Broadband Outdoor Radiometer Calibration
Longwave

BORCAL-LW
2018-04

Calibration Facility

Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Calibration date

06/06/2018 to 08/10/2018

Report Date

August 10, 2018

NOTICE

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Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

This report compiles the calibration results from a Broadband Outdoor Radiometer Calibration (BORCAL). The work was accomplished at the Radiometer Calibration Facility shown on the front of this report. The calibration results reported here are traceable to the World Infrared Standard Group (WISG).

This report includes these sections:

- Control Instruments - a group of instruments included in each BORCAL event that provides a measure of process consistency.
- Results Summary - a table of all instruments included in this report summarizing their calibration results and uncertainty.
- Instrument Details - the calibration certificates and application notes for each instrument.
- Environmental and Sky Conditions - meteorological conditions and reference irradiance during the calibration event.

Control Instrument History

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

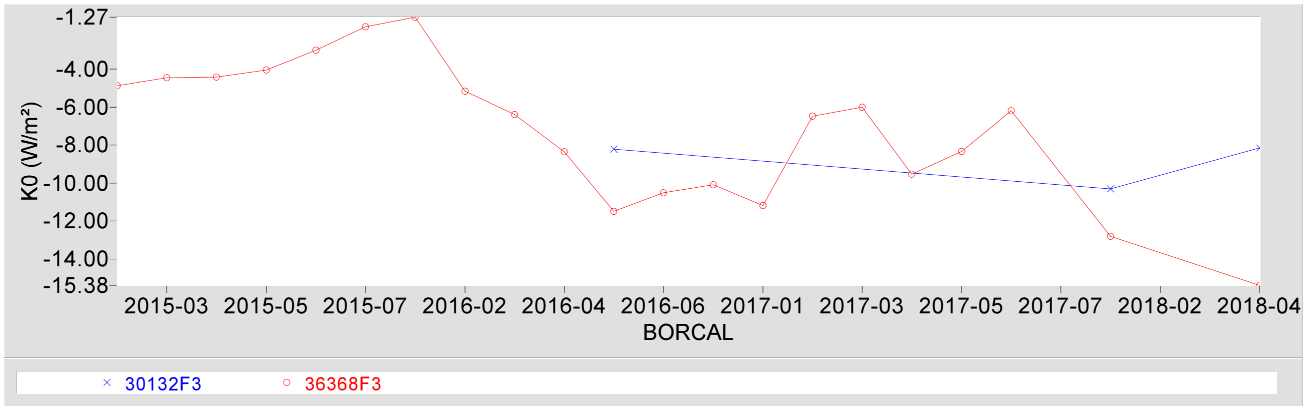


Figure 2. Eppley PIR Control Instrument History (K1 Coefficient)

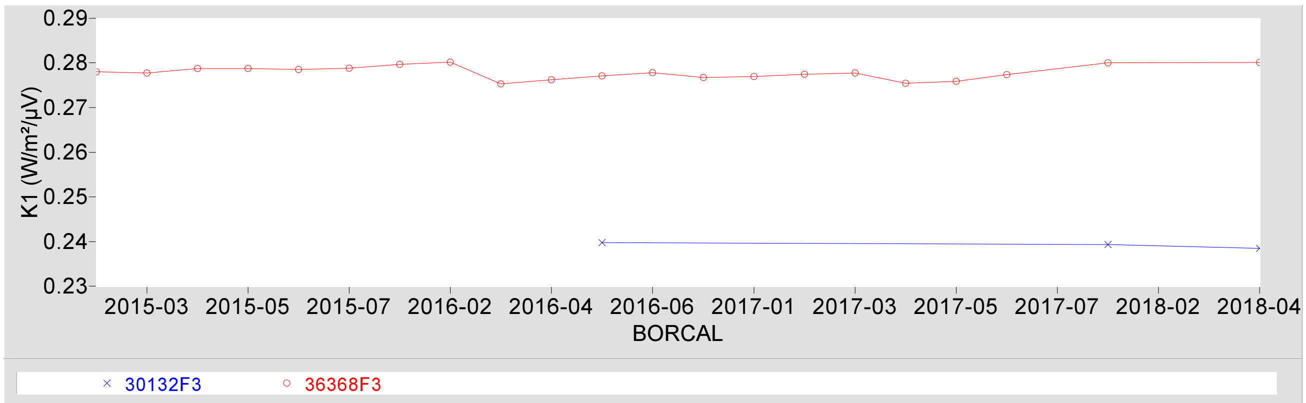


Figure 3. Eppley PIR Control Instrument History (K2 Coefficient)

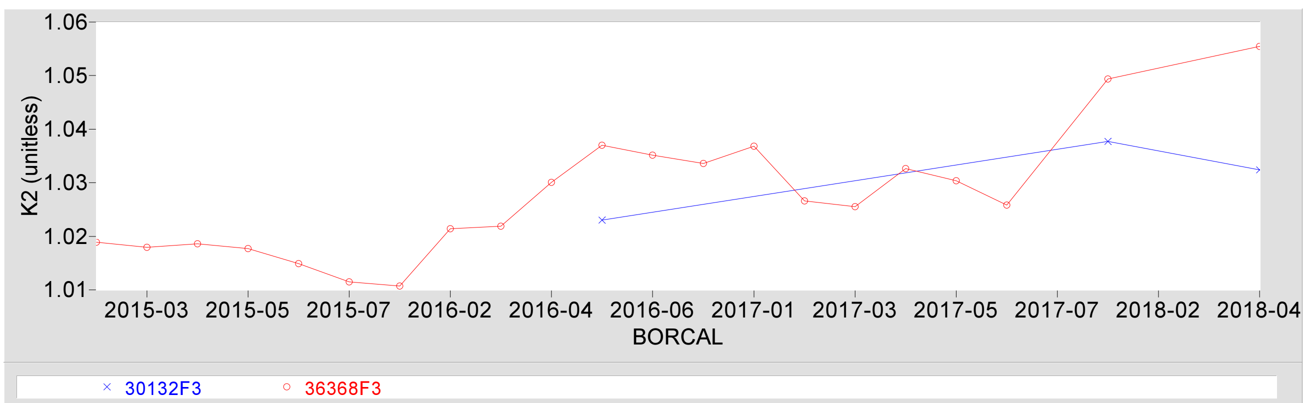
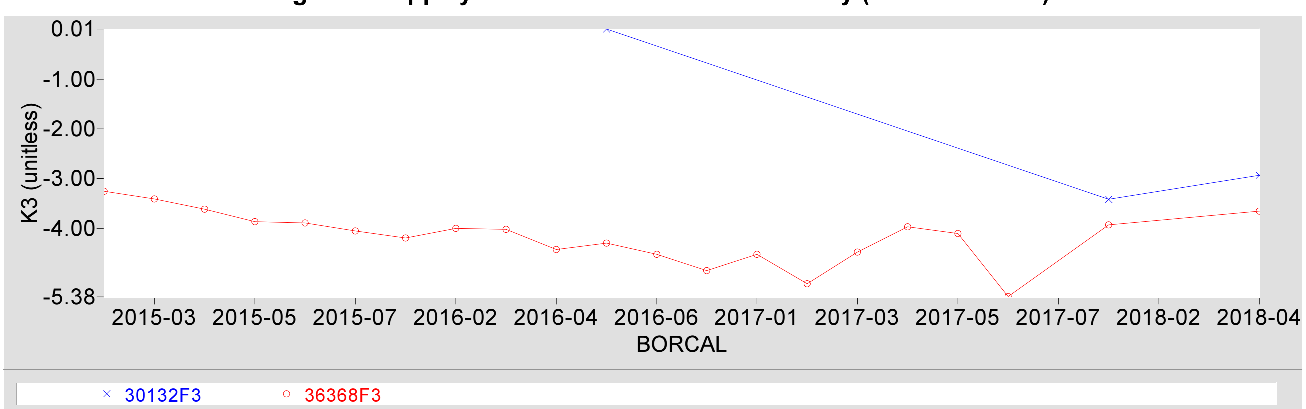


Figure 4. Eppley PIR Control Instrument History (K3 Coefficient)



Results Summary

Table 1. Results Summary

Instrument	Customer	K0 (W/m²)	K1 (W/m²/μV)	K2	K3	Kr * (K/μV)	U95 (W/m²)	Page
29146F3	SGP	-7.9	0.25460	1.0369	-3.01	7.044e-4	±2.9	A1-2
29591F3	SGP	-12.1	0.22759	1.0402	-2.88	7.044e-4	±2.9	A1-5
30011F3	SGP	-13.6	0.27100	1.0410	-3.38	7.044e-4	±2.9	A1-8
30013F3	SGP	-16.0	0.27935	1.0467	-4.31	7.044e-4	±2.9	A1-11
30132F3	SGP	-8.2	0.23843	1.0324	-2.93	7.044e-4	±2.9	A1-14
30344F3	SGP	-11.9	0.23598	1.0406	-3.33	7.044e-4	±2.9	A1-17
30358F3	SGP	-12.9	0.23231	1.0453	-3.35	7.044e-4	±2.9	A1-20
30782F3	SGP	-7.4	0.23121	1.0322	-2.51	7.044e-4	±2.9	A1-23
30834F3	SGP	-13.7	0.25210	1.0468	-3.31	7.044e-4	±2.9	A1-26
30836F3	SGP	-9.8	0.24348	1.0344	-3.03	7.044e-4	±2.9	A1-29
36367F3	SGP	-13.1	0.31171	1.0427	1.04	7.044e-4	±3.1	A1-32
36368F3	SGP	-15.4	0.28008	1.0554	-3.65	7.044e-4	±2.9	A1-35

Note: Environmental Conditions for BORCAL starts on page A1-38.

* Kr used to derive K0,K1,K2, and K3

Appendix 1
Instrument Details

Calibration Certificates: 3 pages for each radiometer (4 including Environmental Conditions)

Environmental Conditions for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.

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:**	29146F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________ _______________

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

Calibration Results

29146F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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 = σ * *Td*^4 = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

Wr = σ * *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).

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

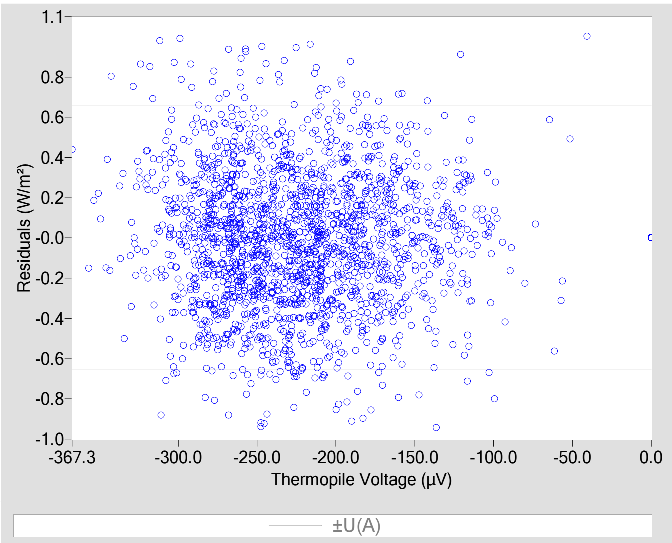


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

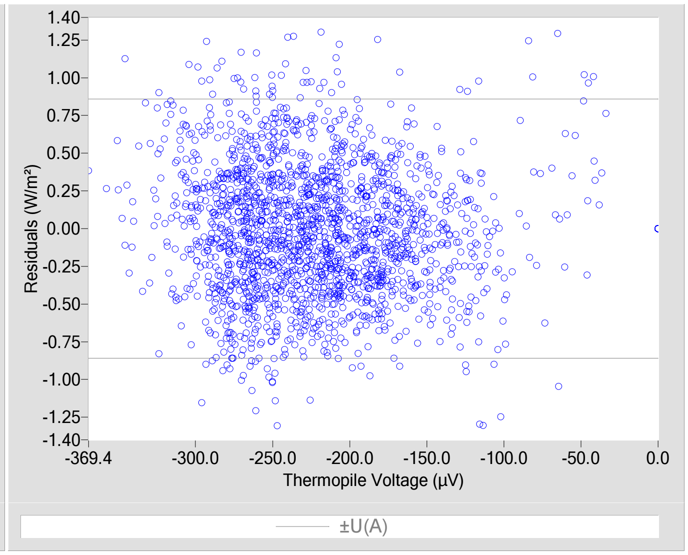


Table 2. Calibration Coefficients for K0<>0

K0	-7.9
K1	0.25460
K2	1.0369
K3	-3.01
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.25429
K2	1.0205
K3	-3.71
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.33
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.44
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Figure 3. History of instrument (K0 Coefficient)

Figure 4. History of instrument (K1 Coefficient)

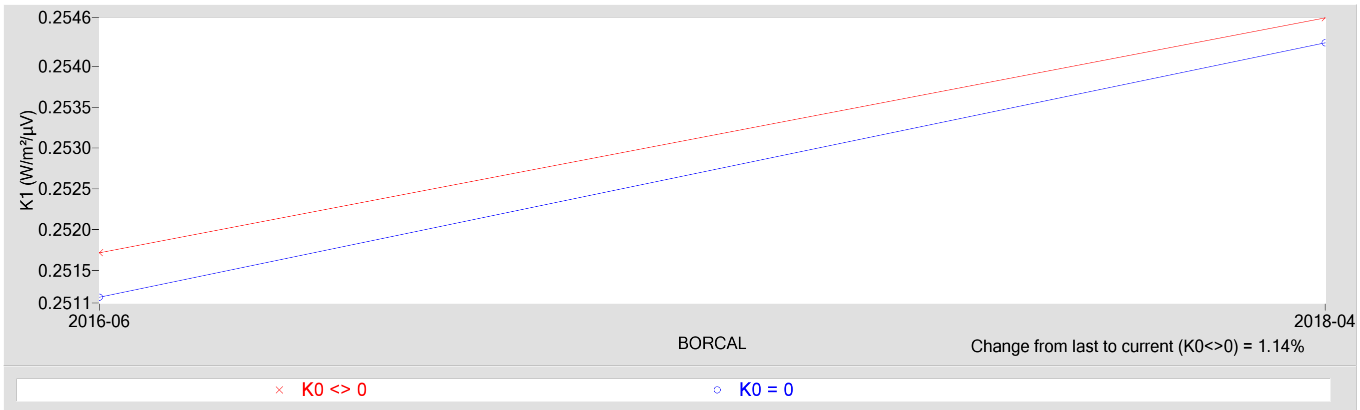


Figure 5. History of instrument (K2 Coefficient)

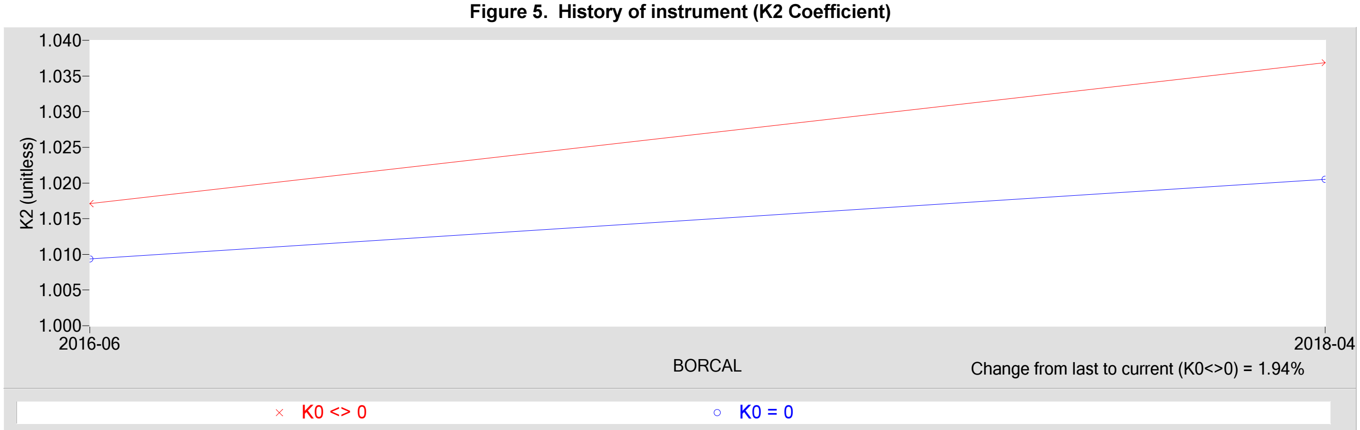
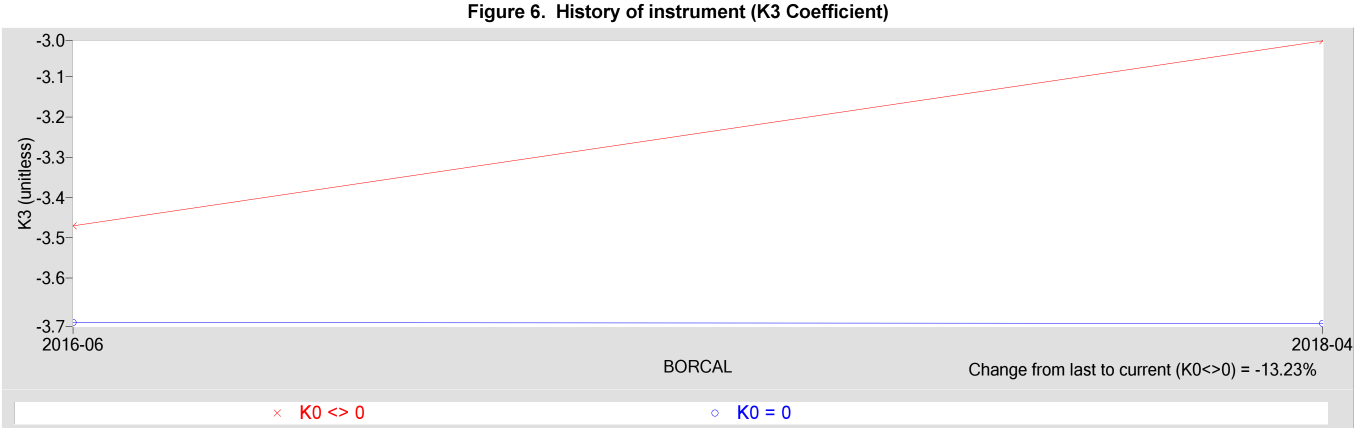


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	29591F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________ _______________

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

Calibration Results

29591F3 Eppley PIR

The incoming irradiance (Win, W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

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

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).

