NATIONAL RENEWABLE ENERGY LABORATORY

Uncertainty Estimates for SIRS, SKYRAD, & GNDRAD Data and Reprocessing the Pyrgeometer Data

ASR Science Team Meeting 2012

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The Guide to the Expression of Uncertainty in Measurement (GUM)*

Basic Steps:

1. ***Determine the measurement equation.***
2. ***Estimate the standard uncertainty*** **(u_i)** associated with each variable in the measurement equation and for each component that might introduce uncertainty to the measurement process (e.g. interpolation, environmental conditions).
3. ***Calculate the combined standard uncertainty*** **(u_c)** by summing in quadrature the standard uncertainties in step 2.
4. ***Calculate the expanded uncertainty*** **(U)** by multiplying the combined standard uncertainty by the coverage factor, k (typically known as Student's "t"), or prescribed coverage factors for known distributions of measurements representing the single value of the quantity to be measured (e.g. Gaussian, triangular, rectangular).

*BIPM; IEC; IFCC; ISO; IUPAP; OIML. (1995).
Guide to the Expression of Uncertainty in Measurement, ISO TAG4, Geneva.

http://www.nrel.gov/docs/fy11osti/52194.pdf

Uncertainty Estimates for SIRS, SKYRAD, & GNDRAD

Simple Expression:

1. ***Determine the measurement equation:***

Pyrheliometers:

W = V / Rs

Pyranometers:

W = (V – Rnet * Wnet) / Rs

W = Flux (Wm^{-2})
V = Thermopile Voltage (µV)
Rs = Shortwave Responsivity ($\mu V/Wm^{-2}$)
Rnet = Longwave Responsity
Wnet = Longwave Irradiance (Pyrgeometer)

2. ***Estimate the standard uncertainty*** **(u_i)** based on Type A and Type B error sources

   Calibration; Responses: Temperature, Spectral, Angular; Linearity, Stability, etc.

3. ***Calculate the combined standard uncertainty*** **(u_c):**

$$u_c = \sqrt{u_A^2 + u_B^2}$$

4. ***Calculate the expanded uncertainty*** **(U)**

$U = k * u_c$ (k = 1.96 for large degrees of freedom)

http://www.nrel.gov/docs/fy11osti/52194.pdf

Calibration Uncertainty Estimates

Traceable to SI Units

Radiometer	Expanded Uncertainty $U95 = U_c * 1.96$
Pyranometer	±3%
Pyrheliometer	±2%
Pyrgeometer	± (1% + 4 Wm^{-2})*

*Due to interim World Infrared Standard Group (WISG)

http://www.nrel.gov/docs/fy11osti/52194.pdf

Uncertainty Estimates for SIRS, SKYRAD & GNDRAD

Measurement	Abbreviation	Eppley Radiometer Model	Typical Responsivity (µV/Wm^{-2})	Estimated Measurement Uncertainty	Value Added (correction for zenith, thermal offset, etc.)
Direct Normal (Beam)	DNI	NIP	8	±3.0% (>700 Wm^{-2})	±2.0% (>700 Wm^{-2})
Diffuse Horizontal (Sky)	DD	PSP	9	+4.0% to -(4%+20 Wm^{-2})	+2.0% to -(2%+4 Wm^{-2})
Diffuse Horizontal (Sky)	DD	8-48	8	+4.0% to -(4%+2Wm^{-2})	+4.0% to -(4%+2Wm^{-2})
Downwelling Shortwave (Global)	DS	PSP	9	+4.0% to -(4%+20 Wm^{-2}) zenith < 80°	+2.0% to -(2%+4 Wm^{-2}) zenith < 80°
Downwelling Longwave (Atmospheric)	DIR	PIR	4	±(5%+4* Wm^{-2})	±(1%+4* Wm^{-2})
Upwelling Shortwave (Reflected SW)	US	PSP	9	±3.0%	±2.0%
Upwelling Longwave (Reflected/Emitted LW)	UIR	PIR	4	± 2 Wm^{-2}	±2 Wm^{-2}

