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Reducing Broadband Shortwave Radiometer Calibration Bias Caused by Longwave Irradiance in the Reference Direct Beam

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I. Introduction

Shortwave (SW) radiometers such as pyranometers and pyrheliometers are calibrated with traceability to a consensus reference, maintained by absolute cavity radiometers (ACRs). An ACR is an open cavity with no window that measures the extended broadband spectrum of the terrestrial direct solar beam irradiance, unlike shortwave radiometers that cover a limited range of the spectrum. The difference between the two spectral ranges may lead to a calibration bias that can exceed 1%. This article describes a method to reduce the calibration bias resulting from using broadband ACRs to calibrate shortwave radiometers by using an ACR with a Schott glass window to measure the reference broadband shortwave irradiance in the terrestrial direct solar beam from 0.3–3 µm. Reducing the calibration bias will result in lowering the historical solar irradiance by at least 0.9%. The published results in this article might raise the awareness of the calibration discrepancy to users of such radiometers and open a discussion within the solar and atmospheric science community to define their expectation from such radiometers to the manufacturers of radiometers and the calibration providers.

II. Pyrgeometer Measurement Equation

The pyrgeometer equation uses the voltage output of the pyrgeometer along with the case and dome temperatures to determine the calculated atmospheric long wave irradiance.

$$W = K_0 + K_1 * V_{tp} + K_2 * W_r + K_3 * (W_d - W_r)$$

where:

- W = calculated atmospheric longwave irradiance (W/m^2)
- K_0, K_1, K_2, and K_3 = calibration coefficients
- V_{tp} = thermopile output voltage (µV)
- W_r = receiver irradiance (W/m^2) = σ * (T_c + 0.0007074 * V_{tp})^4, where T_c is the case temperature (K) and σ is the Stefan Boltzmann constant = 5.6704*10^{-8} W/(m^2 K^4)
- W_d = dome irradiance (W/m^2) = σ * T_d^4, where T_d is the dome temperature (K).

IV. Determine the Direct Beam Longwave Component

Infrared irradiance from the sun = $W_{LW,Sun} = W_u - W_s$

where W_u = measured infrared irradiance using an unshaded precision infrared radiometer (PIR), and W_s = measured infrared irradiance using a shaded PIR (shaded with a Schott glass window; see Figure 4).

Infrared direct normal irradiance from the sun = $W_{DNLW} = \frac{W_{LW,Sun}}{\cos z}$

where z is the solar zenith angle.

III. Determine the Longwave Irradiance from the Sun

Determine the direct-beam longwave component ($W_{LW,Sun}$) of the irradiance by subtracting the irradiance from the shortwave shaded pyrgeometer (W_s) from the unshaded pyrgeometer (W_u) ; see Figure 1).

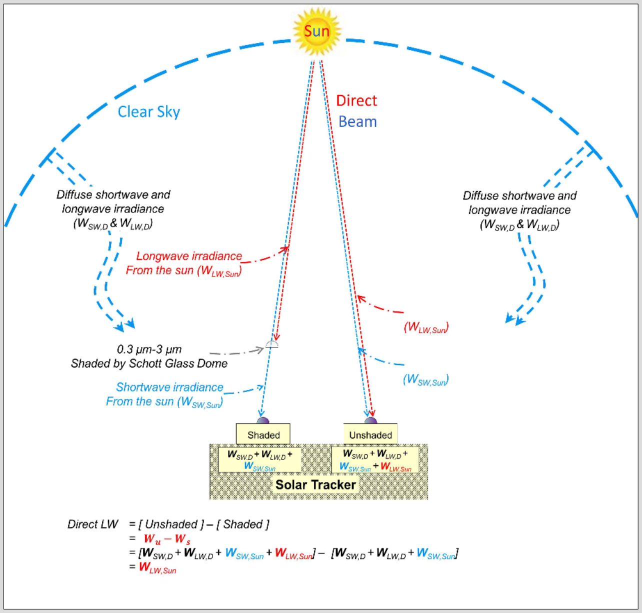

Figure 1. This system of measurement allows for the determination of the longwave irradiance from the sun.

V. Calibration of a Shortwave Cavity

The down-welling shortwave component of the irradiance can be determined by subtracting the direct down-welling longwave component of the irradiance (as determined in Section IV) from the broadband cavity irradiance.

The resulting value can be used to calibrate a shortwave cavity with a Schott glass window. This calibration of a shortwave cavity was performed at NRE.L The results are shown in Table 1, and the physical setup is shown in Figure 2.

Table. 1. Calibration results of the shortwave cavity; this calibration was performed at NREL.

Window Factor (F_{SW})	1.05655
%SD = Type B Standard Uncertainty, u_A	0.0002
%Standard Uncertainty, $u_{95,BB}$	0.19
%Standard Uncertainty , $u_{95,LW}$	0.09
%Combined Standard Uncertainty, u_c	0.21
Coverage Factor	1.96
$\%U_{95, SW}$	0.41

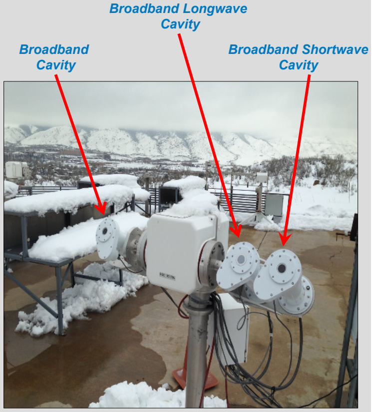

Figure 2. The broadband cavity is used with the setup shown in Section III to calibrate the SW cavity.

VI. Calibration of Five Instruments

The shortwave cavity and the broadband cavity were sent to the Southern Great Plains site to perform a calibration of five sensors, as shown in Figure 3.

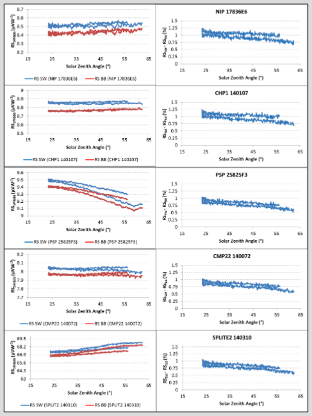

Figure 3. Shortwave and broadband responsivities and percentage differences at SGP on August 17, 2016

VII. Conclusions

We find that using the historical calibration method of broadband shortwave radiometers recommended by the International Organization for Standardization (ISO) 9059:1990 results in an overestimation in the field measurement of the direct broadband shortwave beam solar irradiance by at least 0.75% and the global broadband shortwave solar irradiance by at least 0.6%.

This overestimation might exceed 1% based on the atmospheric conditions during the calibration, primarily water vapor and aerosols. Because shortwave radiometers are designed to measure the broadband shortwave solar irradiance in the spectral range from 0.3–3 µm, per ISO 9060:1990, the calibration method recommended by ISO 9059-1990 would cause biases in the results. These biases might be significant in atmospheric science and solar energy applications and would therefore warrant further study.

References

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