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

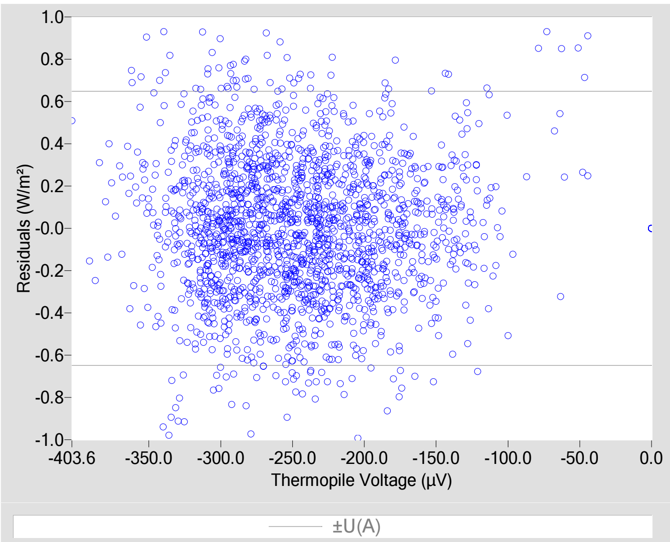


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

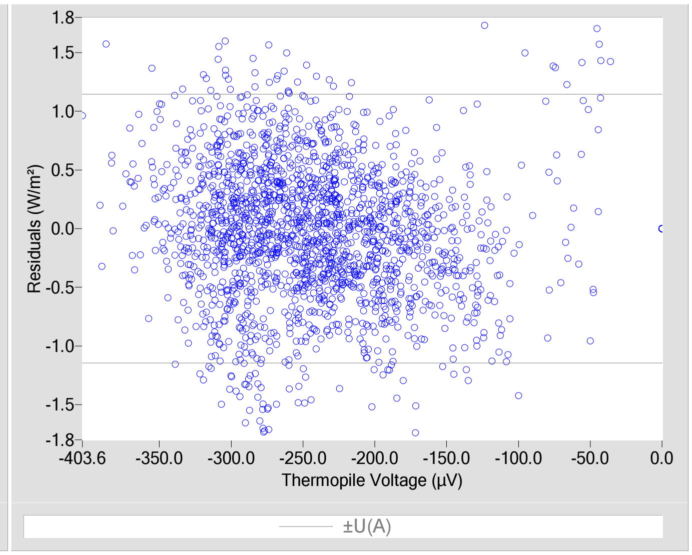


Table 2. Calibration Coefficients for K0<>0

K0	-12.1
K1	0.22759
K2	1.0402
K3	-2.88
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.22730
K2	1.0129
K3	-3.05
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.33
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.58
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.0

Figure 3. History of instrument (K0 Coefficient)

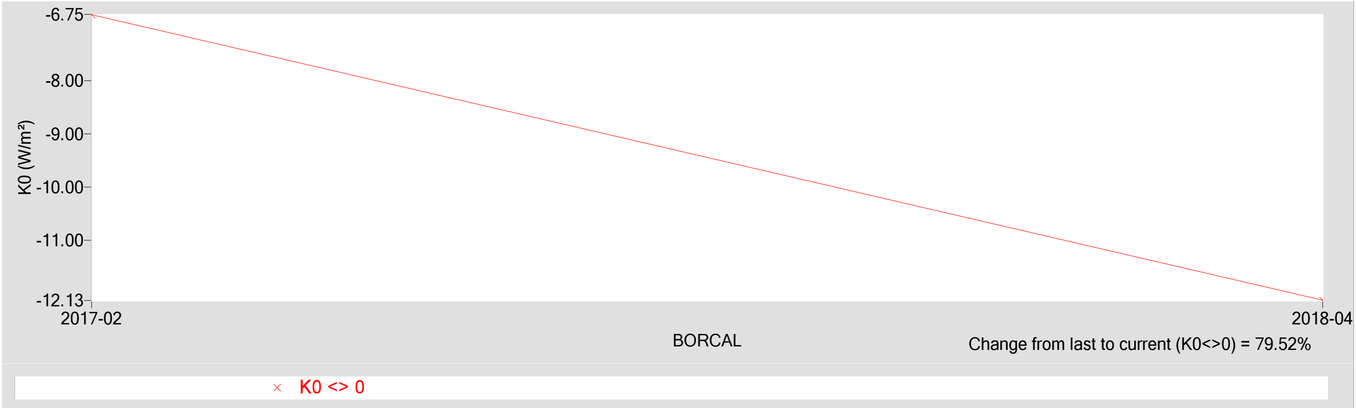


Figure 4. History of instrument (K1 Coefficient)

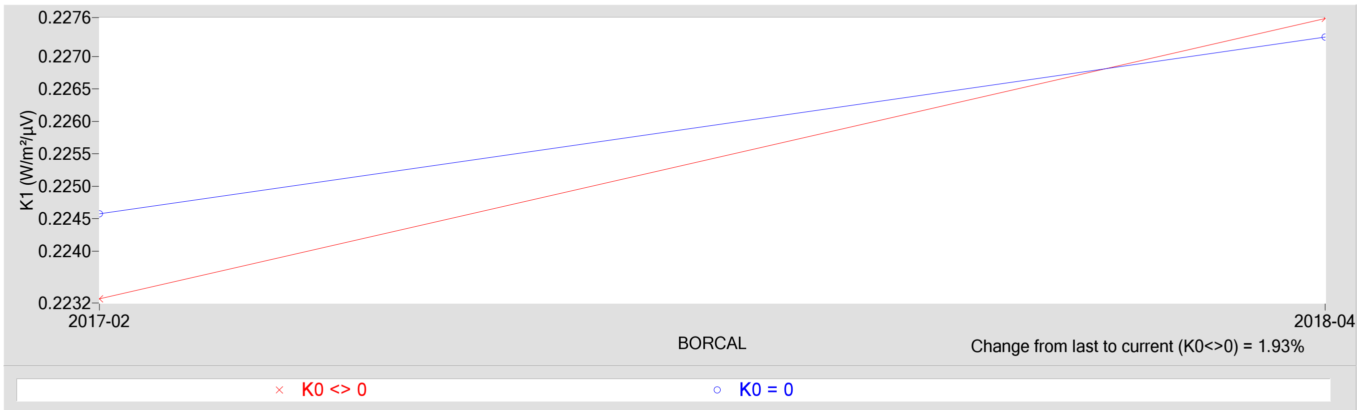


Figure 5. History of instrument (K2 Coefficient)

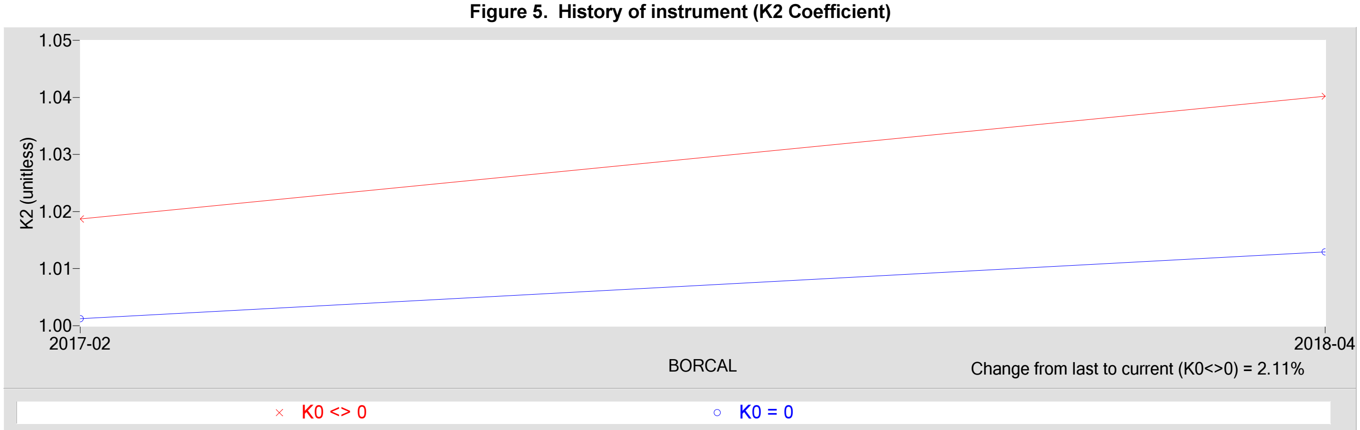
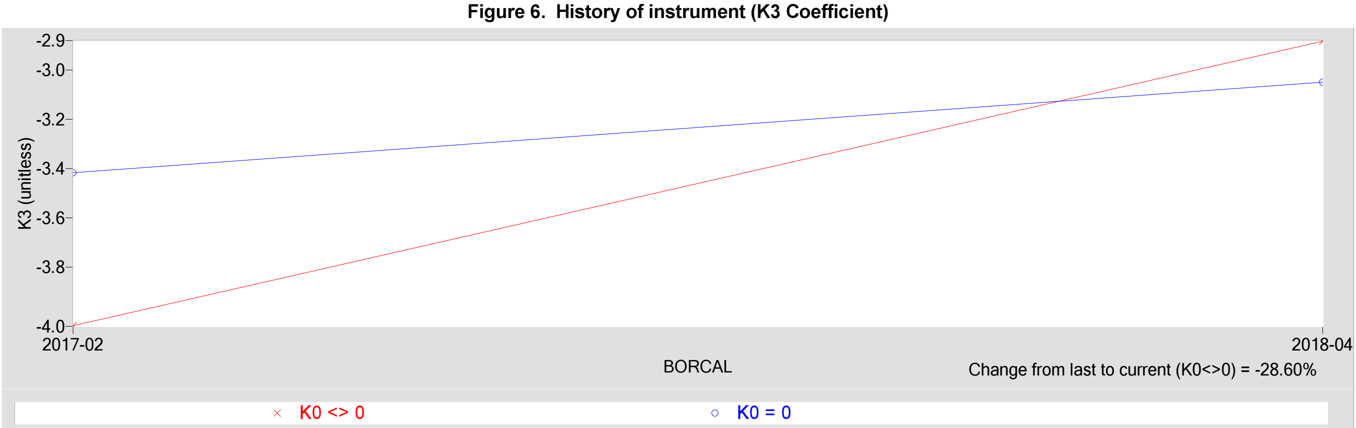


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30011F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________________ ____________________

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

Calibration Results

30011F3 Eppley PIR

The incoming irradiance (Win, W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

K0,K1,K2,K3 = calibration coefficeints,
V = thermopile output voltage (μV),
*Wd = σ * Td^4* = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

*Wr = σ * 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).

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

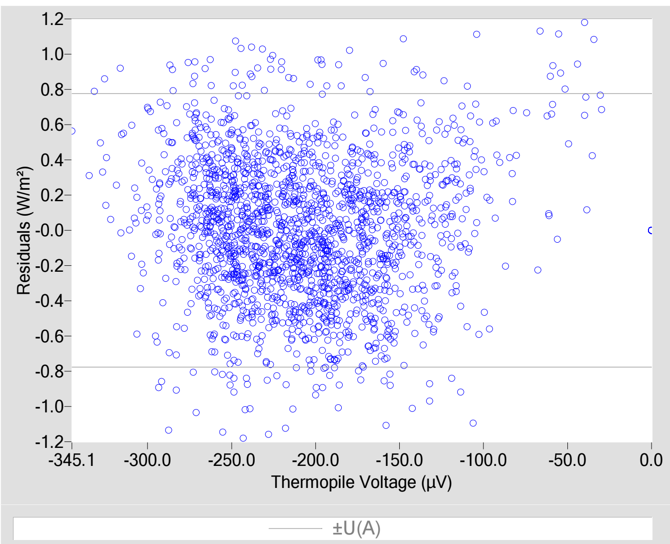


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

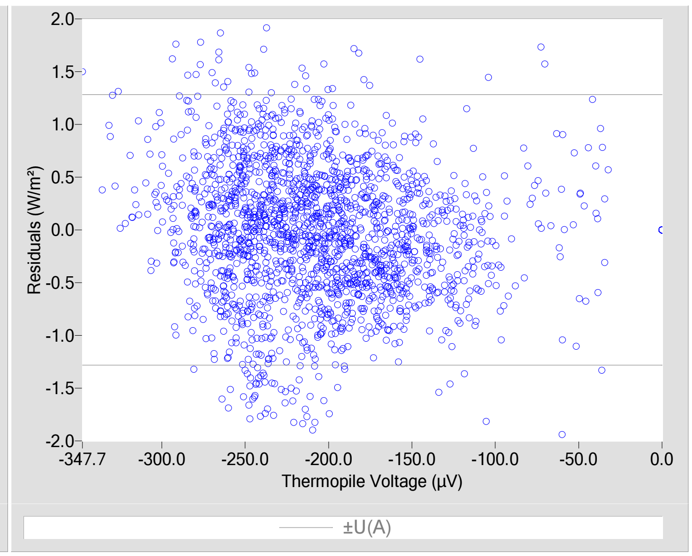


Table 2. Calibration Coefficients for K0<>0

K0	-13.6
K1	0.27100
K2	1.0410
K3	-3.38
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.27033
K2	1.0101
K3	-3.85
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.40
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.65
Combined Standard Uncertainty, u(c) (W/m²)	±1.6
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.1

Figure 3. History of instrument (K0 Coefficient)

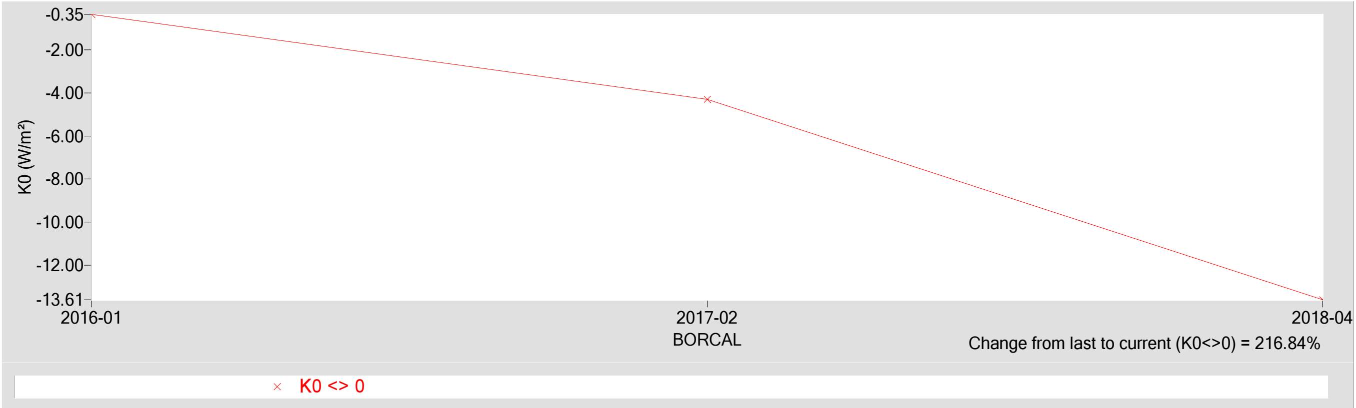


Figure 4. History of instrument (K1 Coefficient)

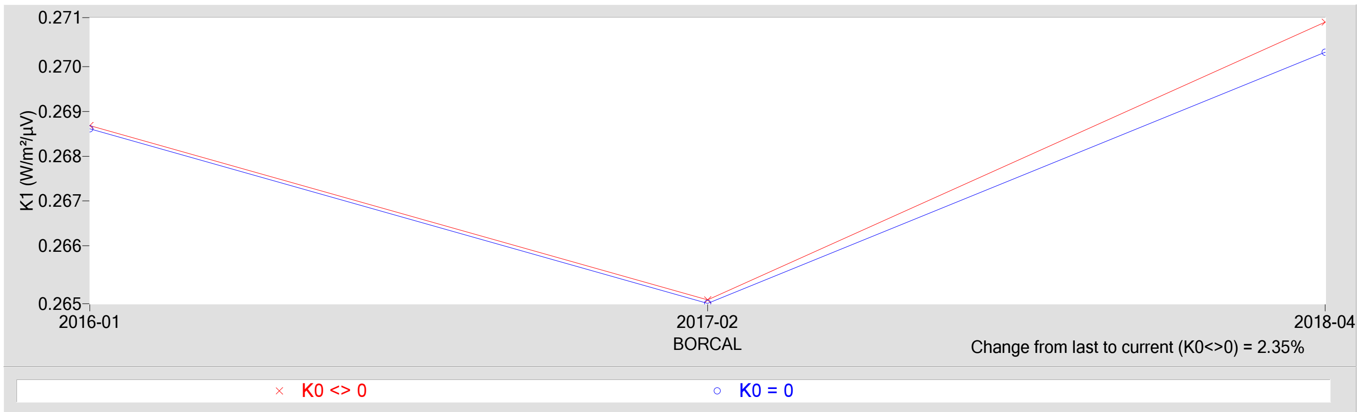


Figure 5. History of instrument (K2 Coefficient)

