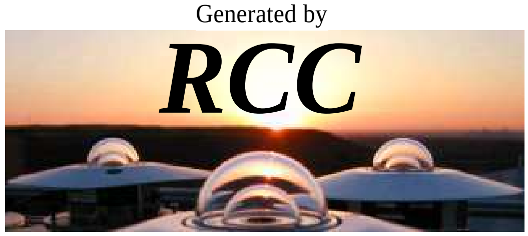
Broadband Outdoor Radiometer Calibration
Longwave

BORCAL-LW
2019-02

Generated by



Radiometer Calibration and Characterization

<u>Calibration Facility</u>

Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Calibration date

03/25/2019 to 04/19/2019

Report Date

April 19, 2019

Broadband Outdoor Radiometer Calibration Report

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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 for each instrument.
- Environmental and Sky Conditions - meteorological conditions and reference irradiance during the calibration event.

BORCAL Notes or Comments

36367F3 removed due to bad dome thermistor reading and resulting high residuals

Control Instrument History

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

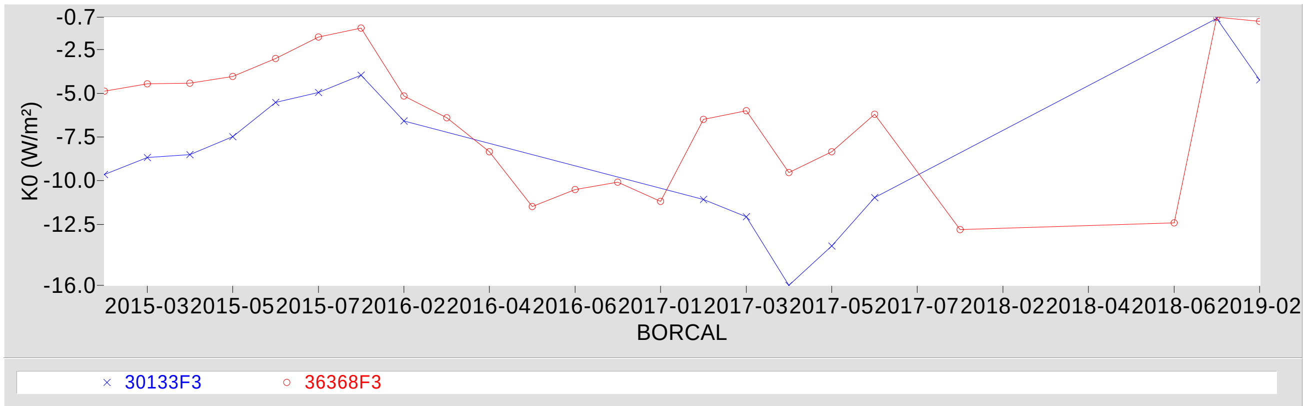


Figure 2. Eppley PIR Control Instrument History (K1 Coefficient)

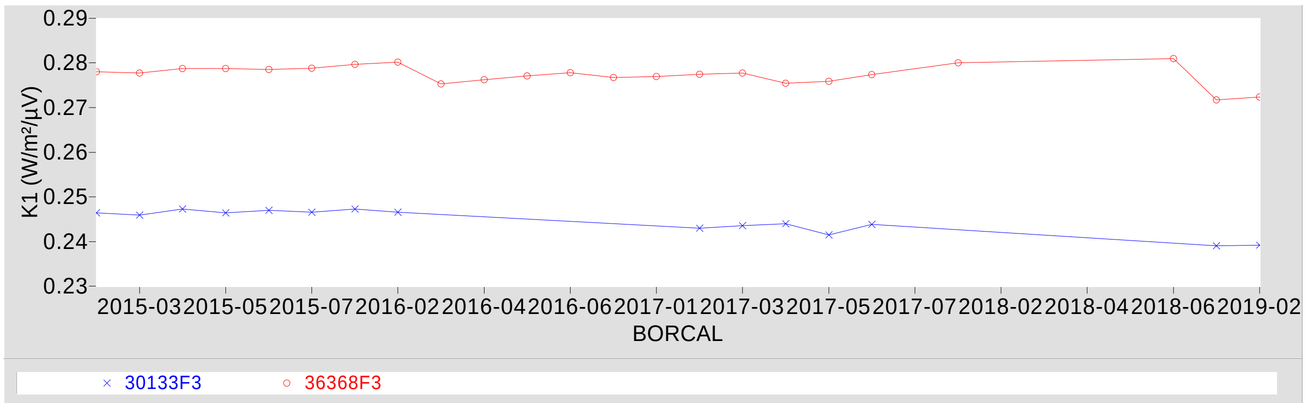


Figure 3. Eppley PIR Control Instrument History (K2 Coefficient)

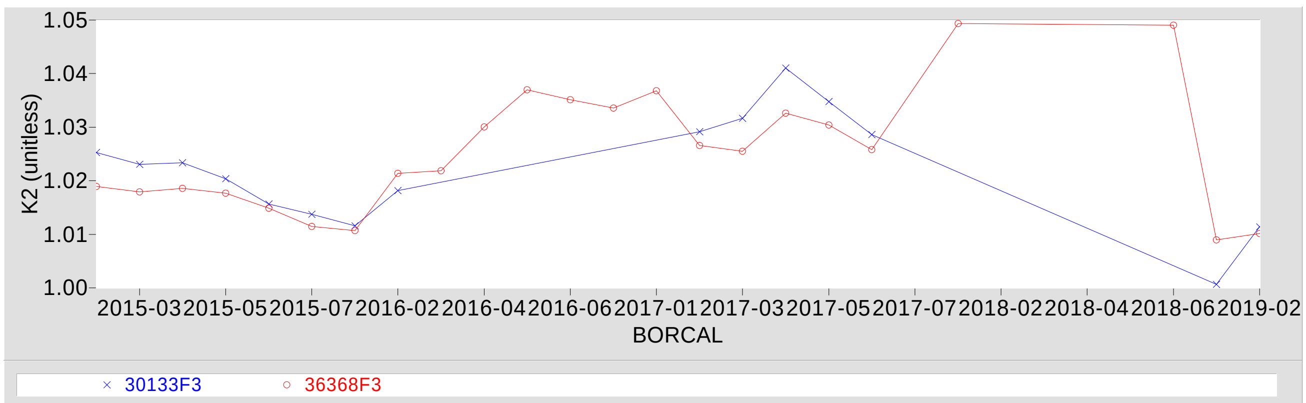
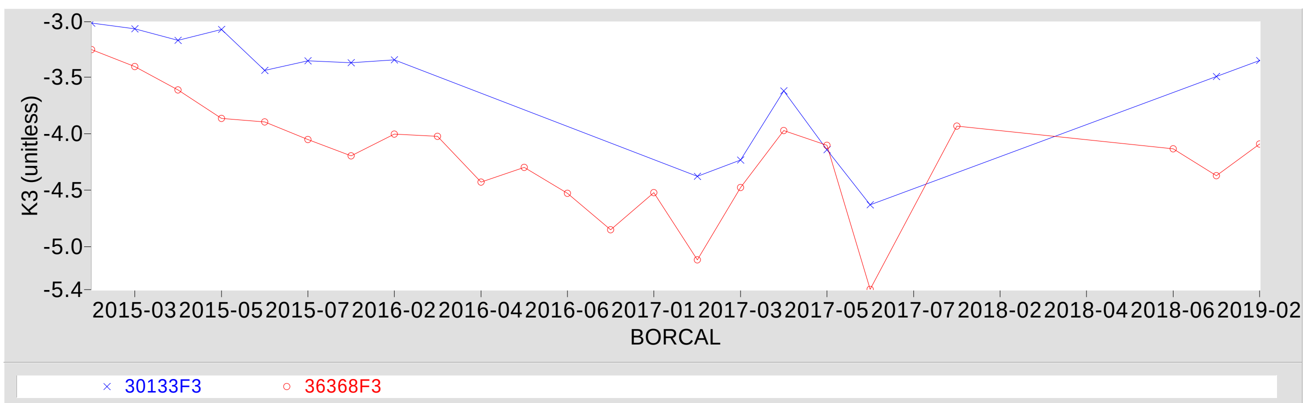


Figure 4. Eppley PIR Control Instrument History (K3 Coefficient)



Results Summary

Table 1. Results Summary

Instrument	Customer	K0 (W/m²)	K1 (W/m²/µV)	K2	K3	Kr * (K/µV)	U95 (W/m²)	Page
28630F3	SGP	-0.7	0.24756	1.0091	-2.67	7.044e-4	±3.0	A1-2
29146F3	SGP	3.6	0.24570	0.9997	-3.32	7.044e-4	±3.0	A1-5
30013F3	SGP	-2.8	0.26928	1.0047	-4.35	7.044e-4	±3.0	A1-8
30133F3	SGP	-4.2	0.23916	1.0114	-3.35	7.044e-4	±3.0	A1-11
30344F3	SGP	-1.5	0.22762	1.0047	-3.32	7.044e-4	±3.0	A1-14
30358F3	SGP	2.2	0.22350	0.9980	-3.27	7.044e-4	±3.0	A1-17
30782F3	SGP	2.9	0.22302	0.9970	-2.72	7.044e-4	±3.0	A1-20
30834F3	SGP	-1.8	0.24253	1.0076	-3.91	7.044e-4	±3.0	A1-23
30836F3	SGP	0.9	0.23470	0.9971	-3.23	7.044e-4	±3.0	A1-26
36368F3	SGP	-0.9	0.27233	1.0102	-4.09	7.044e-4	±3.0	A1-29

Note: Environmental Conditions for BORCAL starts on page A1-32. * 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:**	28630F3
Calibration Date:	4/19/2019	**Due Date:**	4/19/2020
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	3/25-31, 4/1-6, 4/8-19		

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results
28630F3 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

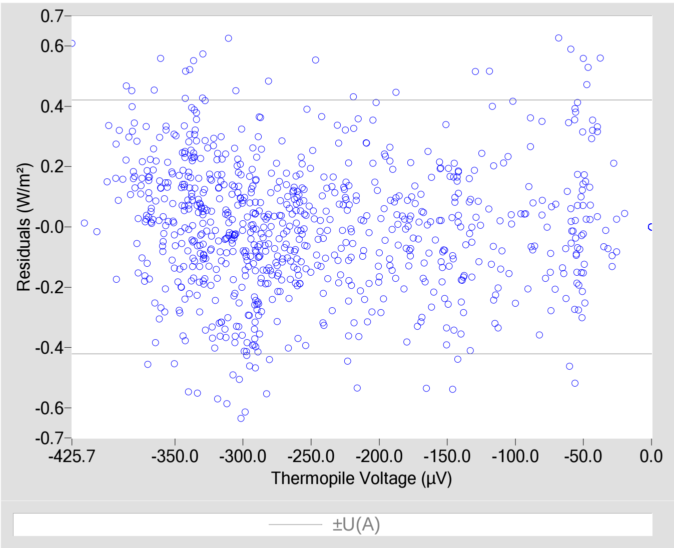


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

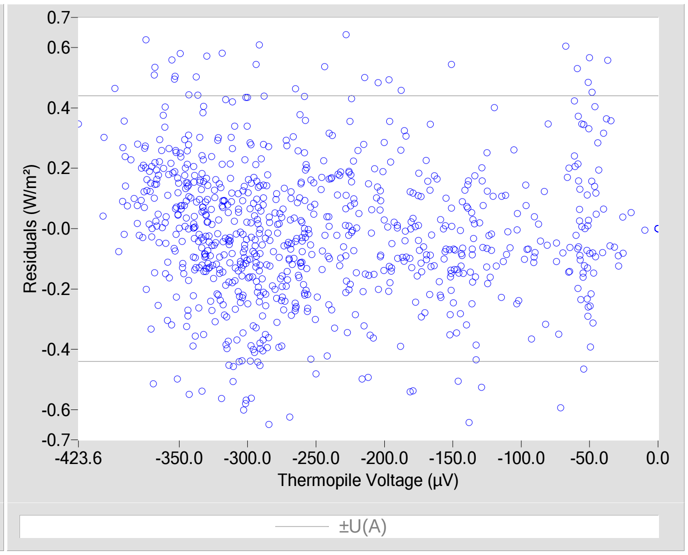


Table 2. Calibration Coefficients for K0<>0

K0	-0.7
K1	0.24756
K2	1.0091
K3	-2.67
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24767
K2	1.0073
K3	-2.64
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.21
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

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.22
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)

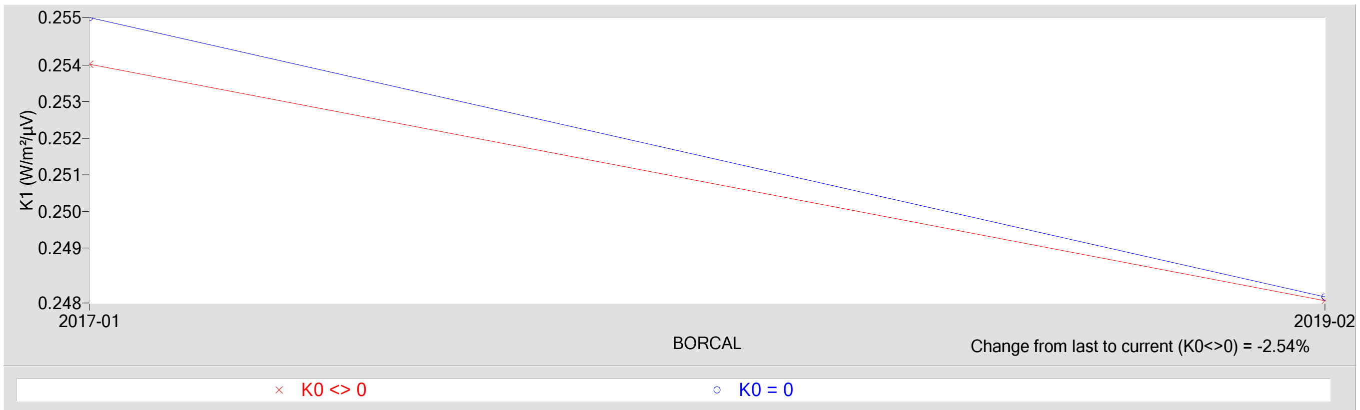


Figure 5. History of instrument (K2 Coefficient)

