
# Using an Absolute Cavity Pyrgeometer to Validate the Calibration of a Transfer Standard Pyrgeometer Outdoors, Independent from the Reference Value of the Atmospheric Longwave Irradiance

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# *Abstract*

A unique method of pyrgeometer calibration has been developed to improve the measurement uncertainty [1]. The results of this method yielded irradiance values within ±3 $W/m^2$ of those traceable to the World Infrared Standard Group (WISG). The absolute cavity pyrgeometers (ACPs) and pyrgeometer model passive infrared (PIR) were deployed outdoors, the PIR was placed on a temperature controller like the ACP's temperature controller. The responsivity of the pyrgeometer is then calculated by cooling its case temperature, as described in the next slide. The irradiance measured by the pyrgeometer was compared against the irradiance measured by ACP95F3. Based on the results, it is possible to achieve an uncertainty of ±3.51 $W/m^2$. These results suggest that this pyrgeometer  calibration method might be useful in addressing the international need for a transfer standard pyrgeometer traceable to the International System of Units (SI).

*[1] Reda, I.; J. R. Hickey, J.; Gröbner, A.; Andreas, A.; Stoffel, T. 2006. Calibrating Pyrgeometers Outdoors Independent from the Reference Value of the Atmospheric Longwave Irradiance. Journal of Atmospheric and So-lar-Terrestrial Physics, Vol. 68 (12), August, 1416-1424.*

*[2] Reda, I.; Andreas, A.; Gotseff, P.; Kutchenreiter, M. 2020, Using an Absolute Cavity Pyrgeometer to Validate the Calibration of a Secondary Standard Pyrgeometer Outdoors, Independent from the Reference Value of the Atmospheric Longwave Irradiance. Atmospheric and Climate Sciences , 10*

# National Renewable Energy Laboratory (NREL) Pyrgeometer Equation

$$W_{atm}=K_1V + K_2W_r + K_3(W_d - W_r) \qquad (1)$$

**Where:**

$W_{atm}$ is the atmospheric longwave radiation in W/$m^2$

$K_2$ and $K_3$ are the calibration coefficients of the pyrgeometer, calibrated at the PMOD or Blackbody

$K_1$ is the reciprocal of the pyrgeometer's responsivity (RS), calculated from the outdoor calibration described below

V is the pyrgeometer thermopile output, in microvolts $W_r$ is the pyrgeometer receiver radiation, $\sigma \times T_r^4$, and $T_r = T_c$+$K_4 \times$ V

**Where:**

$\sigma$ is the Stefan-Boltzmann constant, $5.6704 \times 10^{-8}$ W/$m^2K^4$

$T_c$ is the pyrgeometer case temperature in Kelvin

S is the Seebeck coefficient, 39 V/$K$

n is the number of thermopile junctions, 56 junctions

E is the thermopile efficiency factor, 0.65 (manufacturer specification)

$K^4$ is the thermopile efficiency factor, $1/$(S $\times$ n $\times$ E)=0.0007044 K u$V^{-1}$

$W_d$ is the pyrgeometer dome radiation, $\sigma \times T_d^4$, where $T_d$ is the dome temperature in Kelvin.

# NREL Pyrgeometer Equation Continued

Equation 1 is rewritten in the following form: $W_{out} = W_{atm} - W_{net} = W_{atm} - K_1 V$ (2)

**Where:**

$W_{net}$ is the net irradiance measured by the pyrgeometer thermopile.

$W_{out}$ is the outgoing irradiance from the pyrgeometer.

$$W_{out} = K_2 W_r + K_3 (W_d - W_r) \quad (3)$$

A fundamental principle for this calibration procedure is to lower the outgoing irradiance while the atmospheric longwave irradiance ($W_{atm}$) is constant, i.e., stable during clear-sky conditions to within 1 $W/m^2$ from the start to the end of the calibration, at least 7 minutes. Lowering $W_{out}$ was achieved by cooling the pyrgeometer's case using the temperature controller. While lowering $W_{out}$, all signals from the pyrgeometer were measured every 10 seconds (i.e., thermopile output voltage, $T_d$, and $T_r$). Differentiating Eq. 2 with respect to time then yields:

