Improvements in the Blackbody Calibration of Pyrgeometers

By
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Abstract

Pyrgeometers are used to measure the atmospheric longwave irradiance through out the ARM program sites. Previous calibrations of pyrgeometers using ARM/Eppley/NREL blackbody were consistent, but introduced a difference in the historical clear sky measured irradiance. This difference was believed to be in the order of 12 W/m^2. In this poster we show the improvements to the blackbody and calibration methodology by comparing our results to the results of a group of pyrgeometers that were recently calibrated against the World Infrared Standard Group, in the World Radiation Center, Davos/Switzerland.

Improvements in the Blackbody

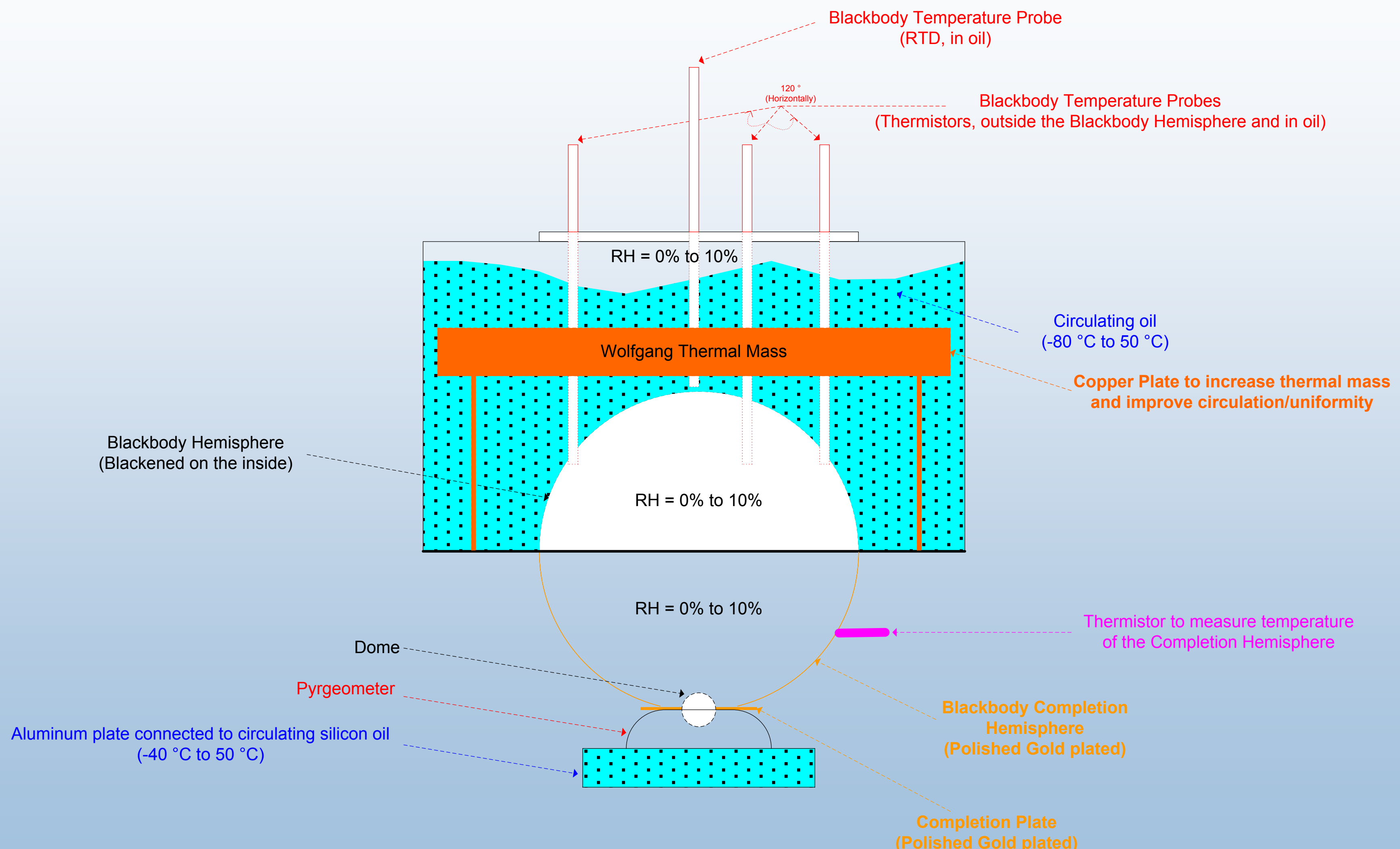
- Lower viscosity oil in temperature circulator for Blackbody (BB); reduced BB temperature gradient from 3 C to 0.8 C @ -30 C temperature plateau; decreased clear sky bias from 12 W/m^2 to 6 W/m^2