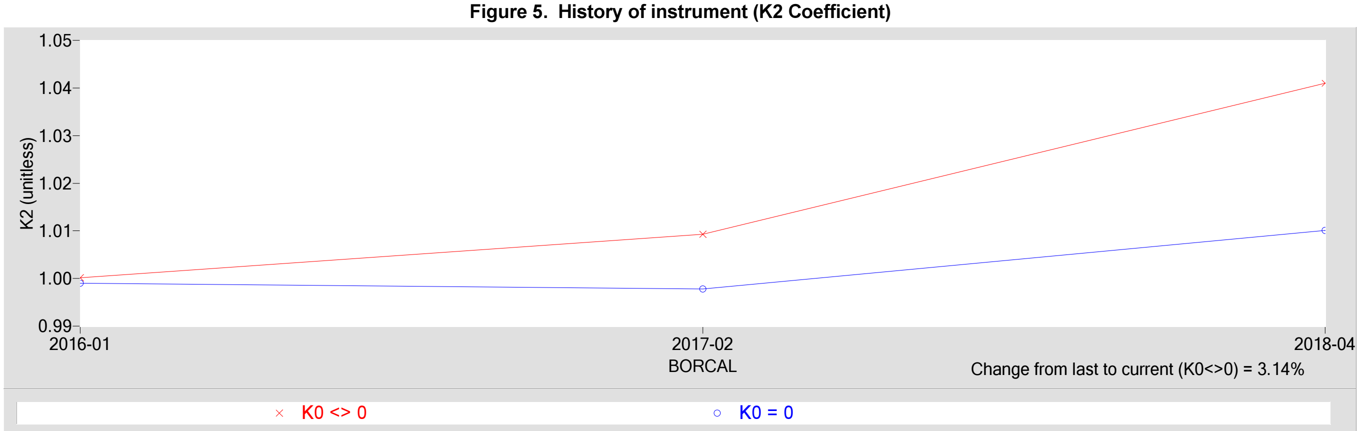
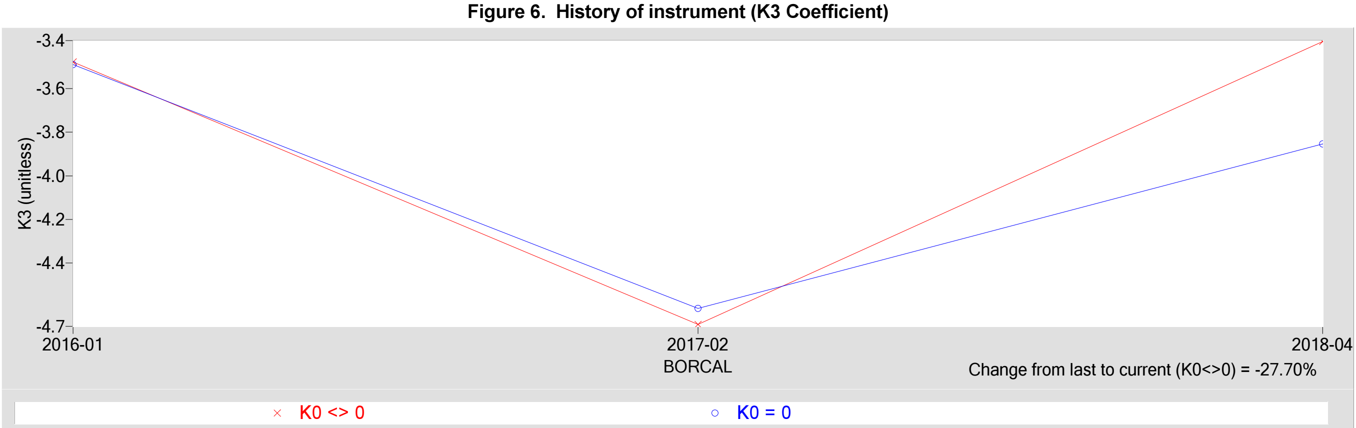


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30013F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________ _______________

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

Calibration Results

30013F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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).

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

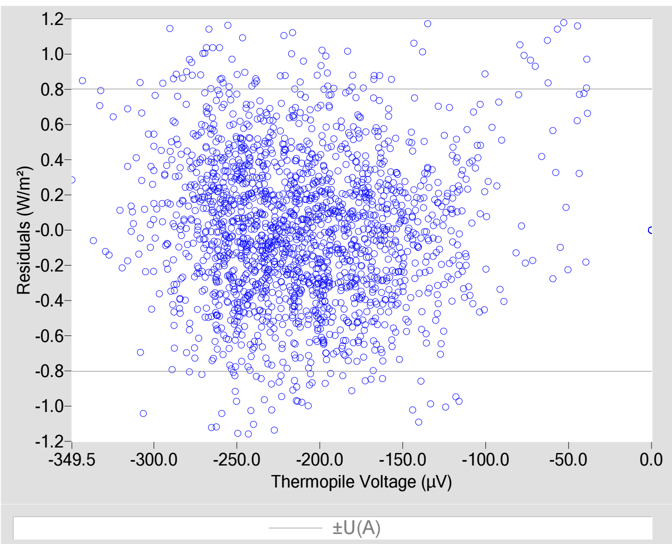


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

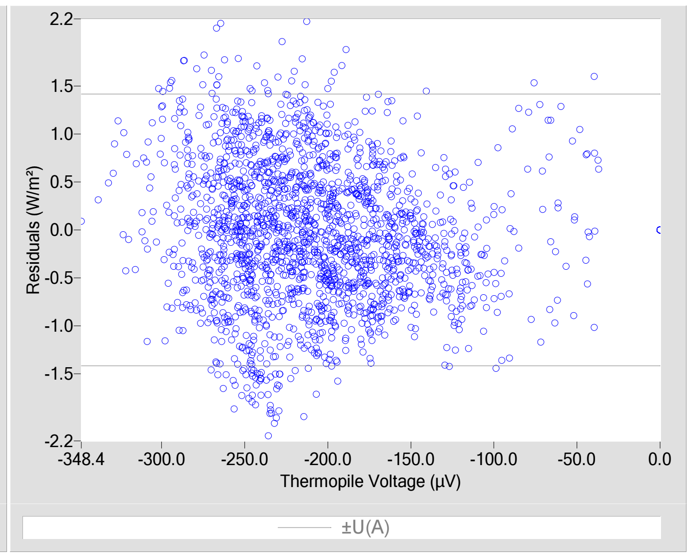


Table 2. Calibration Coefficients for K0<>0

K0	-16.0
K1	0.27935
K2	1.0467
K3	-4.31
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.27829
K2	1.0106
K3	-4.36
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.41
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.72
Combined Standard Uncertainty, u(c) (W/m²)	±1.6
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.1

Figure 3. History of instrument (K0 Coefficient)

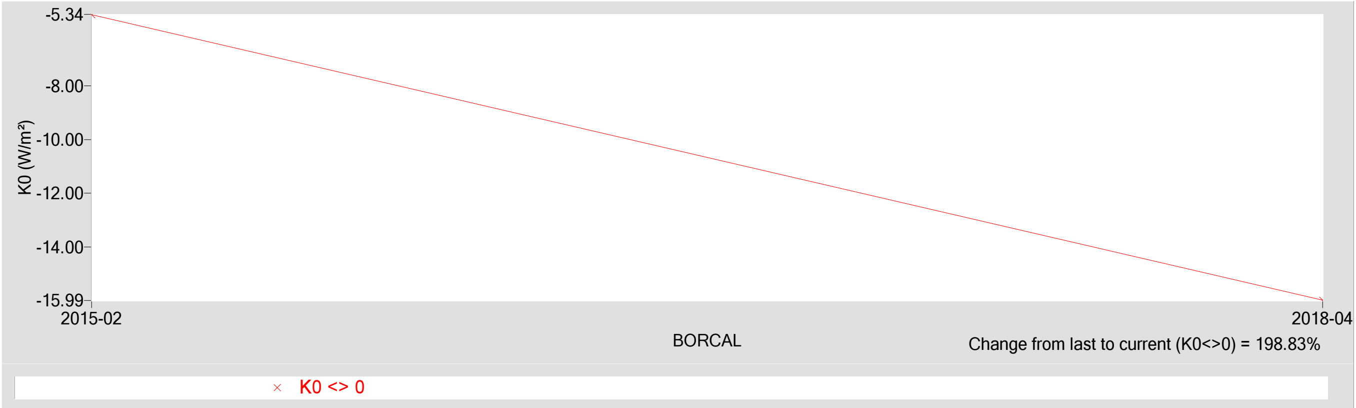


Figure 4. History of instrument (K1 Coefficient)

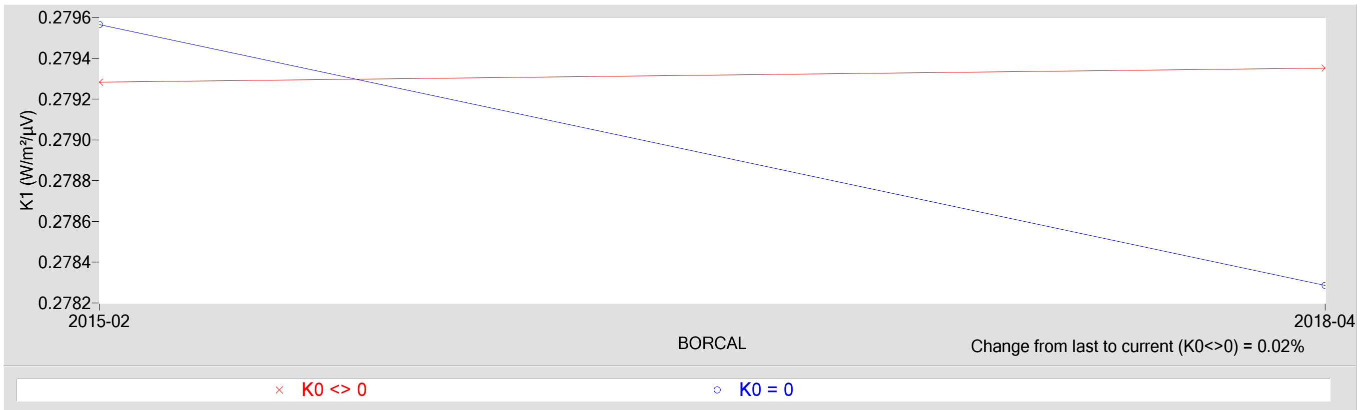


Figure 5. History of instrument (K2 Coefficient)

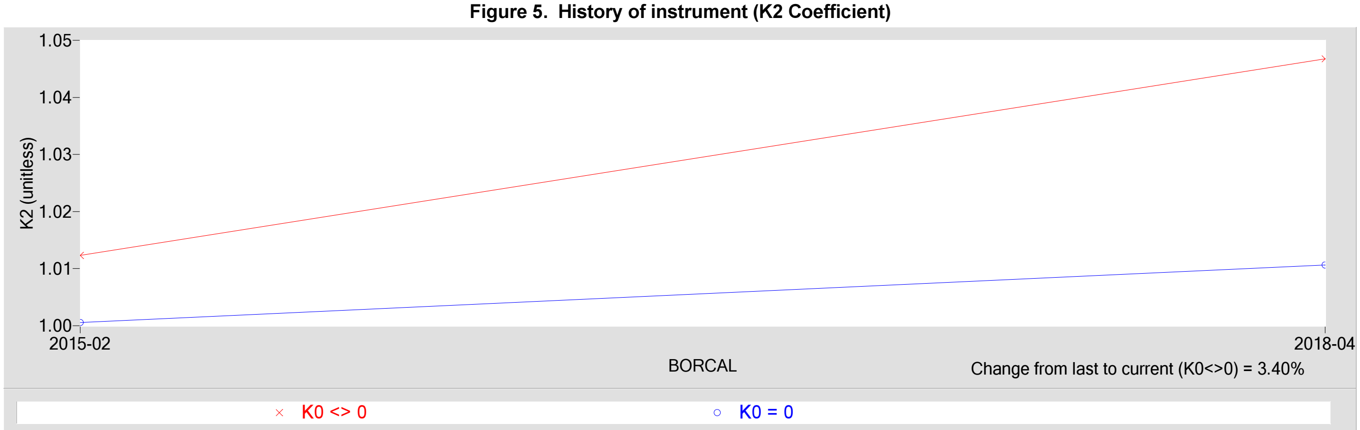
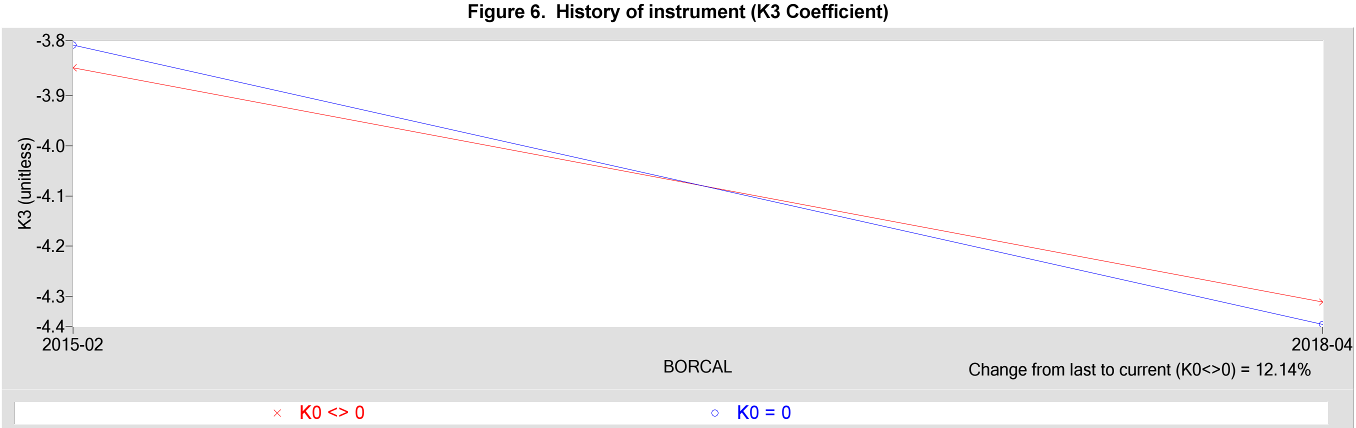


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30132F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

________________________________ ____________

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

Calibration Results

30132F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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 = σ * Td^4* = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

*Wr = σ * 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).

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

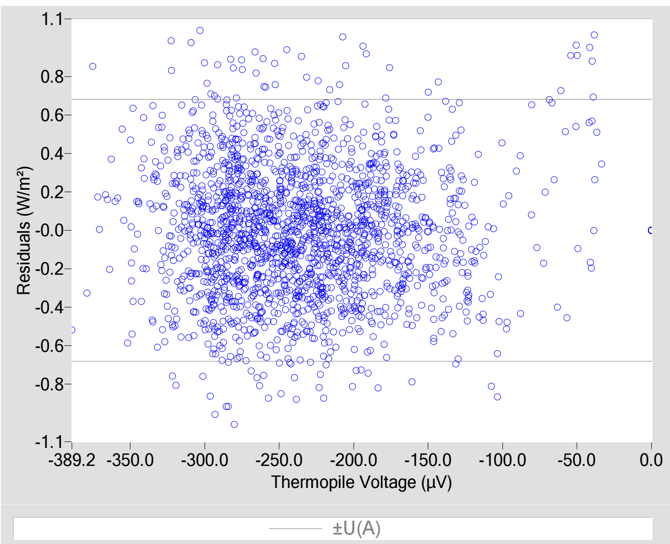


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

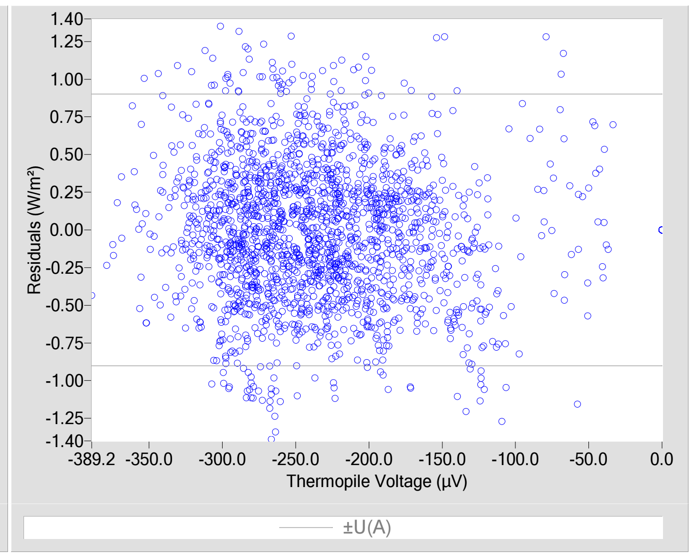


Table 2. Calibration Coefficients for K0<>0

K0	-8.2
K1	0.23843
K2	1.0324
K3	-2.93
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23761
K2	1.0141
K3	-3.38
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.35
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.46
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Figure 3. History of instrument (K0 Coefficient)

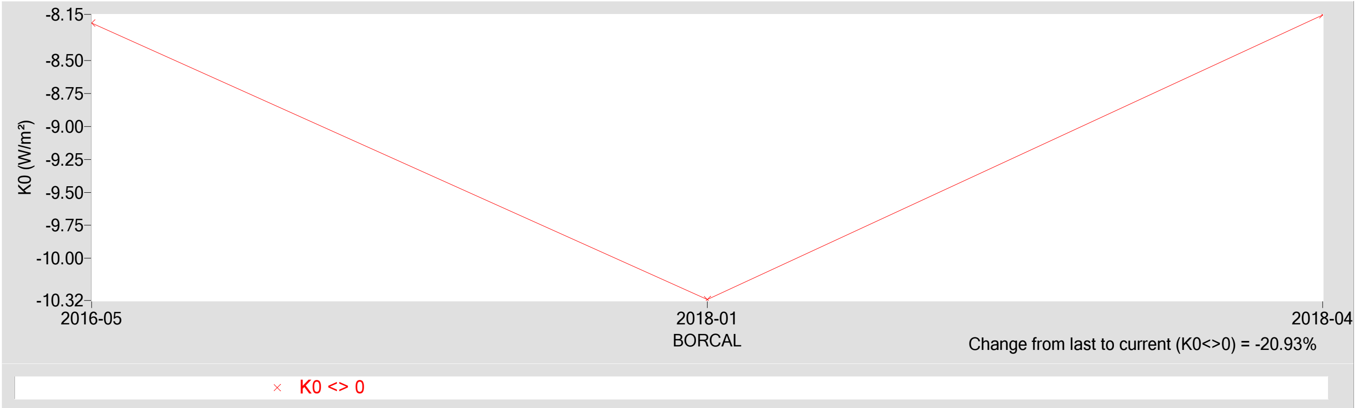


Figure 4. History of instrument (K1 Coefficient)