$$\frac{dW_{out}}{dt} = \frac{dW_{atm}}{dt} - K_1 \frac{dV}{dt} \quad (4)$$

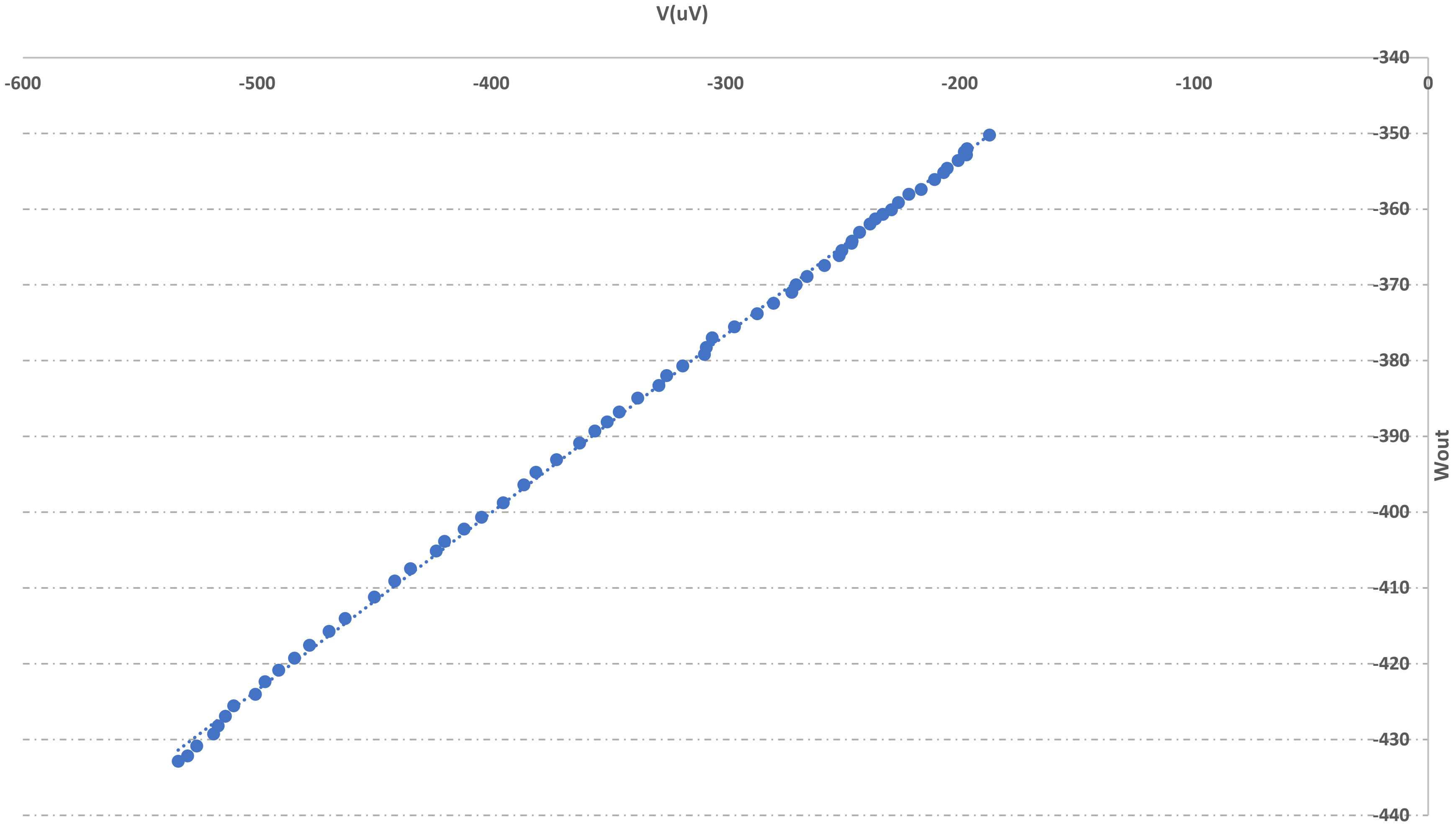
If $W_{atm}$ is assumed constant, Eq. 4 then yields:

$$K_1 = \frac{-dW_{out}}{dV} \quad (5)$$

Equation 5 implies that the change of $W_{out}$ versus the change of $V$ yields $K_1$, which is independent from the absolute value of $W_{atm}$.

