Broadband Outdoor Radiometer Calibration
Longwave

BORCAL-LW
2020-04

Generated by

RCC

Radiometer Calibration and Characterization

Calibration Facility

Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Calibration date

08/05/2020 to 09/14/2020

Report Date

September 17, 2020

ARM

NOTICE

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

BORCAL Notes or Comments

Due to data quality problems the following PIRs (although tested) were removed from this report.
31309F3, 30830F3, 29665F3,29924F3, 30011F3, 30032F3, 31236F3, 31298F3, 31303F3. See the TM for additional details.

Control Instrument History

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

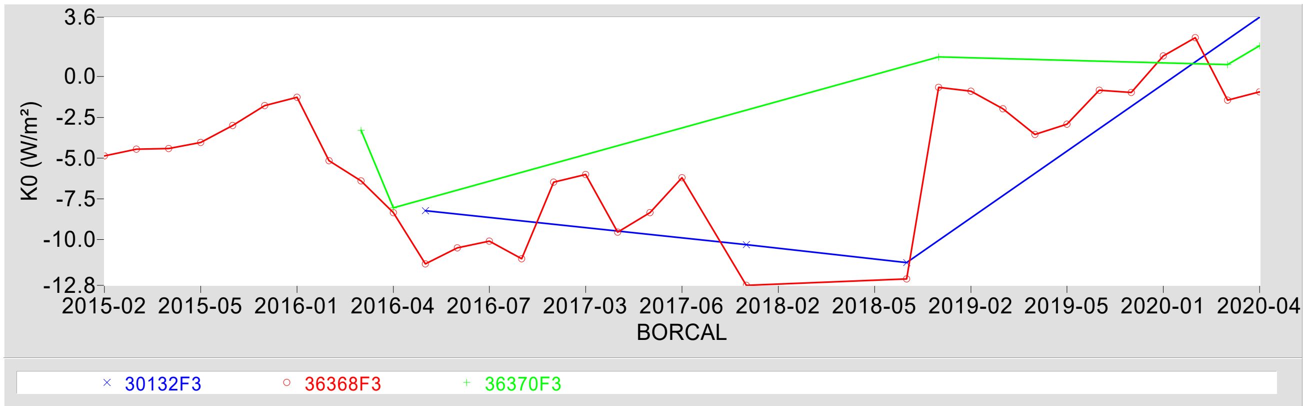


Figure 2. Eppley PIR Control Instrument History (K1 Coefficient)

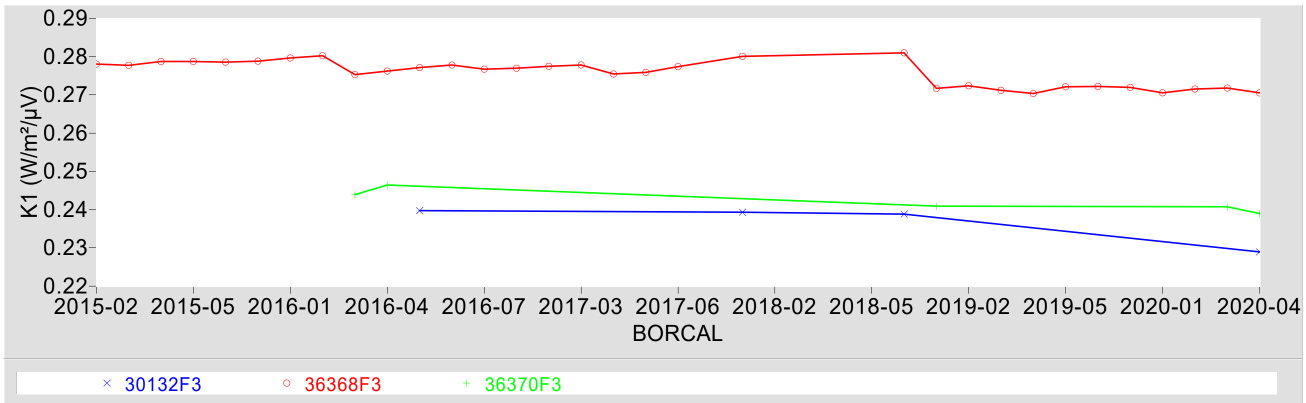


Figure 3. Eppley PIR Control Instrument History (K2 Coefficient)