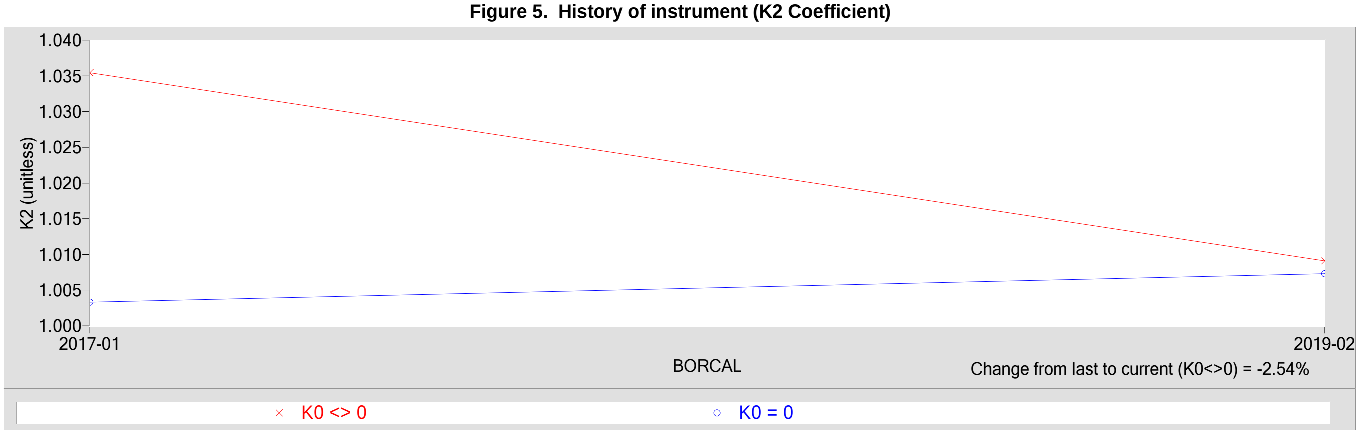
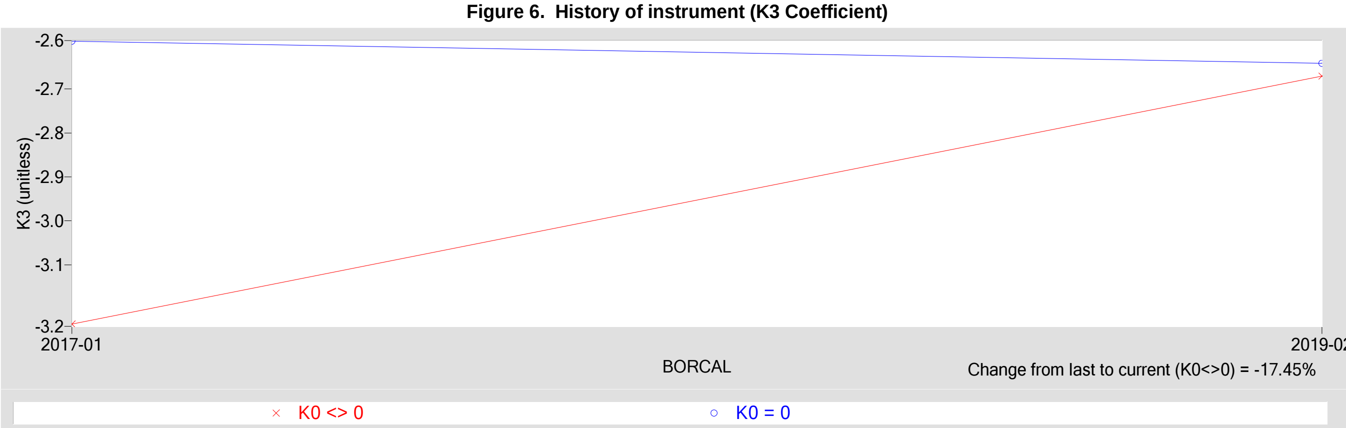


Figure 6. History of instrument (K3 Coefficient)



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:**	29146F3
Calibration Date:	4/19/2019	**Due Date:**	4/19/2020
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	3/25-31, 4/1-6, 4/8-19		

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

______________________________ _______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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)* [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

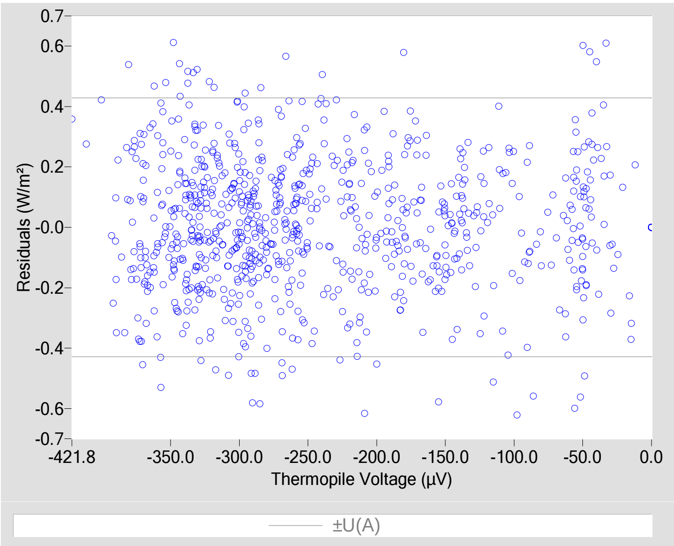


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

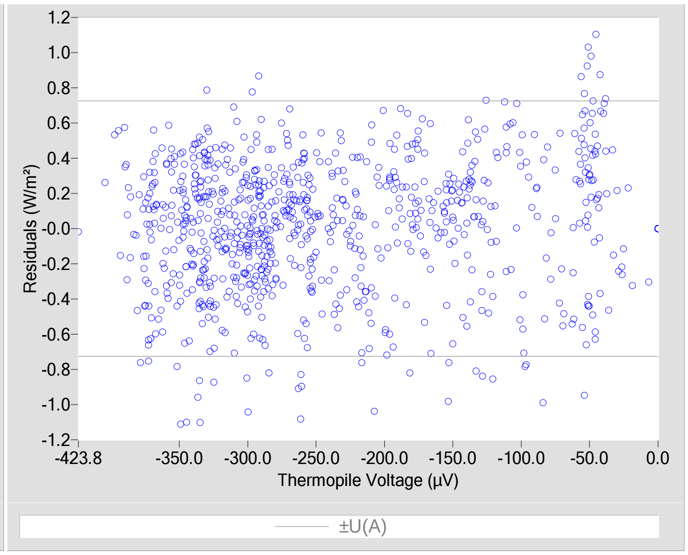


Table 2. Calibration Coefficients for K0<>0

K0	3.6
K1	0.24570
K2	0.9997
K3	-3.32
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24570
K2	1.0091
K3	-3.19
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.22
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

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.37
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)

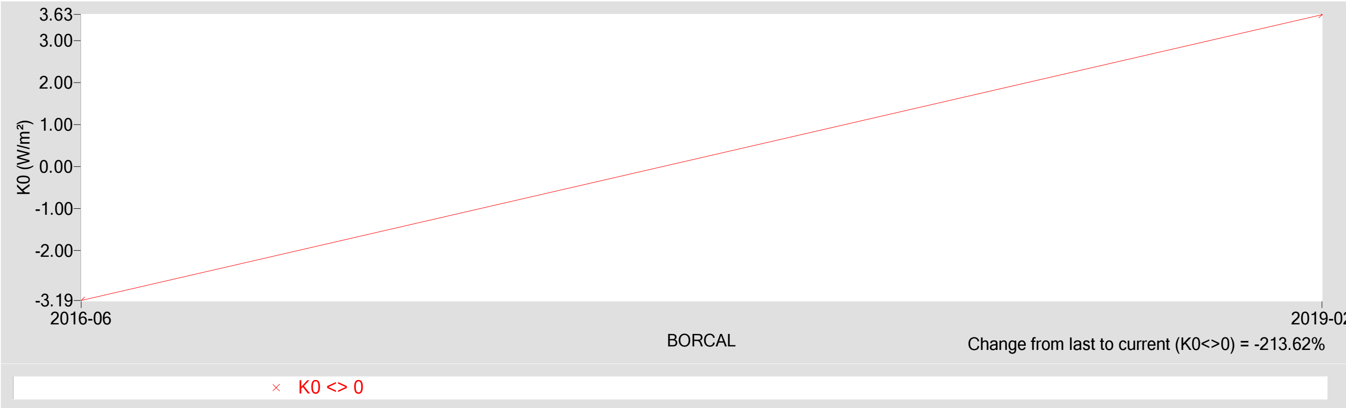


Figure 4. History of instrument (K1 Coefficient)

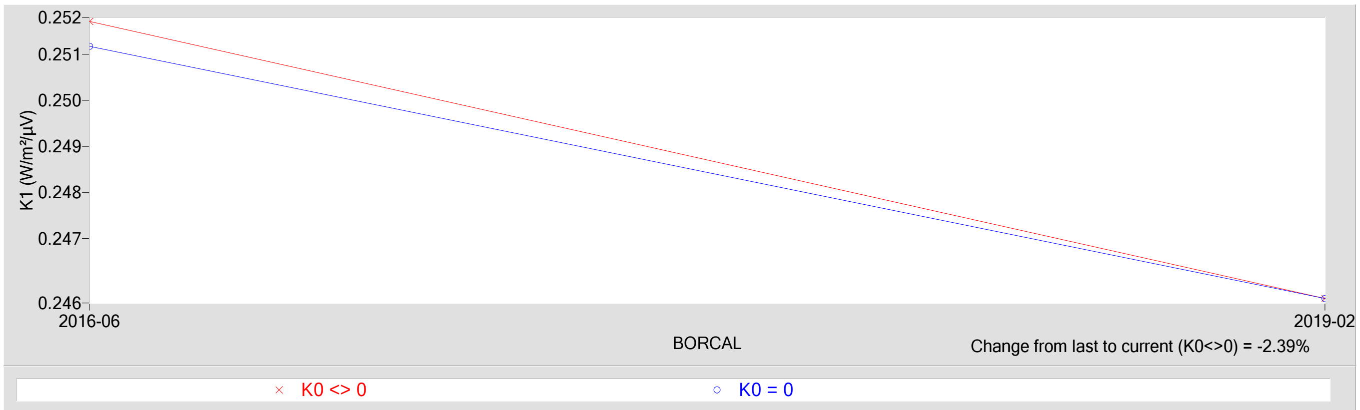


Figure 5. History of instrument (K2 Coefficient)

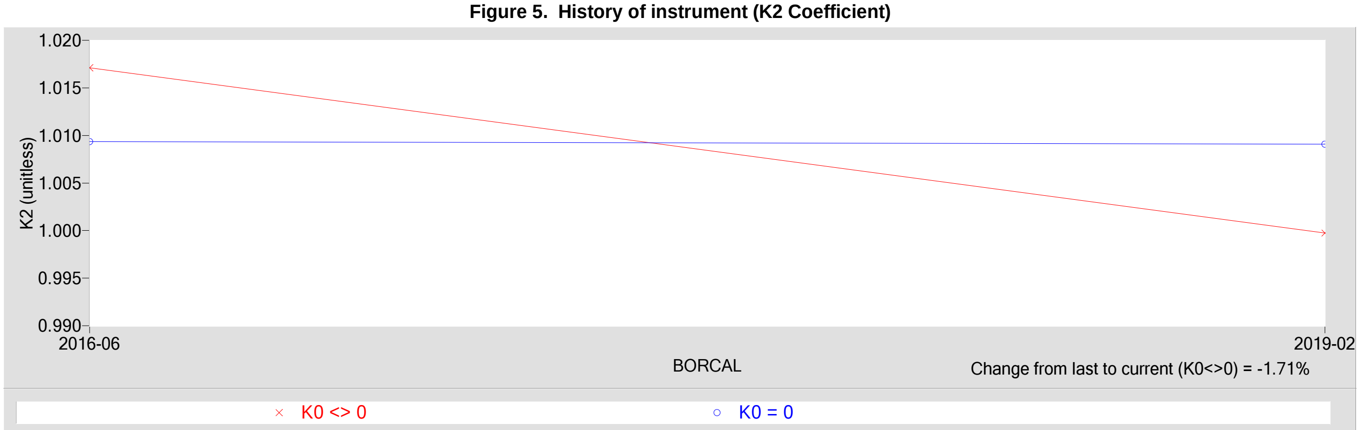
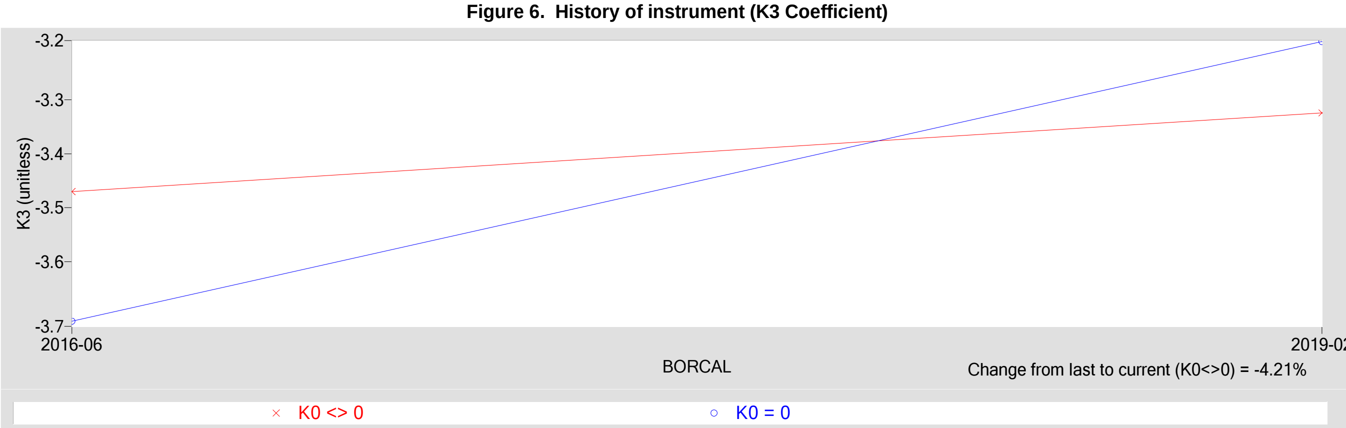


Figure 6. History of instrument (K3 Coefficient)



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: 30013F3

Calibration Date: 4/19/2019

Due Date: 4/19/2020

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 3/25-31, 4/1-6, 4/8-19

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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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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)* [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