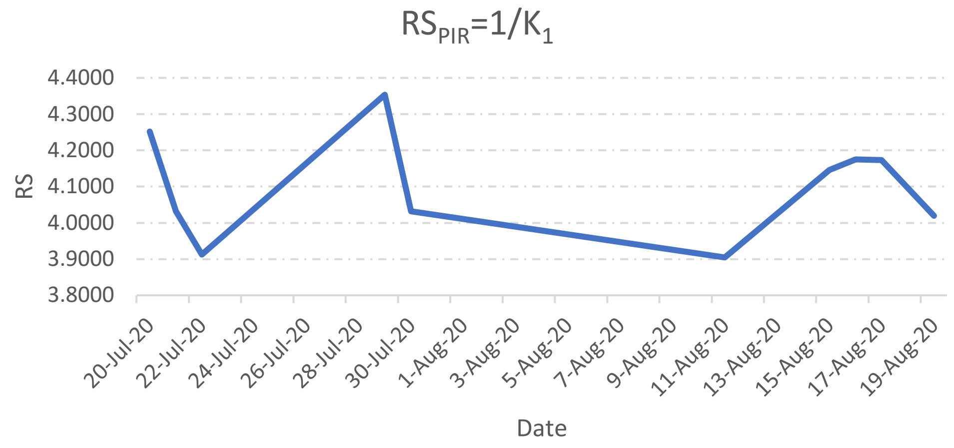
Once $K_1$ was calculated, using the previous procedure, Eq. 1 was used to calculate the measured atmospheric longwave irradiance for 2 hours, and then, the procedure was repeated from a solar zenith angle of >95 (PM) to <95 (AM).

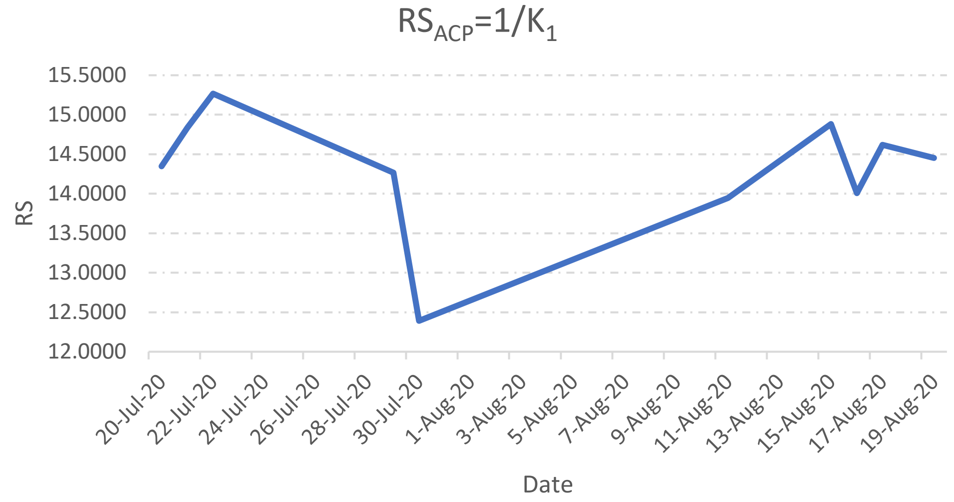
# $W_{out}$ versus thermopile output voltage during the calibration of PIR31197F3 to calculate $K_1$ using equation 5 Above