* WISG uncertainty

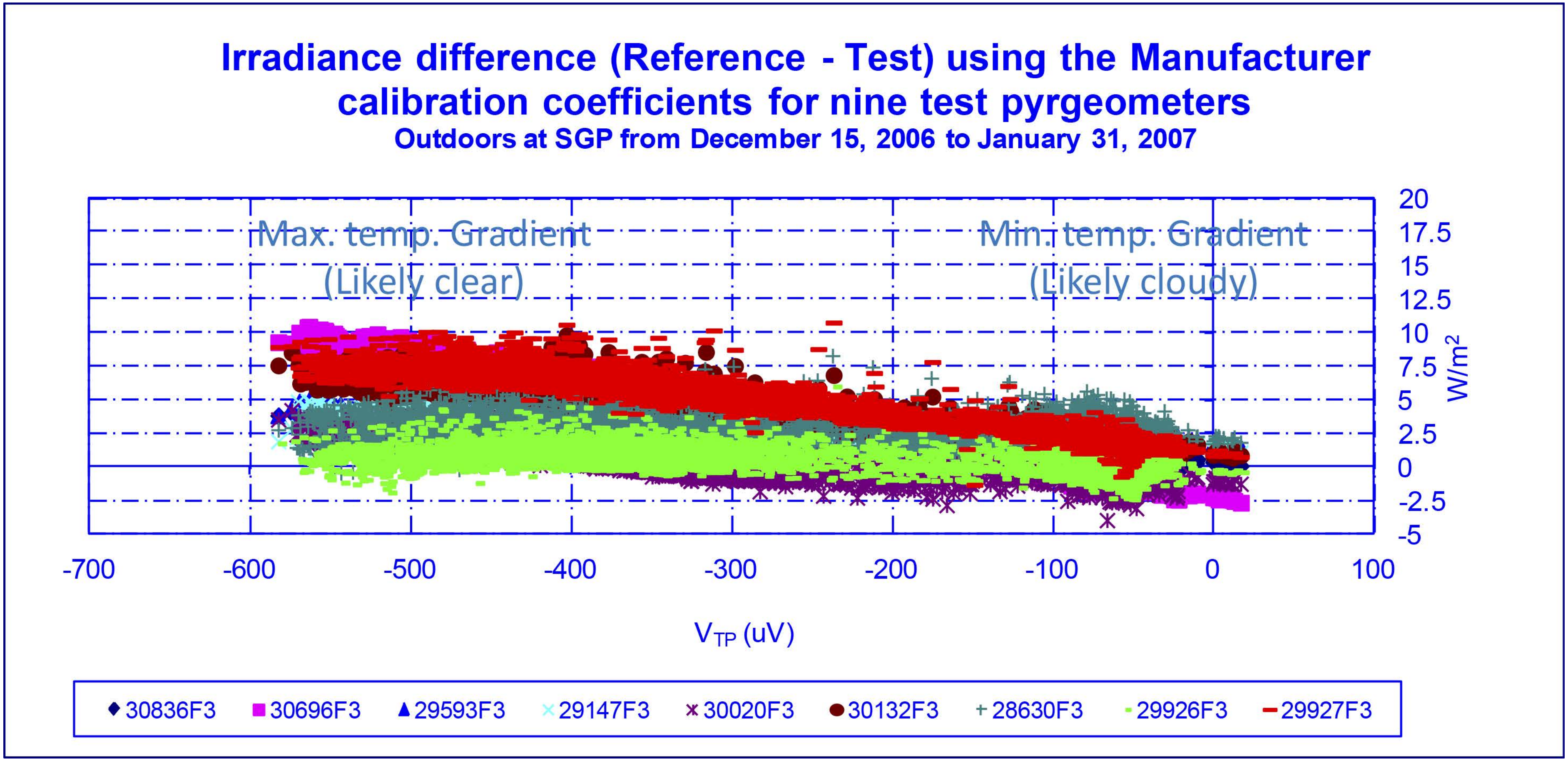
All uncertainties are estimated with respect to the Système international d'unités (SI) and represent optimal maintenance and installation.