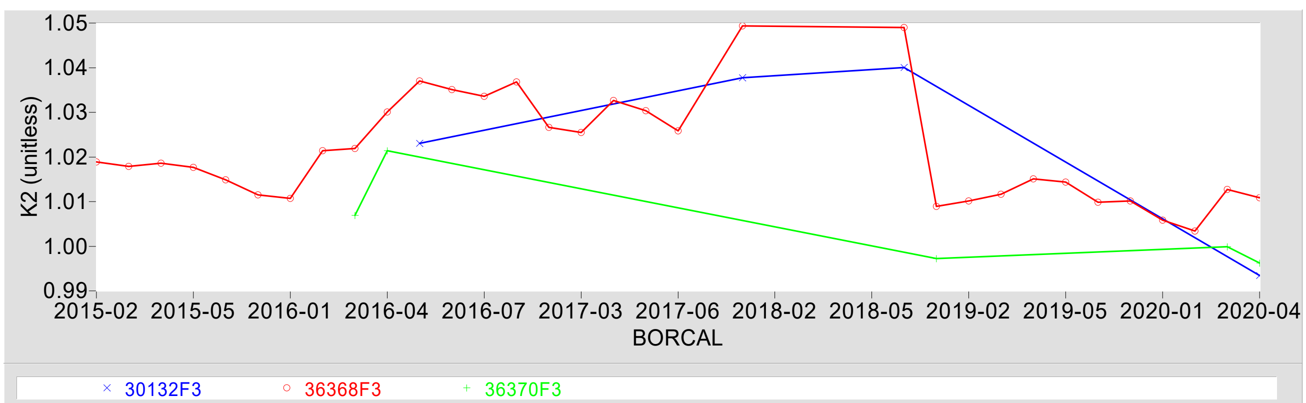
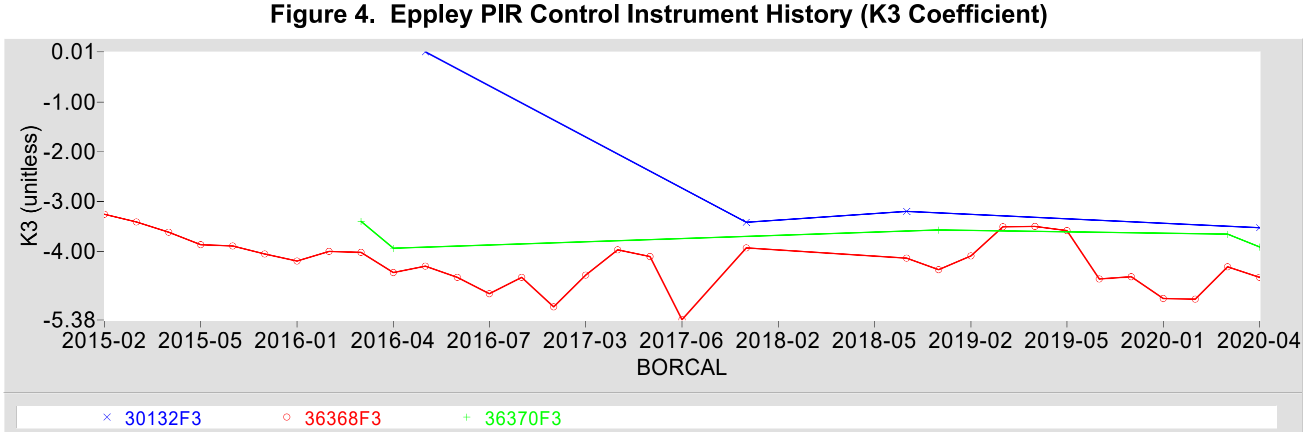


