ARM/NREL Pyrgeometer Calibration with Traceability to the World Infrared Standard Group (WISG)

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Abstract

For global acceptance, ARM broadband irradiance measurements must be made with radiometers calibrated to internationally recognized references. The World Meteorological Organization's Commission for Instruments and Methods of Observation (CIMO) established an interim pyrgeometer calibration standard in February 2006. The *World Infrared Standard Group (WISG),* comprised of four pyrgeometers, was developed by the Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC). Working with PMOD/WRC, NREL has established a group of reference pyrgeometers with traceability to the WISG. Our goal is to compare pyrgeometer performance based on calibrations traceable to the manufacturer, ARM/NREL blackbody, and WISG. We used 48 days of outdoor measurements at the SGP Radiometer Calibration Facility from seven ARM pyrgeometers and two reference PIR traceable to WISG. The nine pyrgeometers were previously calibrated in the ARM Blackbody System. Applying the manufacturer calibration coefficient and assuming a dome correction factor of -3.5 to the outdoor data resulted in agreement from -2.5 W/m^2 to 10 W/m^2, w.r.t. WISG. Applying ARM/NREL blackbody calibrations to the same data produced differences from 5 W/m^2 to 15 W/m^2, w.r.t. WISG. Adjusting the ARM/NREL blackbody coefficients using the WISG, suggests a longwave irradiance uncertainty of ±2.5 W/m^2 can be achieved under clear and cloudy sky conditions, during daytime and nighttime, thus ***reducing the uncertainty by a factor of four compared to present/historical data collection methods***.

The Process and Traceability Tree

World Infrared Standard Group (WISG)

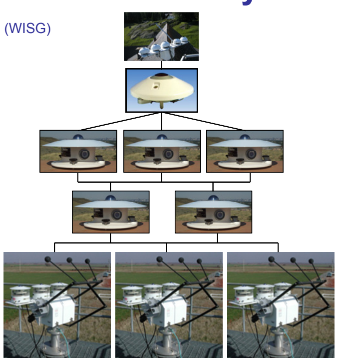
NREL Reference

NREL Transfer Standards
(+/- 2 W/m^2 agreement with NOAA/GMD)

ARM/SGP Transfer Standards

ARM Field Pyrgeometers

- SGP Blackbody characterizations
- Outdoor measurements 15 Dec 2006 to 31 Jan 2007
- Blackbody coefficients adjusted to ARM/SGP transfer standards



The Process Equation

<u>Reda et al. (2002):</u> ***Journal of Atmospheric and Solar Terrestrial Physics***

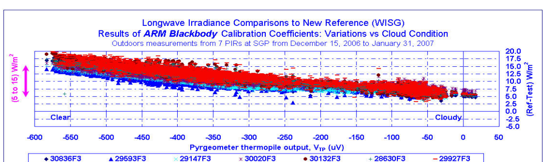
$$W_{in} = K_0 + K_1 * V + K_2 * W_r + K_3 * (W_d - W_r)$$

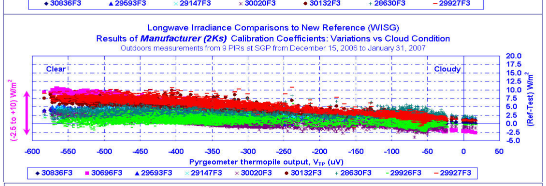
Where:

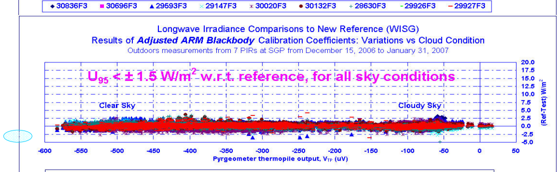
- W_{in} = incoming irradiance (W/m^2).
- K_0, K_1, K_2, and K_3 = calibration coefficients.
- V = thermopile output voltage (uV).
- W_r = receiver outgoing irradiance (W/m^2) $= \sigma * T_r^{\,4} = \sigma * (T_c + 0.0007044 * V)^4$, where T_r & T_c = receiver & case temperatures (K).
- W_d = dome irradiance (W/m^2) $= \sigma * T_d^{\,4}$ where T_d = dome temperature (K).