- Added Wolfgang's thermal mass to increase thermal capacity of BB; reduced scatter in outdoor data from 6 W/m^2 to 2 W/m^2

- Proper polishing and gold plating for BB completion hemisphere. A Nickel layer is inserted between copper and gold to prevent copper/gold diffusion *(Chang, C., 1986, J. Appl.Phys., Vol. 60, No. 3, 1);* improved BB emissivity

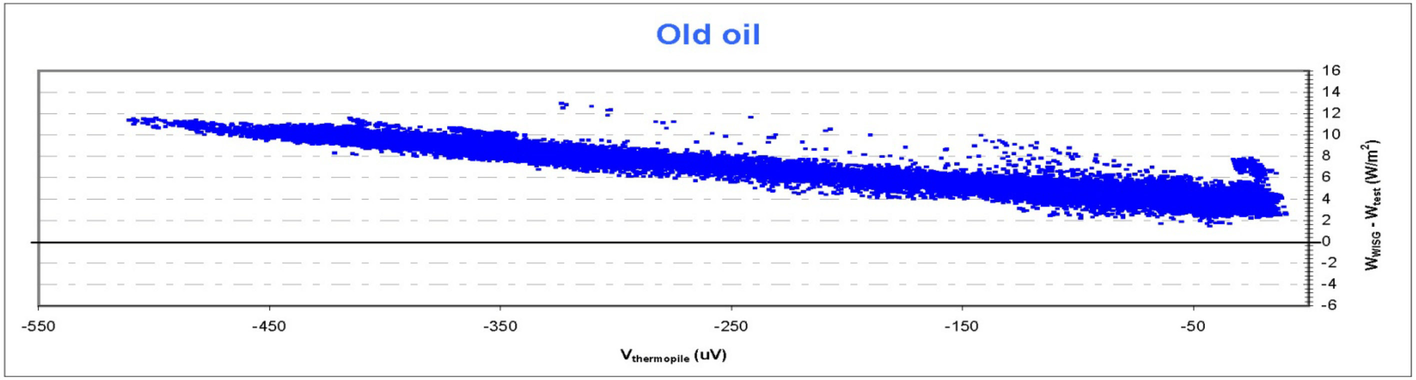
- Attached a thermistor to gold completion hemisphere to add it's emitted irradiance in calculation of BB irradiance, e_G = 0.02 (*NIST Data);* increased BB irradiance by 4 W/m^2 (1 W/m^2 per T-plateaus).

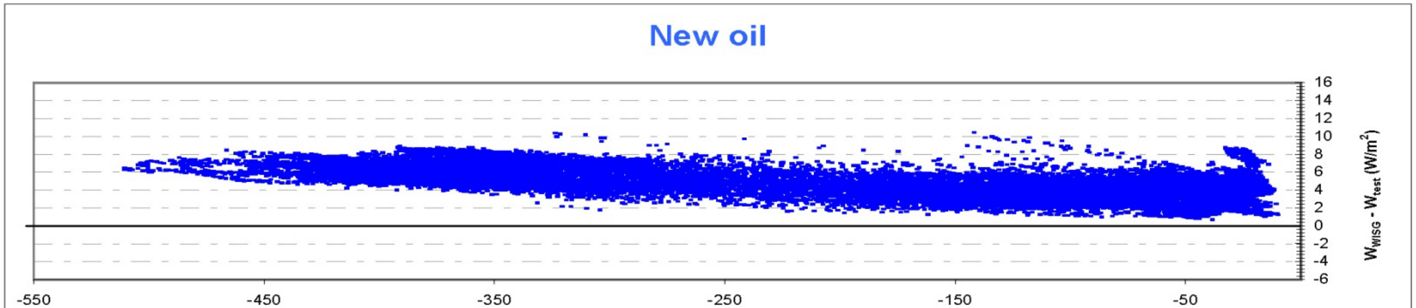
Pyrgeometer Blackbody Calibration System Simplified Diagram



Difference between the reference irradiance and the irradiance measured by 30557F3 using NREL-BB-Coefficients (Old vs New oil)