References:

- Reda, I. (2011). "Method to Calculate Uncertainty Estimate of Measuring Shortwave Solar Irradiance using Thermopile and Semiconductor Solar Radiometers". 20 pp.; NREL Report No. TP-3B10-52194
- Reda, I.; Zeng, J.; Scheuch, J.; Hanssen, L.; Wilthan, B.; Myers, D.; Stoffel, T., 2012. "An absolute cavity pyrgeometer to measure the absolute outdoor longwave irradiance with traceability to International System of Units, SI". Journal of Atmospheric and Solar-Terrestrial Physics 77 (2012) 132-143. http://dx.doi.org/10.1016/j.jastp.2011.12.011

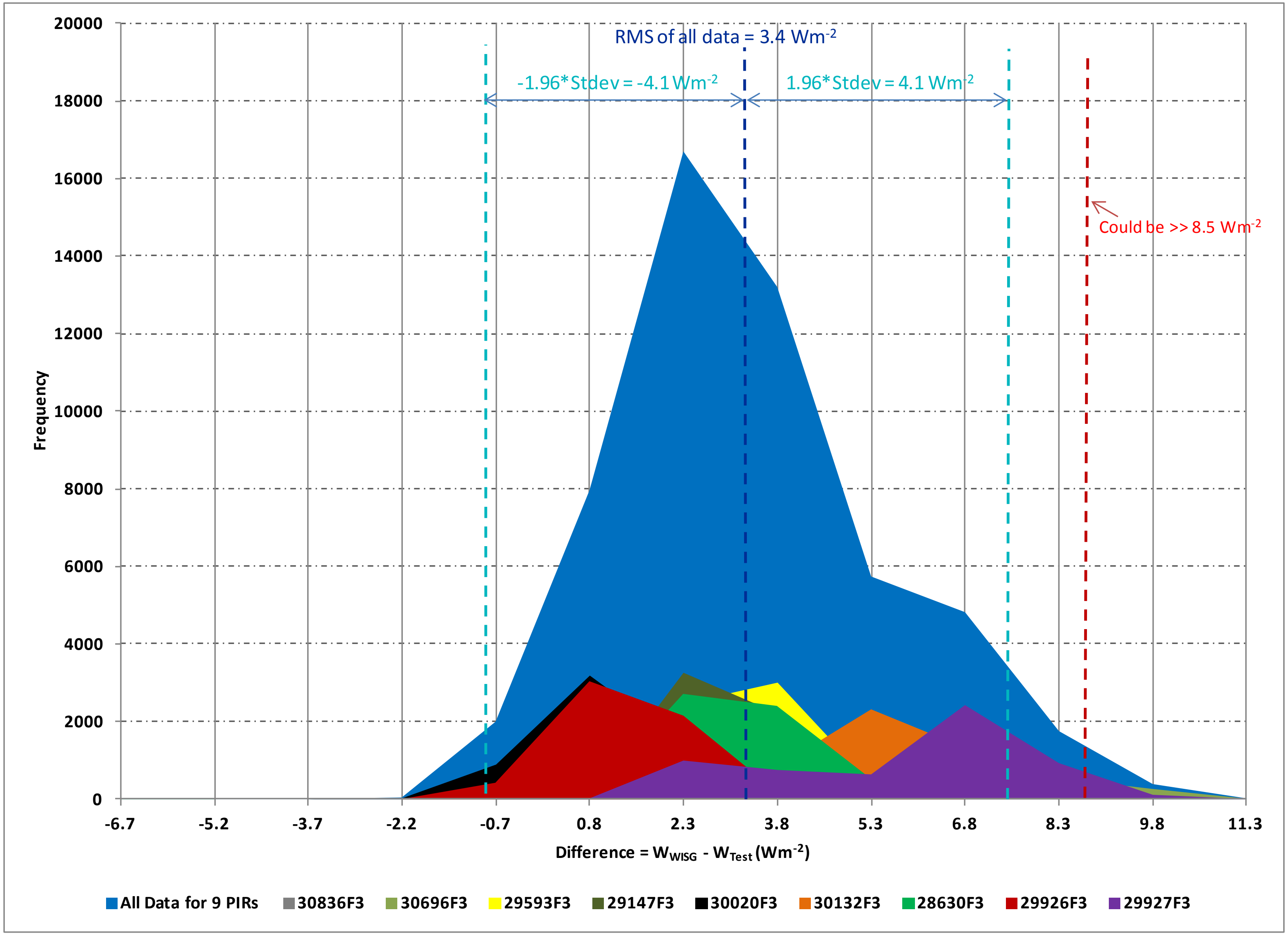
Pyrgeometer Calibrations: WISG vs. Blackbody Results