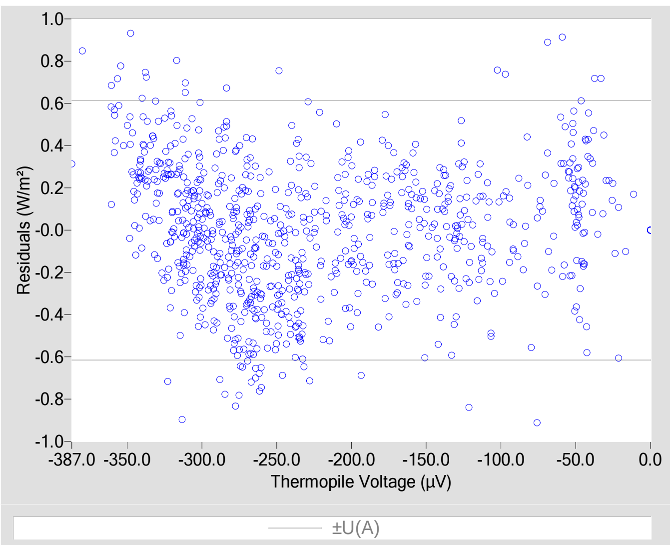


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

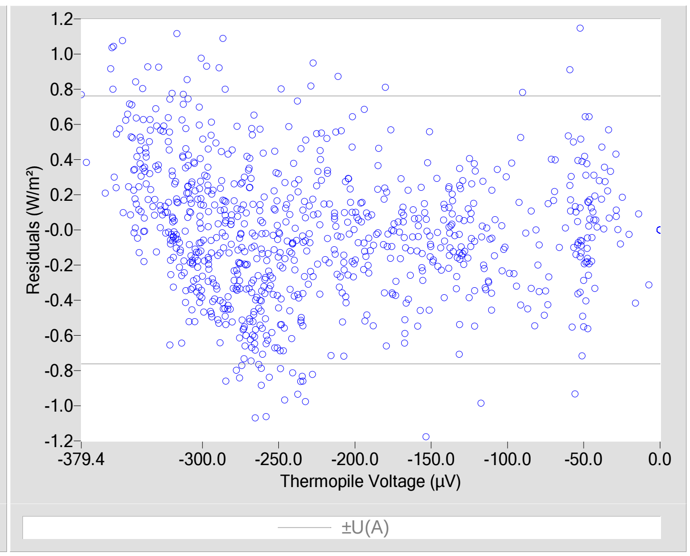


Table 2. Calibration Coefficients for K0<>0

K0	-2.8
K1	0.26928
K2	1.0047
K3	-4.35
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.26962
K2	0.9975
K3	-4.20
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.31
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

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.39
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)	±3.0

Figure 3. History of instrument (K0 Coefficient)

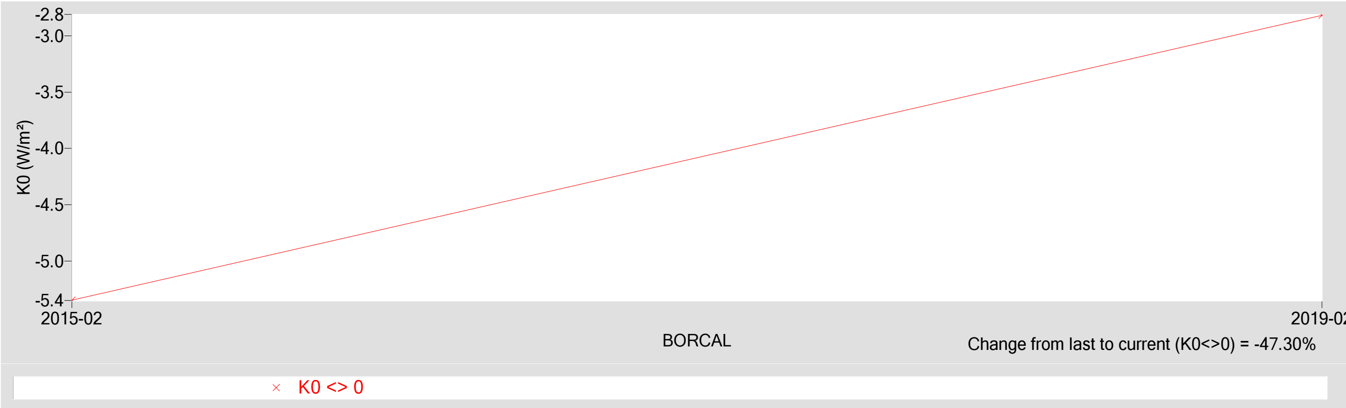


Figure 4. History of instrument (K1 Coefficient)

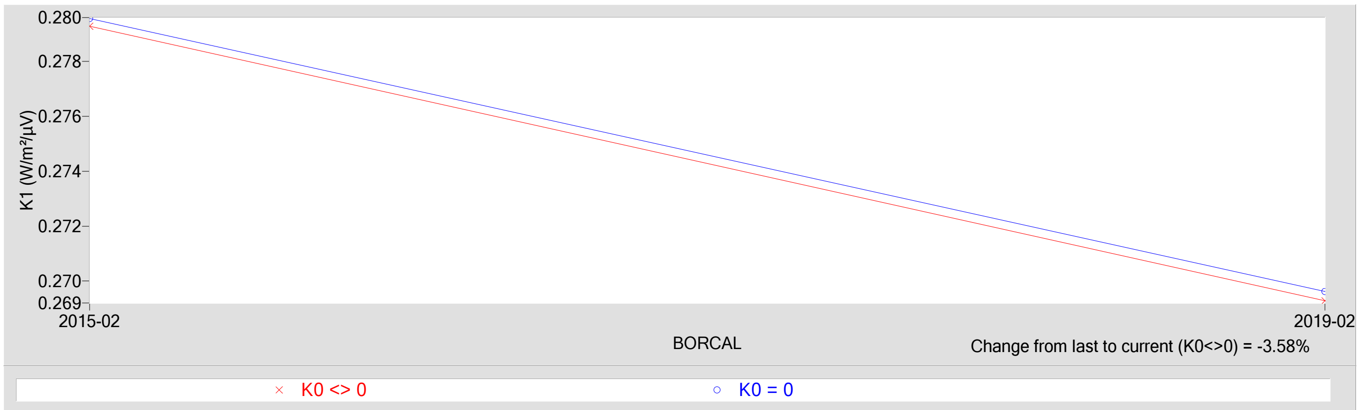


Figure 5. History of instrument (K2 Coefficient)

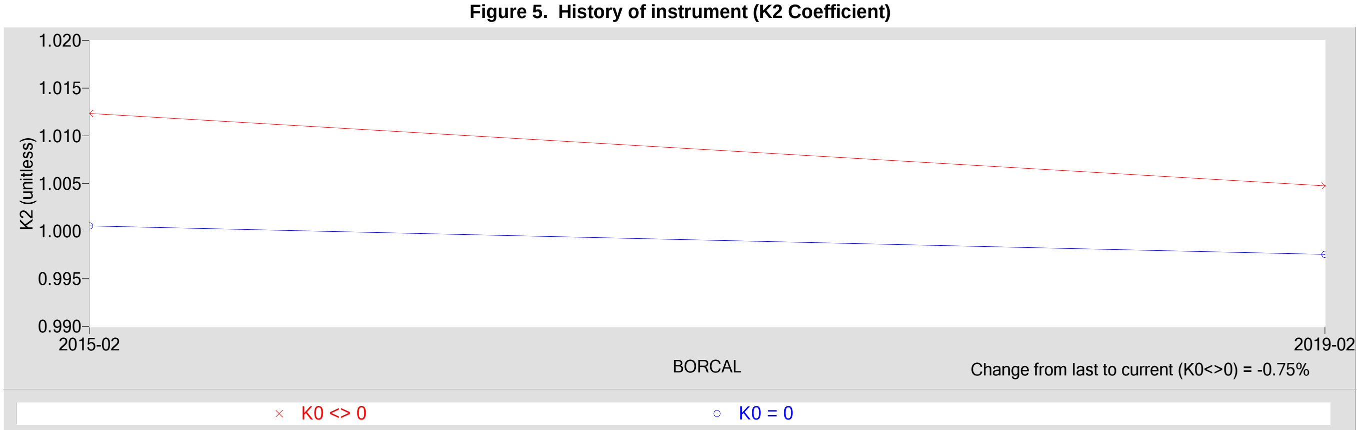
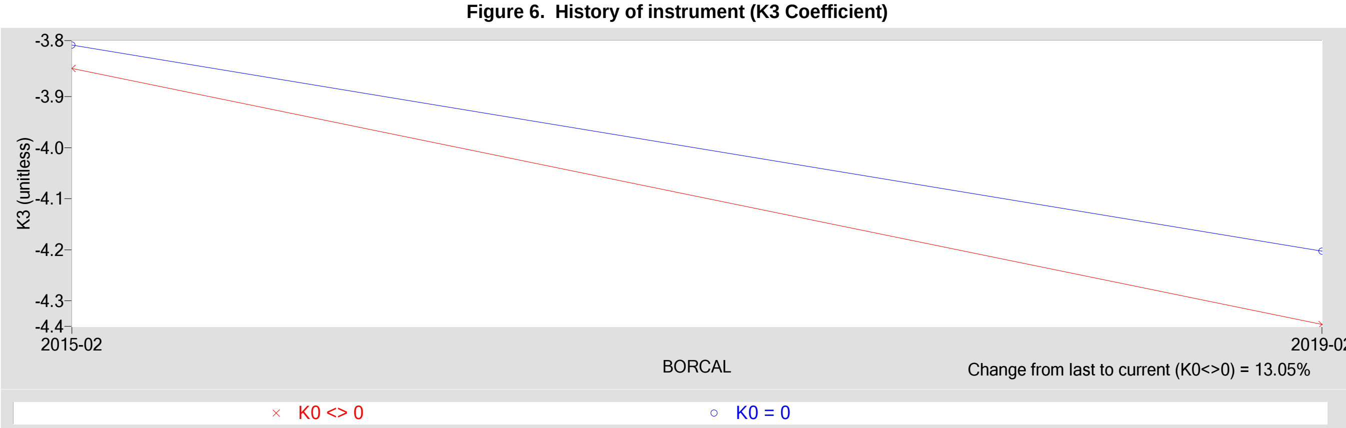


Figure 6. History of instrument (K3 Coefficient)



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:**	30133F3
Calibration Date:	4/19/2019	**Due Date:**	4/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	3/25-31, 4/1-6, 4/8-19		

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

______________________________ ______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30133F3 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

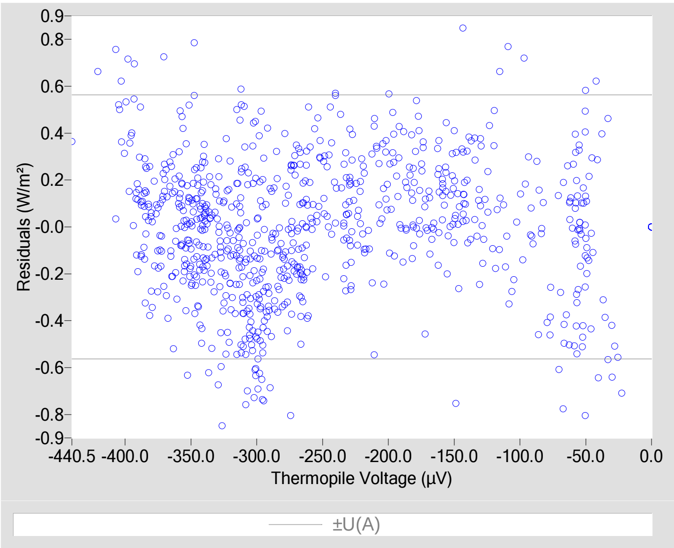


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

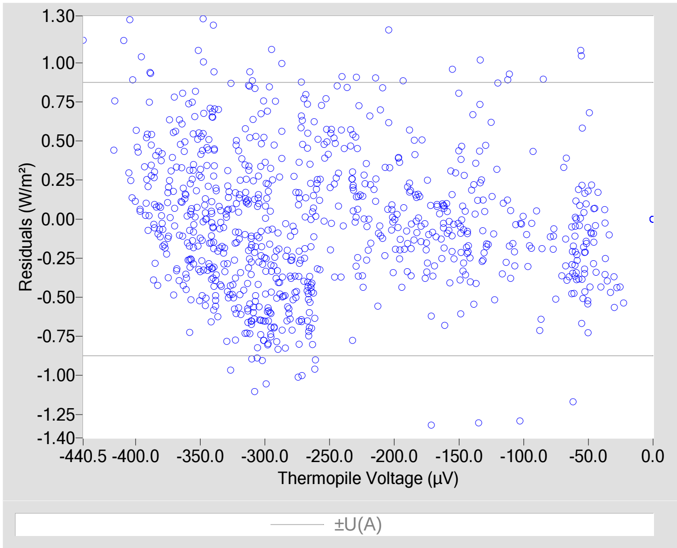


Table 2. Calibration Coefficients for K0<>0

K0	-4.2
K1	0.23916
K2	1.0114
K3	-3.35
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23980
K2	1.0007
K3	-3.04
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
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)	±3.0

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.45
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)

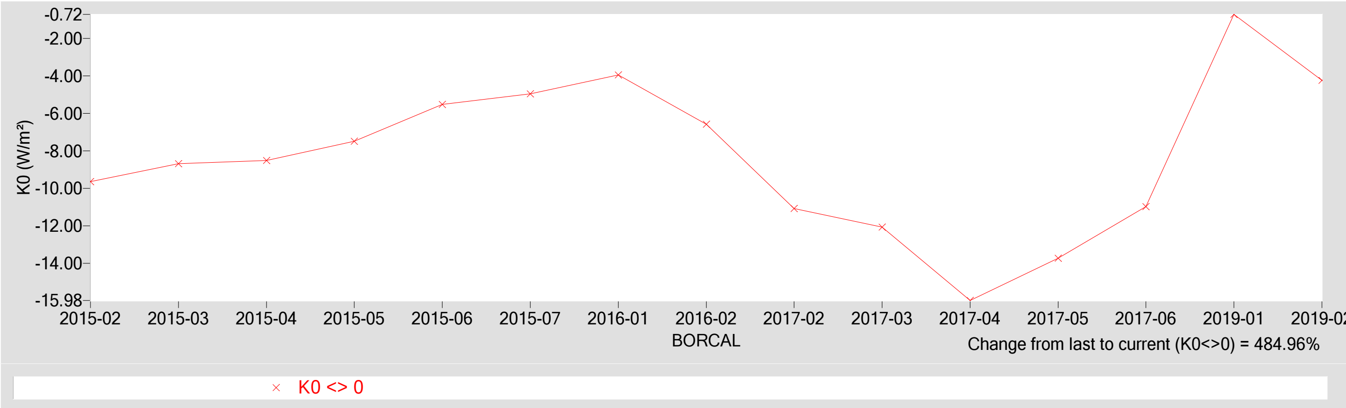


Figure 4. History of instrument (K1 Coefficient)