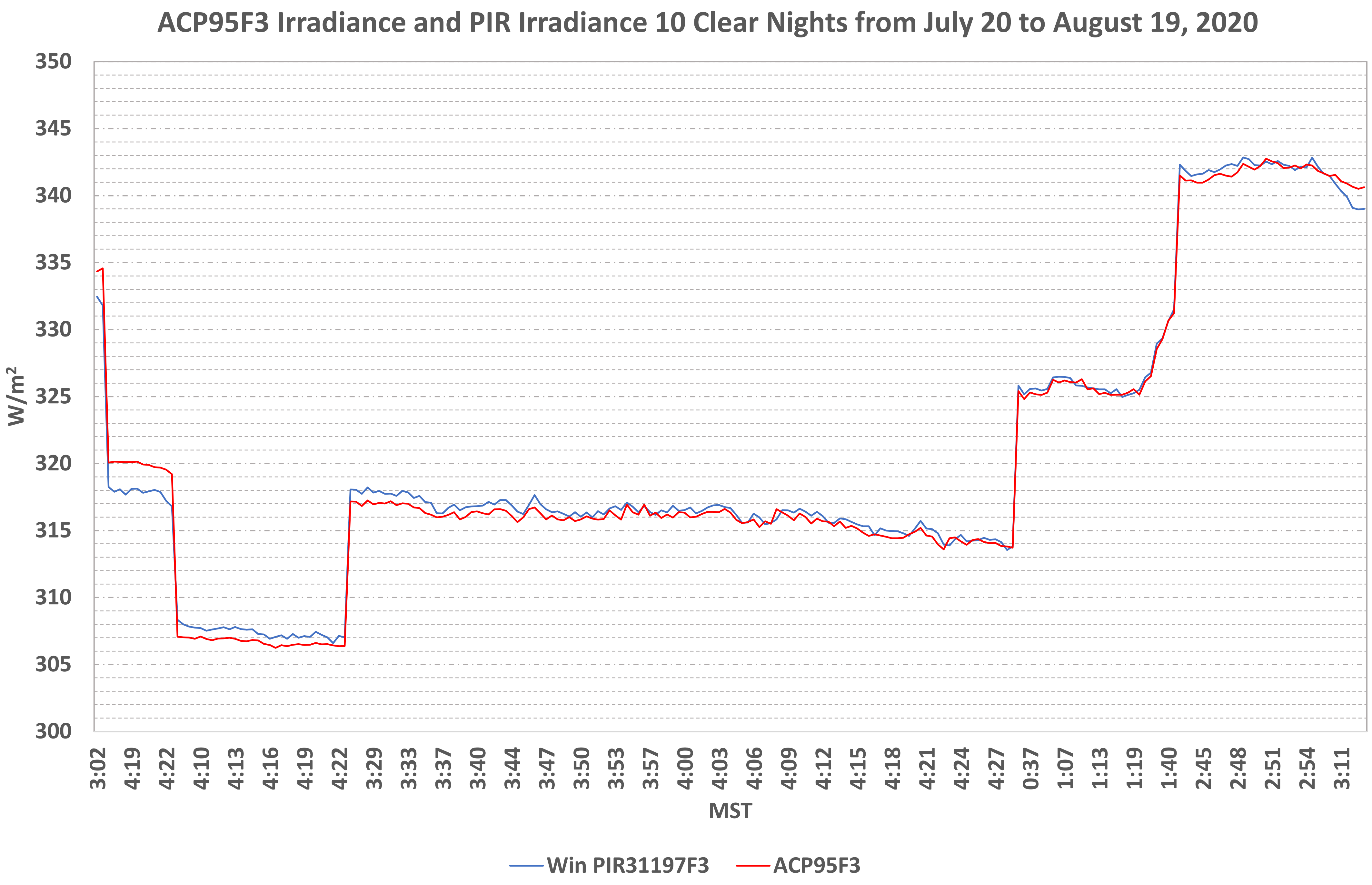


# Sample of the calculated Responsivity for PIR and ACP95F3

| Date | $K_1$ for PIR | $RS_{PIR}=1/K_1$ | $K_1$ for AC95F3 | $RS_{ACP}=1/K_1$ |
|---|---|---|---|---|
| 20-Jul-20 | 0.2352 | 4.2517 | 0.0697 | 14.3472 |
| 21-Jul-20 | 0.2480 | 4.0323 | 0.0674 | 14.8368 |
| 22-Jul-20 | 0.2556 | 3.9124 | 0.0655 | 15.2672 |
| 29-Jul-20 | 0.2297 | 4.3535 | 0.0701 | 14.2653 |
| 30-Jul-20 | 0.2480 | 4.0323 | 0.0807 | 12.3916 |
| 11-Aug-20 | 0.2561 | 3.9047 | 0.0717 | 13.9470 |
| 15-Aug-20 | 0.2412 | 4.1459 | 0.0672 | 14.8810 |
| 16-Aug-20 | 0.2395 | 4.1754 | 0.0714 | 14.0056 |
| 17-Aug-20 | 0.2396 | 4.1736 | 0.0684 | 14.6199 |
| 19-Aug-20 | 0.2488 | 4.0193 | 0.0692 | 14.4509 |




ACP95F3 Irradiance and PIR Irradiance 10 Clear Nights from July 20 to August 19, 2020
W/m²
350
345
340
335
330
325
320
315
310
305
300
3:02
4:19
4:22
4:10
4:13
4:16
4:19
4:22
3:29
3:33
3:37
3:40
3:44
3:47
3:50
3:53
3:57
4:00
4:03
4:06
4:09
4:12
4:15
4:18
4:21
4:24
4:27
0:37
1:07
1:13
1:19
1:40
2:45
2:48
2:51
2:54
3:11
MST
Win PIR31197F3
ACP95F3

