Analyzing the Calibration History of Radiometers for Determining Optimal Calibration Day(s)

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Abstract

- Accurate solar resource information—for example, acquired from pyranometers and pyrheliometers—is essential for various solar energy project phases to improve their efficiency and reduce deployment costs.
- Radiometer calibration is one method that ensures data accuracy. The recalibration frequency recommended by many ASTM and ISO standards is every year or two for two or more days as the preferred frequency for calibration to cover a broad range of atmospheric and environmental conditions.
- On the other hand, annually, NREL performs outdoor calibration services through the Broadband Outdoor Radiometer Calibration (BORCAL) method on a clear-sky day. The BORCAL method, which is often completed within one cloudless day, provides outdoor calibration responsivity of radiometers at a 45° solar zenith angle and responsivity as a function of solar zenith angle determined by comparisons to reference irradiance.
- This study investigates the effects of calibrating radiometers using one day or multiple cloudless days as recommended by the standards.
- This study will support radiometer standards updates and development, find the optimal calibration interval, improve the understanding of the quality of the instruments, save time and costs for calibration service providers and users of radiometric data, and enable solar energy operators to verify that the deployed radiometers are performing within their technical specifications and are not regularly drifting outside their tolerances.

Method

Some sources of radiometer measurement uncertainty:

- ***Calibration***
- *Spectral response*
- *Directional response*
- *Maintenance*
- *Thermal offset*
- *Temperature dependence*
- *Nonlinearity*
- *Stability.*

Instrument selection

- *Radiometers that are part of the control during each BORCAL event were used for this study.*
- *These radiometers (e.g., Fig. 1) have been calibrated every year during each BORCAL event.*
- *The calibration data for each year and event were used for this study.*

Figure 1. Radiometers deployed at NREL and ready for BORCAL calibration. *Photos by Afshin Andreas, NREL*

Outdoor calibration methods:

- *Alternating sun-and-shade (shade/unshade)*
- *Continuous sun-and-shade (component sum).*

International standards describe these methods:

- *ISO 9846:1993 Solar energy—Calibration of a pyranometer using a pyrheliometer*
- *ISO 9059:1990 Solar energy—Calibration of field pyrheliometers by comparison to a reference pyrheliometer*
- *E816-15(2023) Standard Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers*
- *G167-15(2023) Standard Test Method for Calibration of a Pyranometer Using a Pyrheliometer*

Results

BORCAL control radiometers at NREL, Colorado

BORCAL control radiometers at the Southern Great Plains (SGP) facility, Oklahoma

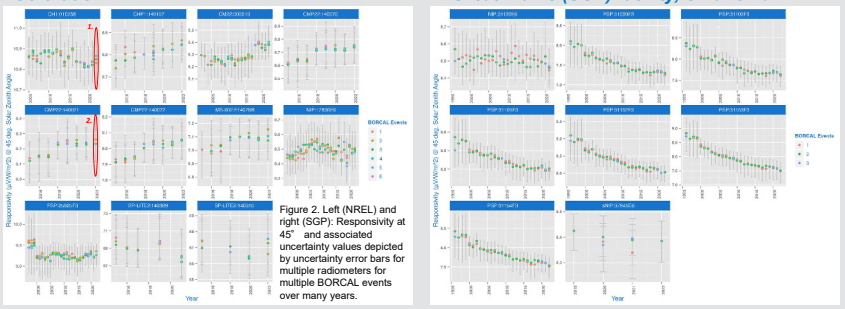

Figure 2. Left (NREL) and right (SGP): Responsivity at 45° and associated uncertainty values depicted by uncertainty error bars for multiple radiometers for multiple BORCAL events over many years.

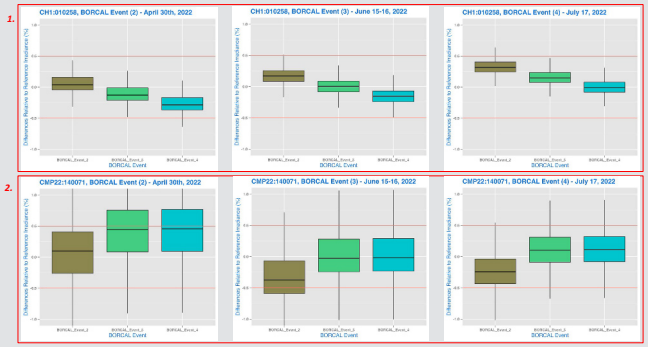

Figure 3. (Top, left to right): CH1 comparison with reference irradiance data using BORCAL events 2, 3, and 4, respectively. (Bottom, left to right) CMP22.

Note:

a) Each plot represents a difference in percentage when computing irradiance differences between the reference irradiance and unit under calibration. For example, the top left figure illustrates the percentage difference using a reference irradiance for ***BORCAL Event 2*** *and the unit under calibration irradiance (G), which was calculated from the* ***BORCAL Event 2*** *output voltage (V) and respective responsivity (R) for* ***BORCAL events 2, 3, and 4.***

$$G = \frac{V}{R}$$

b) The difference is relatively smaller when the unit under calibration and reference radiometer are compared from the same BORCAL event; however, when using reference data from one BORCAL event with data for the unit under calibration from a different BORCAL event, the difference increases slightly.

Discussion

- NREL completes the calibration within a day if clear and stable conditions with enough data points are obtained. In the revision of ISO 9059 and ISO 9846, an attempt was made to accommodate more days and less days (single day) to perform outdoor calibrations.
- The results in Fig. 2 demonstrate good responsivity agreement with estimated uncertainty error bars over the years for various radiometers under various BORCAL events in both NREL and SGP. BORCAL events are performed during the time frame from May to sometimes August each year. The same radiometer is calibrated in various events within the same year.
- The BORCAL method appears to justify the use of a single calibration day with enough data points to attain repeatable calibration results.
- The reproducibility of the NREL calibration is confirmed by round-robin/interlaboratory comparisons.
- Future analysis could be performed by doing a round-robin within different labs (e.g., single day vs. multiple day calibration methods).

Summary

- The result demonstrated good responsivity agreement over the years under various BORCAL events.
- The BORCAL method appears to justify the use of single calibration day is enough to get repeatable calibration result.
- Some radiometer calibration standards recommend multiple days for calibration to cover various environmental and atmospheric conditions.
- Therefore, the decision of calibration day(s) should consider the environmental and atmospheric condition of a location, history and performance of radiometers under test, and repeatability and reproducibility of the calibration method. For example, for BORCAL, Golden Colorado historically demonstrated relatively pristine atmosphere (e.g., clear sky) which is conducive for outdoor calibration.

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