

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I. Introduction

Traceable radiometric data sets are essential for solar energy plant operations, solar resource assessment, validation of satellite-based models, and solar radiation forecasts. The measurement uncertainty of current radiometers is 2%–5% and sometimes higher[1].

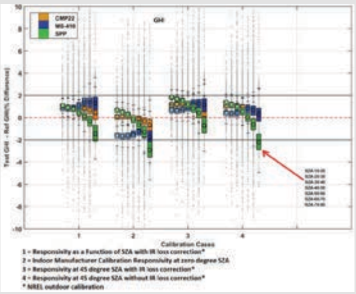
The National Renewable Energy Laboratory (NREL), manufacturers, and many other organizations are currently conducting research on identifying and quantifying uncertainties, improving measurement performance, and developing a consensus standard methodology for radiometric measurements.

This poster demonstrates the impact of various sources of uncertainties—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. Some of the Sources of Uncertainties and Uncertainty Mitigation Methodologies

A. Calibration Uncertainty

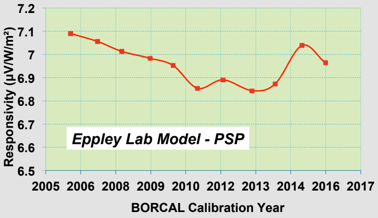
The difference between values indicated by the radiometer during calibration and "true value."



Calibrations are conducted under specific conditions, whereas radiometers might be operated in conditions that are different from those of the calibrations. For example, the radiometers calibrated during the NREL Broadband Radiometer Calibration (BORCAL) process use clear-sky conditions. The radiometers calibrated in BORCAL are operated under all conditions, including cloudy skies, and the calibration coefficient might potentially vary under those conditions. Another example is when a radiometer that is calibrated indoors might have a different responsivity when it is calibrated outdoors (see figure above).

C. Non-Stability

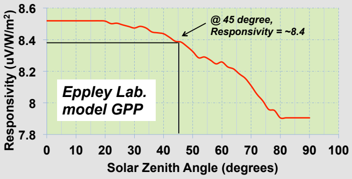
A percentage change of the responsivity per year; it is a measure of long-term non-stability.



The responsivity might change over time, as shown in the figure.

B. Cosine Response Uncertainty

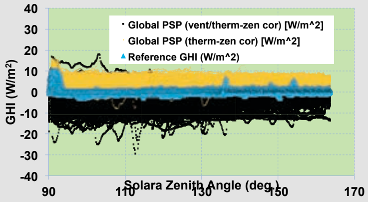
A measure of deviation due to responsivity change versus solar zenith angle.



Instruments might respond differently based on the solar zenith angle. This leads to cosine uncertainty if a single value is used for all zenith angles (in most cases, 45°responsivity is used). An example of the change in responsivity is shown in the figure above. It is obvious that a single value is generally not representative for this instrument when used for measurements under various solar zenith angles.

D. Thermal Offset Uncertainty

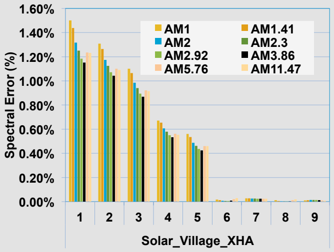
Energy imbalances not directly caused by the incident shortwave radiation.



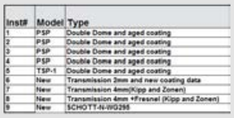
Surface temperature has a higher temperature than the sky temperature. Likewise, thermopile radiometers equilibrate to ambient temperature, which is typically higher than the sky temperature, and this creates an infrared energy imbalance between the thermopile radiometer and the sky.
This situation produces a thermal energy exchange in which the thermopile emits energy to the sky, and this was evident in the data as a negative output of irradiance by the thermopile radiometers in the absence of solar radiation.

E. Spectral Uncertainty

A deviation introduced by the change in the spectral distribution of the incident solar radiation and the difference between the spectral response of the radiometer with respect to a radiometer with completely homogeneous spectral response in the wavelength range of interest.



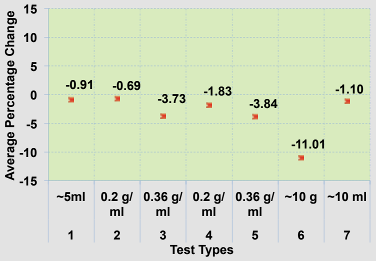
The spectral error of shortwave radiometers under different air masses (AM) and locations [5]. Note: Spectral irradiance simulation was performed using SMARTS model.



Inst#	Model	Type
1	PSP	Double Dome and aged coating
2	PSP	Double Dome and aged coating
3	PSP	Double Dome and aged coating
4	PSP	Double Dome and aged coating
5	TSP-1	Double Dome and aged coating
6	New	Transmission 2mm and new coating data
7	New	Transmission 4mm(Kipp and Zonen)
8	New	Transmission 4mm +Fresnel (Kipp and Zonen)
9	New	SCHOTT-N-WG295

F. Soiling

A percentage change in measurement due to the amount of soiling on the radiometer's optics.



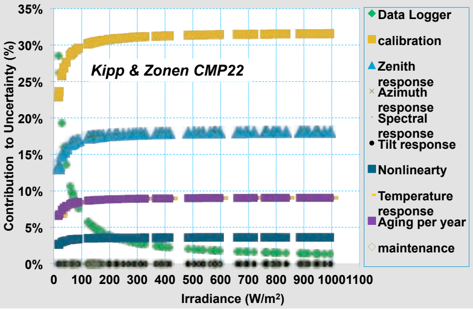
1 Water droplets
2 Water droplets - water and salt
3 Water droplets - water, salt & soil
4 Water droplets - water & soil
5 Water droplets - water & extra soil
6 Simulated snow
7 Simulated dew/condensation

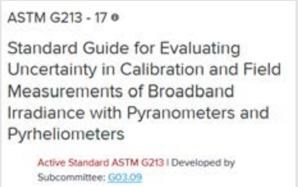
Various degrees of soiling reduce the optical transmittance of the glass dome of the pyranometer, which ultimately reduces the detector output (energy loss). The observed reduction was 0.69% to 11%.

Note: Indoor method to measure soiling to thermopile radiometers. The indoor method provides the ability to control the other environmental effects. Various simulated soiling types were sprayed to the radiometer domes [5].

III. Combining All Errors: The GUM Method and ASTM International Standard

The overall uncertainty or expanded uncertainty (U_{95}) is then calculated by multiplying the combined uncertainty (standard uncertainty of the sources and sensitivity coefficient) by a coverage factor (k=1.96, for infinite degrees of freedom), which represents a 95% confidence level. Details of the methodology are described in the ASTM G213-17 standard.
Each source of uncertainty has a magnitude of contribution to the overall uncertainty (left figure).





ASTM G213 - 17

Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers

Active Standard ASTM G213 | Developed by Subcommittee: G03.09

https://www.astm.org/Standards/G213.htm

IV. Conclusions

- Solar resource data with known and traceable uncertainty estimates are essential for the site selection of renewable energy technology deployment, system design, system performance, and system operations.
- Developing consensus methodologies of determining solar resource measurement uncertainties are essential in obtaining accurate radiometric data.
- Calibration differences between manufacturers' and outdoor NREL BORCAL provided irradiance differences up to 1% to 2% for pyranometers and less than 1% for pyrheliometers.
- Spectral mismatch contributed to spectral error up to 1.6% for indoor transmittance measurement.
- Various degrees of soiling reduce the optical transmittance of the glass dome of the pyranometer, which ultimately reduces the detector output (energy loss). The observed reduction was 0.2% to 27%.

V. References and Contacts

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