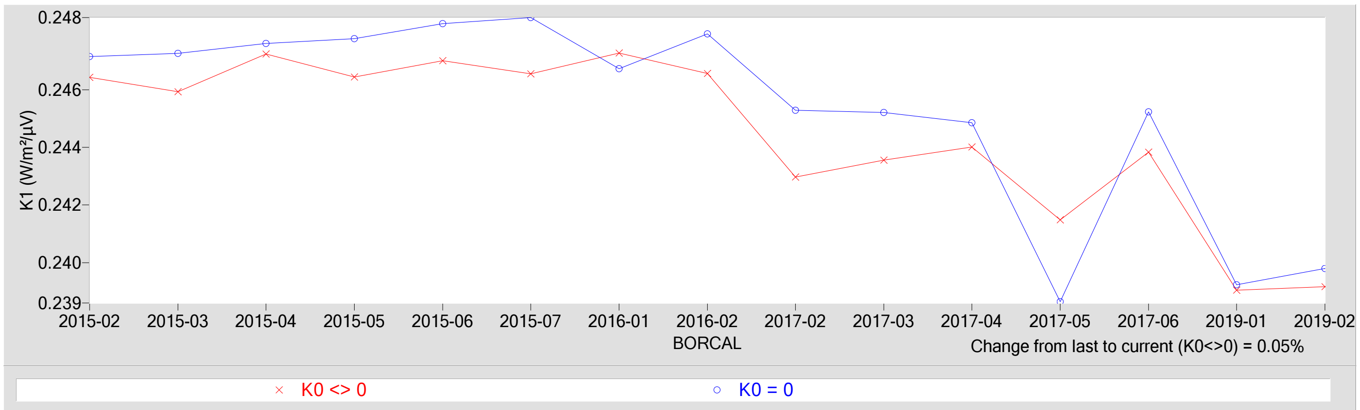


Figure 5. History of instrument (K2 Coefficient)

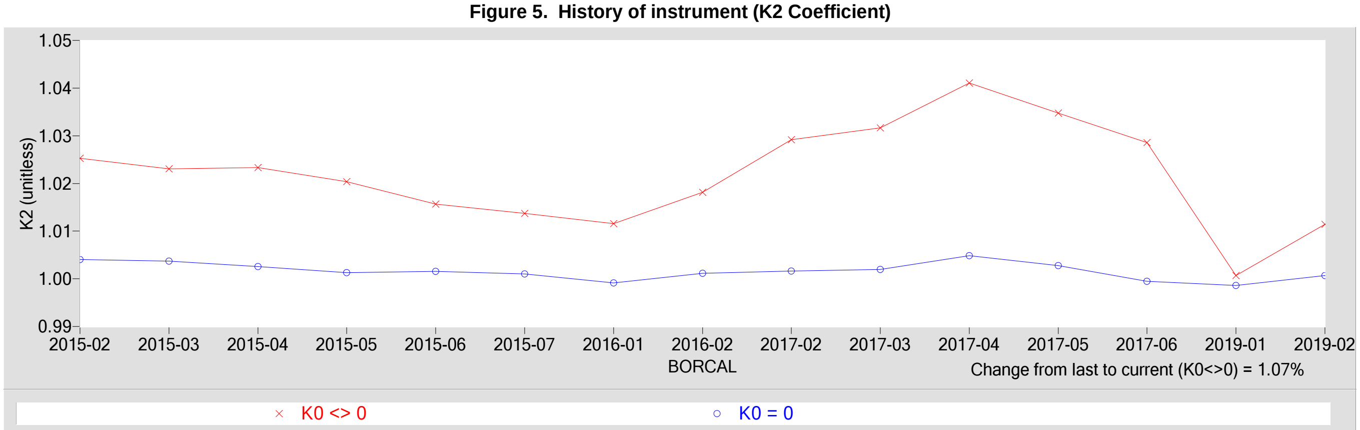
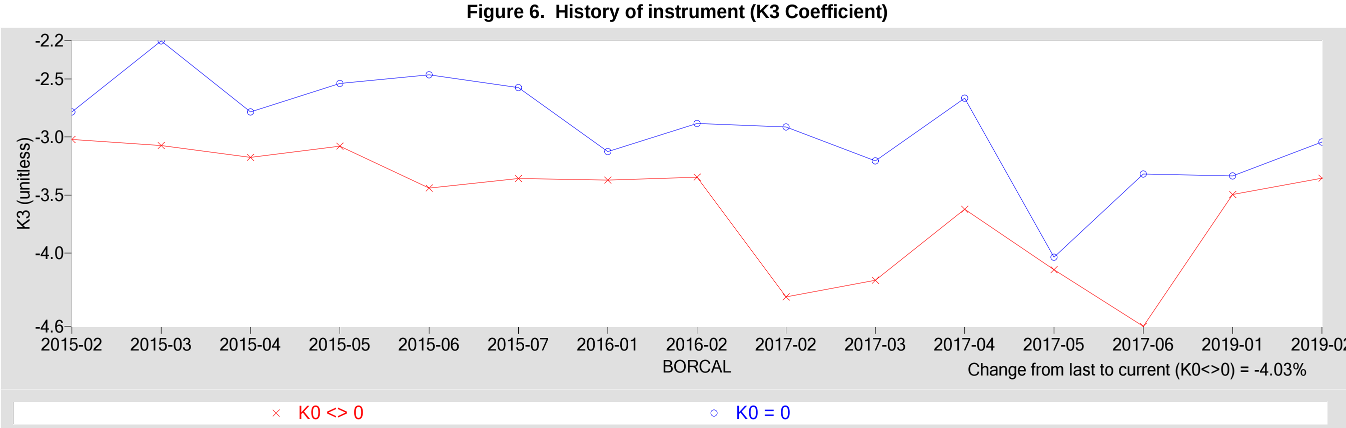


Figure 6. History of instrument (K3 Coefficient)



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:**	30344F3
Calibration Date:	4/19/2019	**Due Date:**	4/19/2020
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	3/25-31, 4/1-6, 4/8-19		

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

____ __________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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

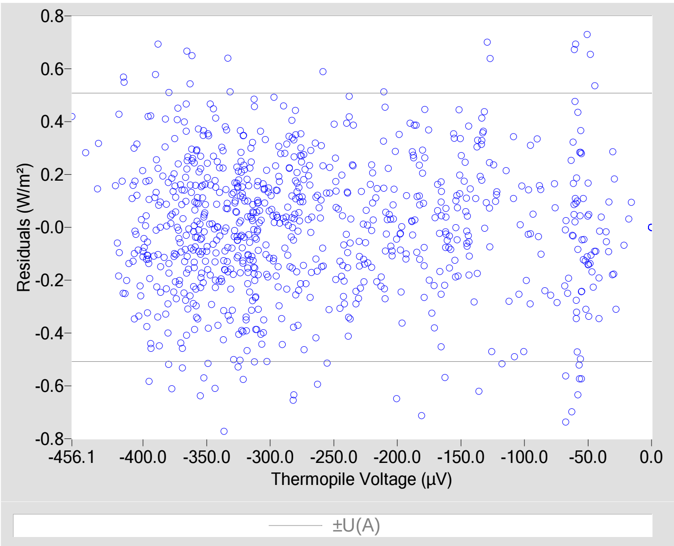


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

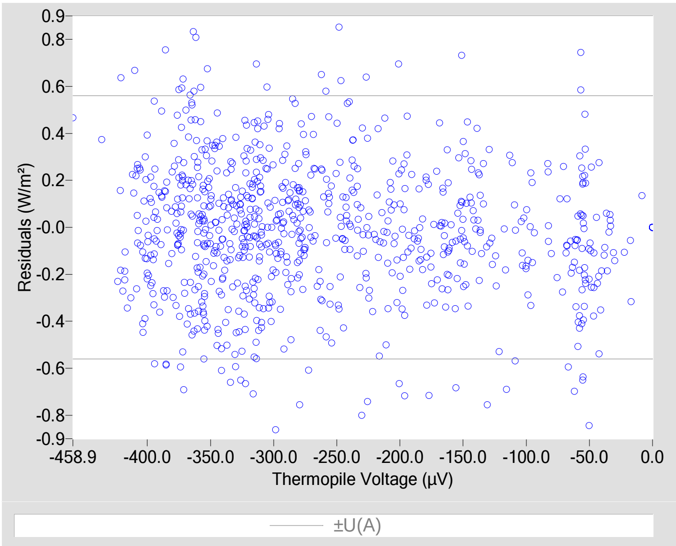


Table 2. Calibration Coefficients for K0<>0

K0	-1.5
K1	0.22762
K2	1.0047
K3	-3.32
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.22779
K2	1.0008
K3	-3.26
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.26
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

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
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)	±3.0

Figure 3. History of instrument (K0 Coefficient)

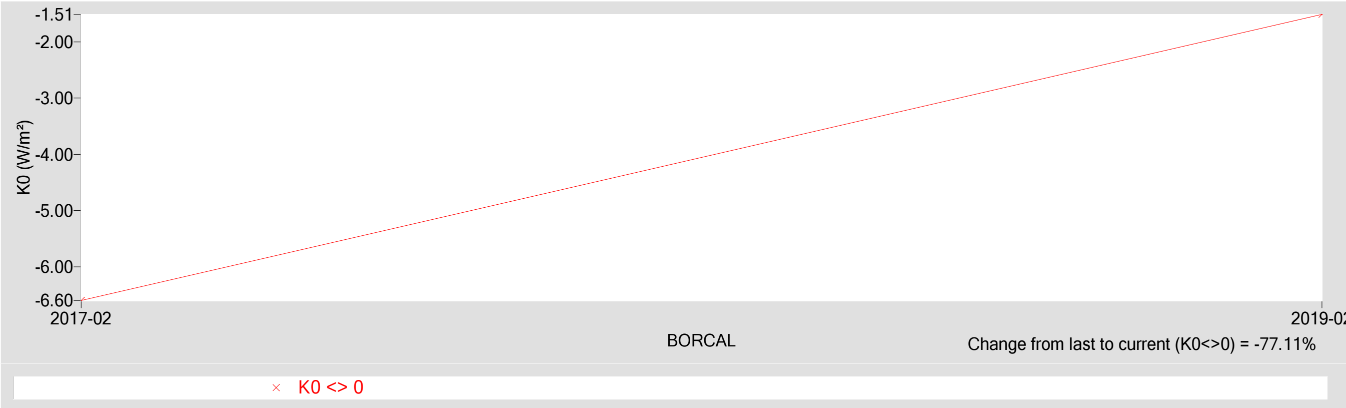


Figure 4. History of instrument (K1 Coefficient)

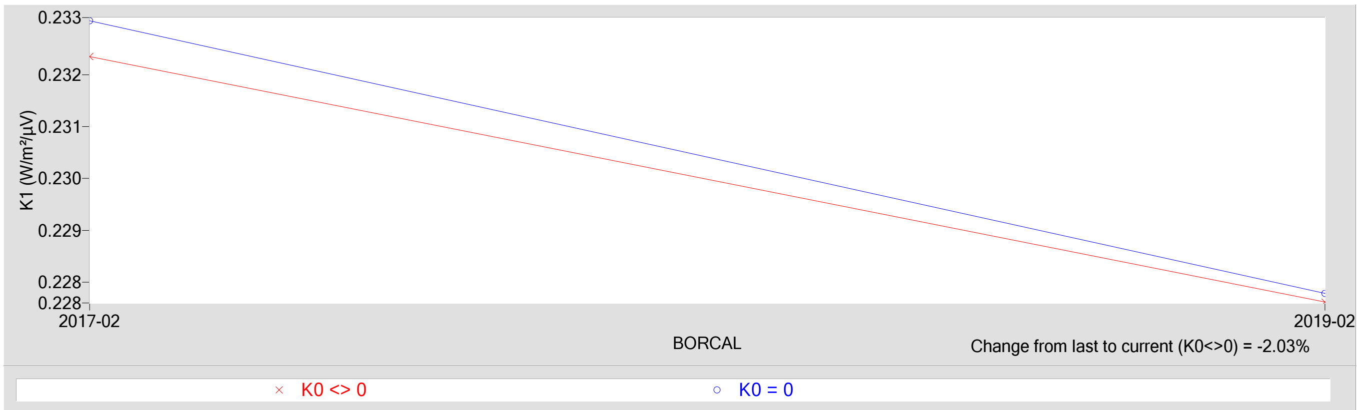


Figure 5. History of instrument (K2 Coefficient)

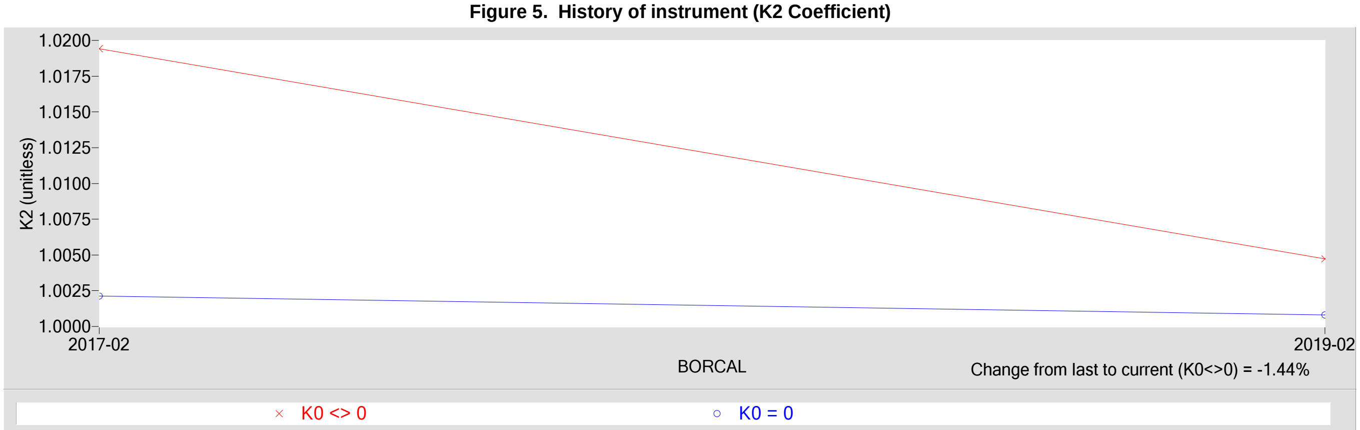
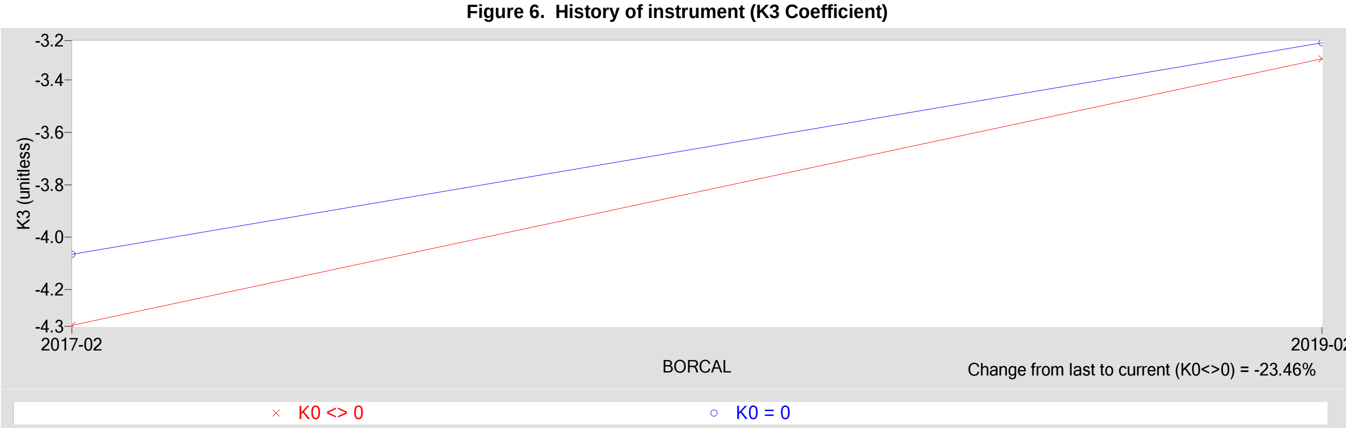