Figure 4. Eppley PIR Control Instrument History (K3 Coefficient)



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	4.4	0.24375	0.9979	-3.64	7.044e-4	±3.1	A1-2
29591F3	SGP	-0.3	0.21856	1.0005	-3.50	7.044e-4	±3.1	A1-5
30012F3	TWP	4.1	0.26579	0.9926	-3.43	7.044e-4	±3.1	A1-8
30085F3	SGP	-2.7	0.23128	1.0061	-4.99	7.044e-4	±3.2	A1-11
30131F3	TWP	0.3	0.23978	1.0003	-4.20	7.044e-4	±3.2	A1-14
30132F3	SGP	3.6	0.22897	0.9934	-3.53	7.044e-4	±3.1	A1-17
30167F3	TWP	5.6	0.20815	0.9893	-4.10	7.044e-4	±3.2	A1-20
30168F3	NSA	3.5	0.36313	0.9879	-4.14	7.044e-4	±3.2	A1-23
30357F3	SGP	0.3	0.23316	0.9986	-4.06	7.044e-4	±3.1	A1-26
30681F3	SGP	4.3	0.24572	0.9859	-4.03	7.044e-4	±3.1	A1-29
30690F3	SGP	-3.5	0.24469	1.0053	-3.34	7.044e-4	±3.1	A1-32
30692F3	SGP	0.5	0.25031	0.9981	-3.59	7.044e-4	±3.1	A1-35
30781F3	SGP	1.0	0.27043	0.9936	-3.51	7.044e-4	±3.2	A1-38
30828F3	SGP	2.9	0.21399	0.9921	-3.32	7.044e-4	±3.1	A1-41
30834F3	SGP	-1.1	0.24175	1.0062	-4.26	7.044e-4	±3.1	A1-44
30836F3	SGP	4.0	0.23229	0.9898	-3.42	7.044e-4	±3.2	A1-47
31299F3	NSA	-0.8	0.22366	0.9894	-4.08	7.044e-4	±3.2	A1-50
31301F3	TWP	3.9	0.26345	0.9917	-4.02	7.044e-4	±3.2	A1-53
31302F3	TWP	2.1	0.25715	0.9947	-3.99	7.044e-4	±3.2	A1-56
31308F3	TWP	-5.6	0.29830	1.0093	-3.51	7.044e-4	±3.1	A1-59
31311F3	TWP	-1.8	0.24196	1.0006	-3.30	7.044e-4	±3.1	A1-62
31640F3	SGP	1.4	0.24029	0.9952	-3.84	7.044e-4	±3.2	A1-65
32040F3	NSA	3.6	0.24167	0.9904	-3.86	7.044e-4	±3.1	A1-68
32050F3	NSA	1.5	0.22987	0.9948	-3.39	7.044e-4	±3.1	A1-71
36363F3	SGP	-2.5	0.33042	1.0098	-4.60	7.044e-4	±3.2	A1-74
36368F3	SGP	-0.9	0.27052	1.0109	-4.52	7.044e-4	±3.2	A1-77
36370F3	SGP	1.9	0.23899	0.9962	-3.91	7.044e-4	±3.1	A1-80

Note: Environmental Conditions for BORCAL starts on page A1-83. * 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:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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:

