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Measuring Broadband IR Irradiance in the Direct Solar Beam and Recent Developments

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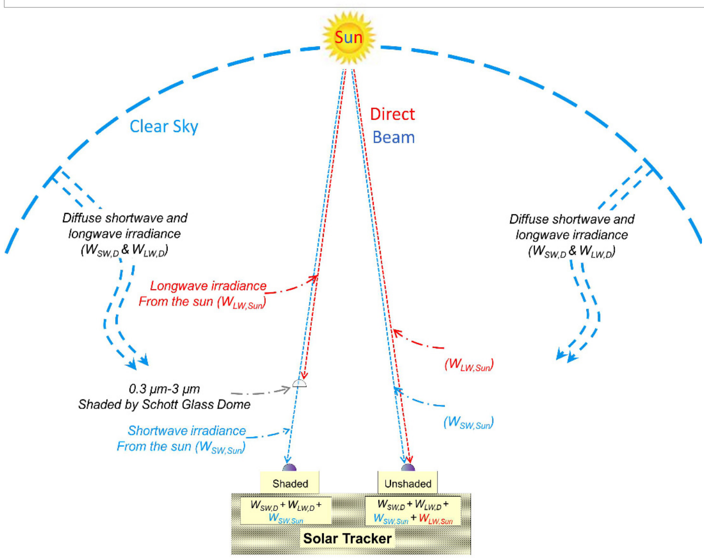
Abstract: Solar and atmospheric science radiometers such as pyranometers, pyrheliometers, and photovoltaic cells are calibrated with traceability to a consensus reference which is maintained by Absolute Cavity Radiometers (ACRs). An ACR is an open cavity with no window, developed to measure the extended broadband spectrum of the terrestrial direct solar beam irradiance that extends beyond the ultraviolet and infrared bands; i.e. below 0.2 µm and above 50 µm, respectively. On the other hand, the pyranometers and pyrheliometers were developed to measure broadband shortwave irradiance from approximately 0.3 µm to 3 µm, while the present photovoltaic cells are limited to the spectral range of approximately 0.3 µm to 1 µm. The broadband mismatch of ACR versus such radiometers causes discrepancy in radiometers' calibration methods that has not been discussed or addressed in the solar and atmospheric science literature. Pyrgeometers, which measure the atmospheric longwave irradiance, are also used for solar and atmospheric science applications and calibrated with traceability to a consensus reference, yet they are calibrated during nighttime only, because no consensus reference has been established for the daytime longwave irradiance. This poster describes a method to measure the broadband longwave irradiance in the terrestrial direct solar beam from 3 µm to 50 µm, as a first step that might be used to help develop calibration methods to address the mismatch between broadband ACR and shortwave radiometers, and the lack of a daytime reference for pyrgeometers. The described method is used to measure the irradiance from sunrise to sunset; the irradiance varied from approximately 1 Wm^{-2} to 16 Wm^{-2} with an estimated uncertainty of 1.5 Wm^{-2}, for a solar zenith angle range from 80° to 16°, respectively. Recent development shows that there is greater than 1.1% bias in measuring shortwave solar irradiance.



Direct LW = [Unshaded] – [Shaded]
= [$W_{SW,D}$ + $W_{LW,D}$ + $W_{SW,Sun}$ + $W_{LW,Sun}$] – [$W_{SW,D}$ + $W_{LW,D}$ + $W_{SW,Sun}$]
= $W_{LW,Sun}$

Figure 1. Illustration of sensed irradiance by unshaded and shaded pyrgeometers

IR irradiance from the Sun =

$$W_{LW,Sun} = W_u - W_s$$

where W_u = measured IR irradiance using unshaded PIR, and W_s = measured IR irradiance using shaded PIR.

IR direct normal irradiance from the sun =

$$W_{DNLW} = \frac{W_{LW,Sun}}{\cos Z}$$

where z is the solar zenith angle

Pyrgeometer Measurement Equation:

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

where:
- *W = calculated atmospheric longwave irradiance (Wm^{-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 Stefan Boltzmann constant = 5.6704*10^{-8} $W m^{-2} K^{-4}$*
- *W_d = dome irradiance (Wm^{-2}) = σ * T_d^4, where T_d is the dome temperature (K).*

Recent Development

W_{DNSW} = $W_{BB-Cavity}$ - W_{DNLW}, is then used to calibrate SW-Cavity with Schott glass window

Table 1. Calibration results of the SW-Cavity

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. Calibrated five SW radiometers using SW-Cavity and BB-Cavity

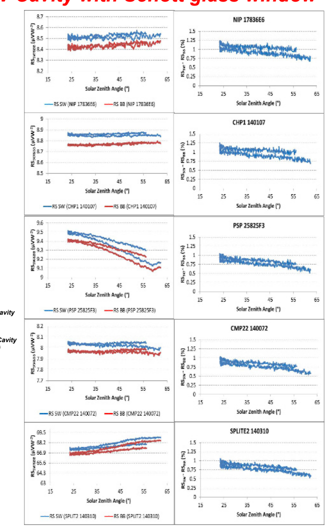


Figure 3. Shortwave and broadband responsivities and percentage differences at SGP on August 17, 2016

Conclusion: We find that using the historical calibration method of broadband shortwave radiometers recommended by ISO 9059:1990 results in an overestimation in the field-measurement of the direct broadband shortwave solar beam irradiance by at least 1.1% and the global broadband shortwave solar irradiance by at least 1%. This overestimation might exceed 1.1% based on the atmospheric conditions during the calibration, primarily due to water vapor and aerosols. Since shortwave radiometers are designed to measure the broadband shortwave solar irradiance in the spectral range from 0.3 µm to 3 µm, per ISO 9060:1990, the recommended calibration method by ISO 9059-1990 would result in biases in the calibration results that exceeds 1.1% (See Figure 3).

References:
1) *ISO, 1990. ISO 9059: Solar energy-Calibration of field pyrheliometers by comparison to a reference pyrheliometer. International Organization for Standardization,Geneva, Switzerland, 8 pp.*
2) *Reda, I., Hickey, J.R., Stoffel, T., Myers, D., 2002. Pyrgeometer calibration at the National Renewable Energy Laboratory (NREL). J. Atmos. Sol-Terr. Phy. 64 (2002) 1623–1629*
3) *I. Reda; J. Konings; Y. Xie 2015. Method to Measure the Broadband Longwave Irradiance in the Terrestrial Direct Solar Beam. Journal of Atmospheric and Solar-Terrestrial Physics Vol. 129 July 2015 pp. 23-29.*

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