Figure 6. History of instrument (K3 Coefficient)



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: 4/19/2019

Due Date: 4/19/2020

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 3/25-31, 4/1-6, 4/8-19

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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:

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

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

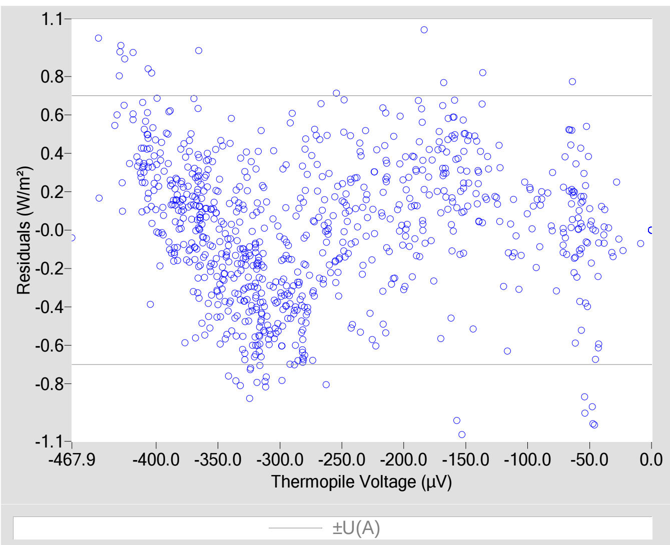


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

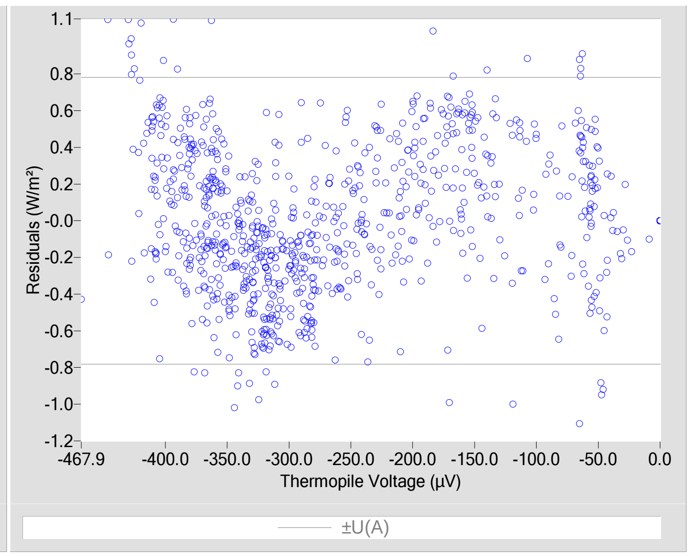


Table 2. Calibration Coefficients for K0<>0

K0	2.2
K1	0.22350
K2	0.9980
K3	-3.27
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.22333
K2	1.0037
K3	-3.31
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
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)	±3.0

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.40
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)	±3.0

Figure 3. History of instrument (K0 Coefficient)

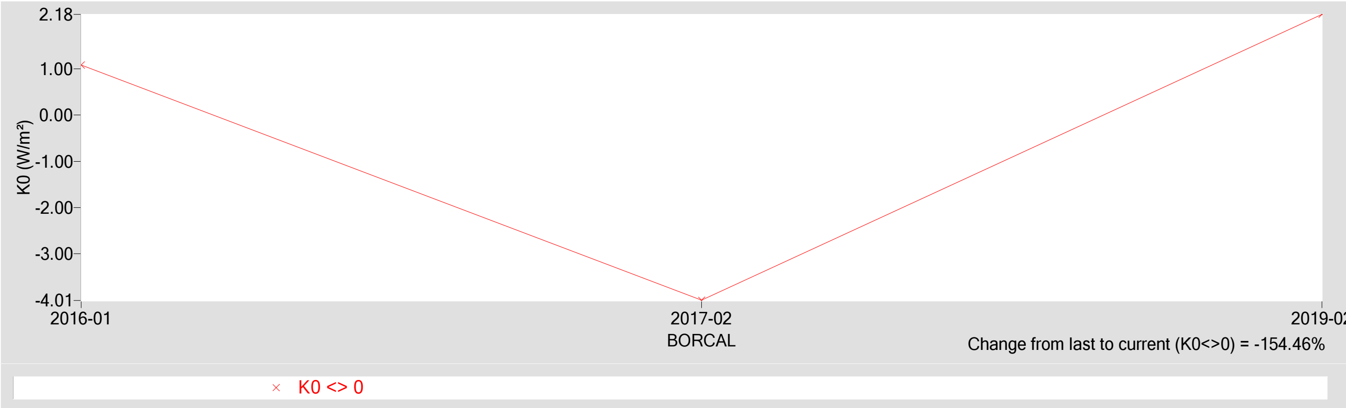


Figure 4. History of instrument (K1 Coefficient)

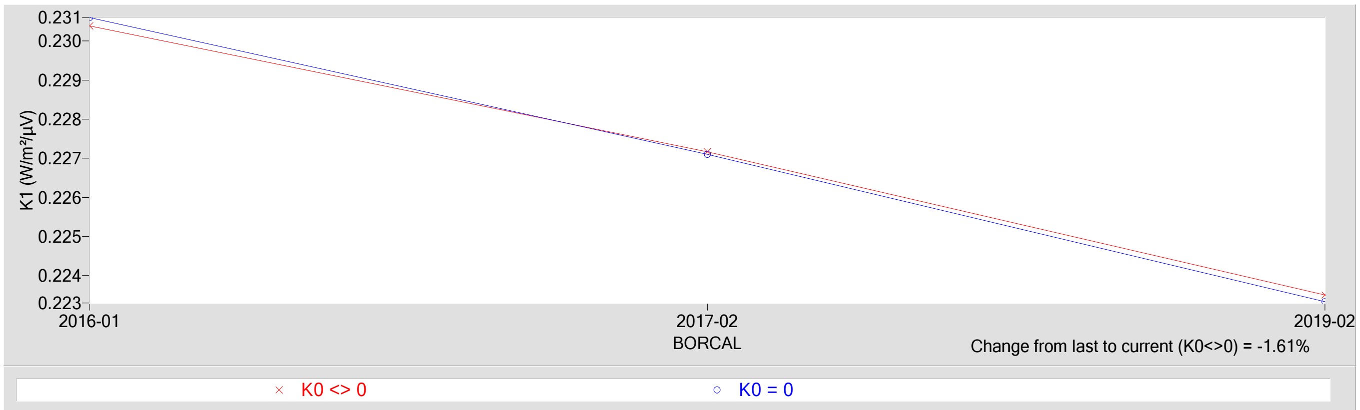


Figure 5. History of instrument (K2 Coefficient)

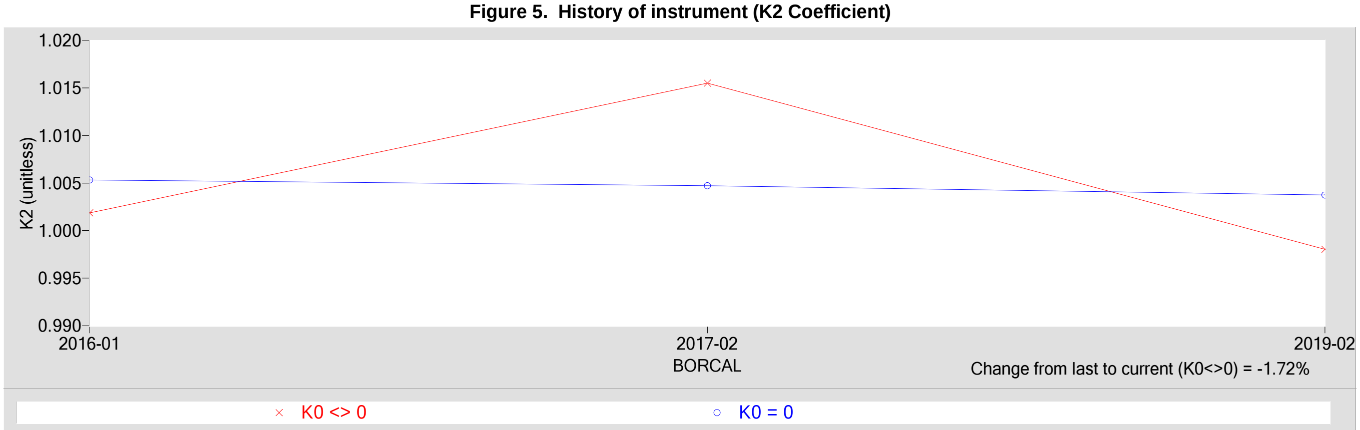
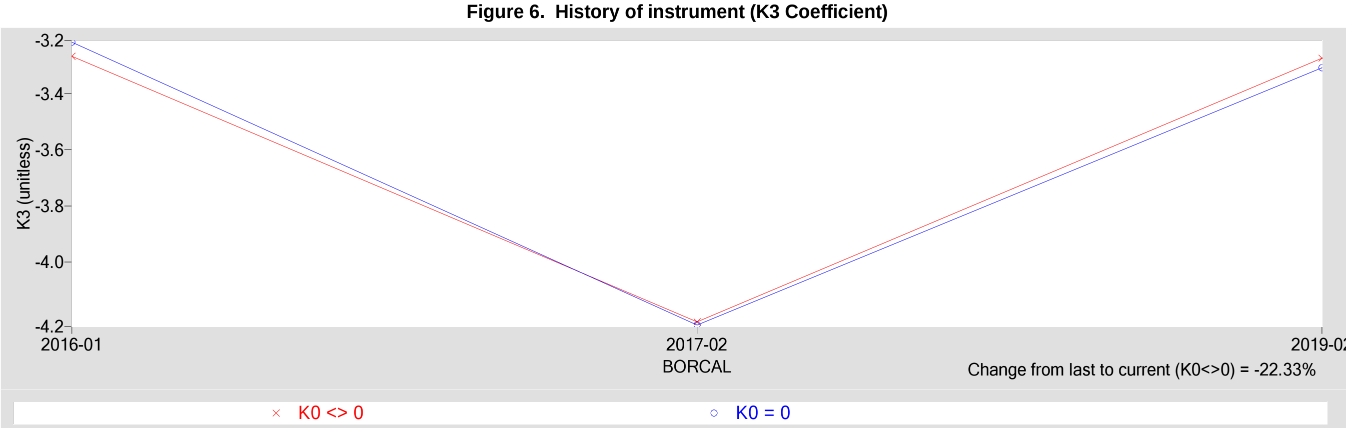


Figure 6. History of instrument (K3 Coefficient)



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:	4/19/2019	**Due Date:**	4/19/2020
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	3/25-31, 4/1-6, 4/8-19		

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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

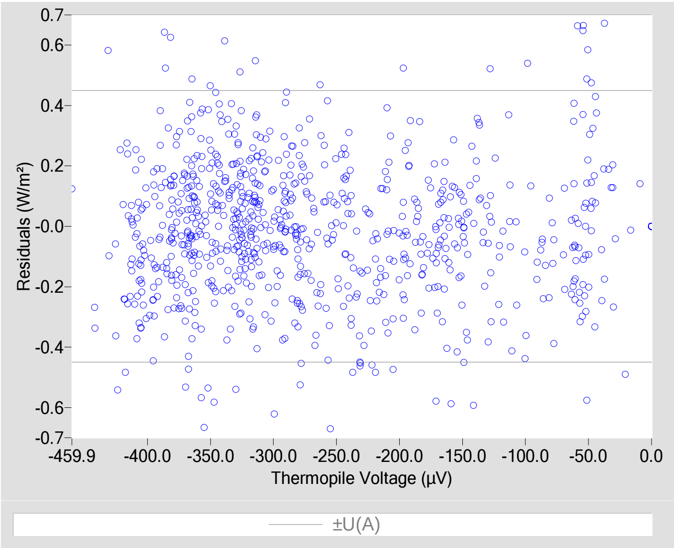


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

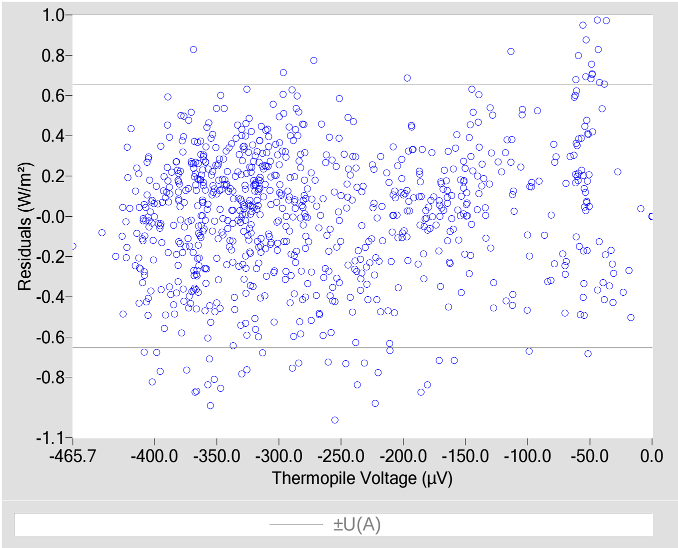


Table 2. Calibration Coefficients for K0<>0

K0	2.9
K1	0.22302
K2	0.9970
K3	-2.72
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.22308
K2	1.0047
K3	-2.65
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.23
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

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
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)	±3.0

Figure 3. History of instrument (K0 Coefficient)

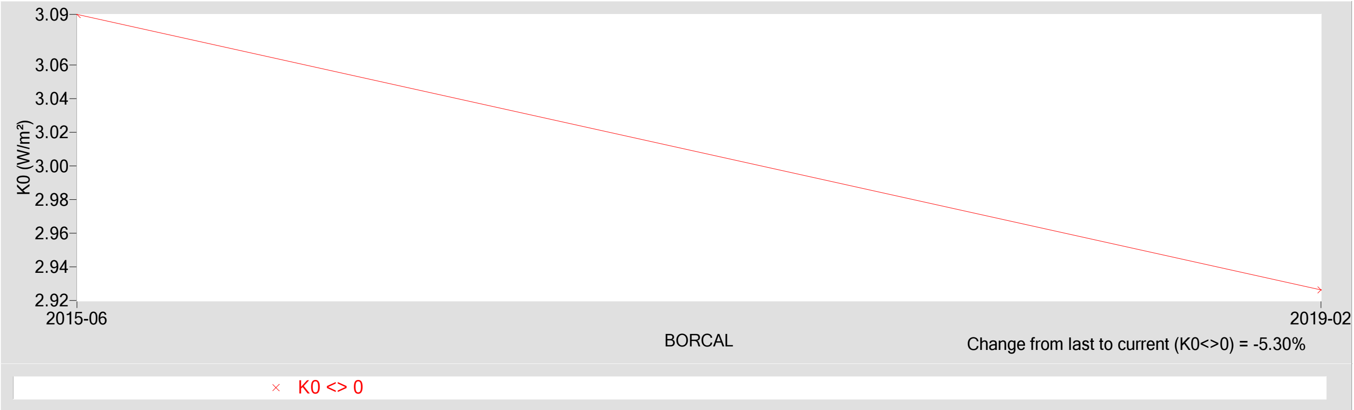


Figure 4. History of instrument (K1 Coefficient)

