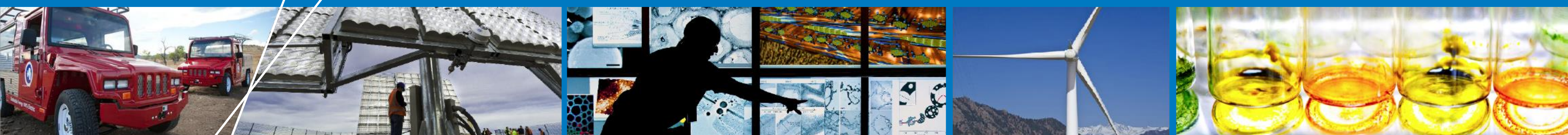
Traceable Pyrgeometer Calibrations



2016 ARM/ASR PI Meeting

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May 2, 2016

Abstract

The Atmospheric Radiation Measurement (ARM) program provides high quality radiometric data from approximately 150 instruments deployed at Southern Great Plains (SGP), Eastern North Atlantic (ENA), North Slope of Alaska (NSA), Oliktok (OLI), and the ARM Mobile Facilities (AMF) sites. These instruments are deployed on the Solar Infrared Radiation Station (SIRS), SKYRAD, and GNDRAD instrument platforms. In addition to the operational radiometers, there are more than 200 other radiometers that are calibrated and used for instrument swaps and replacements. The National Renewable Energy Laboratory (NREL) and ARM, through the Radiometric Calibration Facility (RCF) at the Southern Great Plains (SGP) site, provides Broadband Outdoor Radiometer Calibrations (BORCAL) for all shortwave (SW) and longwave (LW) radiometers that are deployed by the ARM program. The BORCAL-SW is traceable to the International System of Units (SI), through the World Radiometric Reference (WRR). On the other hand, the SI standard is not yet established for longwave measurements. Both NREL and ARM continue to improve radiometric measurement through the introduction of new methods to reduce uncertainty in calibration and field measurements. A significant part of this effort is to establish the longwave traceability to SI units and deploy the BORCAL-LW using an interim World Infrared Standard Group (WISG) for traceability. Deployment of BORCAL-LW capability has been performed under ARM program ECO-00781, "Establish Pyrgeometer Calibrations Traceable to the WISG". The stated purpose of the ECO is to adopt the consensus WISG for calibrating pyrgeometers used by ARM for broadband longwave irradiance data collected from SIRS, SKYRAD, and GNDRAD instrument platforms. This poster presents the development, implementation, and operation of the LW-BORCAL system at the SGP RCF for the calibration of pyrgeometers that provide traceability to WISG.

Longwave Calibration Process

Documentation of the longwave and shortwave BORCAL processes conducted at SGP can be found here: http://www.nrel.gov/docs/fy15osti/65035.pdf

In summary, this is the process for longwave BORCAL (BORCAL-LW) calibrations:

- At the beginning of the season, the SGP RCF operator (Craig Webb) will send in the multimeters, temp/RH probe, reference (2) and measurement assurance standard (1) pyrgeometers to NREL for calibration.
    - The meters and temp/RH probe are calibrated and returned within a couple weeks.
    - The pyrgeometers are included in NREL's BORCAL-LW and returned to the SGP RCF operator for use in the next year's calibration events.
- The SGP RCF operator sets up the test instruments (up to 11), reference standards (2), control (1) and measurement assurance standard (1) on 5 trackers with 15 total positions.
- The SGP RCF operator configures the Radiometer Calibration and Characterization (RCC)‡ software to accommodate the instruments being calibrated and all associated information.
- The SGP RCF operator sends a layout of the instrument positions on the trackers to the SRRL ARM mentor.