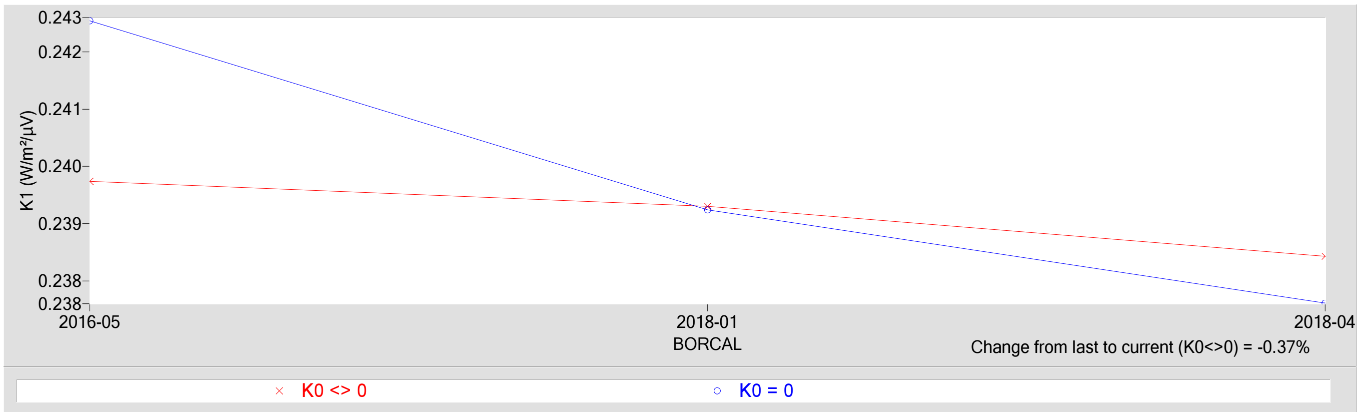


Figure 5. History of instrument (K2 Coefficient)

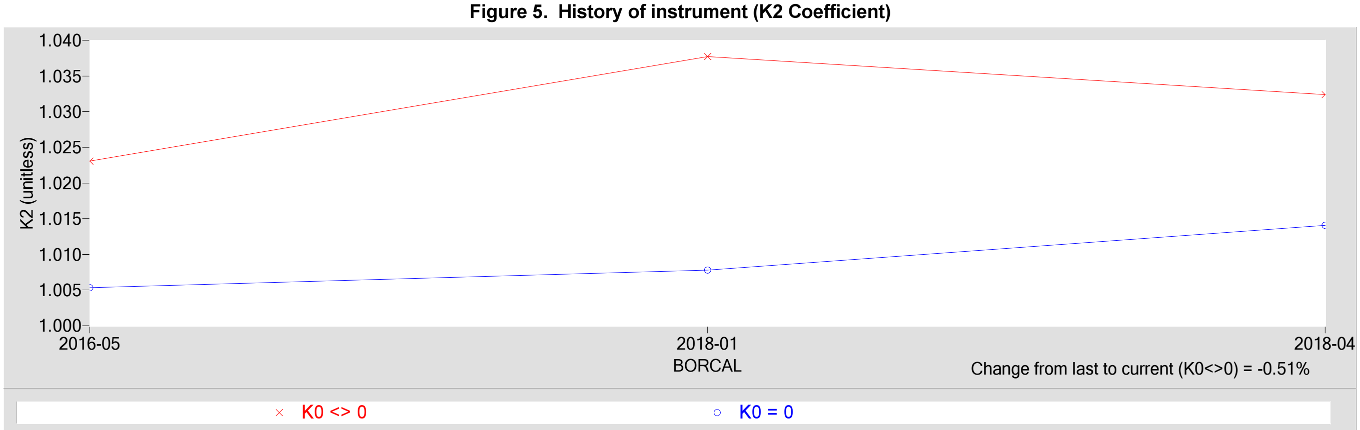
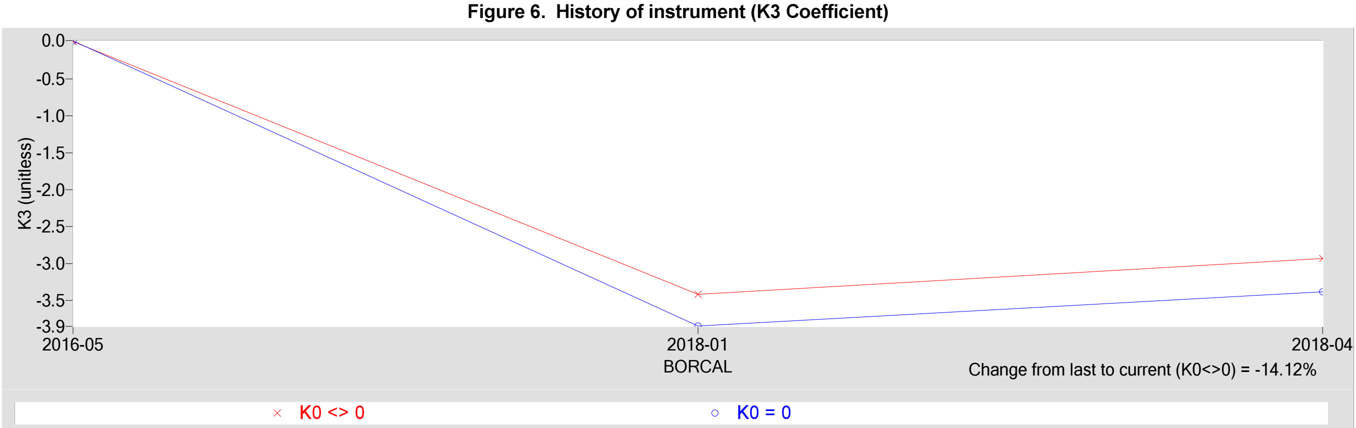


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30344F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

_______________________________ _______________

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

Calibration Results

30344F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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).

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

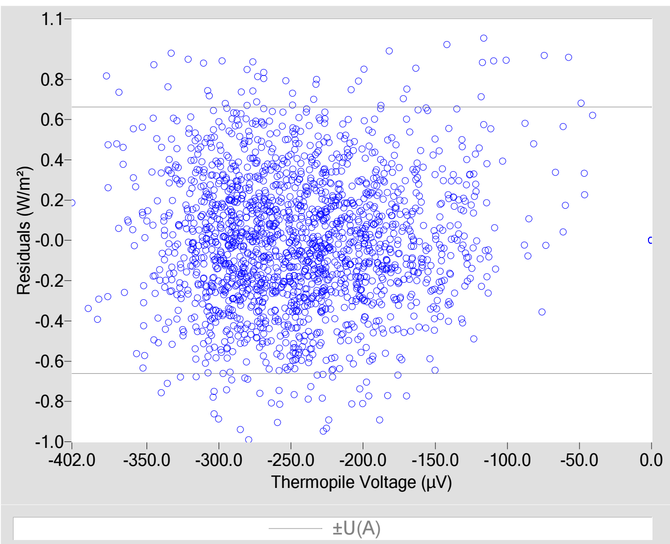


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

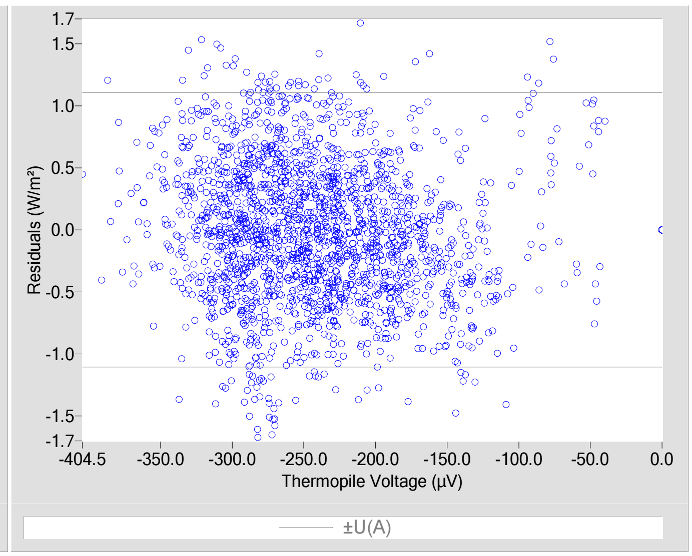


Table 2. Calibration Coefficients for K0<>0

K0	-11.9
K1	0.23598
K2	1.0406
K3	-3.33
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23550
K2	1.0140
K3	-3.70
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.34
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.56
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.0

Figure 3. History of instrument (K0 Coefficient)

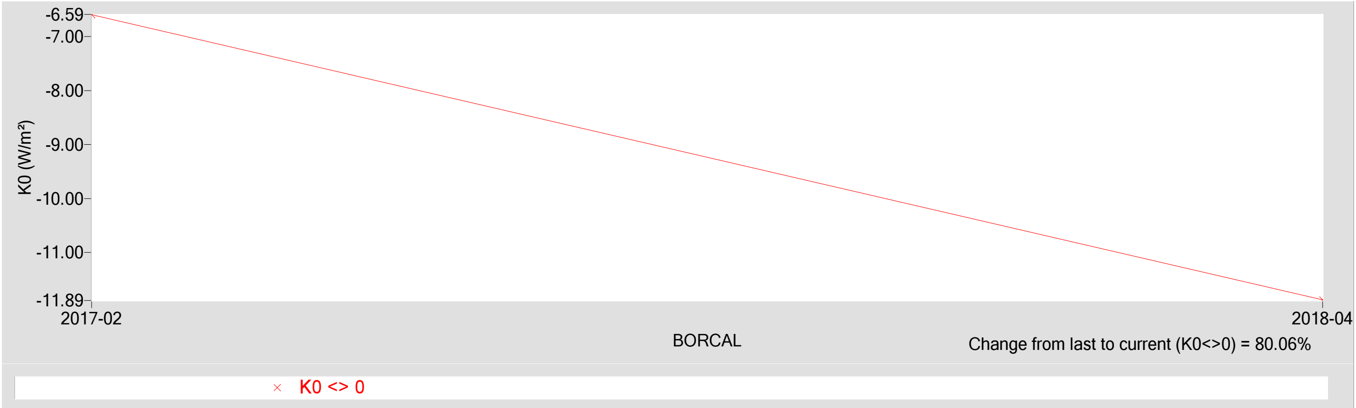


Figure 4. History of instrument (K1 Coefficient)

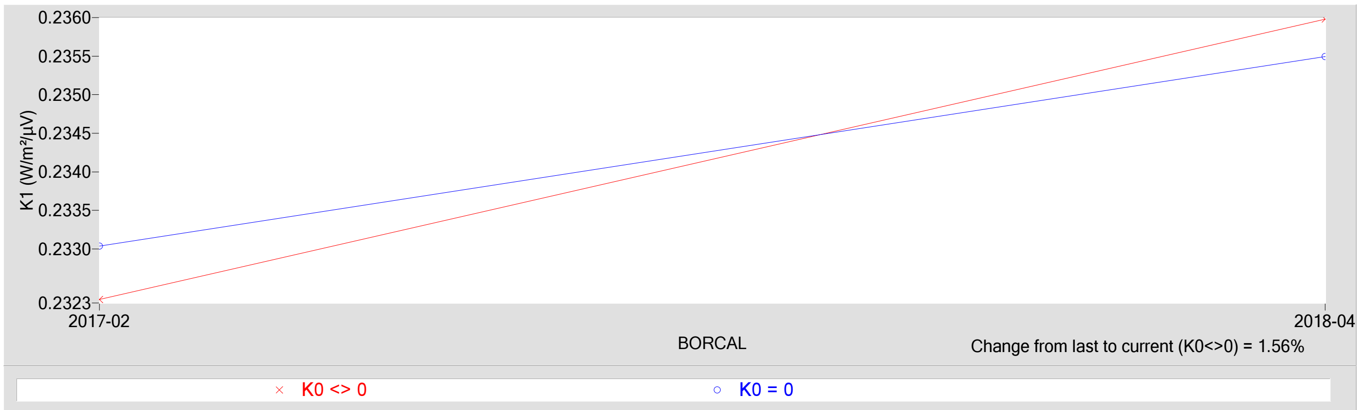


Figure 5. History of instrument (K2 Coefficient)

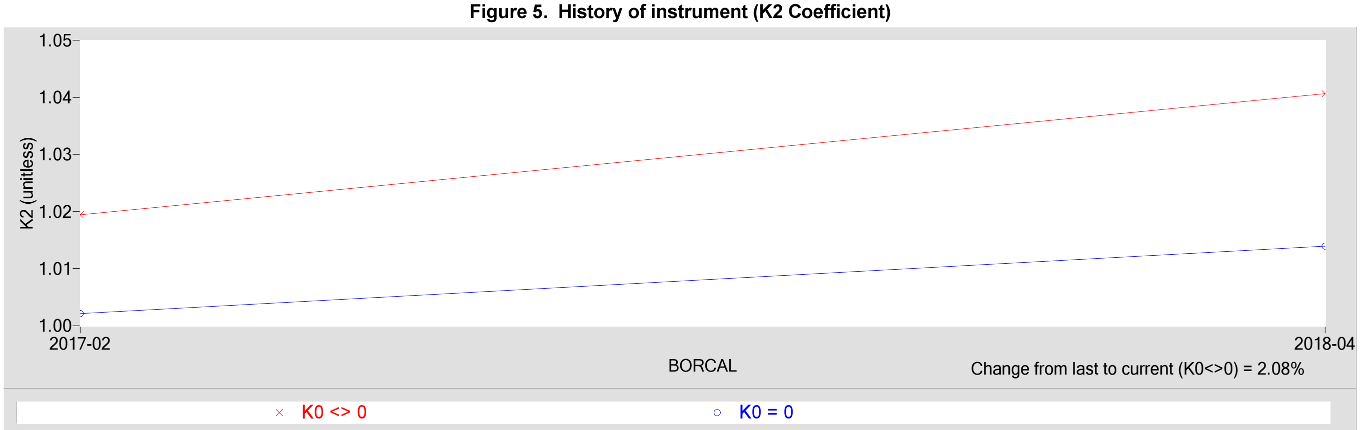
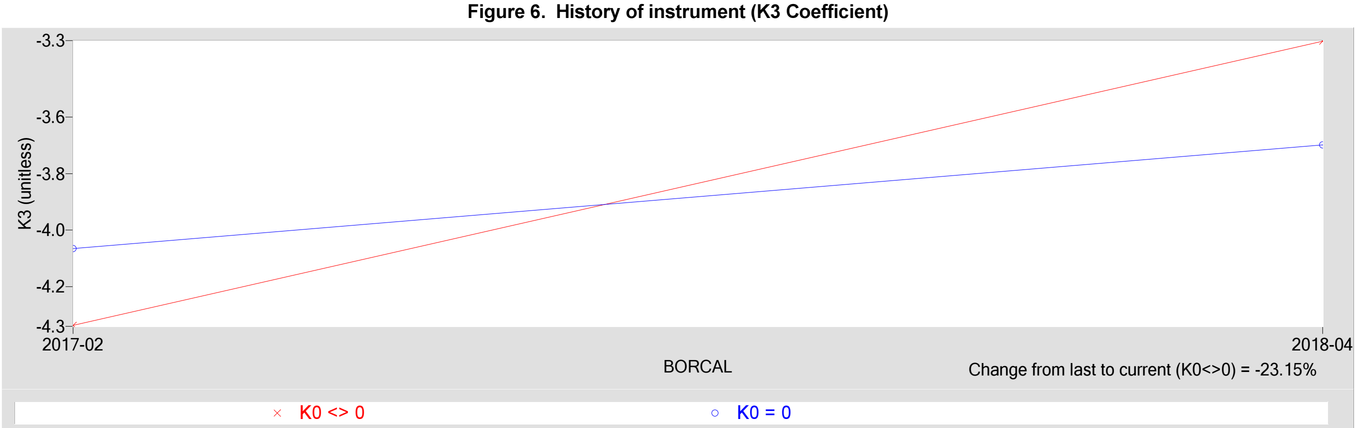


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30358F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________ ____________

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

Calibration Results

30358F3 Eppley PIR

The incoming irradiance (Win, W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

K0,K1,K2,K3 = calibration coefficeints,
V = thermopile output voltage (μV),
*Wd = σ * Td^4* = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

*Wr = σ * 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).