Without e_G correction





Clear Sky

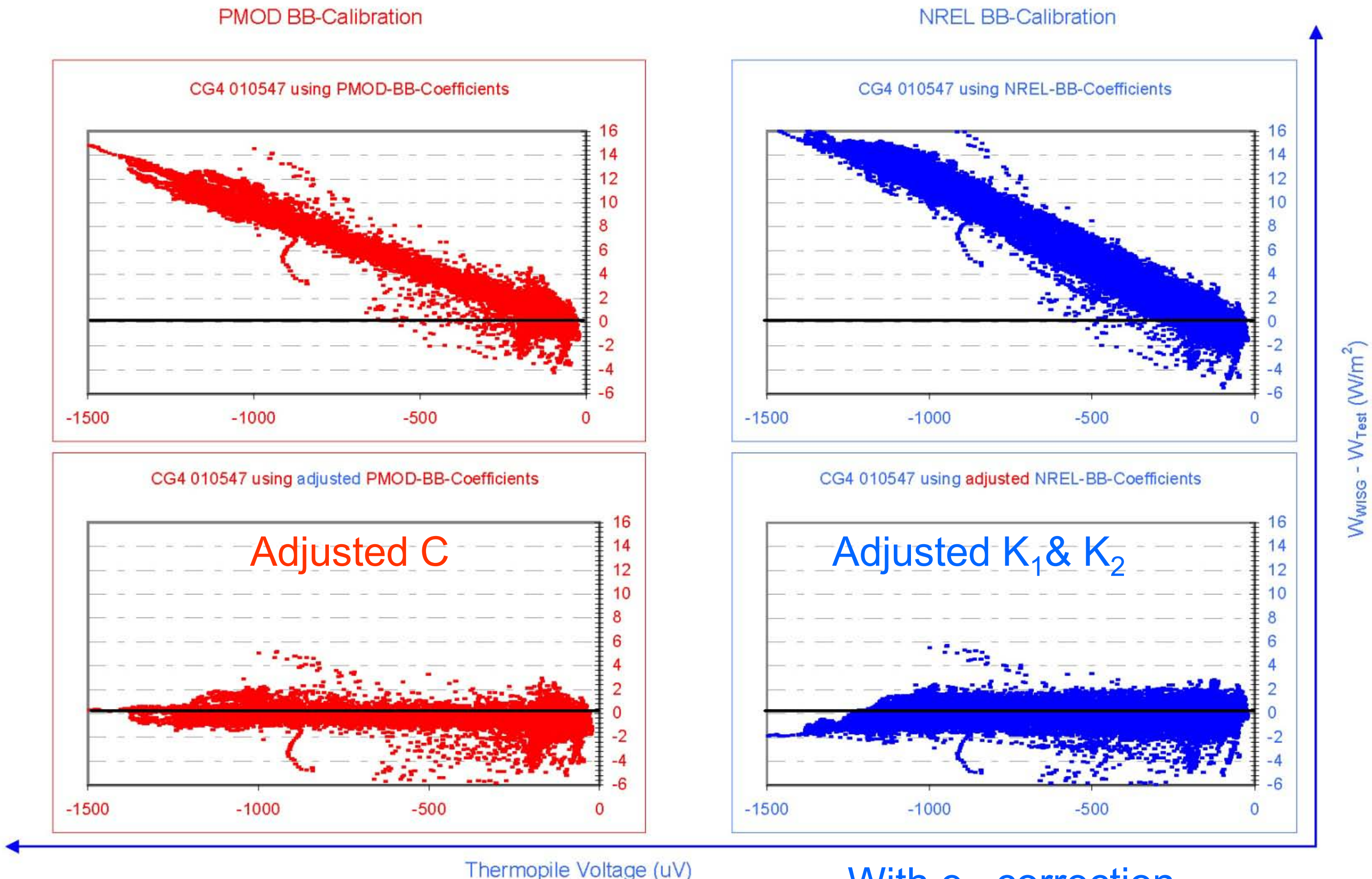
Cloudy Sky

Decreased dependence on sky conditions

Evaluation Method

- Five pyrgeometers calibrated at PMOD to establish the NREL Reference Group (NRG): 3-PIRs and 2-CG4s
- Calibrated NRG using PMOD Blackbody (BB)
- NRG deployed outdoors at PMOD with the World Infrared Standard Group (WISG) for more than 4-months
- Adjusted PMOD-BB coefficient (C) to match the WISG irradiance
- Calibrated NRG using NREL Blackbody (BB)
- Using the same outdoor data at Davos, adjusted NREL-BB coefficients (K_1 and K_2) to match the WISG irradiance, and K_3 to reduce scatter
- Compared the results from PMOD's and NREL's BB and outdoor calibrations

Difference between the reference irradiance (WISG) and the irradiance measured by the test pyrgeometer at PMOD/WRC between July and December 2007.