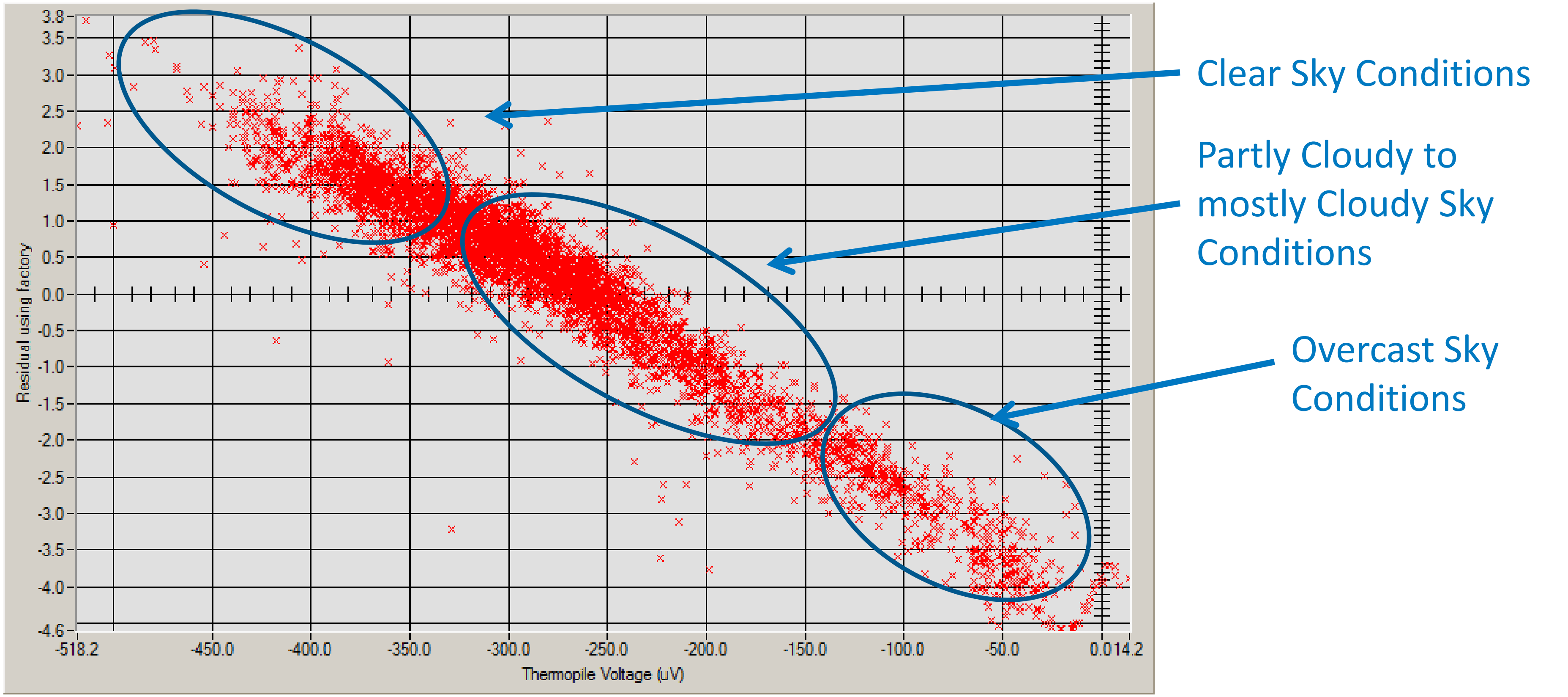
‡ http://www.nrel.gov/docs/fy16osti/65844.pdf

Longwave Calibration Process (cont.)

- The SRRL ARM mentor (Mike Dooraghi or Mark Kutchenreiter) creates a "Parameters for Reference Instruments" sheet which includes all reference instrument information.
- The SRRL ARM mentor then verifies the configuration as entered by the SGP RCF operator.
- The SRRL ARM mentor gives the SGP RCF operator the "go ahead" to start taking measurements.
- Measurements for the BORCAL-LW are taken at night and are done so through an automated process.
- The SRRL ARM periodically checks the data to determine if enough data under the correct conditions have been collected.
- Once enough data has been collected, the SRRL ARM mentor notifies the SGP RCF operator to cease data collection.
- The SRRL ARM mentor reviews the data and RCC generated report.
- Stickers are mailed to the SGP RCF operator for application to the instruments.
- Calibration results and report are uploaded to the AIM database.

When has enough Data Been Collected?

- LW calibration data are collected at night only.
- Data is collected under all sky conditions.
- The voltage output of the pyrgeometer is the least under overcast skies and most under clear sky conditions. By capturing all conditions we can calibrate the instrument under its full output range.
- The PIR measures net radiation of the thermopile to the sky; under clear skies this is greatest.