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

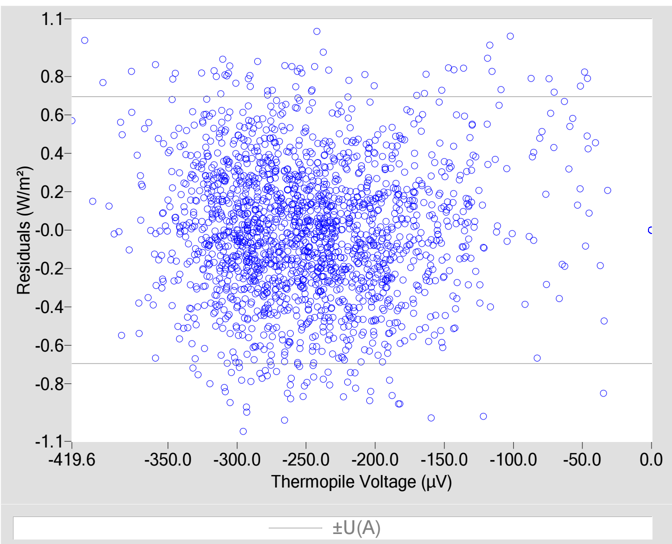


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

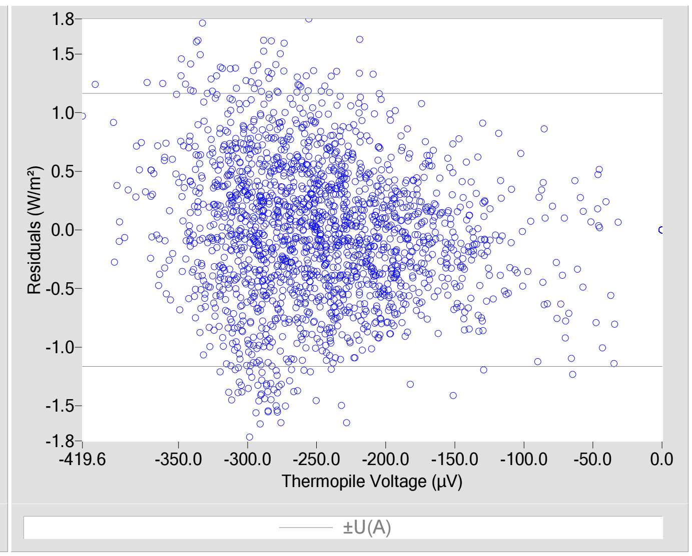


Table 2. Calibration Coefficients for K0<>0

K0	-12.9
K1	0.23231
K2	1.0453
K3	-3.35
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23094
K2	1.0160
K3	-3.69
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.35
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.59
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.0

Figure 3. History of instrument (K0 Coefficient)

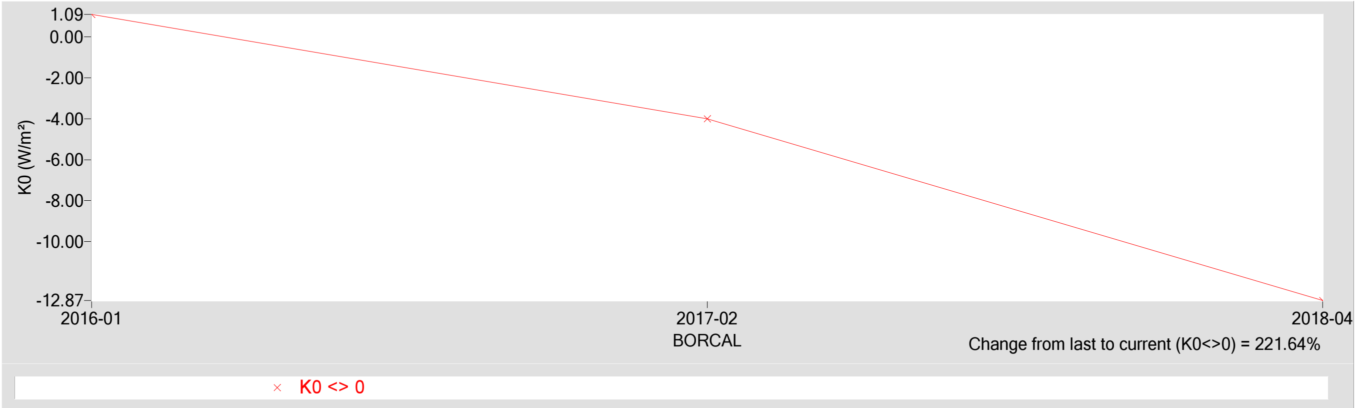


Figure 4. History of instrument (K1 Coefficient)

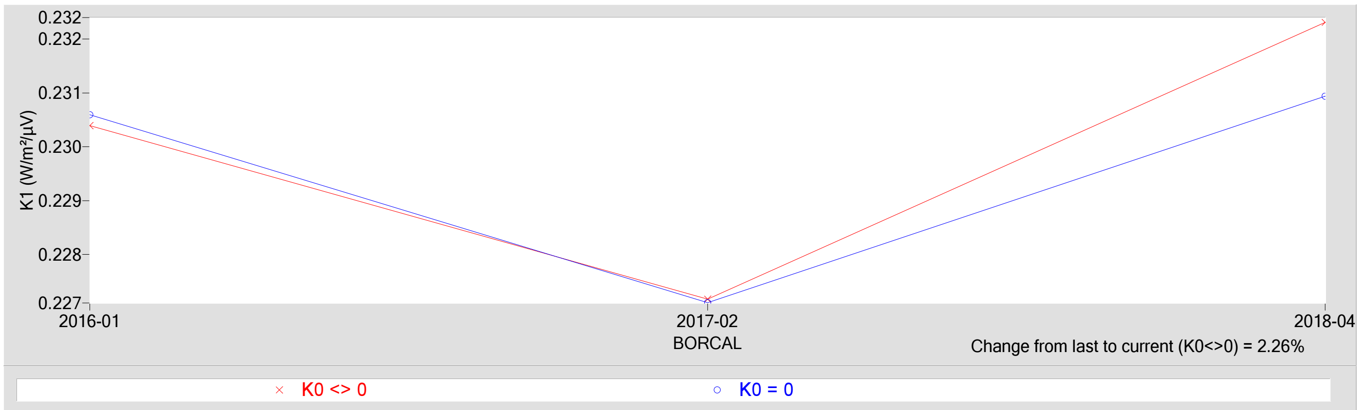


Figure 5. History of instrument (K2 Coefficient)

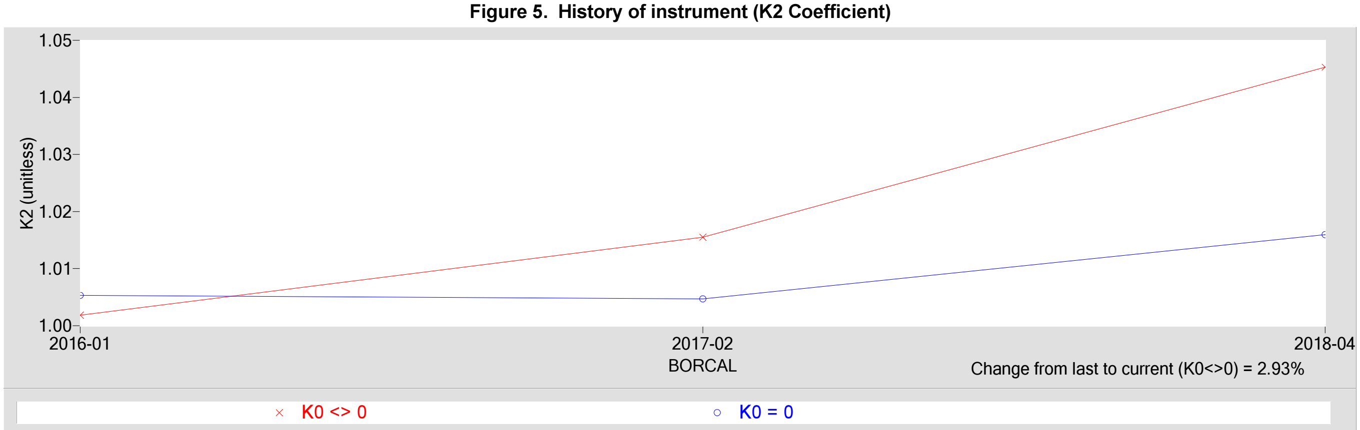
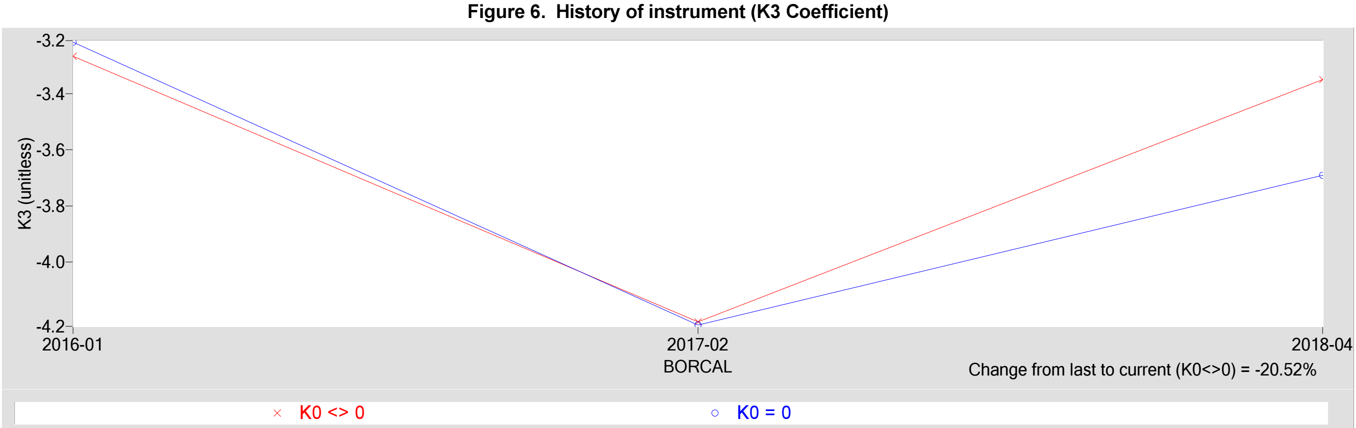


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30782F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________ ____________

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

Calibration Results

30782F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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 = σ * *Td^4* = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

Wr = σ * *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).

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

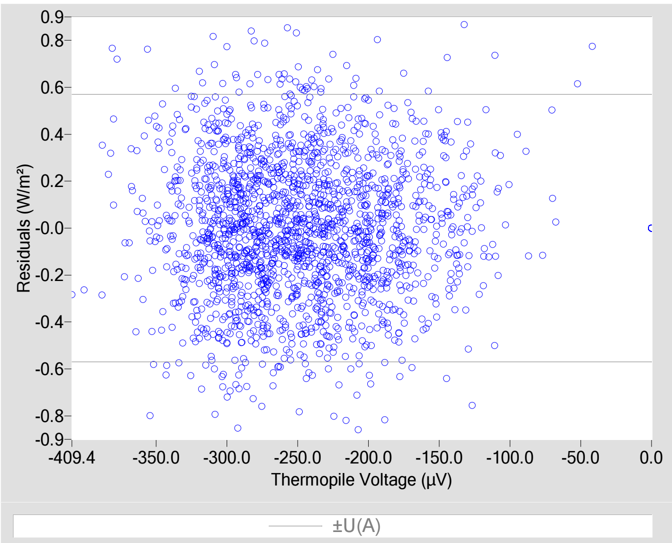


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

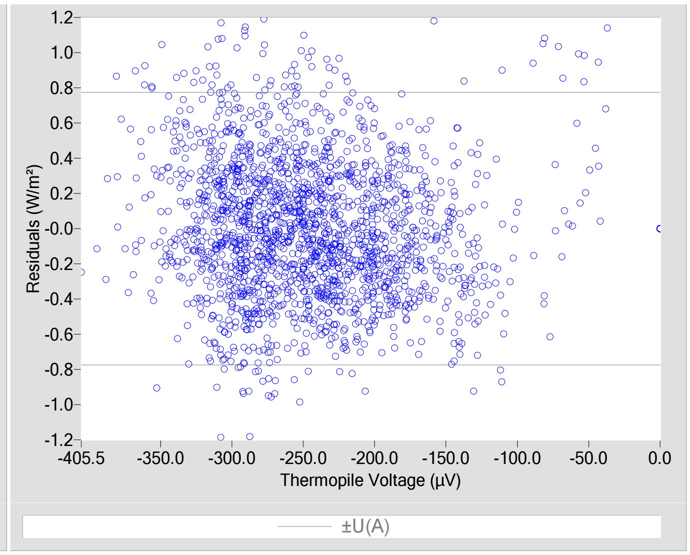


Table 2. Calibration Coefficients for K0<>0

K0	-7.4
K1	0.23121
K2	1.0322
K3	-2.51
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23074
K2	1.0161
K3	-3.14
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.29
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.39
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Figure 3. History of instrument (K0 Coefficient)

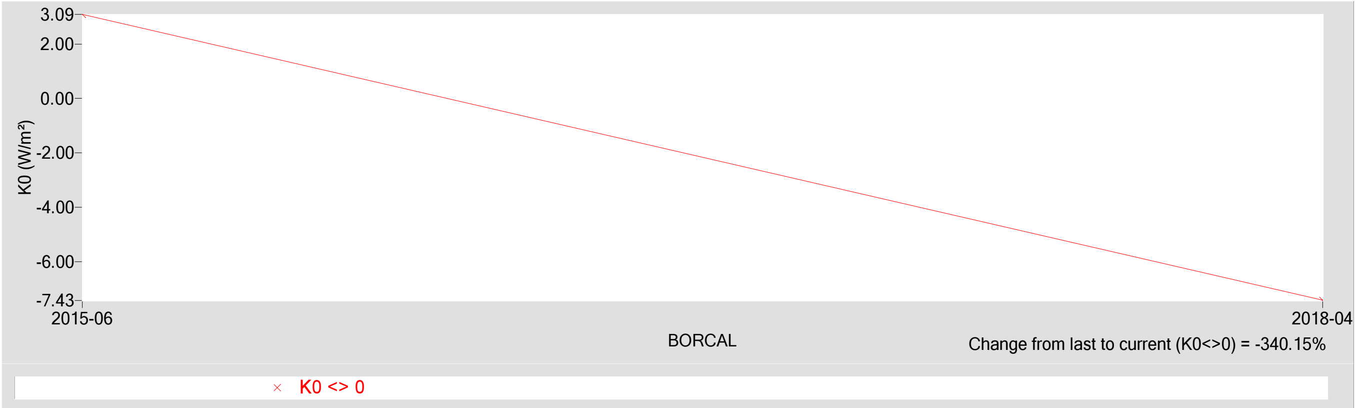


Figure 4. History of instrument (K1 Coefficient)

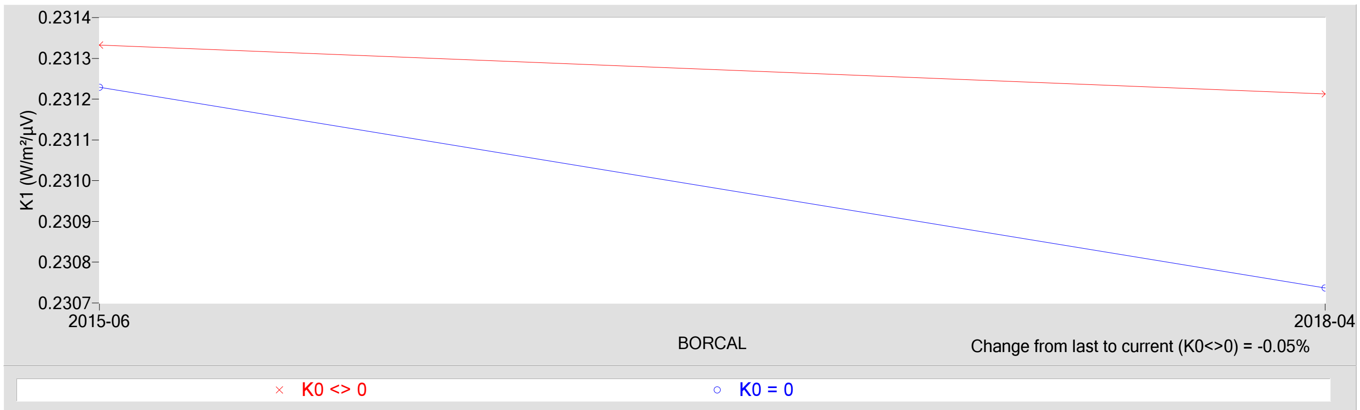


Figure 5. History of instrument (K2 Coefficient)

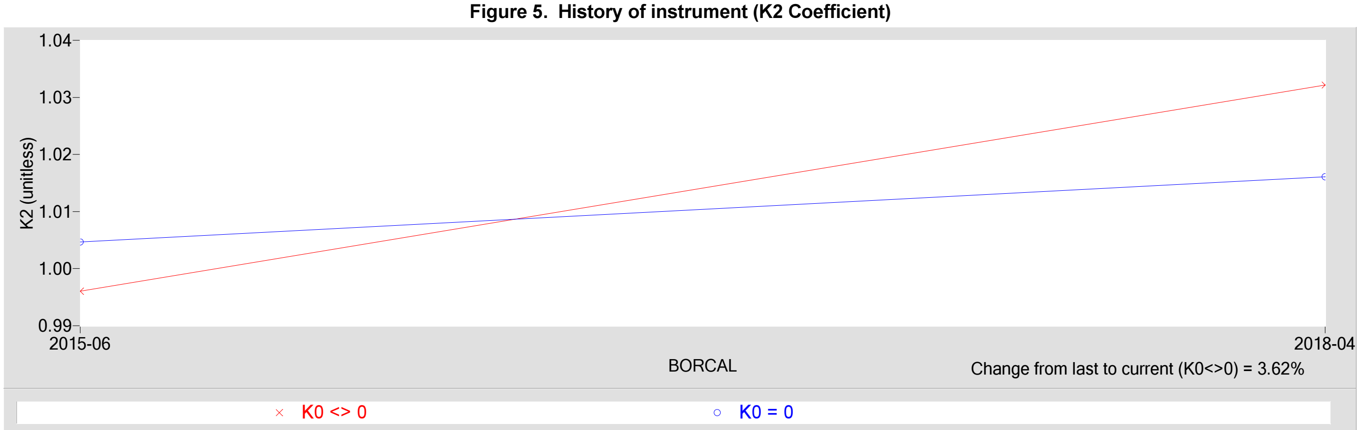
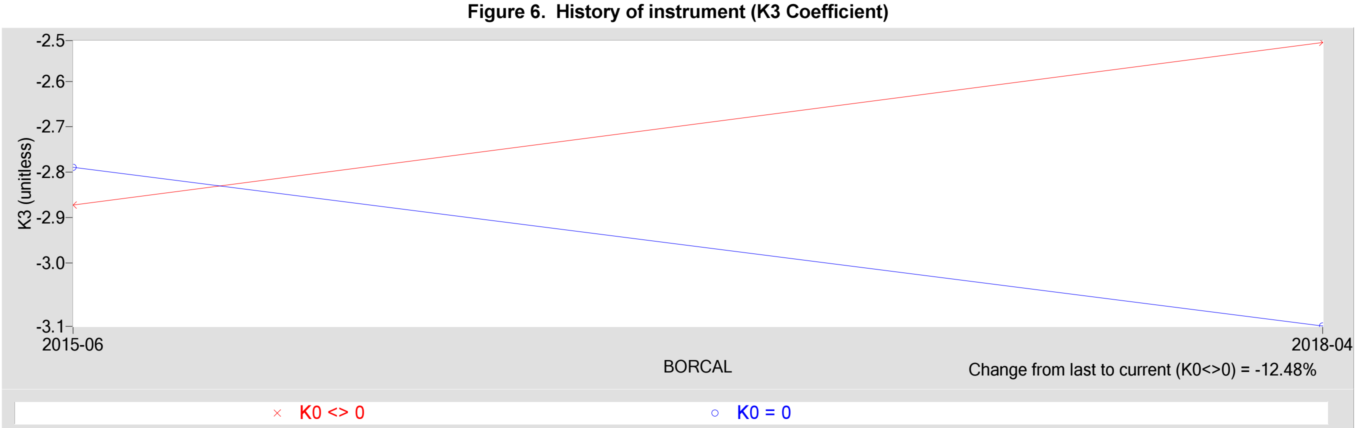


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30834F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________ ______________

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

Calibration Results

30834F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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 = *σ* * *Td*^4 = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

Wr = *σ* * *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).