With e_G correction

$$W_{in} = \frac{V}{C} * (1 + k_1 * \sigma * T_c^3) + k_2 * W_c$$

$$W_{in} = K_0 + K_1 * V + K_2 * W_r$$

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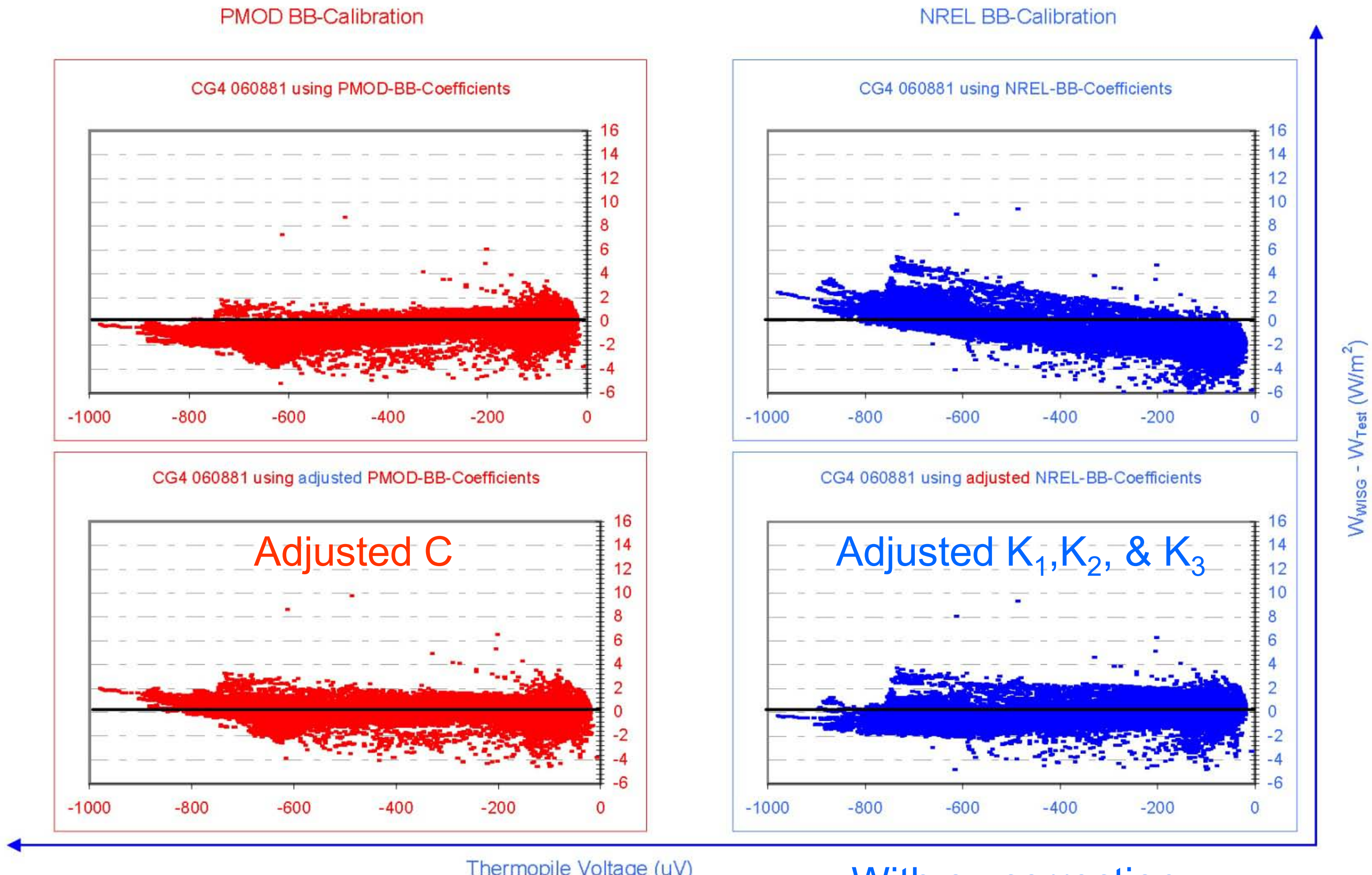
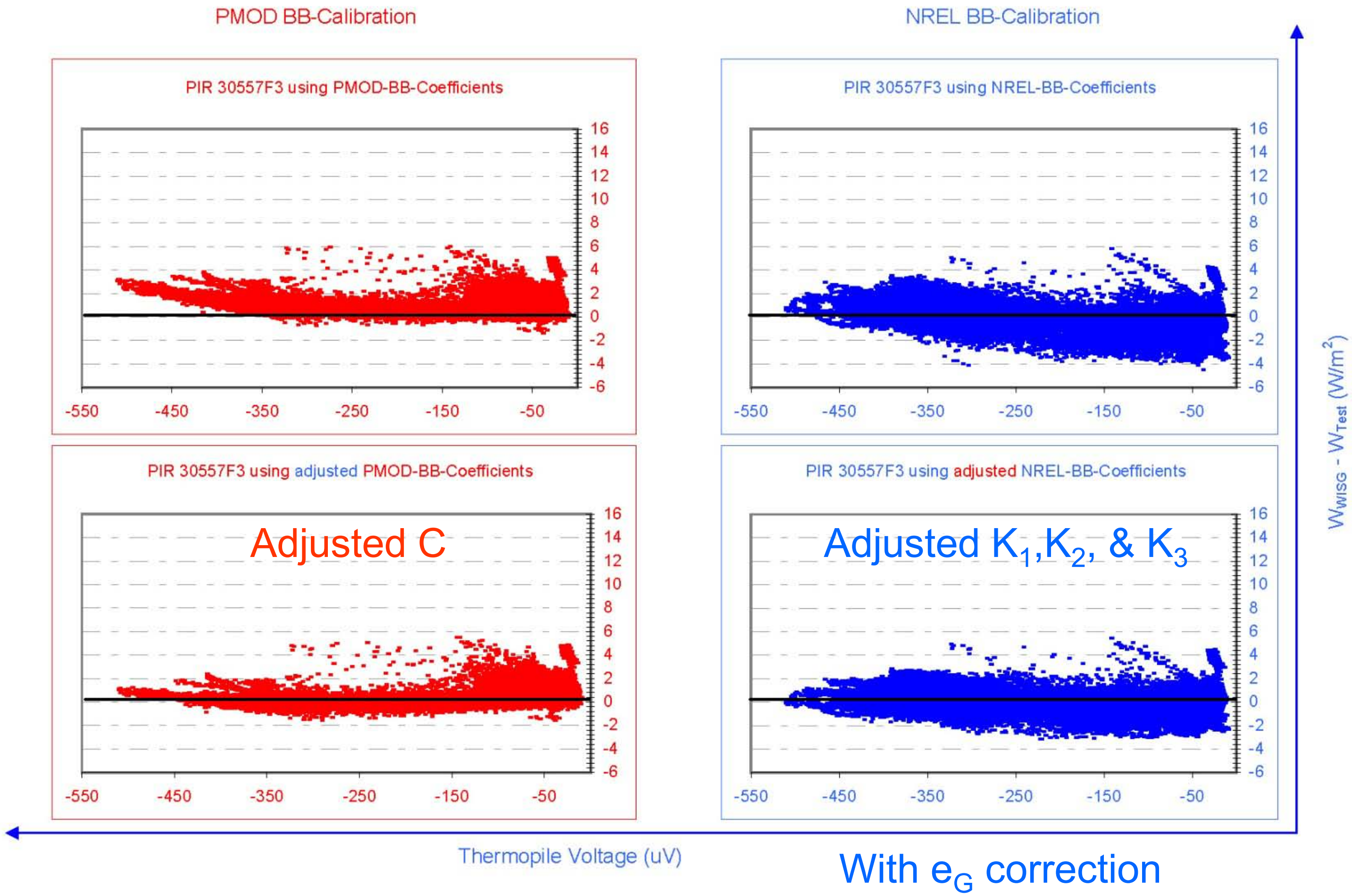