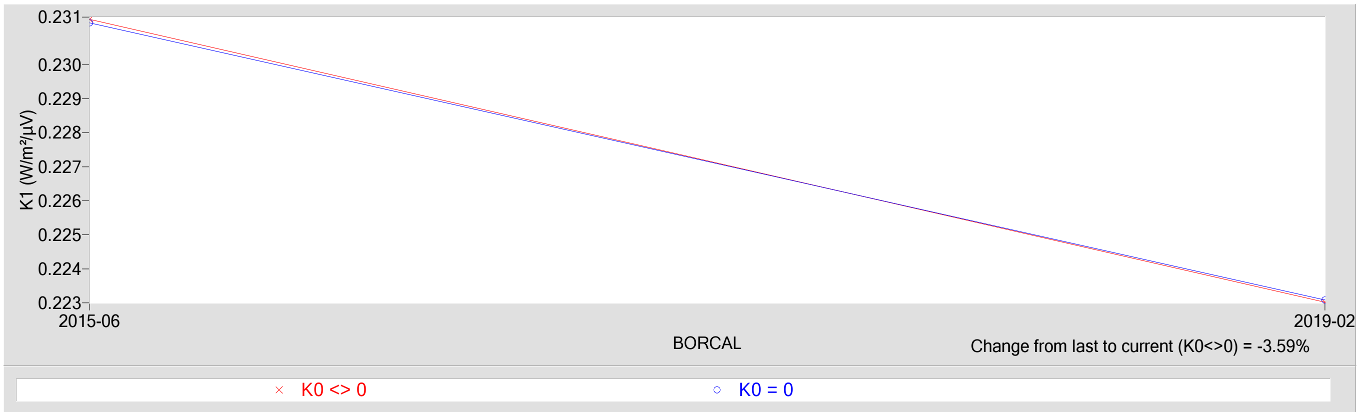


Figure 5. History of instrument (K2 Coefficient)

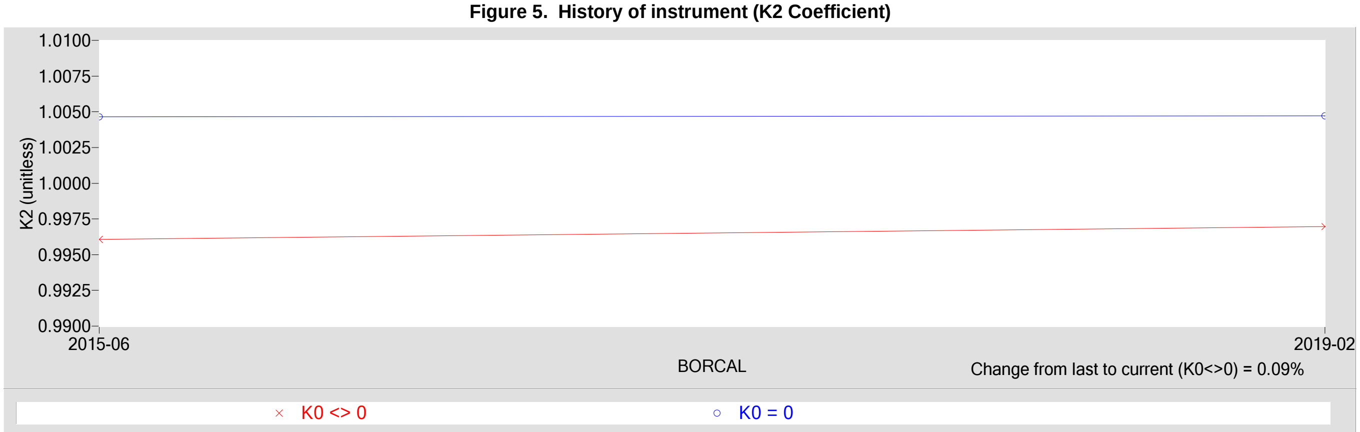
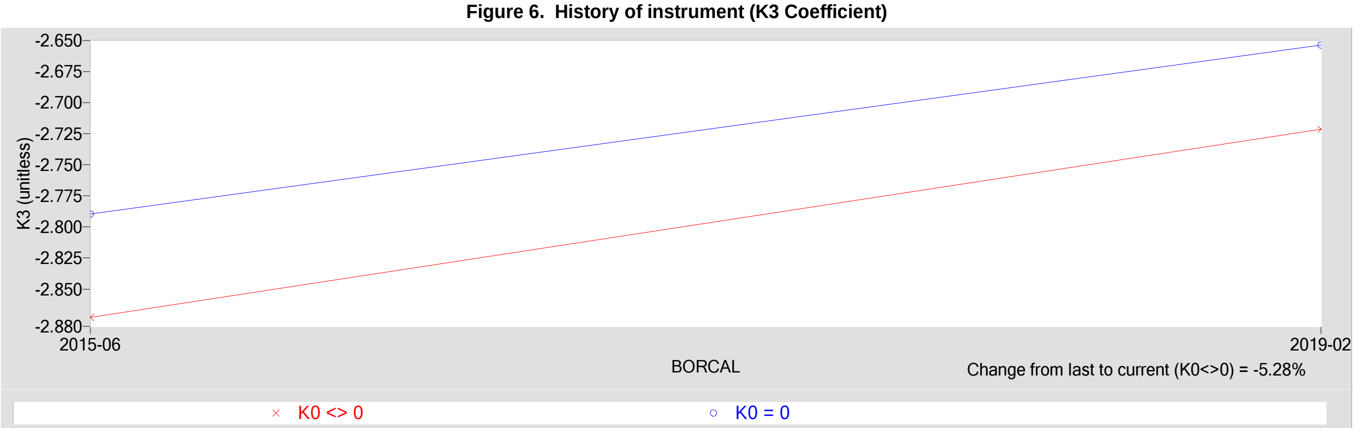


Figure 6. History of instrument (K3 Coefficient)



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:**	30834F3
Calibration Date:	4/19/2019	**Due Date:**	4/19/2020
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	3/25-31, 4/1-6, 4/8-19		

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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

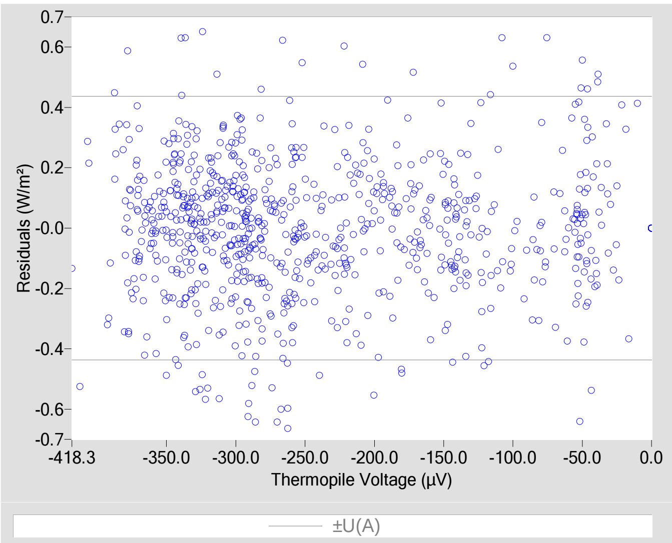


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

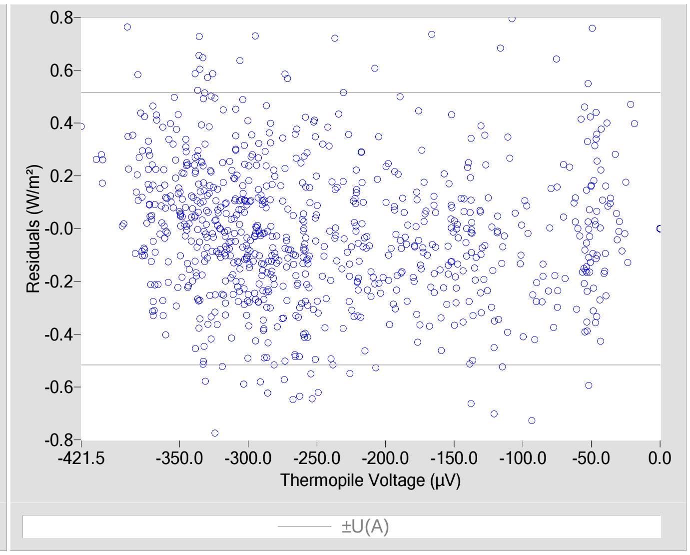


Table 2. Calibration Coefficients for K0<>0

K0	-1.8
K1	0.24253
K2	1.0076
K3	-3.91
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24282
K2	1.0029
K3	-3.77
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.22
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

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.26
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)

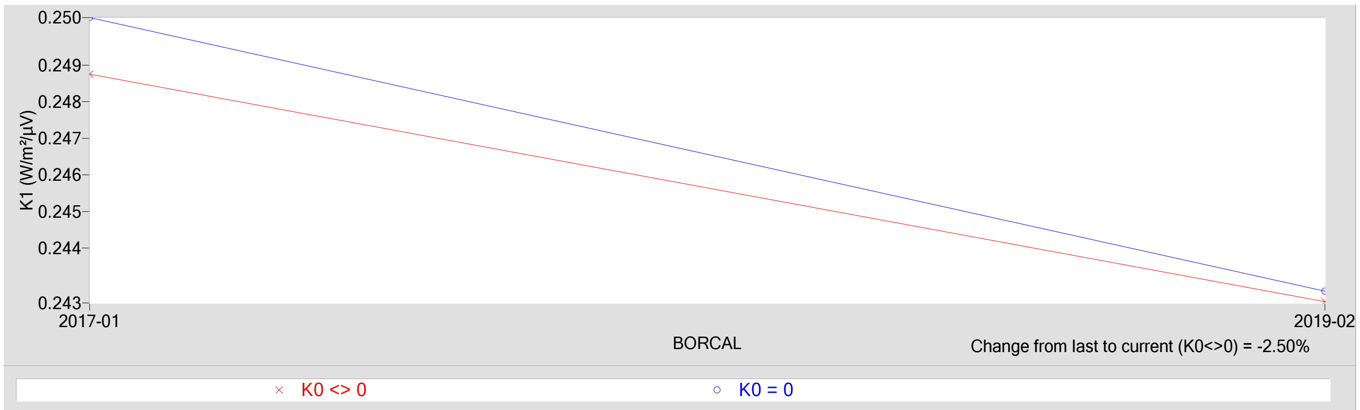


Figure 5. History of instrument (K2 Coefficient)

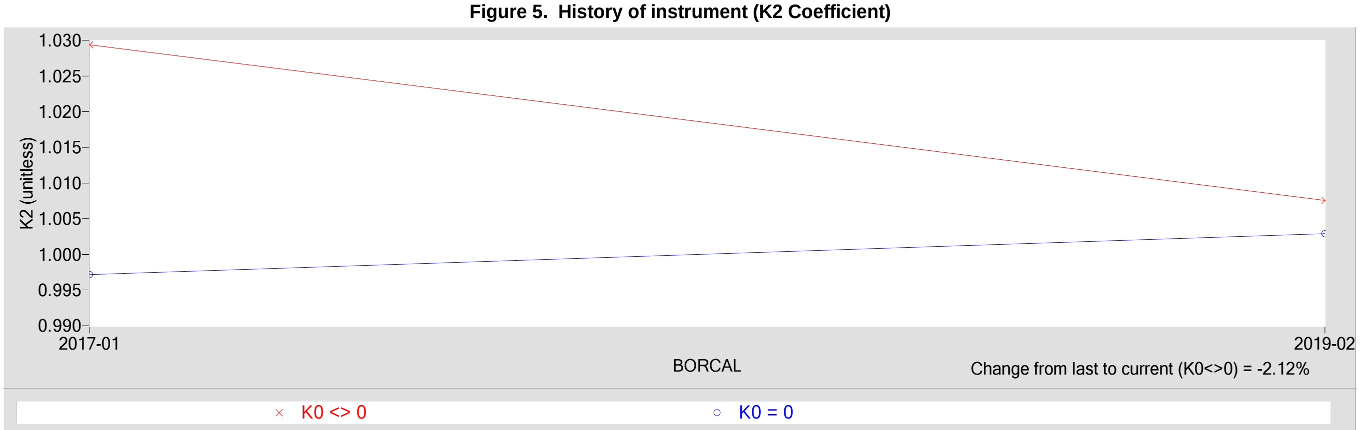
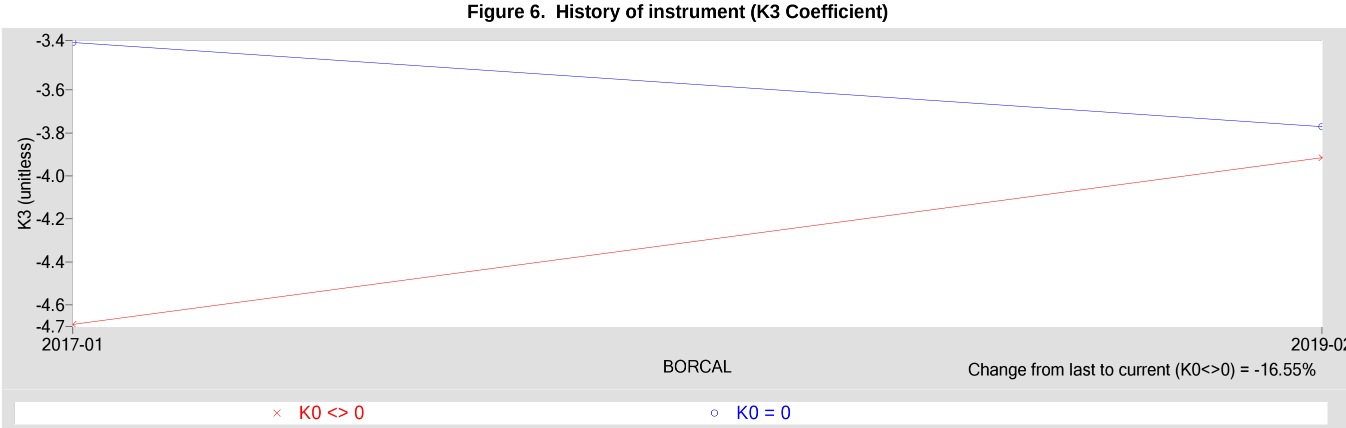