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

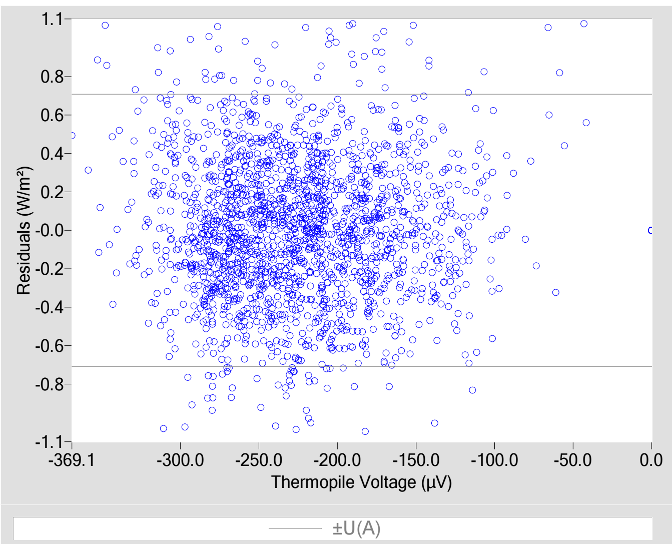


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

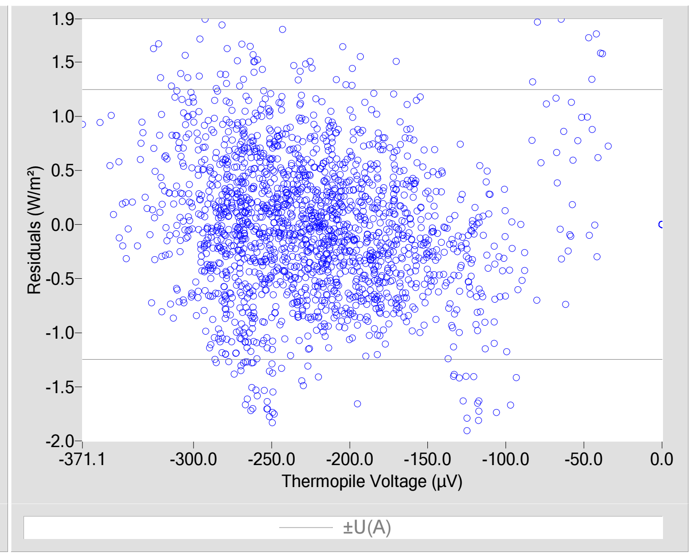


Table 2. Calibration Coefficients for K0<>0

K0	-13.7
K1	0.25210
K2	1.0468
K3	-3.31
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.25186
K2	1.0166
K3	-3.85
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.36
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.64
Combined Standard Uncertainty, u(c) (W/m²)	±1.6
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.1

Figure 3. History of instrument (K0 Coefficient)

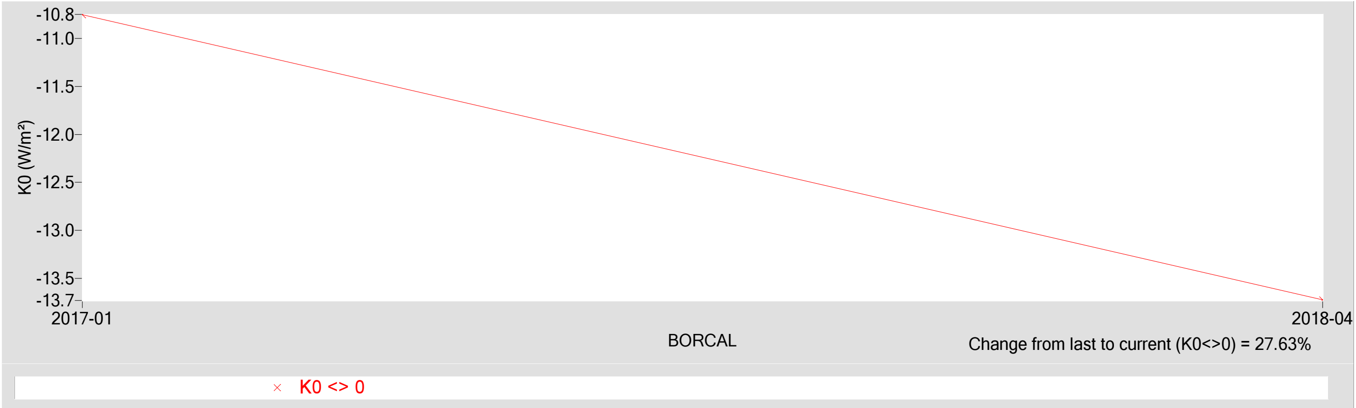


Figure 4. History of instrument (K1 Coefficient)

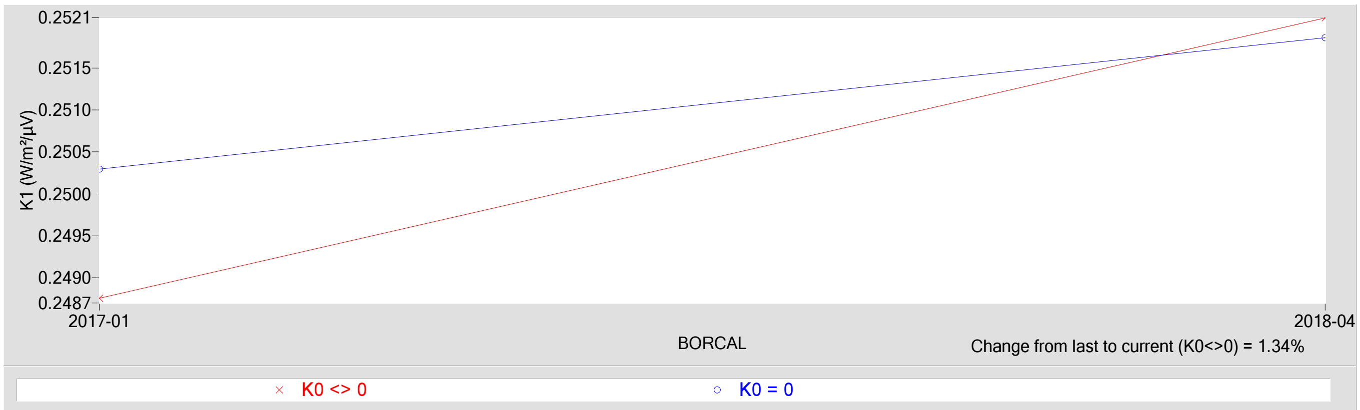


Figure 5. History of instrument (K2 Coefficient)

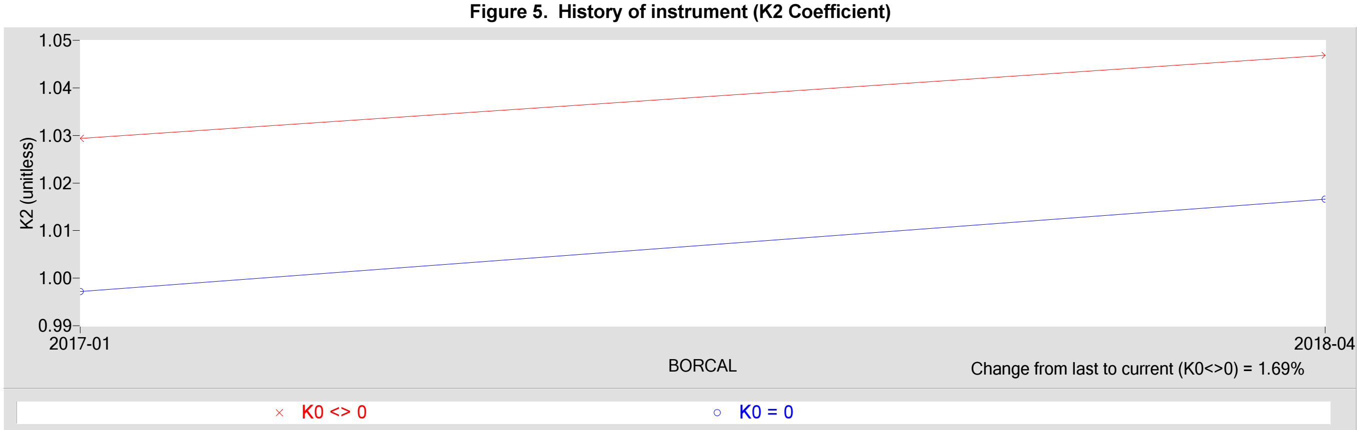
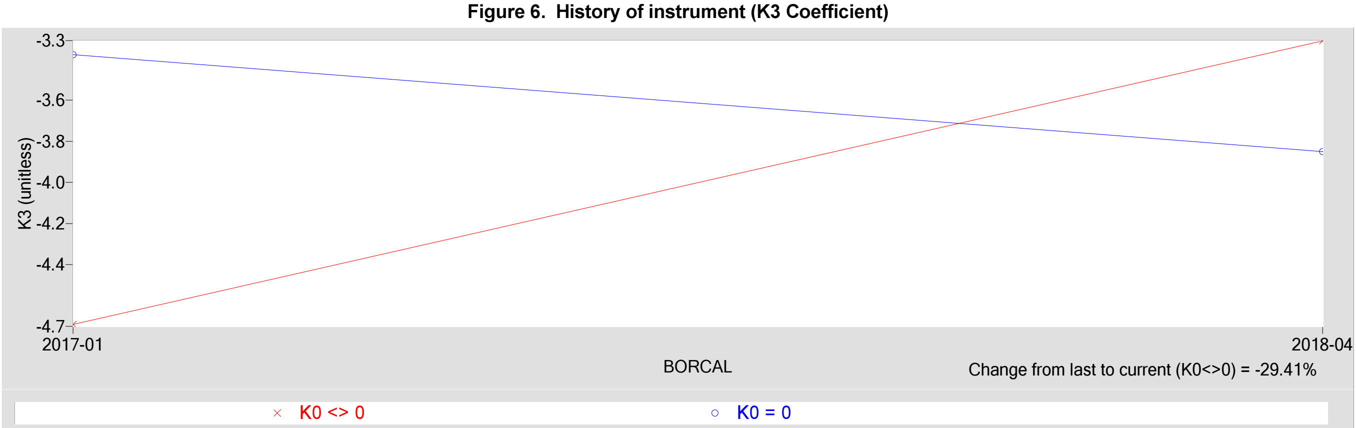


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	30836F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

_______________________________ _______________

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

Calibration Results

30836F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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 = σ * *Td*^4 = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

Wr = σ * *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).

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

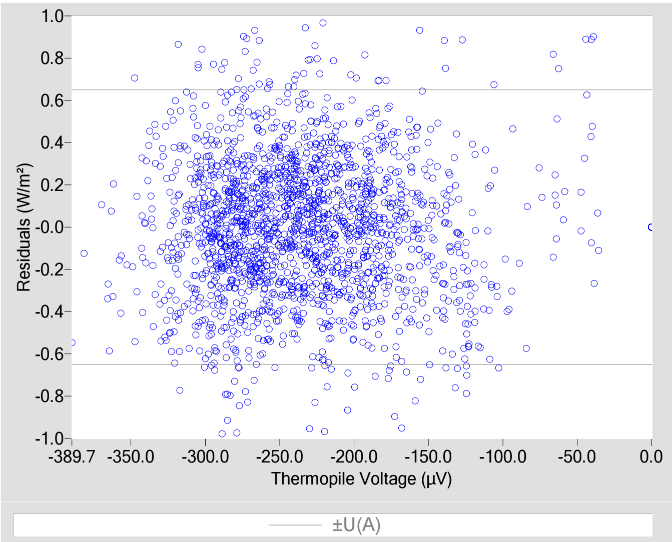


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

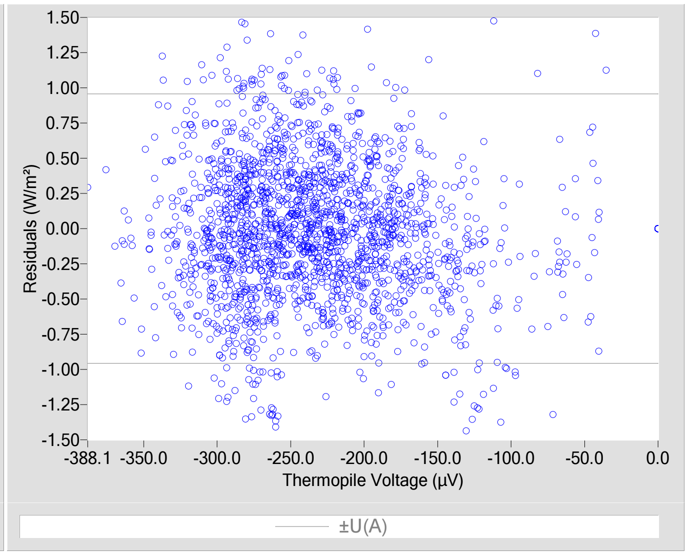


Table 2. Calibration Coefficients for K0<>0

K0	-9.8
K1	0.24348
K2	1.0344
K3	-3.03
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24277
K2	1.0121
K3	-3.47
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.33
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.49
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.0

Figure 3. History of instrument (K0 Coefficient)

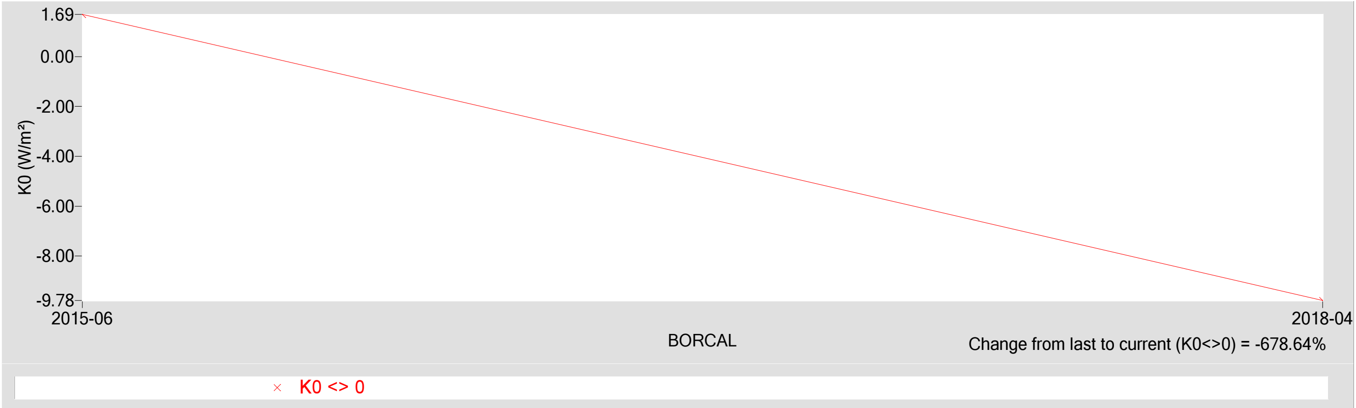


Figure 4. History of instrument (K1 Coefficient)

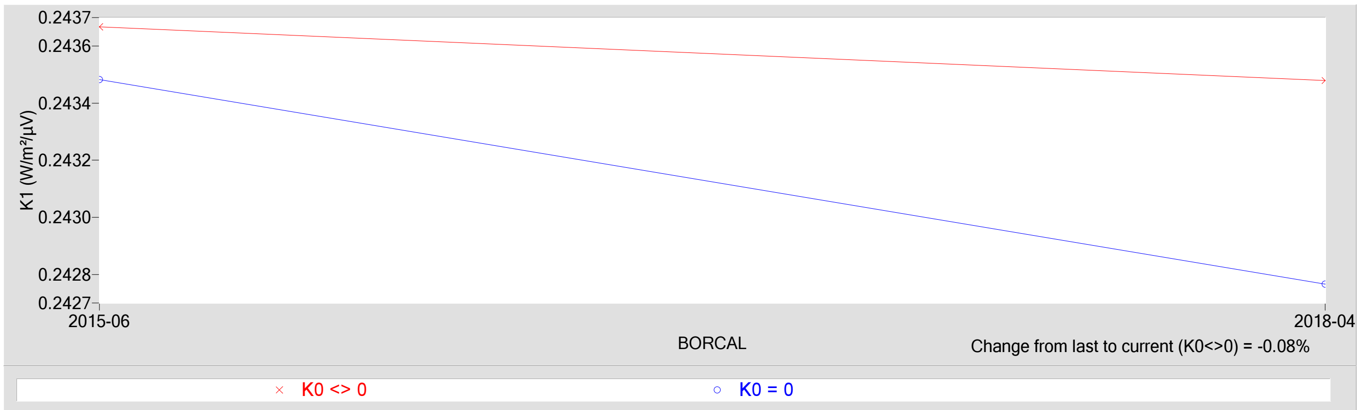


Figure 5. History of instrument (K2 Coefficient)