With e_G correction

$$W_{in} = \frac{V}{C} * (1 + k_1 * \sigma * T_c^3) + k_2 * W_c - k_3 * (W_d - W_c)$$

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

Difference between the reference irradiance (WISG) and the irradiance measured by the test pyrgeometer at PMOD/WRC between July and December 2007.



$$W_{in} = \frac{V}{C} * (1 + k_1 * \sigma * T_c^3) + k_2 * W_c - k_3 * (W_d - W_c)$$

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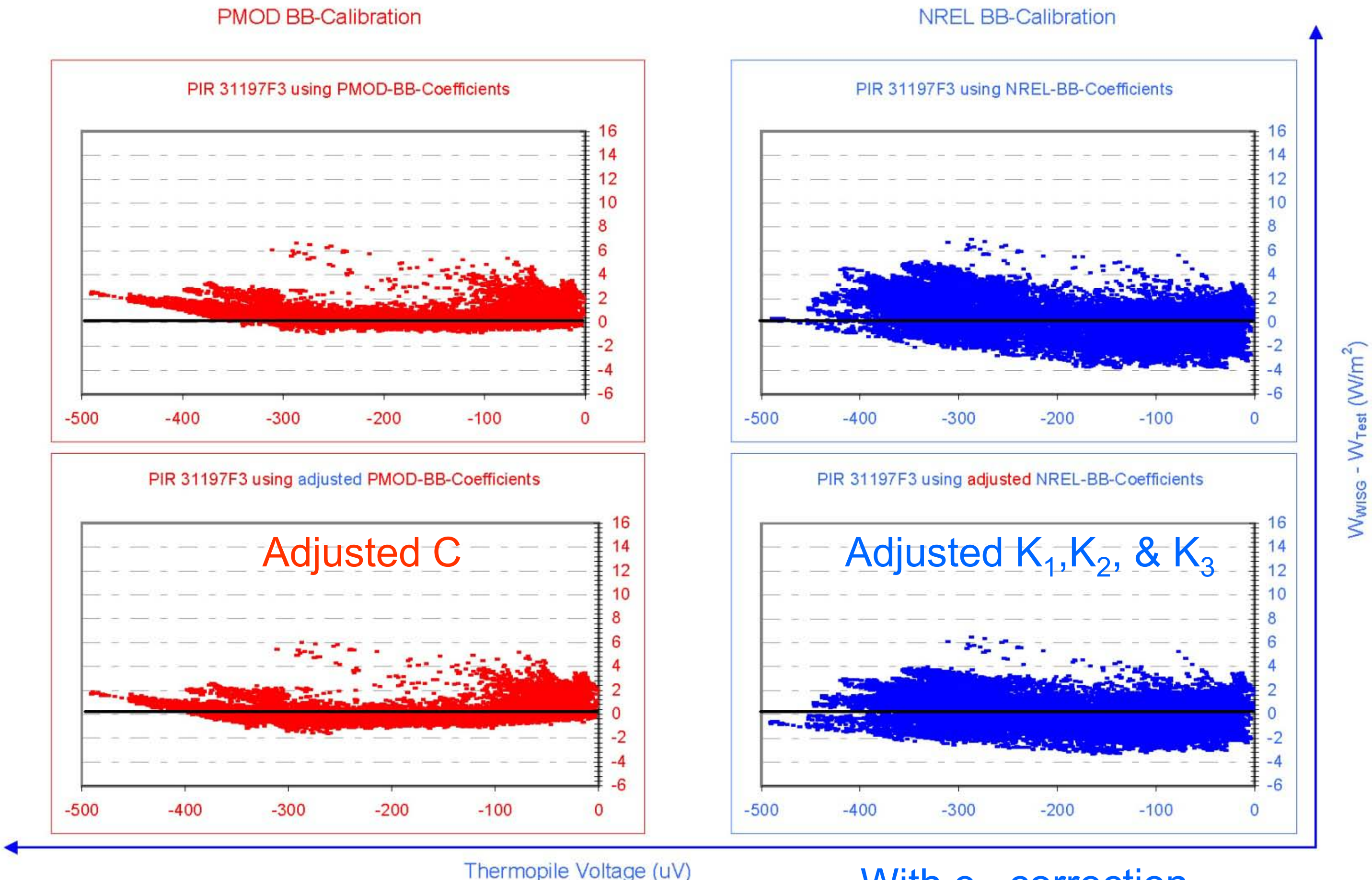

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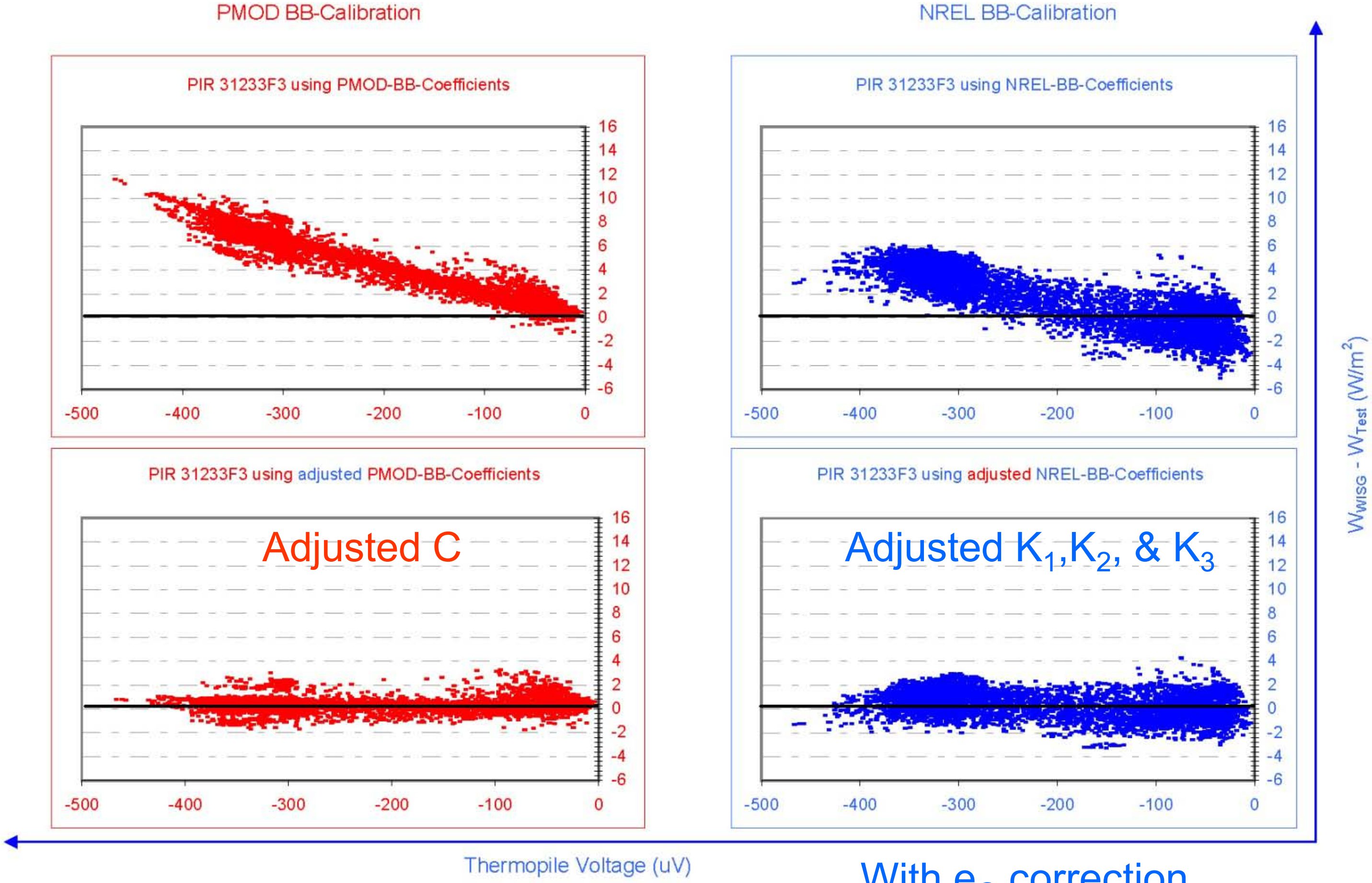
Difference between the reference irradiance (WISG) and the irradiance measured by the test pyrgeometer at PMOD/WRC between July and December 2007.