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Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Downwelling Pyrgeometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PIR	**Serial Number:**	36368F3
Calibration Date:	3/17/2016	**Due Date:**	3/17/2017
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	2/10-29, 3/1-17		

Customer and Pyrgeometer Information

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the World Infrared Standard Group (WISG).

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/30/2015	04/15/2016
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	06/19/2015	06/19/2017
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	06/19/2015	06/19/2017

‡ Through the World Infrared Standard Group (WISG)

Traceability

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL-LW Calibration Procedure

Setup: Radiometers are calibrated outdoors, using the atmosphere as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.

Calibrated by: Mike Dooraghi and Craig Webb

Description of procedure

Michael Dooraghi, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Mike.Dooraghi@nrel.gov; 303-384-6329; 15013 Denver West Parkway, Golden, CO 80401, USA

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Calibration Results
30133F3 Eppley PIR

The incoming irradiance (Win) of the test instrument during calibration is calculated using this Measurement Equation:

$$Win = K0 + K1*V + K2*Wr + K3*(Wd - Wr) \quad [1]$$

where,

- $K0, K1, K2, K3$ = calibration coefficeints,
- V = thermopile output voltage (µV),
- $Wd = \sigma * Td^4$ = dome irradiance (W/m²),
  - where, Td = dome temperature (K),
- $Wr = \sigma * Tr^4$ = receiver irradiance (W/m²),
  - where, σ = 5.6704e-8 W·m-2·K-4,
  - $Tr = Tc + Kr * V$ = receiver temperature (K),
  - Tc = case temperature (K),
  - Kr = efficiency coefficient (K/µV).

Measurement equation used to determine irradiance.

Figure 1. Residuals for calc. vs ref. irradiance using K0<>0 Coefficients

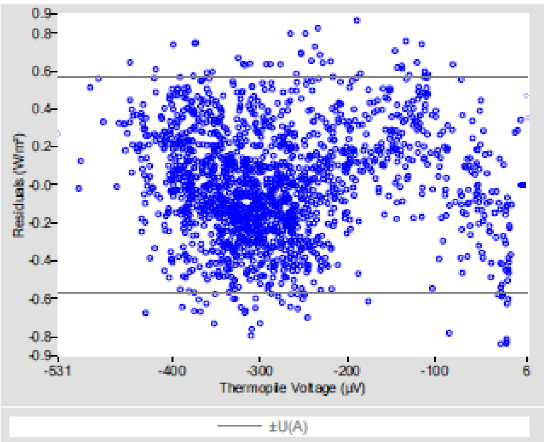
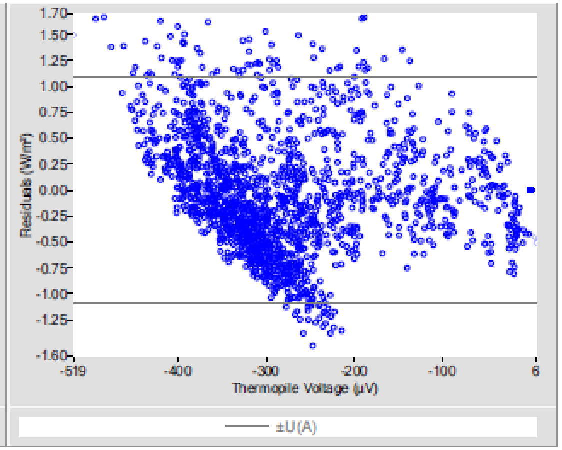


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients



Difference between calculated longwave irradiance using calibration coefficients for K<>0 and reference Irradiance on left and the same using calibration coefficients for K = 0 on the right.

Table 2. Calibration Coefficients for K0<>0

K0	-6.5798
K1	0.24655
K2	1.0181
K3	-3.3464
Kr used to derive coefficients	0.00070440

Table 3. Calibration Coefficients for K0=0

K0	0
K1	0.24793
K2	1.0012
K3	-2.8841
Kr used to derive coefficients	0.00070440

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.14
Type-A Standard Uncertainty, u(A) (W/m²)	±0.29
Combined Standard Uncertainty, u(c) (W/m²)	±1.18
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.31

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.14
Type-A Standard Uncertainty, u(A) (W/m²)	±0.56
Combined Standard Uncertainty, u(c) (W/m²)	±1.27
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.49

Calibration coefficients and uncertainties for K<>0 on left and for K = 0 on the right.