Figure 6. History of instrument (K3 Coefficient)



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: 30836F3
Calibration Date: 4/19/2019
Due Date: 4/19/2020
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 3/25-31, 4/1-6, 4/8-19

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

______________________________ _______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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)* [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

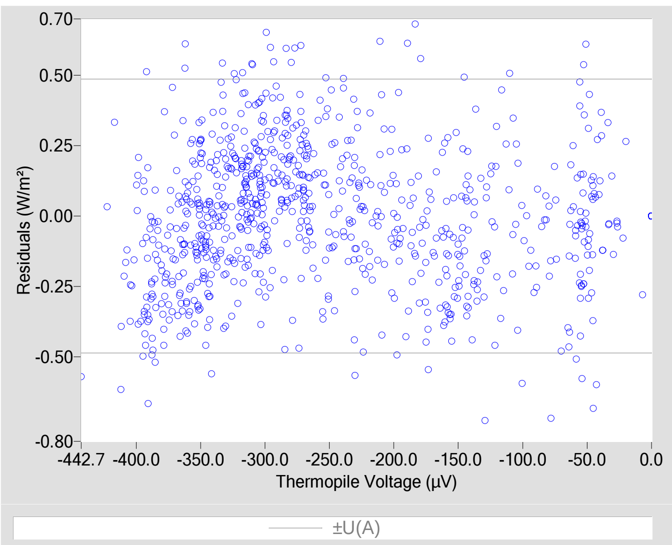


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

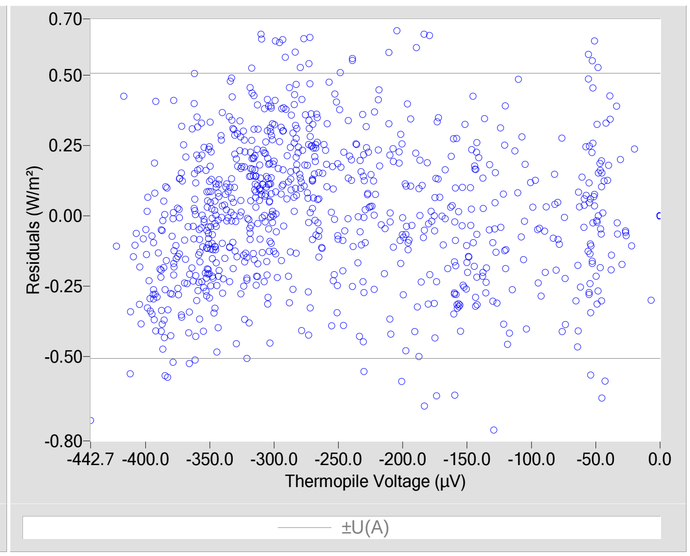


Table 2. Calibration Coefficients for K0<>0

K0	0.9
K1	0.23470
K2	0.9971
K3	-3.23
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23466
K2	0.9996
K3	-3.23
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.25
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

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.26
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)

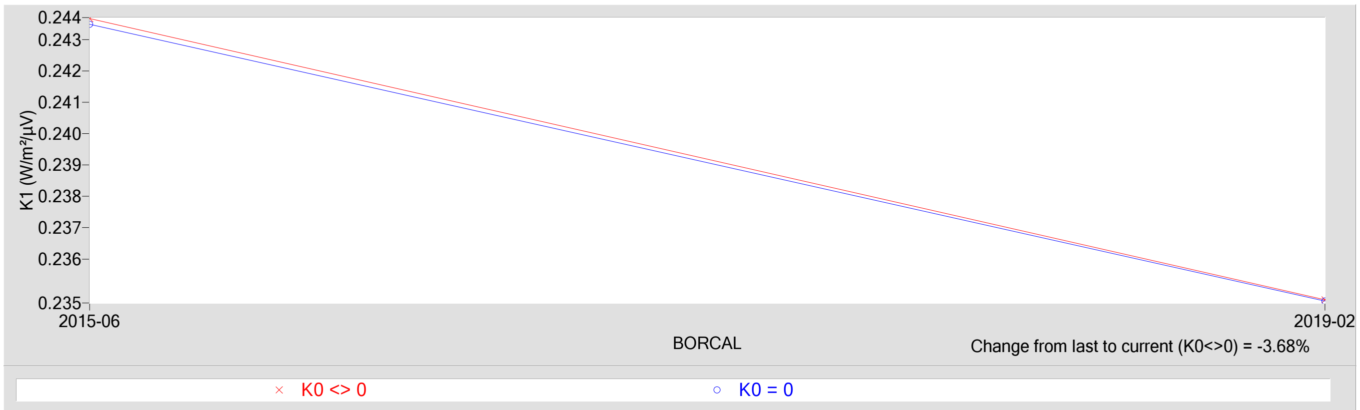


Figure 5. History of instrument (K2 Coefficient)

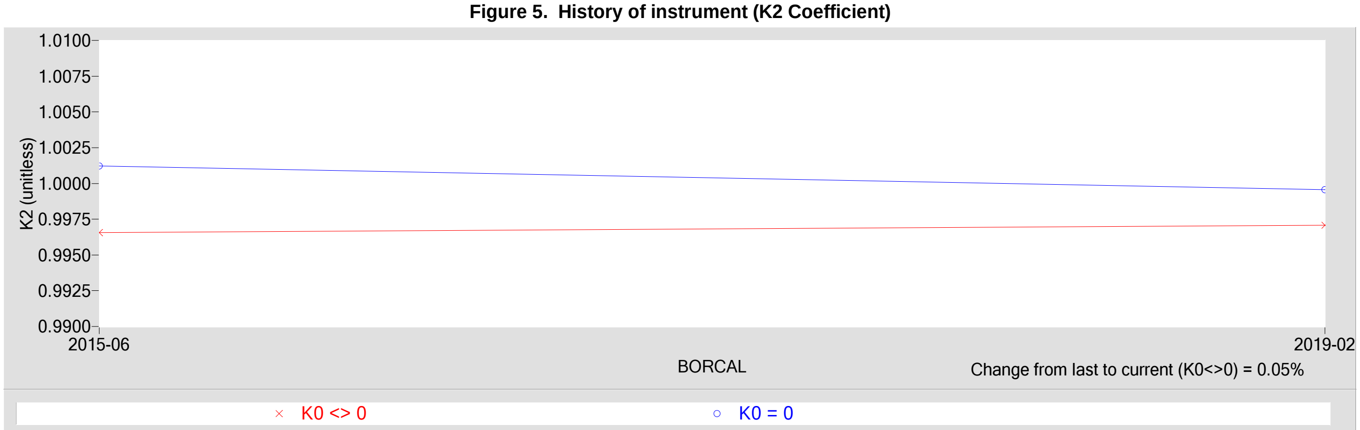
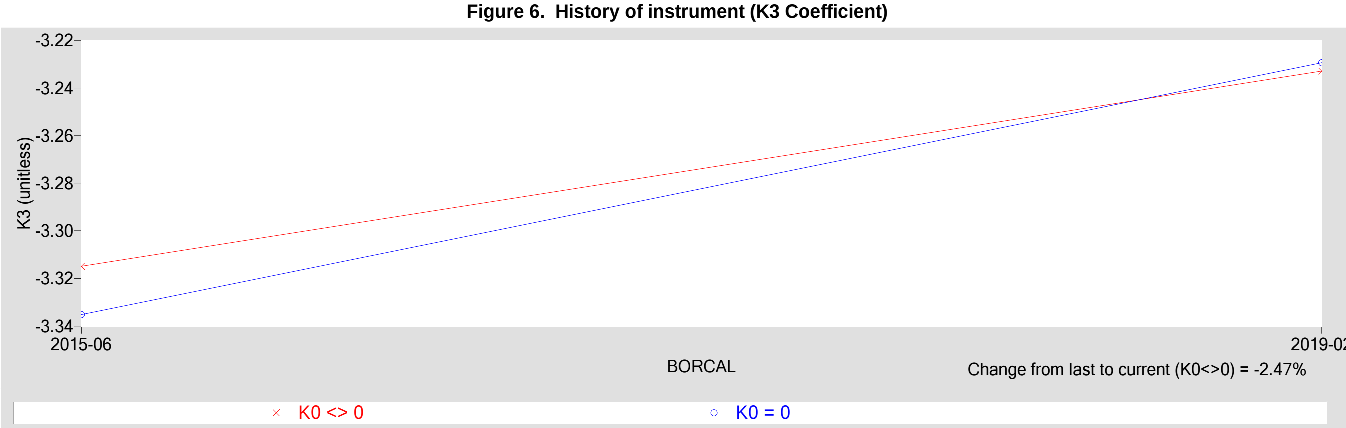


Figure 6. History of instrument (K3 Coefficient)



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:**	36368F3
Calibration Date:	4/19/2019	**Due Date:**	4/19/2020
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	3/25-31, 4/1-6, 4/8-19		

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 2009-1206	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	02/12/2019	02/12/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	02/12/2019	02/12/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	04/16/2018	04/16/2020
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	04/16/2018	04/16/2020

‡ 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: Peter Gotseff and Craig Webb

____ __________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 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 coeffiiceints,
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

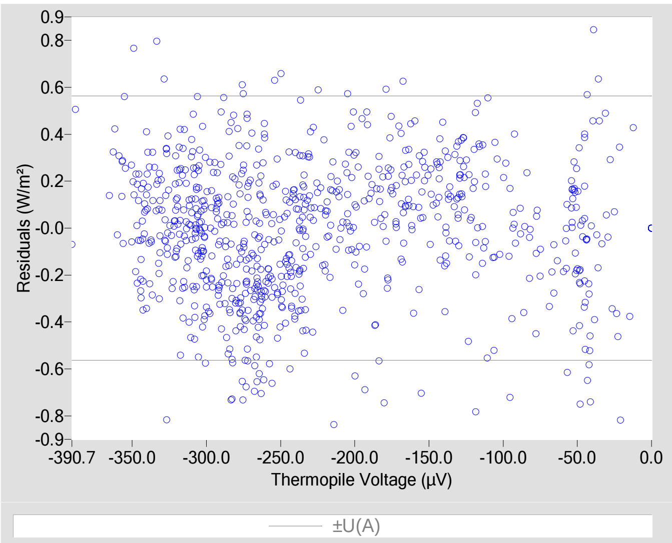


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

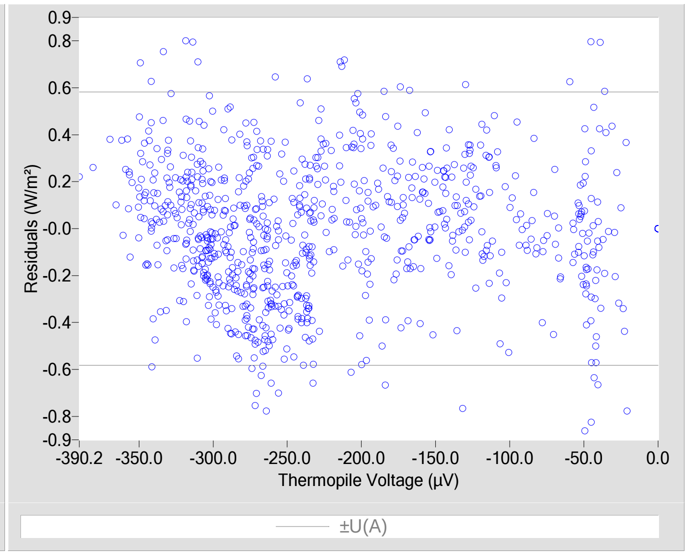


Table 2. Calibration Coefficients for K0<>0

K0	-0.9
K1	0.27233
K2	1.0102
K3	-4.09
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.27240
K2	1.0078
K3	-4.05
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
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)	±3.0

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.5
Type-A Standard Uncertainty, u(A) (W/m²)	±0.30
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)

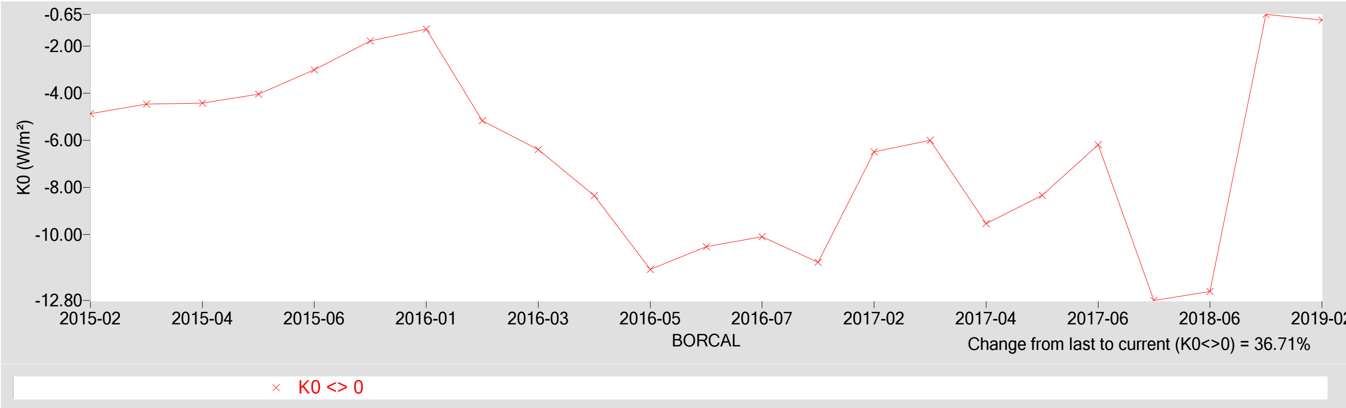


Figure 4. History of instrument (K1 Coefficient)

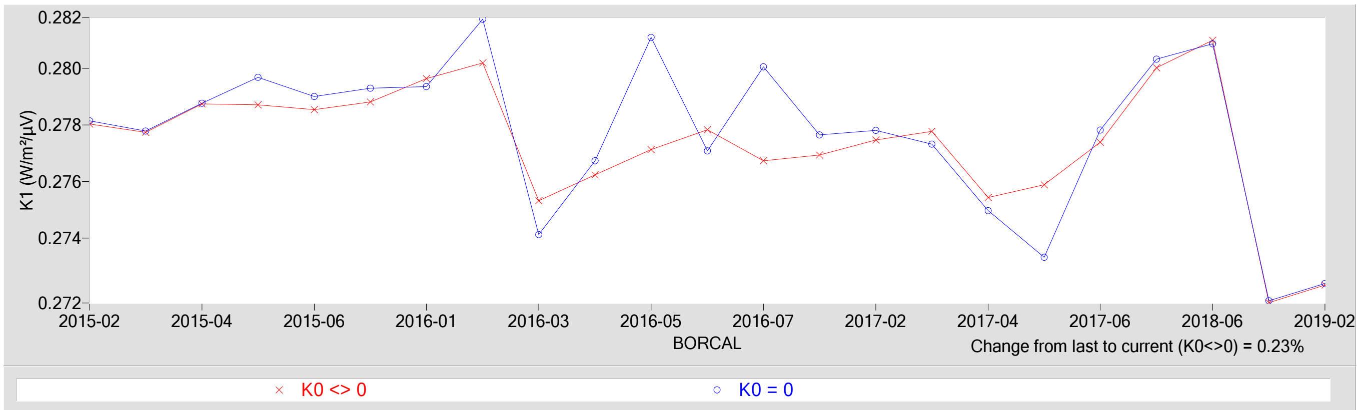


Figure 5. History of instrument (K2 Coefficient)