# Results

The measurement uncertainty was calculated using the following equation:

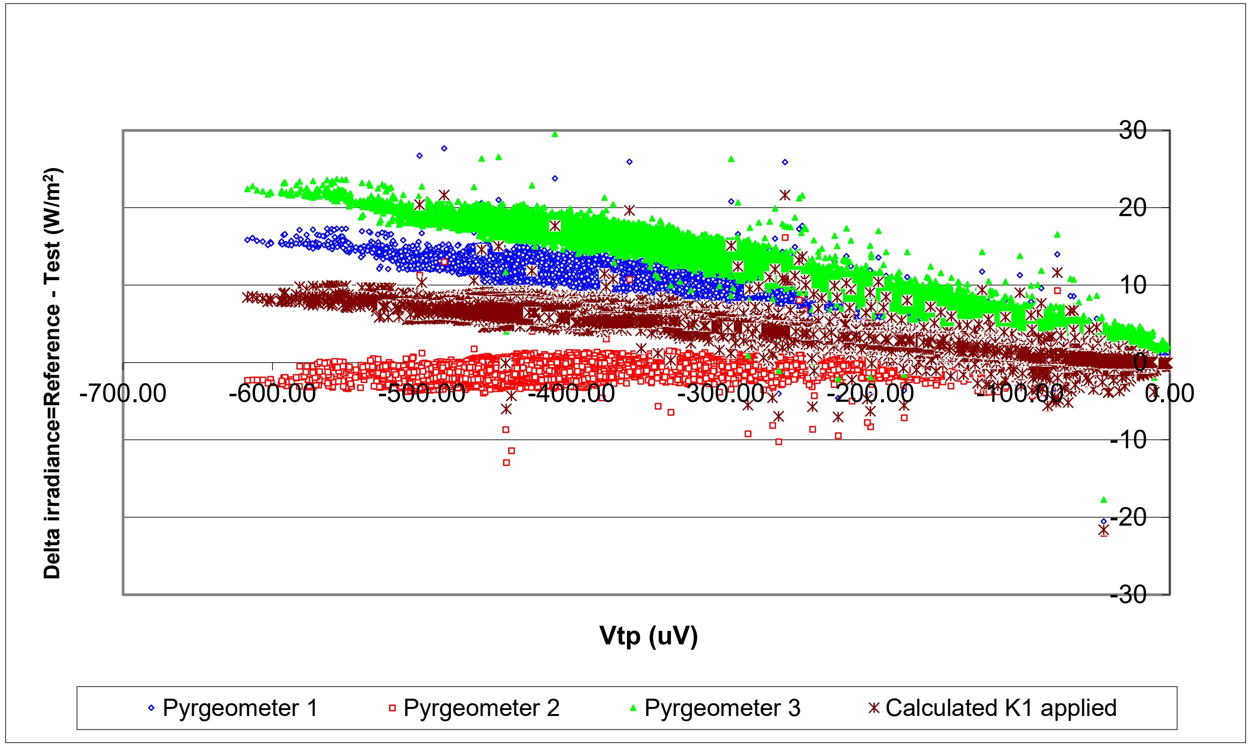
$$U_{95} = \sqrt[2]{U_{95ACP}^{2} + U_{95PIR}^{2}} \qquad (6)$$

where $U_{95ACP}$ equals $\pm 2$ W/m$^2$ with respect to SI, $U_{95PIR}$ equals $\pm 2.88$ W/m$^2$ with respect to ACP; therefore, $U_{95PIR}$ equals $\pm 3.51$ W/m$^2$ with respect to SI.

- These results suggest that the pyrgeometer calibration method might be useful in addressing the international need for a transfer standard pyrgeometer traceable to SI.
- The pyrgeometer calibration might be independent method to validate the ACP uncertainty from 2 to 3 W/m$^2$ traceable to SI.

# Calibrating Three Test Pyrgeometers Using Transfer Standard Pyrgeometer

- $K_2$ and $K_3$ in Equation 1 are calculated using the BB calibration.
- $K_1$ is calculated by deploying the test pyrgeometers with the transfer standard pyrgeometer outdoor during nighttime clear sky conditions for two hours to account for the spectral response of pyrgeometers and the spectral mismatch between the BB and the atmospheric longwave irradiance.
- The test pyrgeometers are then used as a secondary transfer reference to calibrate other pyrgeometers during nighttime under all sky conditions.



# Thank You

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