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Figure 3. History of instrument (K0 Coefficient)

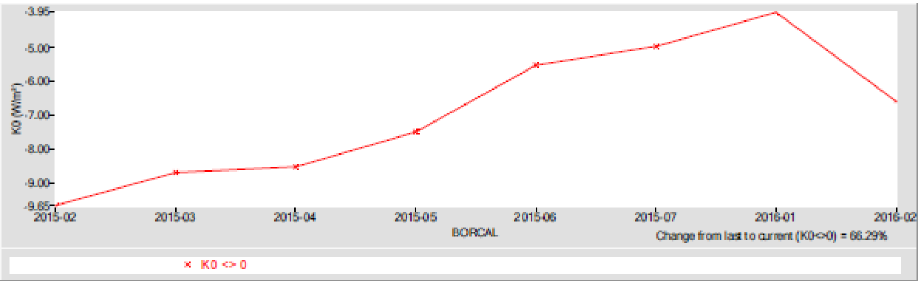


Figure 4. History of instrument (K1 Coefficient)

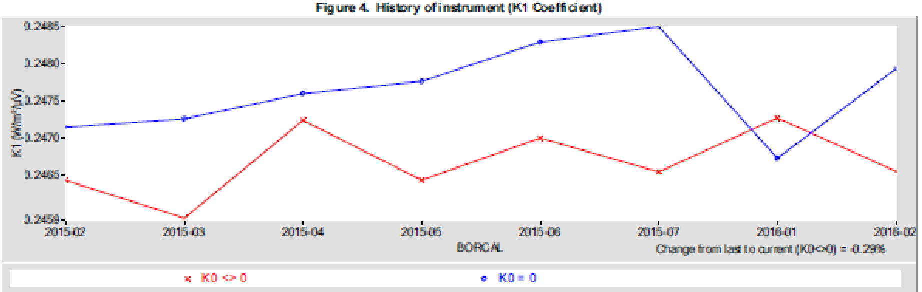


Figure 5. History of instrument (K2 Coefficient)

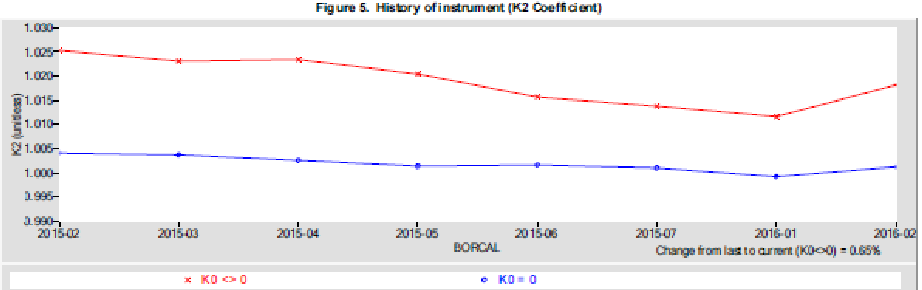
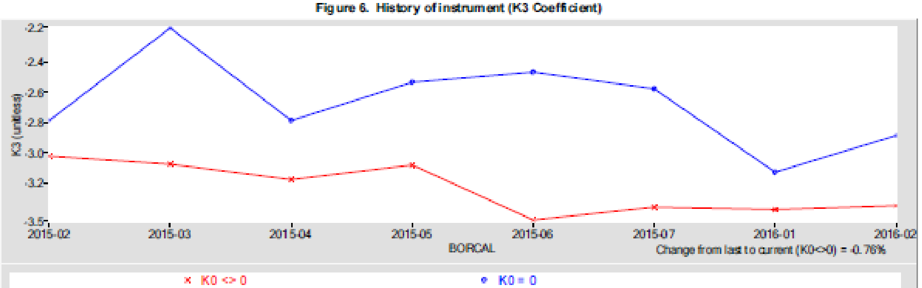


Figure 6. History of instrument (K3 Coefficient)



K0

K1

K2

K3

References:

[1] Reda, I.; Stoffel, T. (2010). Pyrgeometer Calibration for DOE-Atmospheric System Research Program using NREL Method (Presentation). 9 pp.; NREL Report No. PR-3B0-47756; http://www.nrel.gov/docs/fy10osti/47756.pdf.