With e_G correction

$$W_{in} = \frac{V}{C} * (1 + k_1 * \sigma * T_c^3) + k_2 * W_c - k_3 * (W_d - W_c)$$

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

Results Tables

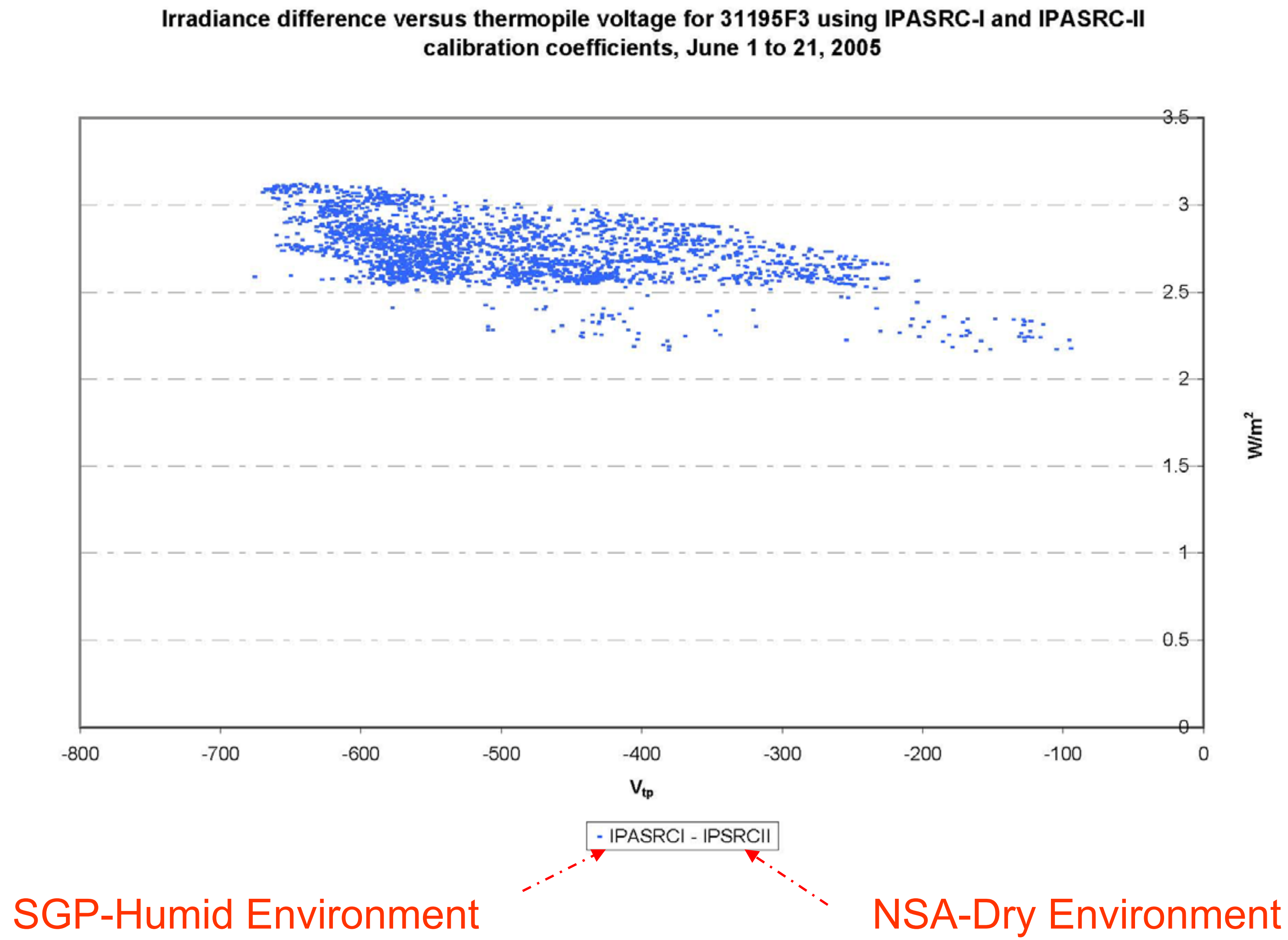
PMOD and NREL BB calibration coefficients vs adjusted coefficients to match the WISG irradiance, using PMOD equation