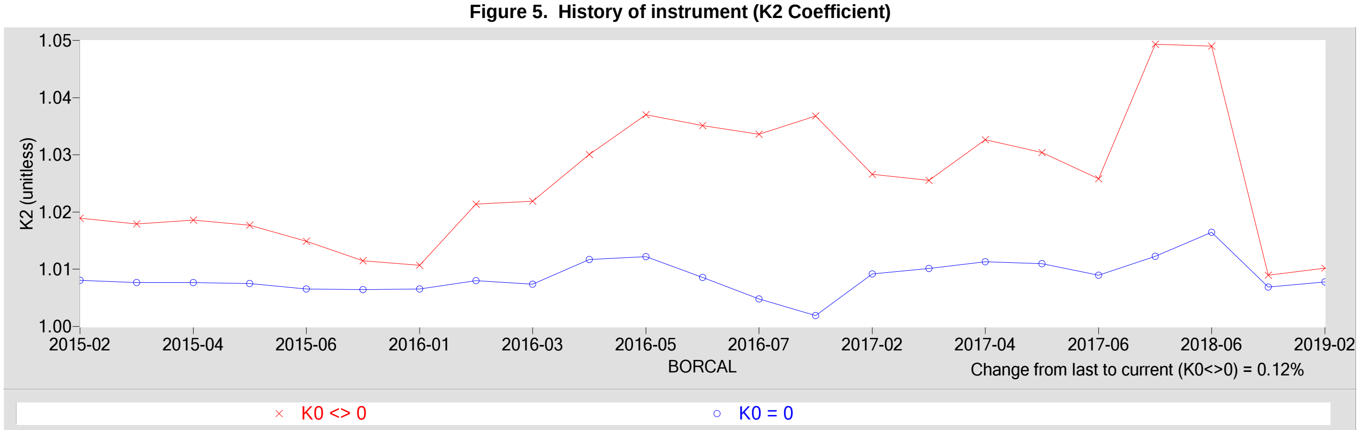
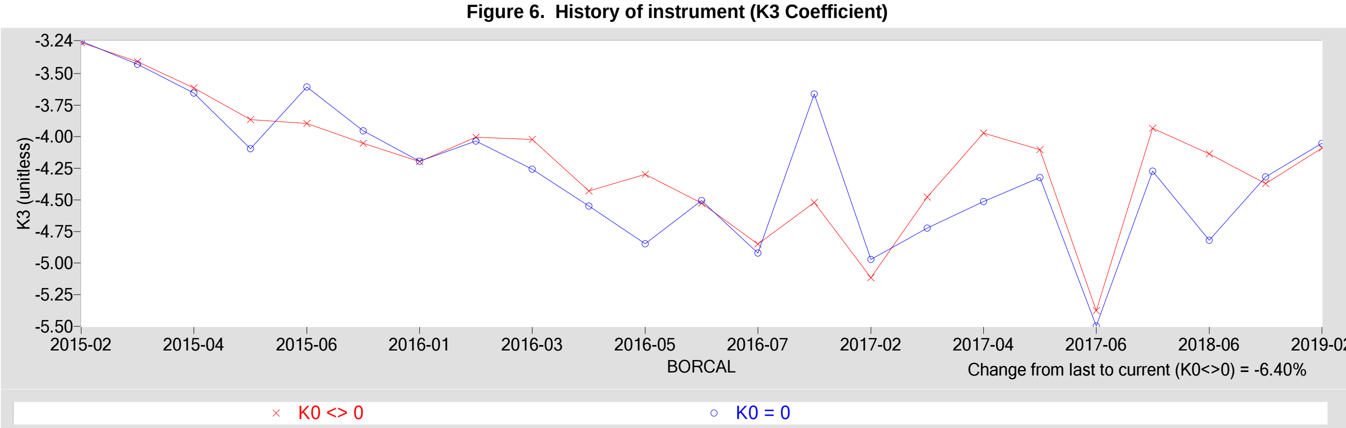


Figure 6. History of instrument (K3 Coefficient)



References:

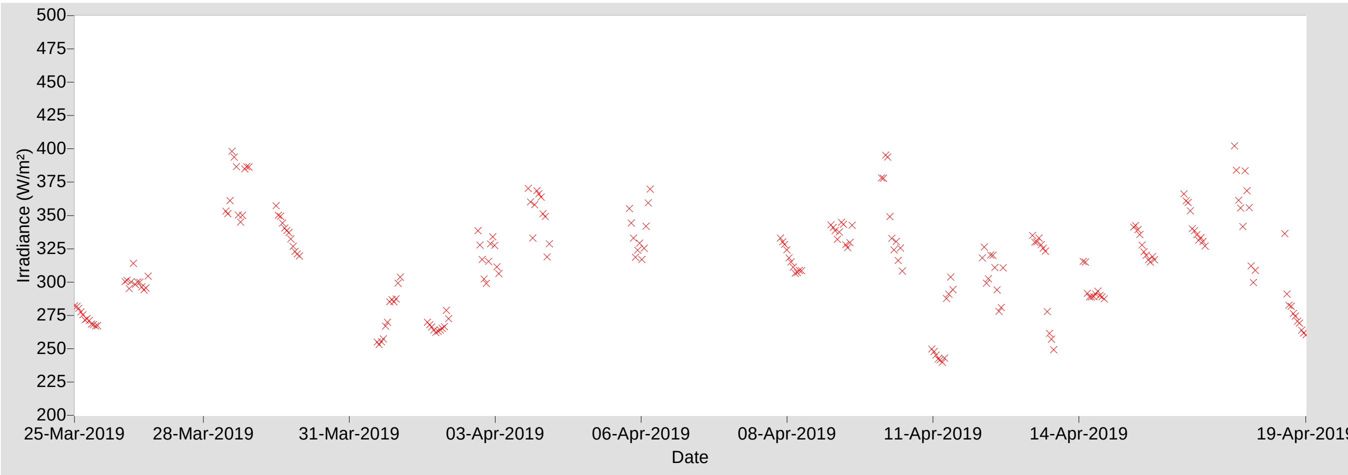
[1] Reda, I.; Stoffel, T. (2010). Pyrgeometer Calibration for DOE-Atmospheric System Research Program using NREL Method (Presentation). 9 pp.; NREL Report No. PR-3B0-47756; http://www.nrel.gov/docs/fy10osti/47756.pdf.

Environmental and Sky Conditions for BORCAL-LW 2019-02

Calibration Facility: Southern Great Plains

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

Figure 6. Reference Irradiance



Meteorological Observations (hourly averages):

Figure 7. Temperature

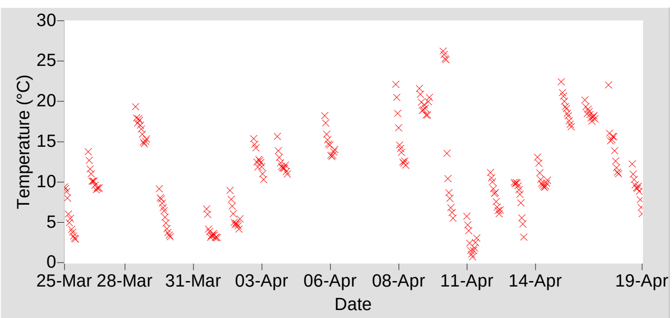


Figure 8. Humidity

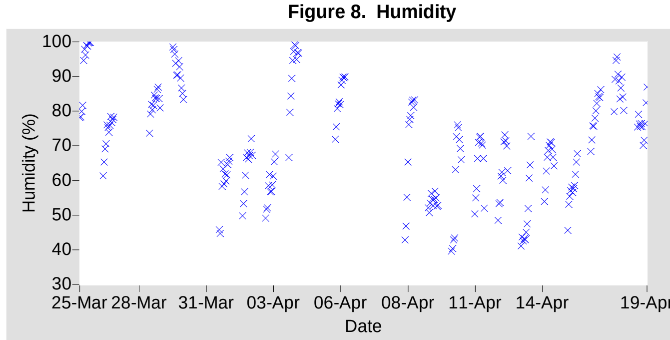


Figure 9. Pressure

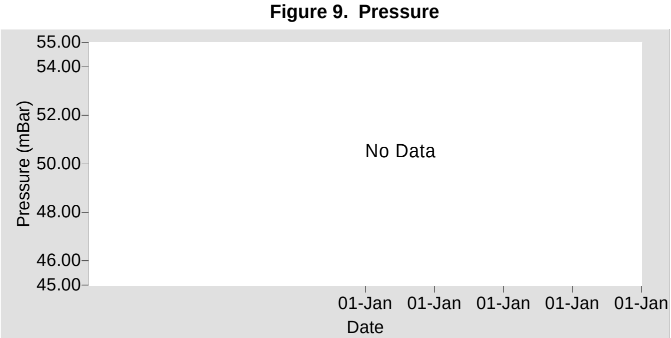


Figure 10. Estimated Precipitable Water Vapor (PWV)

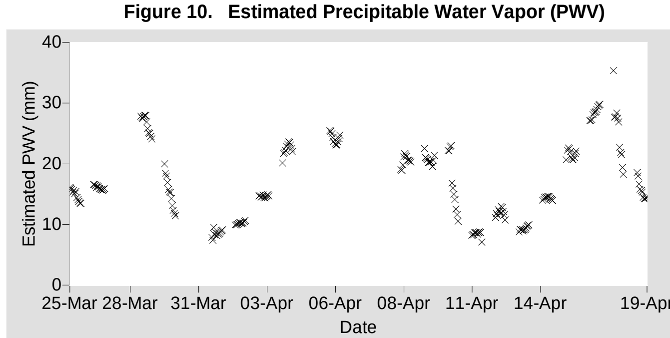


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	11.37	0.03	26.68
Humidity (%)	71.44	36.93	99.90
Pressure (mBar)	N/A	N/A	N/A
Est. Precipitable Water Vapor (mm)	17.3	6.6	35.4

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).

Appendix 3
Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL/LW 2019-02 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): 69.284
Atmos. Refraction (deg): 0.5667

METEOROLOGICAL INSTRUMENTS

	Channel	Junction Box	Cable	Location	Scale	Offset
Temperature: E0710026T Vaisala HMP155 T	239			Temp	100	-40
Humidity: E0710026H Vaisala HMP155 H	255			Hum	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	2009-1206 NREL RAP-DAQ	MY42002863 Agilent 34420A
Unit 1	2009-1207 NREL RAP-DAQ	MY42002864 Agilent 34420A
Unit 2	2009-1208 NREL RAP-DAQ	MY42002866 Agilent 34420A
Unit 3	2014-1302 NREL RAP-DAQ	SG42000596 Agilent 34420A

		Unit 0	Unit 1	Unit 2	Unit 3
	Cal Date	02/12/2019	02/12/2019	02/12/2019	02/12/2019
	Cal Due Date	02/12/2020	02/12/2020	02/12/2020	02/12/2020
System Offsets:	Volts DC (µV)	1.41	1.41	1.41	1.41
	2-Wire Res. (mOhms)	2571.00	2571.00	2571.00	2571.00
	4-Wire Res. (mOhms)	0.00	0.00	0.00	0.00

Communications

	Unit	Type	Addr.	Board	Parity	Stop	Data
DMM	0	GPIB	21	0	0	0	0
Relay	0	GPIB	24	1	0	0	0
DMM	1	GPIB	22	0	0	0	0
Relay	1	GPIB	25	1	0	0	0
DMM	2	GPIB	23	0	0	0	0
Relay	2	GPIB	26	1	0	0	0
DMM	3	GPIB	1	0	0	0	0
Relay	3	GPIB	4	1	0	0	0

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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: 31237F3 Eppley PIR (Ventilated)													
04/16/2018	04/16/2020	3.50000	0.22892	0.99110	-3.69000	7.04400E-4	2.60	9	71		2	T6-2	✔
Pyrgeometer 1: Case 10K Temperature									67		2		
Pyrgeometer 1: Dome 10K Temperature									75		2		
Pyrgeometer 2: 31206F3 Eppley PIR (Ventilated)													
04/16/2018	04/16/2020	-0.20000	0.26400	0.99940	-3.26000	7.04400E-4	2.60	9	23		2	T5-2	✔
Pyrgeometer 2: Case 10K Temperature									19		2		
Pyrgeometer 2: Dome 10K Temperature									27		2		

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INSTRUMENTS

Serial Number / Model	Customer	Mfg RS	Ch	Box	Cable	Act	ISO	AIM	Stickr	Vent	Use	Kr	Location	Due
28630F3	SGP	3.8100	231		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-3	12
PIR	(Case 10K Temperature)		227		3									
	(Dome 10K Temperature)		235		3									
29146F3	SGP	3.6900	103		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-1	12
PIR	(Case 10K Temperature)		99		1									
	(Dome 10K Temperature)		107		1									
30013F3	SGP	3.5700	39		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T5-3	12
PIR	(Case 10K Temperature)		35		3									
	(Dome 10K Temperature)		43		3									
30133F3 ‡	SGP	3.9000	215		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-2	24
PIR	(Case 10K Temperature)		211		2									
	(Dome 10K Temperature)		219		2									
30344F3	SGP	3.9600	135		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-3	12
PIR	(Case 10K Temperature)		131		3									
	(Dome 10K Temperature)		139		3									
30358F3	SGP	4.2600	55		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T6-1	12
PIR	(Case 10K Temperature)		51		1									
	(Dome 10K Temperature)		59		1									
30782F3	SGP	4.0500	151		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-1	12
PIR	(Case 10K Temperature)		147		1									
	(Dome 10K Temperature)		155		1									
30834F3	SGP	3.7500	87		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T6-3	12
PIR	(Case 10K Temperature)		83		3									
	(Dome 10K Temperature)		91		3									
30836F3	SGP	3.9300	119		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-2	12
PIR	(Case 10K Temperature)		115		2									
	(Dome 10K Temperature)		123		2									
36367F3	SGP	3.0300	183		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-3	12
PIR	(Case 10K Temperature)		179		3									
	(Dome 10K Temperature)		187		3									
36368F3 ‡	SGP	3.0200	167		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-2	12
PIR	(Case 10K Temperature)		163		2									
	(Dome 10K Temperature)		171		2									

‡ Control Instrument