- Historical record of calibration coefficient results from BORCAL to BORCAL
- We are establishing allowable limits for the deviation of these 4 coefficients.
- Most instruments that have been calibrated recently and have only one value for each calibration coefficient.
- The control and measurement assurance standard have been in each of the 8 calibrations so far and thus have 8 results each.
- The values shown on the left are for the measurement assurance standard instrument 30133F3.
- The red line represents the traceable coefficient results and the blue line represents coefficient results obtained when forcing the intercept through 0

Control and Measurement Assurance Standard

- Results are from 8 LW BORCAL events for the control instrument (36368F3) and the Measurement Assurance Standard (30133F3) are shown below.
- Yearly calibrations are currently scheduled for the first 2-3 years to allow for enough collection of data to determine what are acceptable levels for the K0, K1, K2, and K3.
- It is preferable to have ~21 samples to establish a significantly acceptable level for each K value. This will better allow us to evaluate what is an acceptable change from a previous BORCAL or what may be suspect.

Control and Measurement Assurance Standard Calibration Coefficient History

Figure 1. Eppley PIR Control Instrument History (K0 Coefficient)

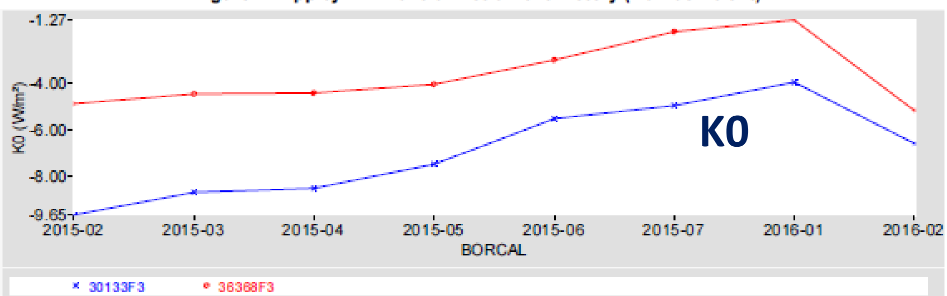


Figure 2. Eppley PIR Control Instrument History (K1 Coefficient)

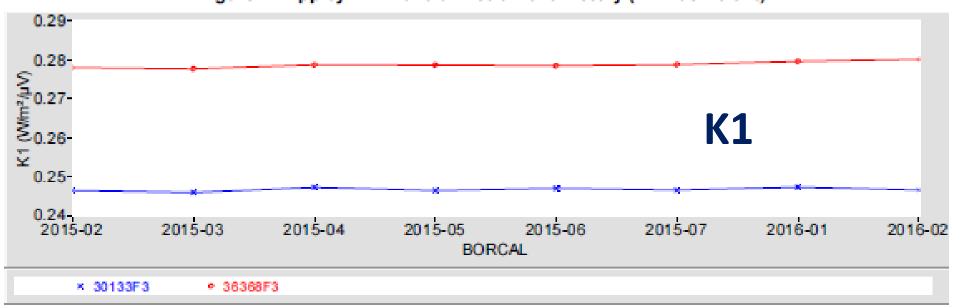


Figure 3. Eppley PIR Control Instrument History (K2 Coefficient)