Coefficient	Source	CG4-010547		CG4-060881		PIR-30557F3		PIR-31197F3		PIR-31233F3	
		PMOD-BB	NREL-BB	PMOD-BB	NREL-BB	PMOD-BB	NREL-BB	PMOD-BB	NREL-BB	PMOD-BB	NREL-BB
C	BB	11.562	9.542	8.547	7.560	4.322	3.628	4.193	3.488	3.615	2.955
	Adjusted	12.921	11.500	8.395	7.950	4.379	3.850	4.233	3.600	3.881	3.250
k1	BB	0.0211	-0.0728	0.0267	-0.0203	0.0065	-0.0804	0.0557	-0.0552	0.0376	-0.0901
k2	BB	0.99875	1.00947	0.99769	1.00866	0.99871	1.01128	1.00247	1.01328	1.00080	1.01181
	Adjusted		0.99800		0.99900		1.00500		1.00850		1.00500
k3	BB	N/A	N/A	0.00	0.00	2.70	3.31	2.61	3.16	3.66	4.14
U_{95} (W/m^2)		1.9	1.9	1.7	1.9	2.0	1.5	1.8	1.8	1.4	1.4

PMOD and NREL BB calibration coefficients vs adjusted coefficients to match the WISG irradiance, using NREL equation

Coefficient	Source	CG4-010547		CG4-060881		PIR-30557F3		PIR-31197F3		PIR-31233F3	
		PMOD-BB	NREL-BB	PMOD-BB	NREL-BB	PMOD-BB	NREL-BB	PMOD-BB	NREL-BB	PMOD-BB	NREL-BB
K0	BB	-0.29	-11.2	0.0589	-5.38	-1.77	-11.61	0.45	-11.4	0.117	-17.534
K1	BB	0.0854	0.0892	0.1174	0.12207	0.2205	0.22556	0.2422	0.24941	0.2735	0.27188
	Adjusted	0.076	0.0756	0.1195	0.1186	0.2174	0.222	0.2398	0.245	0.2537	0.2571
	C_{adj} =1/K1	13.158	13.228	8.368	8.432	4.600	4.505	4.170	4.082	3.942	3.890
K2	BB	0.9996	1.03485	0.9975	1.01891	1.0039	1.03738	1.0011	1.03854	1.0006	1.05145
	Adjusted		1.03		1.013		1.038		1.04		1.051
K3	BB	N/A	N/A	0.00	1.03	2.70	2.09	2.61	2.08	3.65	2.30
	Adjusted	N/A	N/A	0.00	0.00		2.70		2.80		3.30
U_{95} (W/m^2)		1.5	2.0	2.0	1.8	1.7	2.0	1.8	2.3	1.9	1.9

Applying Results of Both International Pyrgeometer and Absolute Sky-scanning Radiometer Comparisons (IPASRC)



Comments/Conclusions

1. NREL-BB improvements reduced ~12 W/m^2 bias to (-1 W/m^2 to 3 W/m^2) w.r.t. WISG

2. What is the absolute value?

   Can IT BE FROM:

   - IPASRC-I; Present WISG?

   - IPASRC-II; 2.5 W/m^2 to 3 W/m^2 lower than IPASRC-I?

   - Outdoor calibration independent from reference irradiance *(Reda et al., 2006, J. Atmospheric and Solar Terrestrial Physics, 68, 1416-1424);* 3 W/m^2 from WISG?

   - Improved NREL-BB; -1 W/m^2 to 3 W/m^2 from WISG?

3. The BB calibration coefficients must be adjusted outdoors to an Internationally accepted reference (i.e. WISG) for global uniformity, and to account for the spectral response of pyrgeometers and the mismatch between the BB (indoors) and the outdoors.

4. **Other pyrgeometer calibration systems are needed to evaluate the WISG to establish a consensus reference with traceability to SI units.**