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

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

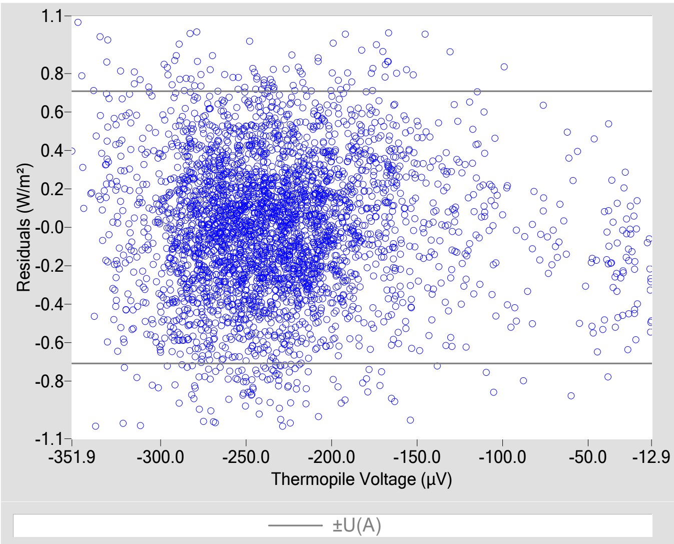


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

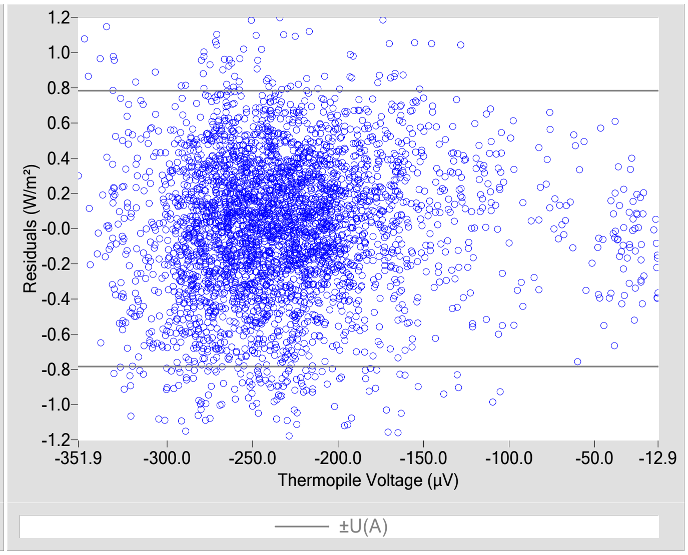


Table 2. Calibration Coefficients for K0<>0

K0	4.4
K1	0.24375
K2	0.9979
K3	-3.64
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24375
K2	1.0074
K3	-3.34
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.36
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)	±1.6
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

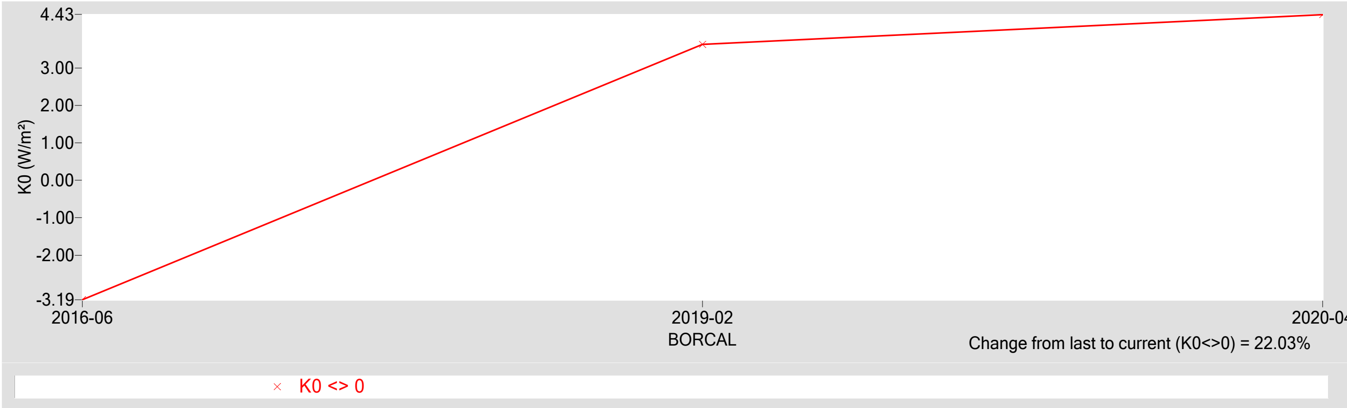


Figure 4. History of instrument (K1 Coefficient)