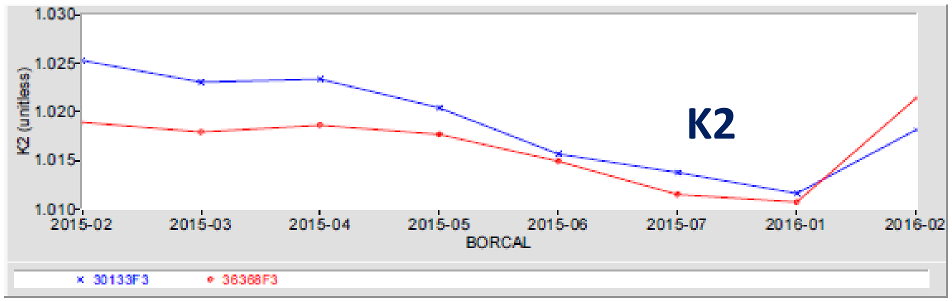
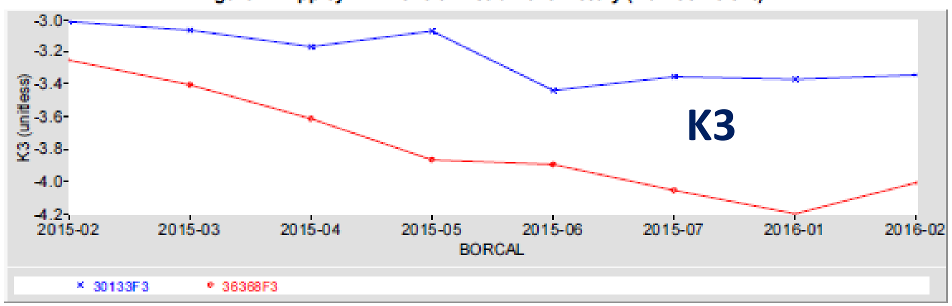
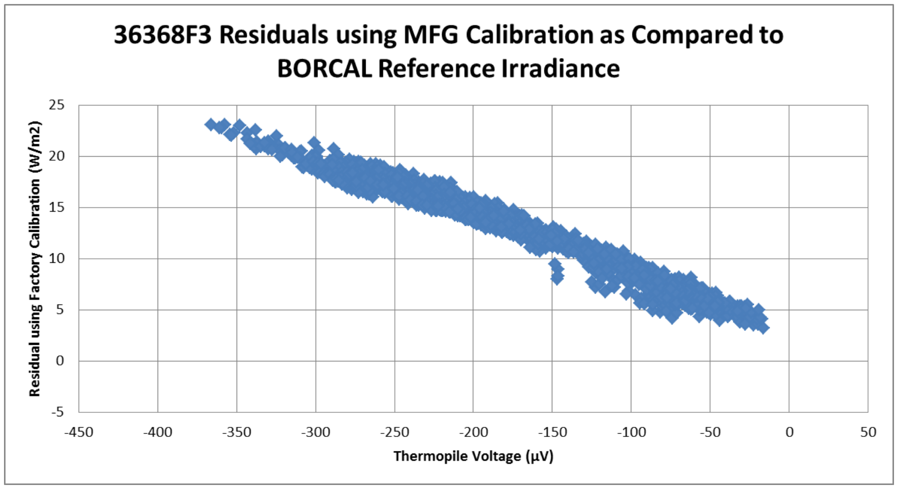


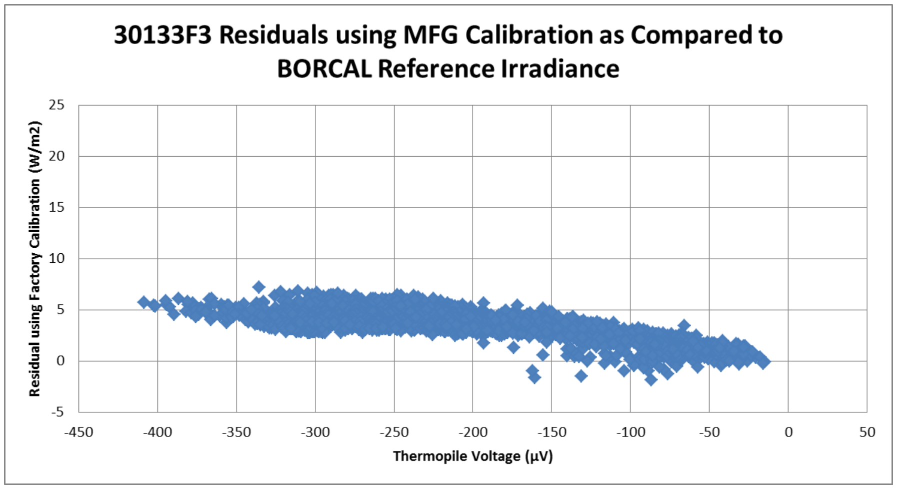
Figure 4. Eppley PIR Control Instrument History (K3 Coefficient)