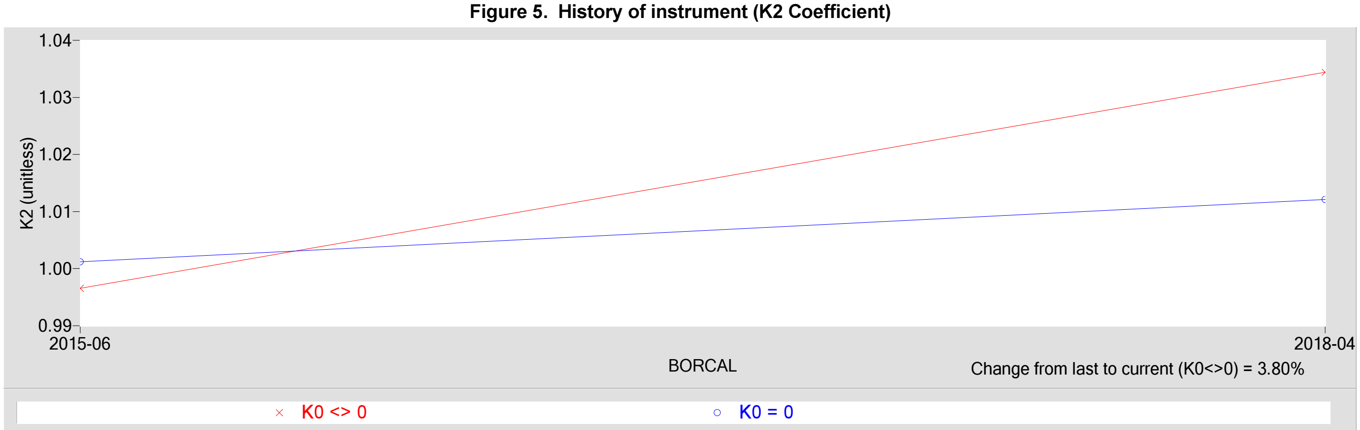
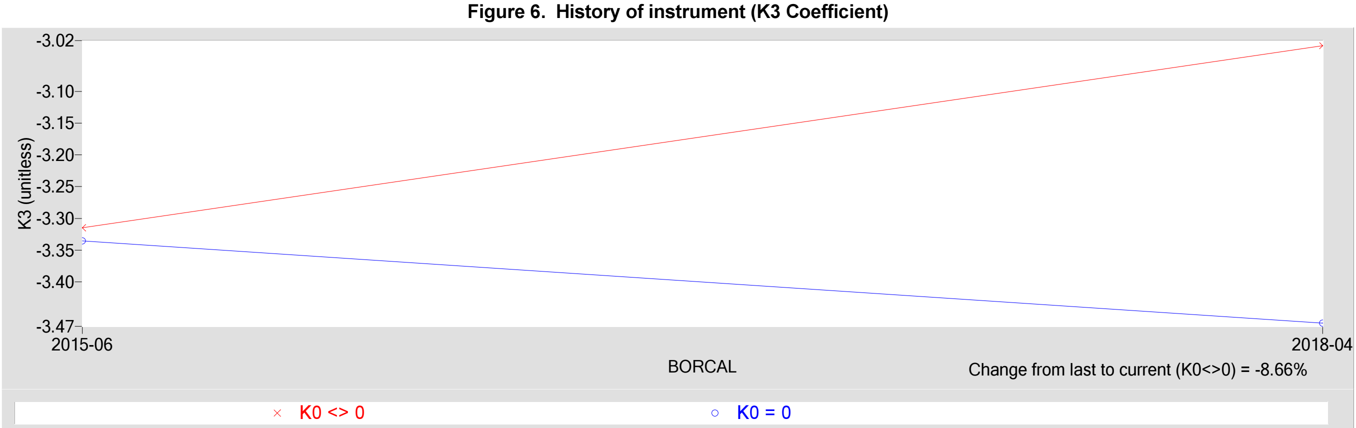


Figure 6. History of instrument (K3 Coefficient)



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.

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:**	36367F3
Calibration Date:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

______________________________ _______________

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

Calibration Results

36367F3 Eppley PIR

The incoming irradiance (Win, W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

K0,K1,K2,K3 = calibration coefficeints,
V = thermopile output voltage (μV),
*Wd = σ * Td^4* = dome irradiance (W/m²),
where, *Td* = dome temperature (K),

*Wr = σ * 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).

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

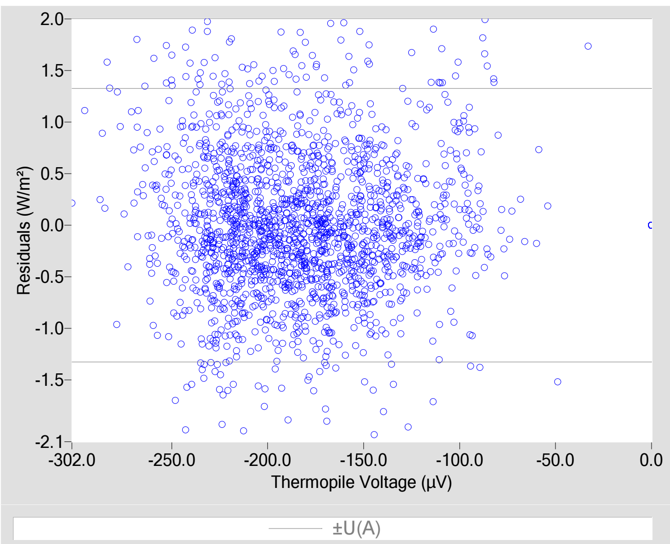


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

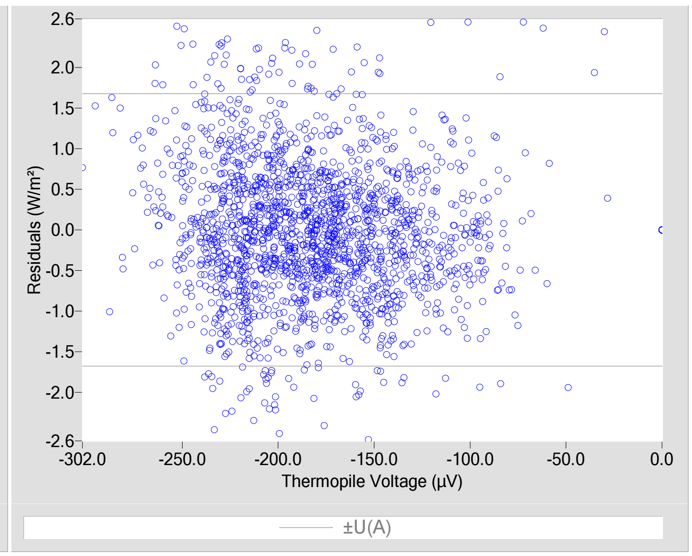


Table 2. Calibration Coefficients for K0<>0

K0	-13.1
K1	0.31171
K2	1.0427
K3	1.04
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.31122
K2	1.0132
K3	1.01
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.68
Combined Standard Uncertainty, u(c) (W/m²)	±1.6
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.1

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.86
Combined Standard Uncertainty, u(c) (W/m²)	±1.7
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.3

Figure 3. History of instrument (K0 Coefficient)

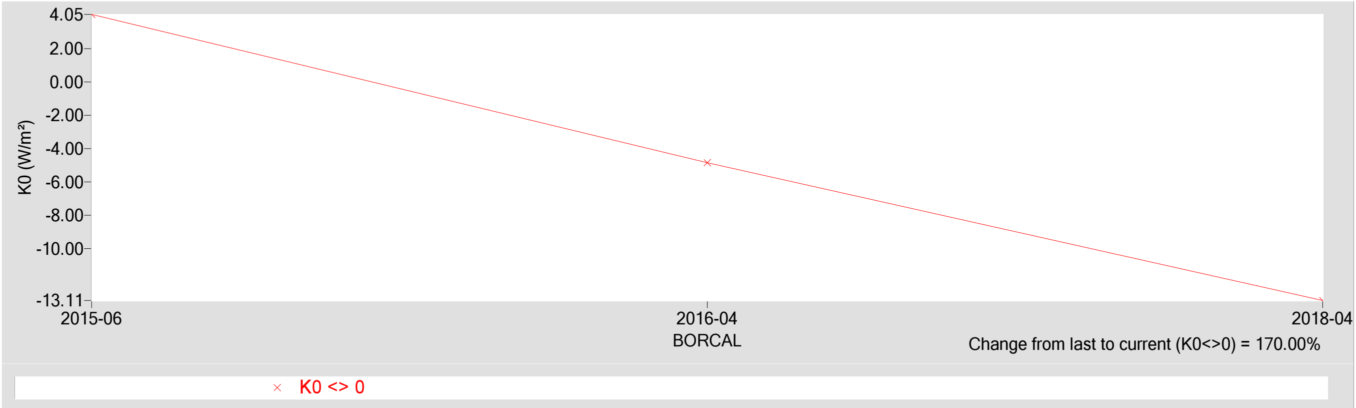


Figure 4. History of instrument (K1 Coefficient)

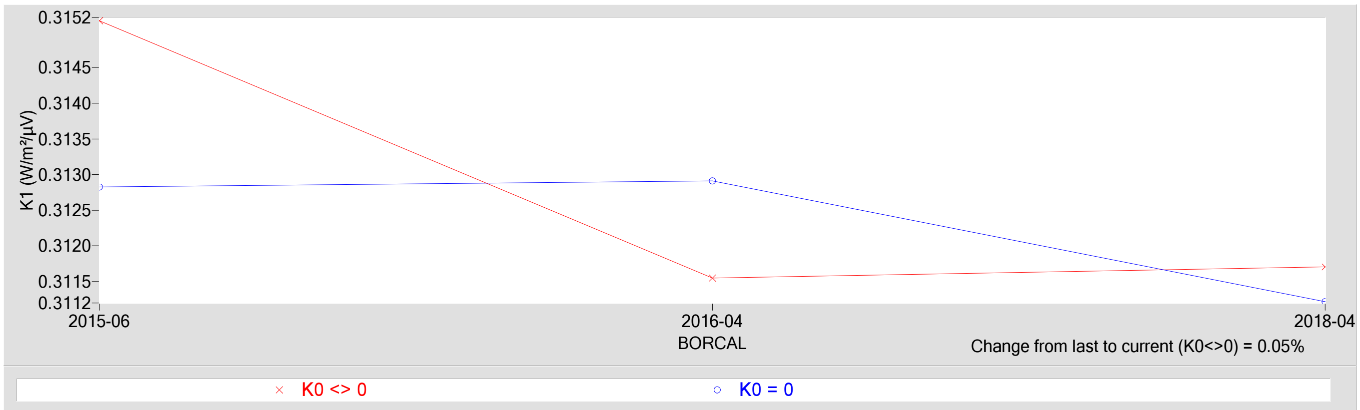


Figure 5. History of instrument (K2 Coefficient)

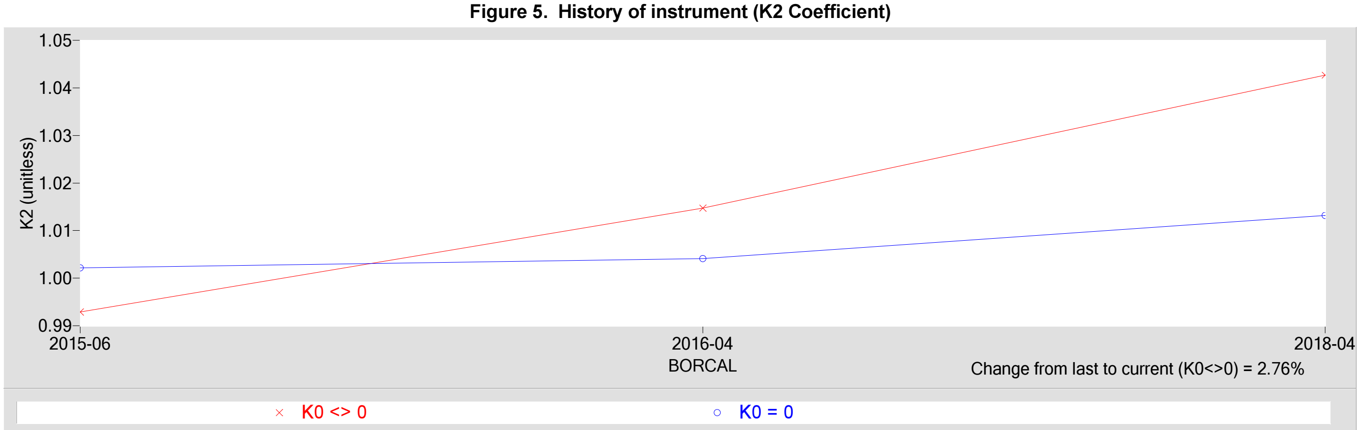
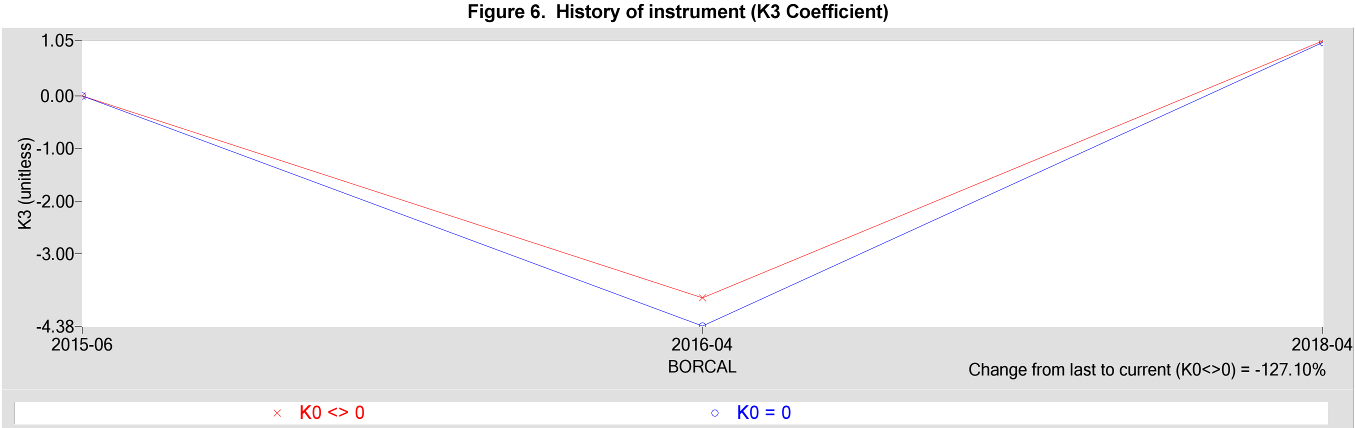


Figure 6. History of instrument (K3 Coefficient)



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.

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:	8/10/2018	**Due Date:**	8/10/2019
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/6-15, 6/18-23, 6/26-30, 7/1-31, 8/1-10		

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	01/19/2018	01/19/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30835F3	05/08/2017	05/08/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31637F3	06/27/2017	06/27/2019

‡ Through the World Infrared Standard Group (WISG)

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

________________________________ ________________

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

Calibration Results
36368F3 Eppley PIR

The incoming irradiance (Win, W/m²) 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).

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

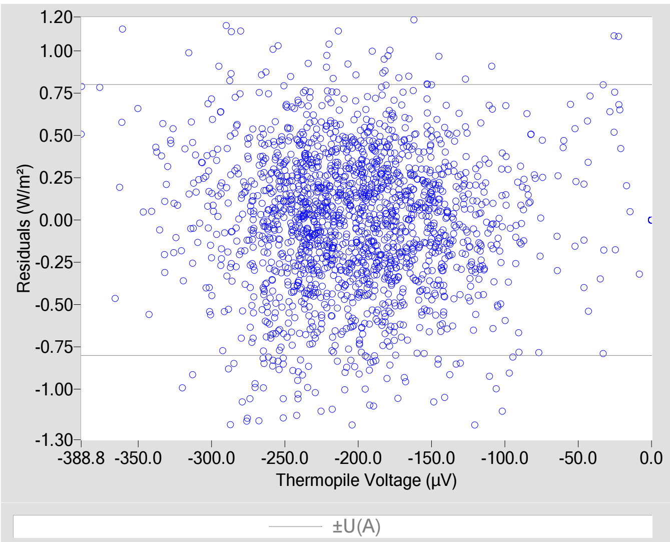


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

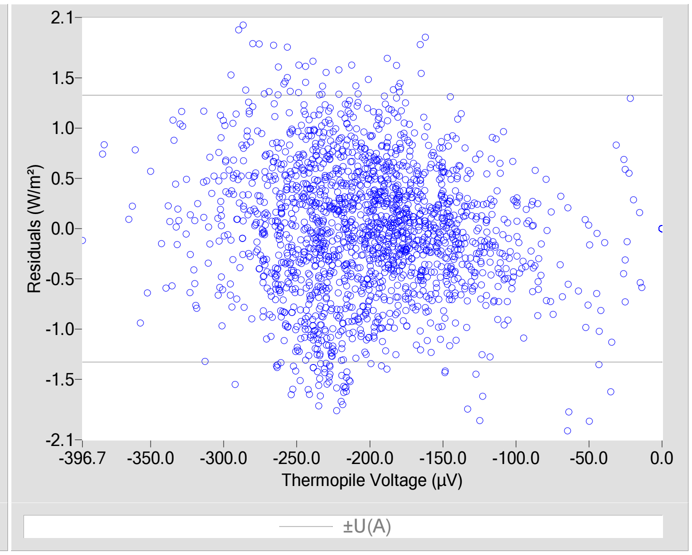


Table 2. Calibration Coefficients for K0<>0

K0	-15.4
K1	0.28008
K2	1.0554
K3	-3.65
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.27902
K2	1.0214
K3	-4.45
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.41
Combined Standard Uncertainty, u(c) (W/m²)	±1.5
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.9

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.4
Type-A Standard Uncertainty, u(A) (W/m²)	±0.68
Combined Standard Uncertainty, u(c) (W/m²)	±1.6
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±3.1

Figure 3. History of instrument (K0 Coefficient)

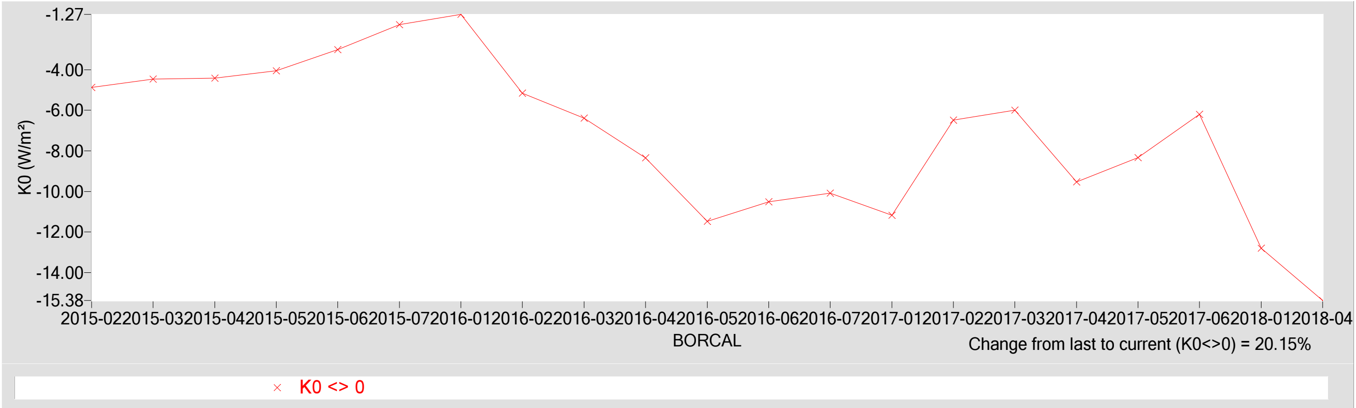


Figure 4. History of instrument (K1 Coefficient)