Dome coefficient = 3.5



Reference: Reda et al., 2007. "ARM/NREL Pyrgeometer Calibrations with Traceability to the World Infrared Standard Group (WISG)". *ARM-CONF-2007, March 2007 Monterey, California*

Pyrgeometer Outdoor Calibration vs. Manufacturer Blackbody Calibration Histograms



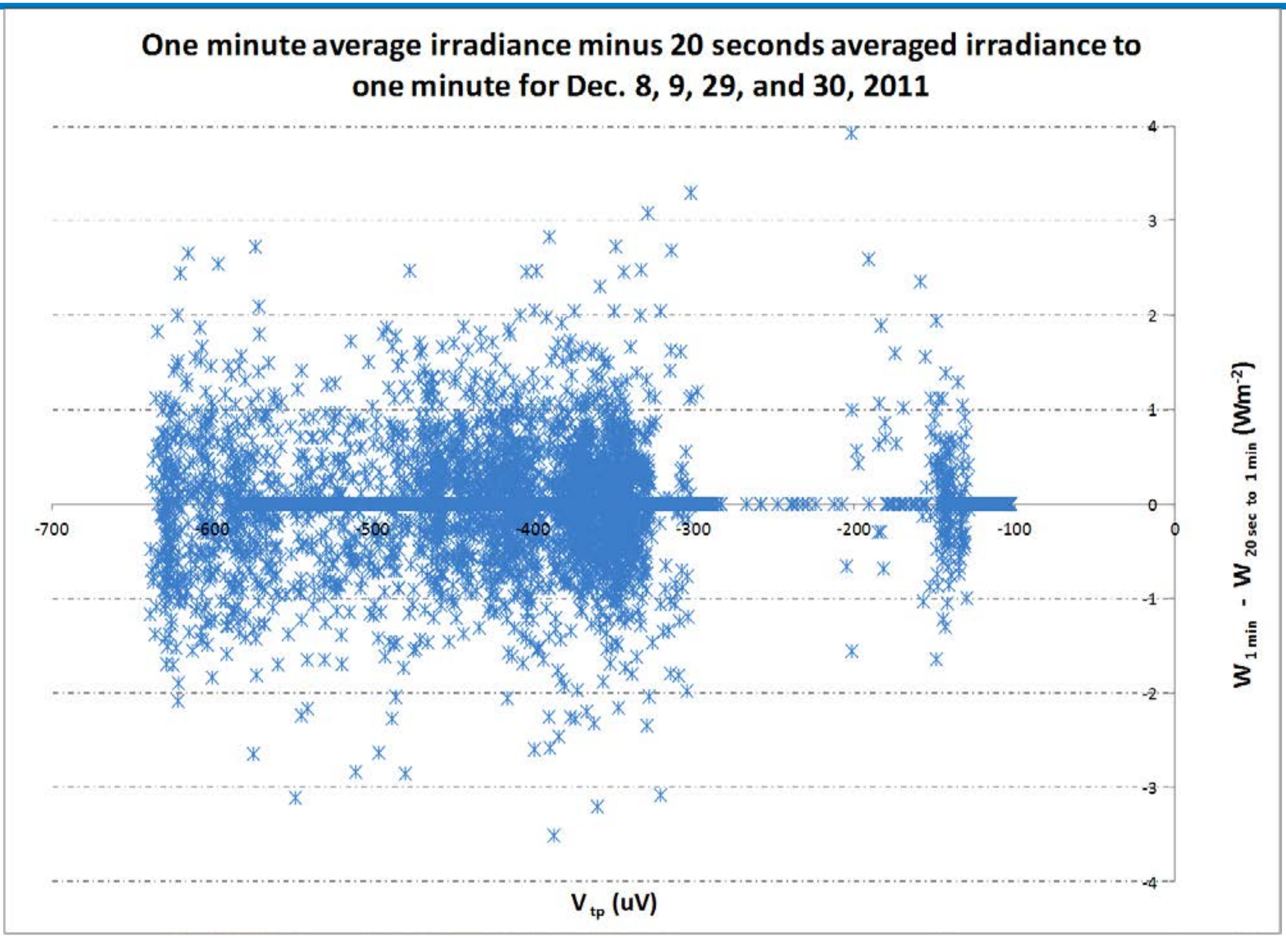
Pyrgeometer Aging Study

Manufacturer BB re-calibration after seven years of field deployment

S/N	Location	Date Deployed	Eppley Cal [uV/Wm^{-2}]	Date Returned from Eppley	New Eppley Cal [uV/(W/m^{-2})]	%difference between cals	%aging/year for a 7-year deployment	Cal interval (Year)	Error in $W_{incoming}$ (Wm^{-2})
30779F3	Ringwood, OK	8/17/2004	3.77	4/28/2011	3.79	0.53	0.08	1	0.15
30832F3	Vici, OK	8/18/2004	3.71	4/28/2011	3.67	-1.08	-0.15	1	-0.31
30688F3	Meeker, OK	8/19/2004	3.88	4/28/2011	3.9	0.52	0.07	1	0.15
30785F3	Ashton, KS	12/14/2004	4.14	4/28/2011	4.09	-1.21	-0.17	1	-0.35
30344F3	Pawhuska, OK	12/7/2004	3.95	4/28/2011	3.96	0.25	0.04	1	0.07
30010F3	Lamont, OK	8/27/2004	3.2	4/28/2011	3.24	1.25	0.18	1	0.35

From the inconsistency of the difference, no conclusion, yet a 2-year cal interval is reasonable

Sampling Rate Effect for Correcting Historical Data



