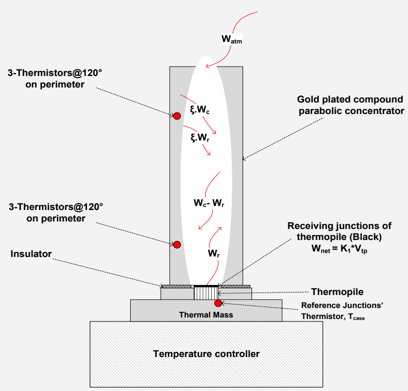
Using an Absolute Cavity Pyrgeometer to Calibrate Pyrgeometers Outdoors with respect to the International System of Units

Ibrahim Reda, Afshin Andreas, Manajit Sengupta, and Aron Habte
National Renewable Energy Laboratory (NREL)

Accurate measurement of the atmospheric longwave irradiance is important for renewable energy and atmospheric science applications. Pyrgeometers are deployed outdoors all over the world to measure the atmospheric longwave irradiance and presently are calibrated with traceability to the interim standards for atmospheric longwave radiation measurement, the standards are based on four pyrgeometers and their average irradiance is the World InfraRed Standard Group (WISG) which is developed and maintained by The Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC). Since 2013 the InfraRed Integrating Sphere (IRIS) developed by PMOD/WRC and the Absolute Cavity Pyrgeometer (ACP) developed by the National Renewable Energy Laboratory (NREL) have been compared outdoors six times at different locations and the difference between the measured atmospheric longwave irradiance by ACP and IRIS was less than 2 w/m² with traceability to the International System of Units (SI). During the six comparisons the irradiance measured by the interim WISG was 5 w/m² lower than the irradiance measured by the average irradiance measured by the ACP and IRIS [1]. Based on this discrepancy, the World Meteorological Organization's Commission for Instruments and Methods of Observation (CIMO) recommended that the interim WISG should be adjusted to be traceable to SI units [2]. In anticipation of CIMO's expert team agreement on establishing the world reference using the average irradiance measured by ACP and IRIS in this article we describe a procedure to calibrate pyrgeometers with traceability to SI. One Absolute Cavity Pyrgeometer (ACP95F3) was used to calibrate four pyrgeometers traceable to SI units. Three Eppley PIRs and one Kipp&Zonen CG4 were originally calibrated with traceability to the interim WISG. Using the described procedure below, the responsivity of each pyrgeometer was then adjusted to match the irradiance measured by ACP. Outdoor data was collected during one clear sky night monitored by the output thermopile voltage of ACP95F3. The irradiance measured by the PIRs and CG4 was calculated using NREL equation. The calculated uncertainty (U95) of the PIRs varied from 2.43 w/m² to 2.67 w/m², and for the CG4 equals 1.97 w/m² with respect to SI.

ACP outdoor set-up at NREL/SRRL

ACP Simplified Diagram



ACP Equations:

ACP Net irradiance:

$$K_1 * V_{tp} = \tau * W_{atm} + (1+\varepsilon) * W_c - (2-\varepsilon) * K_2 * W_r$$

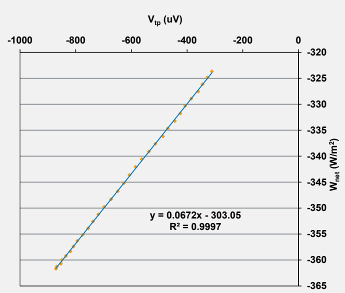
where: K_1 = 1/responsivity; V_{tp} = thermopile voltage; τ & ε are measured at NIST; W_{atm} = atmospheric irradiance; W_c = concentrator irradiance; W_r = receiver irradiance.

- By cooling the ACP case temperature, and since Watm is stable, then,

$$K_1 = \frac{(1+\varepsilon) * \Delta W_c - (2-\varepsilon) * K_2 * \Delta W_r}{\Delta V_{tp}}$$

- Then the atmospheric longwave irradiance is,

$$W_{atm} = \frac{K_1 * V_{tp} + (2-\varepsilon) * K_2 * W_r - (1+\varepsilon) * W_c}{\tau}$$



ACP Calibration: K1 = 0.0672
Intercept = 303.05 = Atmospheric LW irradiance

ACP95F3-IRIS	Difference, W/m²	Standard Deviation, W/m²	U_{95}, W/m²
PMOD February 2013	0.10	0.83	1.66
PMOD IPgC-II October 2015	-0.57	0.31	0.85
SGP phase 1 October 2017	0.86	0.78	1.79
SGP phase 2 November 2017	-1.05	0.85	2.00
PMOD July 2019	0.75	1.11	2.34
PMOD IPgC-III October 2021	0.10	1.20	2.40
Average	0.03	0.85	1.84

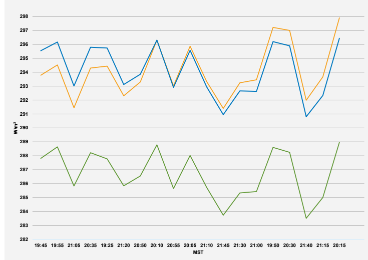
U_{95} of historical ACPIRIS comparisons with respect to SI units.

Calibration coefficients traceable to WISG and SI units of all pyrgeometers

NREL	K_1	K_2	K_3	K_{1SI}
31197F3	0.240	1.002	-3.29	0.223
31205F3	0.278	1.005	-4.14	0.255
36362F3	0.335	1.011	-5.62	0.315
CG4 060881	0.119	0.997	0.00	0.114

U_{95} with respect to SI units for all pyrgeometers

NREL	Residuals (Average) W/m²	Residuals (Standard Deviation) W/m²	ACP95F3 U_{95} W/m²	U_{95}, SI W/m²
31197F3	-0.02	0.97	1.84	2.67
31205F3	0.00	0.82	1.84	2.47
36362F3	-0.01	0.80	1.84	2.43
CG4 060881	0.00	0.36	1.84	1.97



ACP95F3 irradiance and the measured irradiance traceable to WISG and SI units for CG4 060881 on September 23, 2022

Conclusion

This procedure might be used to calibrate pyrgeometers outdoors with traceability to SI units using ACP with U95 less than 2.88 w/m² with respect to SI units. Pyrgeometers calibration must be performed under clear sky conditions to calculate the responsivity of each pyrgeometer during the largest spectral range at the calibration site. Since this calibration procedure requires clear sky conditions at the calibration site and that clear sky conditions that produce the most accurate pyrgeometer responsivity rarely occur, in the future it is planned to repeat the procedure during different seasons to evaluate the consistency of the results.

Acknowledgements
The authors thank the USA Department of Energy Atmospheric Radiation Program, NREL Metrology Laboratory Martina Stoddard for her help related to the logistics of setting up and data collection during this measurement.

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

The Atmospheric Radiation Measurement (ARM)/Atmospheric System Research (ASR) Joint User Facility/Principal Investigator Meeting
Aug 7-10, 2023.
NREL/PO-1900-86221