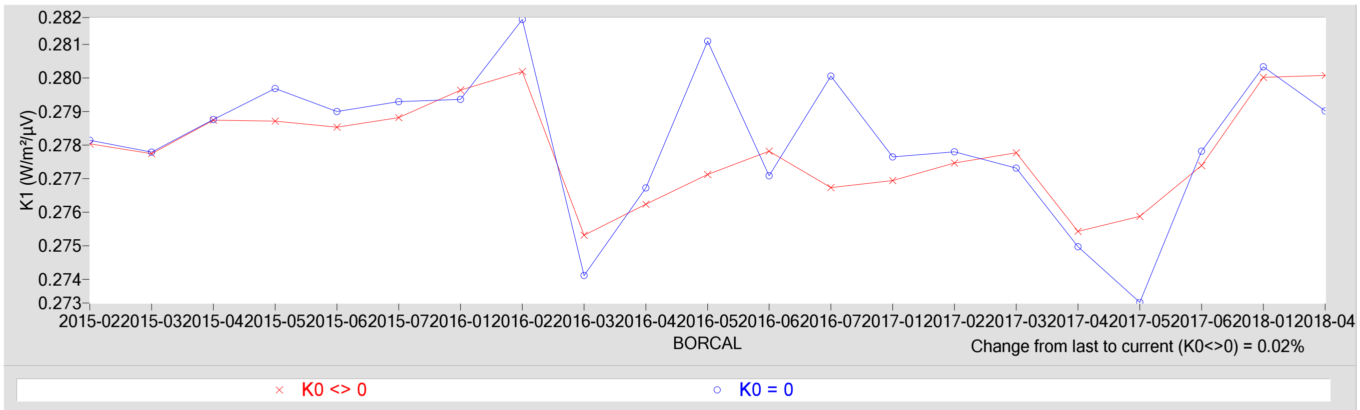


Figure 5. History of instrument (K2 Coefficient)

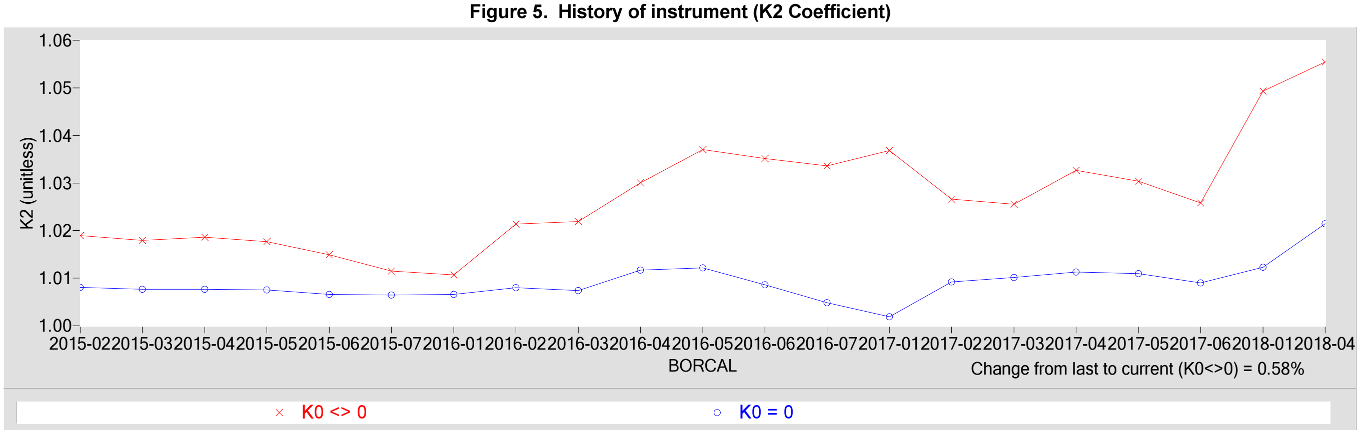
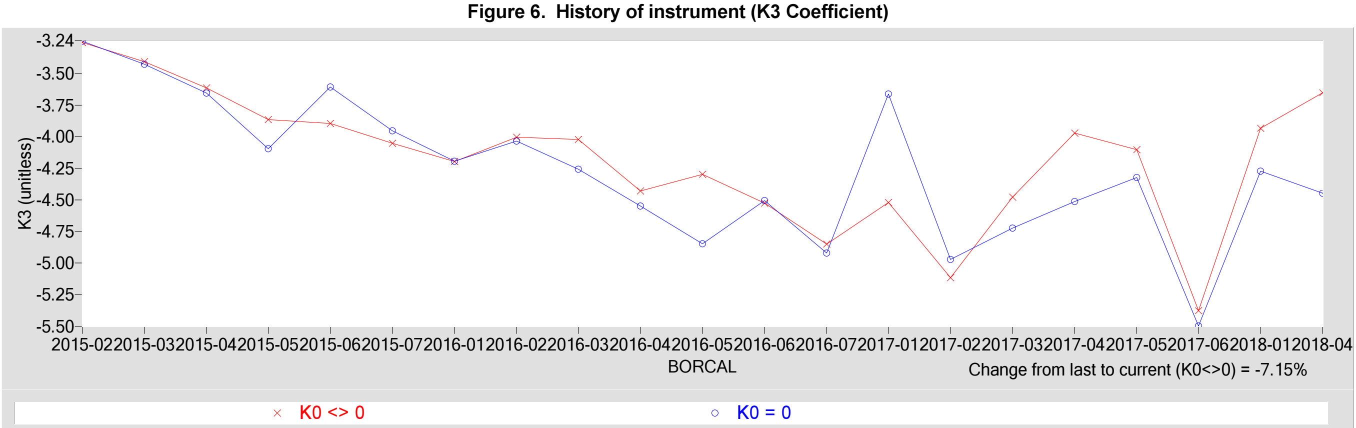


Figure 6. History of instrument (K3 Coefficient)



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.

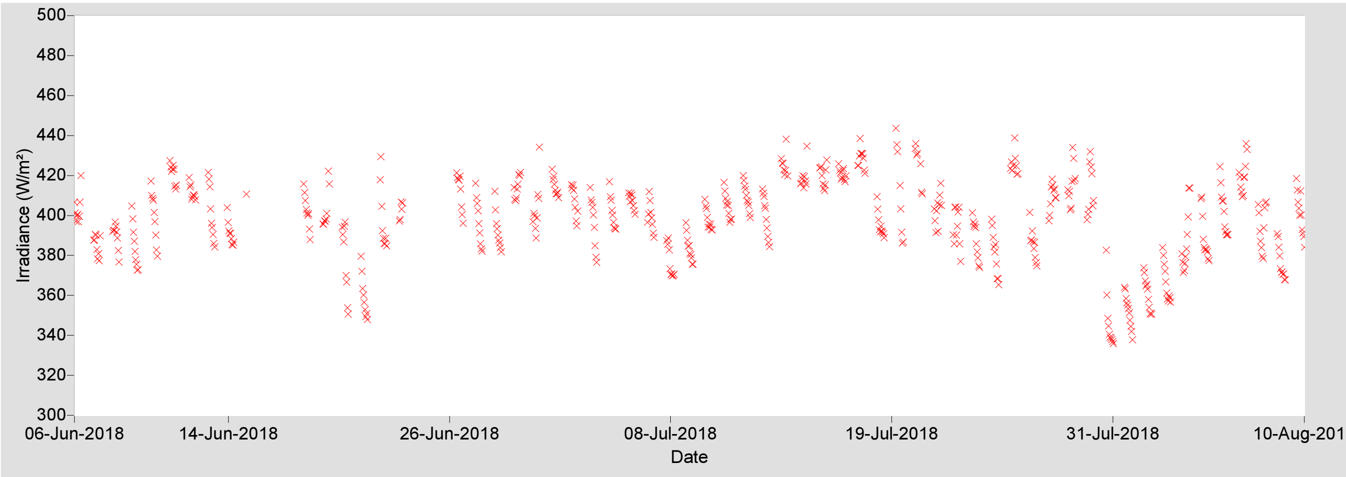
Environmental and Sky Conditions for BORCAL-LW 2018-04

Calibration Facility: Southern Great Plains

Latitude: 36.605°N | Longitude: 97.488°W | Elevation: 317.0 meters AMSL | Time Zone: -6.0

Reference Irradiance (hourly averages):

Figure 6. Reference Irradiance



Meteorological Observations (hourly averages):

Figure 7. Temperature

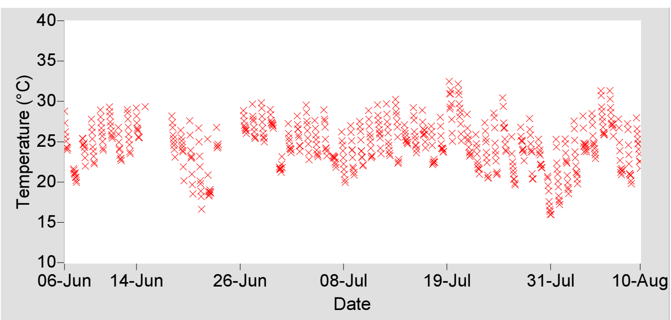


Figure 8. Humidity

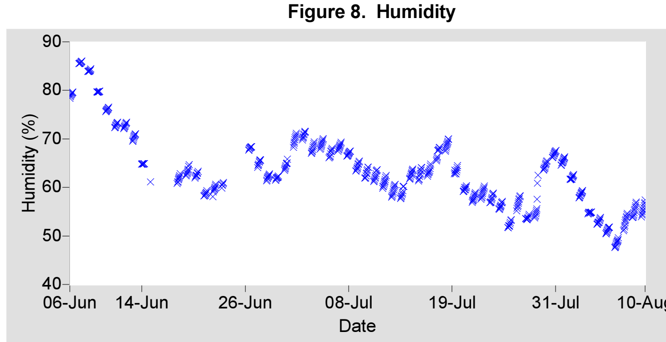


Figure 9. Pressure

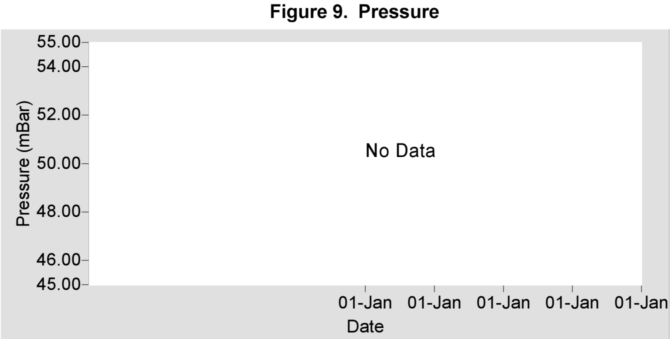


Figure 10. Estimated Precipitable Water Vapor (PWV)

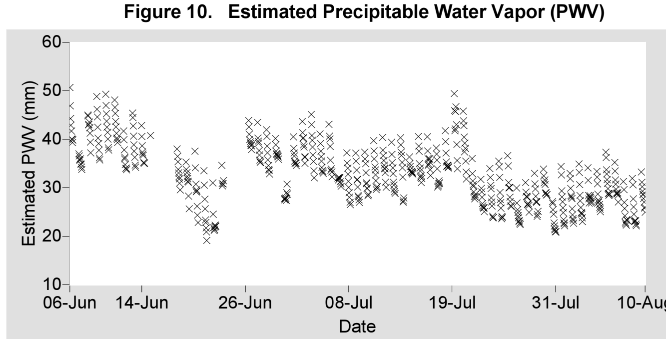


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	24.64	15.90	33.12
Humidity (%)	63.31	47.44	86.14
Pressure (mBar)	N/A	N/A	N/A
Est. Precipitable Water Vapor (mm)	32.8	18.7	52.5

For other information about the calibration facility visit: http://www.arm.gov/docs/sites/sgp/sgp.html

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Southern Great Plains
Comments:
Avg. Station Pressure and Temperature is for Tulsa, OK, which is used for the Solar Position Algorithm (SPA).

Session; Numbers: 10,16
Comments:
RCC: Recovered Session

Appendix 3
Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL/LW 2018-04 Session Configuration Audit Report

LOCATION

Facility	Facility Abbrev.	Contact	Latitude	Longitude	Elevation (m)	Avg press (mbr)	Avg temp (C)	Time zone	ISO
Southern Great Plains	SGP	Craig Webb	36.605	-97.488	317.0	992.0	15.0	-6.0	

SYSTEM

% Error Thresholds

TP(x) / TP(x-1): 25.0

Delta Thresholds

Ref Pyg Stability: 4.0
Temp(x) - Temp(x-1): 5.0
Hum(x) - Hum(x-1): 20.0
Bar(x) - Bar(x-1): 5.0
Thrm(x) - Temp(x): 10.0

Analysis Rejection

Threshold 1 (Blue): 3.000
Threshold 2 (Green): 4.000
Threshold 3 (Brown): 5.000
No. of Std. Dev.: 3

Clock

Reset Interval (m): 0
Warning Threshold (s): 0
Delta UT1: 0.100

Misc

Scan Rate (s): 300
Uncert. Significant Figures: 2

Auto Mode Zenith Angle

Afternoon Startup: 94
Morning Shutdown: 94

Solar Position Algorithm

Delta T (s): 69.084
Atmos. Refraction (deg): 0.5667

METEOROLOGICAL INSTRUMENTS

	Channel	Junction Box	Cable	Location	Scale	Offset
Temperature: E0710025T Vaisala HMP155 T	59		36	36	100	-40
Humidity: E0710025H Vaisala HMP155 H	63		18	18	100	0
Pressure: None					0	0

GPS TIME RECIEVER

GPS: None

Type	Port	Baud	Parity	Stop bits	Data bits
	0	0	0	0	0

DATALOGGER

	Logger/Relay	DMM
Unit 0	2014-1302 NREL RAP-DAQ	SG42000596 Agilent 34420A
Unit 0	None	None
Unit 0	None	None
Unit 0	None	None

	Unit 0	Unit 0	Unit 0	Unit 0
Cal Date	01/19/2018			
Cal Due Date	01/19/2019			
System Offsets: Volts DC (µV)	0.43	0.00	0.00	0.00
2-Wire Res. (mOhms)	2130.00	0.00	0.00	0.00
4-Wire Res. (mOhms)	0.00	0.00	0.00	0.00

Communications

	Unit	Type	Addr.	Board	Parity	Stop	Data
DMM	0	GPIB	1	0	0	0	0
Relay	0	GPIB	4	1	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0

BORCAL/LW 2018-04 Session Configuration Audit Report

PYRGEOMETER REFERENCE INSTRUMENTS

Cal Date	Cal Due Date	K0	K1	K2	K3	Kr	Uncert. (W/m^2)	Max Out (mV)	Channel	Junction Box	Cable	Location	Active
Pyrgeometer 1: 30835F3 Eppley PIR (Ventilated)													
05/08/2017	05/08/2019	-6.30900	0.23009	1.02060	-3.46670	7.04400E-4	1.80	9	5		2	T5-2	✔
Pyrgeometer 1: Case 10K Temperature									4		2		
Pyrgeometer 1: Dome 10K Temperature									6		2		
Pyrgeometer 2: 31637F3 Eppley PIR (Ventilated)													
06/27/2017	06/27/2019	-19.35800	0.24987	1.06090	-3.43960	7.04400E-4	3.00	9	17		2	T6-2	✔
Pyrgeometer 2: Case 10K Temperature									16		2		
Pyrgeometer 2: Dome 10K Temperature									18		2		

(Calibration Coefficients: K0, K1, K2, K3, Kr)

BORCAL/LW 2018-04 Session Configuration Audit Report

INSTRUMENTS

Serial Number / Model	Customer	Mfg RS	Ch	Box	Cable	Act	ISO	AIM	Stickr	Vent	Use	Kr	Location	Due
29146F3	SGP	3.6900	29		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-2	12
PIR	(Case 10K Temperature)		28		2									
	(Dome 10K Temperature)		30		2									
29591F3	SGP	4.1900	45		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-3	12
PIR	(Case 10K Temperature)		44		3									
	(Dome 10K Temperature)		46		3									
30011F3	SGP	3.5900	37		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-1	12
PIR	(Case 10K Temperature)		36		1									
	(Dome 10K Temperature)		38		1									
30013F3	SGP	3.5700	9		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T5-3	12
PIR	(Case 10K Temperature)		8		3									
	(Dome 10K Temperature)		10		3									
30132F3 ‡	SGP	3.9000	53		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-2	12
PIR	(Case 10K Temperature)		52		2									
	(Dome 10K Temperature)		54		2									
30344F3	SGP	3.9600	57		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-3	12
PIR	(Case 10K Temperature)		56		3									
	(Dome 10K Temperature)		58		3									
30358F3	SGP	4.2600	49		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-1	12
PIR	(Case 10K Temperature)		48		1									
	(Dome 10K Temperature)		50		1									
30782F3	SGP	4.0500	21		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T6-3	12
PIR	(Case 10K Temperature)		20		3									
	(Dome 10K Temperature)		22		3									
30834F3	SGP	3.7500	33		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-3	12
PIR	(Case 10K Temperature)		32		3									
	(Dome 10K Temperature)		34		3									
30836F3	SGP	3.9300	13		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T6-1	12
PIR	(Case 10K Temperature)		12		1									
	(Dome 10K Temperature)		14		1									
36367F3	SGP	3.0300	25		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-1	12
PIR	(Case 10K Temperature)		24		1									
	(Dome 10K Temperature)		26		1									
36368F3 ‡	SGP	3.0200	41		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-2	12
PIR	(Case 10K Temperature)		40		2									
	(Dome 10K Temperature)		42		2									

‡ Control Instrument