-Randomness of the data is a result of the nonlinearity of the basic variables in the pyrgeometer equation, i.e., resistance-to-temperature, $(\text{temperature})^4$, etc.
-Correcting the 1-min average might introduce > ± 2 W/m^2 randomness to the corrected data (site dependent)
-Correcting the present 20-sec irradiance data is more appropriate, yet it will introduce greater randomness than that corrected using the 2-second irradiance, site dependent … challenging for space/etc, yet it might not be an issue in the near future.

Implementing a New Calibration System

Broadband Outdoor Radiometer Calibration

System for Data Acquisition, Analyses, Reporting, Archival

BORCAL/SW

- Pyrheliometers
- Pyranometers

BORCAL/LW

- Pyrgeometers

Implementing a New BORCAL/LW System

SRRL – 5 PIRs

BORCAL/LW @ SRRL
Data Acquisition + Auto Analyses + Certs + Reports + Archive

SGP/RCF – 5 PIRs

BORCAL/LW @ SGP/RCF
Hardware & Software Installation
Data Acquisition + Auto Analyses + Certs + Reports + Archive

Validation
(5 PIRs)
Operational
31 March 2013

What Happened to the Schedule?

- SRRL down for 8 months instead of 6 weeks!
- NPC-2011
- BORCAL-2012