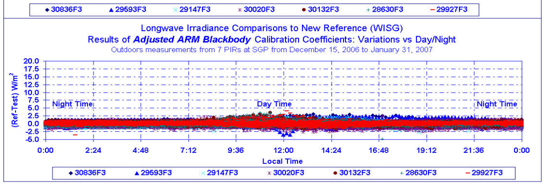
Adjustment Procedure

1. Cloudy sky: Adjust K_2 for irradiance difference [pyrgeometer under test (PUT) – reference (RF)] = minimum.
2. Clear sky: Adjust K_1 for irradiance difference (PUT – RF) = minimum.
3. Adjust K_3 so that the scatter of (PUT – RF) = minimum.









Calibration Coefficients/Results for Reference and Test Pyrgeometers

Coefficients	Calibration Method	29926F3	30696F3	28630F3	29147F3	29593F3	29927F3	30020F3	30132F3	30836F3
		SGP/NREL Blackbody and Outdoor Calibration Coefficients								
		Reference PIRs		Test Pyrgeometers						
K0	BB	-6.0	-12.4	-11.3	-2.6	-10.8	-7.5	-17.0	-10.7	-11.3
K1	BB			0.2635	0.2251	0.2338	0.2833	0.2556	0.2503	0.2539
	Adjusted Outdoors	0.2650	0.2380	0.2476	0.2137	0.2219	0.2630	0.2422	0.2310	0.2343
K2	BB			1.0240	0.9968	1.0205	1.0100	1.0310	1.0210	1.0213
	Adjusted Outdoors	1.0167	1.0320	1.0417	1.0140	1.0360	1.0260	1.0473	1.0350	1.0346
K3	BB			-2.24	-2.79	-2.79	-2.13	-2.52	-2.56	-2.66
	Adjusted Outdoors	-3.18	-3.09	-2.62	-3.15	-3.64	-2.95	-3	-3.3	-3.47
U95 (W/m^2)	After Adjustment			1.3	1.1	1.1	0.9	1.1	0.9	1.0
Number of Readings				5856	5856	5856	5856	5856	5856	5856
		Manufacturer Calibration Coefficients								
K1	BB	0.2890	0.2688	0.2625	0.2309	0.2404	0.2933	0.2639	0.2564	0.2545
K2	Estimated	1	1	1	1	1	1	1	1	1
K3	Estimated	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

<u>Reda et al.:</u>

Win = K0 + K1 * V + K2 * Wr + K3 * (Wd – Wr)

<u>Albrecht & Cox, 2Ks (manufacturer equation):</u>

Win = K1 * V + Wc + K3 * (Wd – Wc)

Conclusions/Recommendations

1. This method adjusts the test pyrgeometers to ANY established reference:
   - outdoor calibration can achieve U95 < 1.5 W/m^2, w.r.t. reference irradiance, for all sky conditions day/night (± 2.5 W/m^2 w.r.t. WISG).
2. Blackbody (BB) is not an ideal calibration source:
   - indoor/outdoor conditions mismatch.
   - difficulty measuring the BB temperature to ±0.01°C, especially below 0°C.

   Nevertheless, BB is an important tool, when refined, in search of an absolute reference
3. The $\mathbf{K_0}$, in 4-coefficient equation, is important to the BB calibration process:
   - Closer to zero => closer to ideal BB and pyrgeometer design.
   - Closer to zero => closer calibration process to outdoor conditions.
4. Manufacturer calibration with 2-K's result in calibration inconsistency [(– 2.5 to +10) W/m^2].
5. ARM Pyrgeometer calibration w.r.t. WISG is important to achieve global uniformity in measuring the atmospheric longwave irradiance.
6. ARM to continue participation in the international effort to establish a reference traceable to SI Units.
7. ARM to compare Irradiance measured with traceability to WISG with irradiance measured by AERI, SIRS, and SKYRAD instruments to help:
   - establish their traceability to a recognized reference.
   - evaluate their field of view and spectral differences.

Acknowledgements

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