EVALUATING SOLAR RESOURCE DATA OBTAINED FROM MULTIPLE RADIOMETERS DEPLOYED AT THE NATIONAL RENEWABLE ENERGY LABORATORY

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ABSTRACT: Solar radiation resource measurements from radiometers are used to predict and evaluate the performance of photovoltaic and concentrating solar power systems, validate satellite-based models for estimating solar resources, and advance research in solar forecasting and climate change. This study analyzes the performance of various commercially available radiometers used for measuring global horizontal irradiances (GHI) and direct normal irradiances (DNI). The radiometers in this study were deployed for one year (from April 1, 2011, through March 31, 2012) and compared to measurements from radiometers with the lowest values of estimated measurement uncertainties for producing reference GHI and DNI. The differences were calculated as a percent of reading for solar zenith angles ranging from 17.5 degrees to 85 degrees (the range of available solar zenith angles throughout the year at SRRL, excluding data near sunrise and sunset). Under clear-sky conditions when the solar zenith angle was less than 60 degrees, differences of less than 5% were observed for both GHI and DNI measurements when they were compared to the reference radiometers. These normalized differences increased during partly cloudy sky conditions when the solar zenith angle was greater than 60 degrees. The intent of this paper is to present a general overview of each radiometer’s performance. The National Renewable Energy Laboratory made no effort to ensure that the radiometers presented here were representative units; therefore, this paper does not guarantee the same results for all radiometers from the same manufacturer or model.

Method and Experimental Design:
Location: Solar Radiation Research Laboratory, Golden, Colorado USA
Deployment: The radiometers in this study were deployed for one year (from April 1, 2011, through March 31, 2012)
Reference Data: A Kipp and Zonen CH1 (DNI) instrument and an Eppley Laboratory, Inc., black-and-white model 8-48 (diffuse horizontal irradiance, or Dhi) instrument
Test Instruments:
- 32 instruments measuring GHI data set
- 19 instruments measuring DNI data set. Some of the instruments had a calculated DNI value.

Data Quality:
- SERI QC—a data quality assessment tool was applied to the radiometric data
Best practices for the operations and maintenance of the instruments were followed.

Data Normalization:
- The solar irradiance data from the radiometers was normalized to remove potential instrument calibration biases.

$$\text{Ratio} = \frac{\text{UUT}}{\text{Reference instrument}}$$

where \( U_{\text{UT}} \) is the irradiance data for the UUT within the 2-degree solar zenith angle bin and \( U_{\text{Reference}} \) is the irradiance data of the reference instrument within the same solar zenith angle range.

The new normalized irradiance data from the UUT were then computed as

$$I_{\text{UT}(\text{norm})} = I_{\text{UT}} \times \text{Ratio}$$

Data Filtering for sky condition was carried out using TSI-880.

Results: GHI Comparisons
- The average mean bias error (MBE, %) appeared to fall within 24% for almost all instruments using the 95% confidence coverage.
- Under clear-sky conditions, the relative difference appeared to exhibit less bias, and the mean differences (red line) for most instruments tended to have less variability than they did under the mostly-cloudy sky condition.
- The average root mean square error (RMSE, %) appeared to fall within 4% for most of the instruments using the 95% confidence coverage.

Results: DNI Comparisons
- Under mostly cloudy sky conditions, some factors, such as temporal responsivity and field of view of the radiometers, become an influence for the higher RMSE in percent.
- The clear-sky conditions demonstrated tighter differences among the instruments than the rest of the sky conditions. The two-Eppley normal incidence pyrheliometers (NIP) and the two Hukseflux model “DR” types had less MBE than others under clear-sky conditions. However, the sensitivity of the DNI was much higher than the GHI under partly or mostly cloudy sky conditions.

Rotating Shadowband Radiometer Correction Algorithm Outcome
- The temperature and zenith dependence appeared to be smaller in the NREL-CRADA/RS-52 than the LI-200.
- The NREL-CRADA/RS-52 instrument has a built-in correction algorithm in the data acquisition system supplied by the manufacturer that minimizes spectral, angular, and temperature sensitivity issues.
- A clear shift of the probability distribution for the clear-sky condition from negative errors for the LI-200 to both and relatively normally distributed errors for the RS-52 was observed.

Eppley PSP Ventilator Effect on Thermal Offset
- The negative output of irradiance is due to a thermal energy exchange in which the thermometer emits energy to the sky.
- The ventilator on the ventilated PSP tended to affect the irradiance by creating an additional temperature imbalance between the case and dome of the instrument.
- More apparent thermal offset during winter or cold ambient temperatures was observed.
- The condition could be exacerbated if the ventilator filter of the PSP is not cleaned for some time and airflow is restricted.

Temperature dependence
- The Hukseflux radiometer model number DR108068 had relatively more evident temperature dependence than model number DR108066.
- The two Eppley NIP radiometers tended to have less temperature dependence, especially at temperatures below 20°C.

Summary:
Under clear-sky conditions when the solar zenith angle was less than 60 degrees, differences of less than 5% were observed for both GHI and DNI measurements when compared to the reference radiometers.
For data periods when the solar zenith angle was greater than 60 degrees, differences in GHI under mostly cloudy and clear-sky conditions increased to 17%. Differences of up to 40% in DNI measurements on a few instruments were found for high solar zenith angles under mostly cloudy sky conditions.
These differences were compared from the various instrument design characteristics for time response, spectral response, angular (cosine) response, field of view, and temperature response.

Acknowledgement
This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28304 with the National Renewable Energy Laboratory.