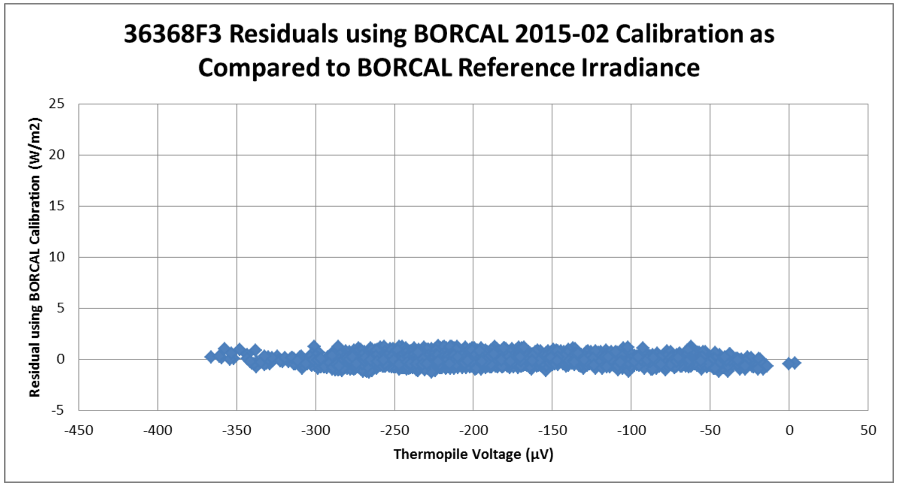


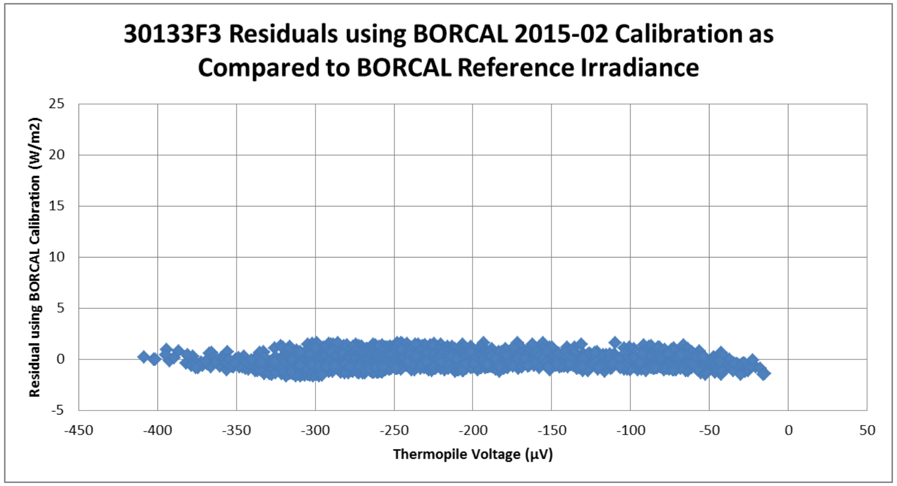
Calibration Residuals as Compared to the Reference

- The residual in W/m^2 as compared to the reference instruments ranges from **3.2 to 23.1** for the control instrument (36368F3) and from **-1.8 to 7.2** for the measurement assurance standard (30133F3) when using the manufacturer's calibration.
- The residual in W/m^2 as compared to the reference instruments ranges from **-1.3 to 1.3** for the control instrument (36368F3) and from **-1.6 to 1.6** for the measurement assurance standard (30133F3) when using the BORCAL-LW calibration.









Metrics

All Metrics are for LW calibrations from July 2015 to March 2016.

- Total number of Instruments calibrated: 92
- Total individual Instruments calibrated : 81
- Total number of failed calibrations: 8 (Most of these were later linked to a failed channel)
- Average Uncertainty: ± 2.31 W/m2
- Highest Uncertainty: ± 2.59 W/m2
- Lowest Uncertainty: ± 2.26 W/m2
- Average number successful calibrations per session: 11.75
- Average length of time for BORCAL-LW to complete: 30.6 days
- Shortest BORCAL-LW event: 17 days
- Longest BORCAL-LW event: 44 days
- Current range of K0 values for all successfully calibrated instruments: -9.6467 to 4.0452
- Current range of K1 values for all successfully calibrated instruments : 0.2152 to 0.34601
- Current range of K2 values for all successfully calibrated instruments : 0.9929   to 1.0253
- Current range of K3 values for all successfully calibrated instruments : -5.1028 to 0.00087