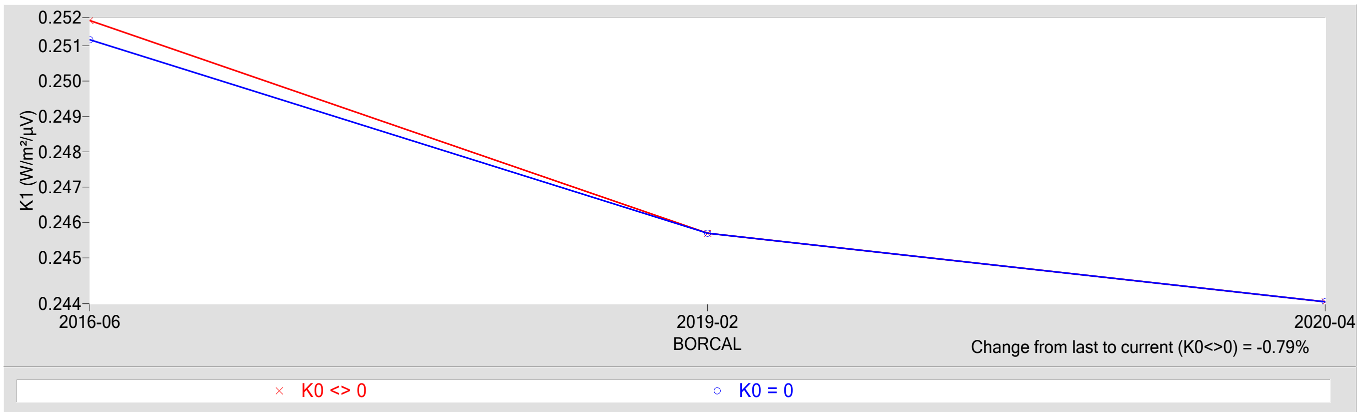


Figure 5. History of instrument (K2 Coefficient)

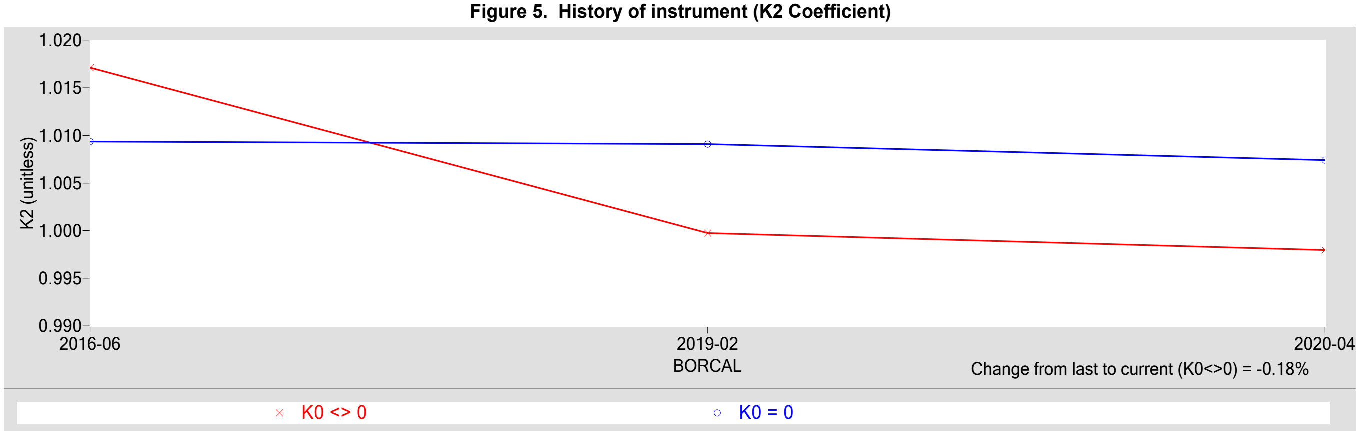
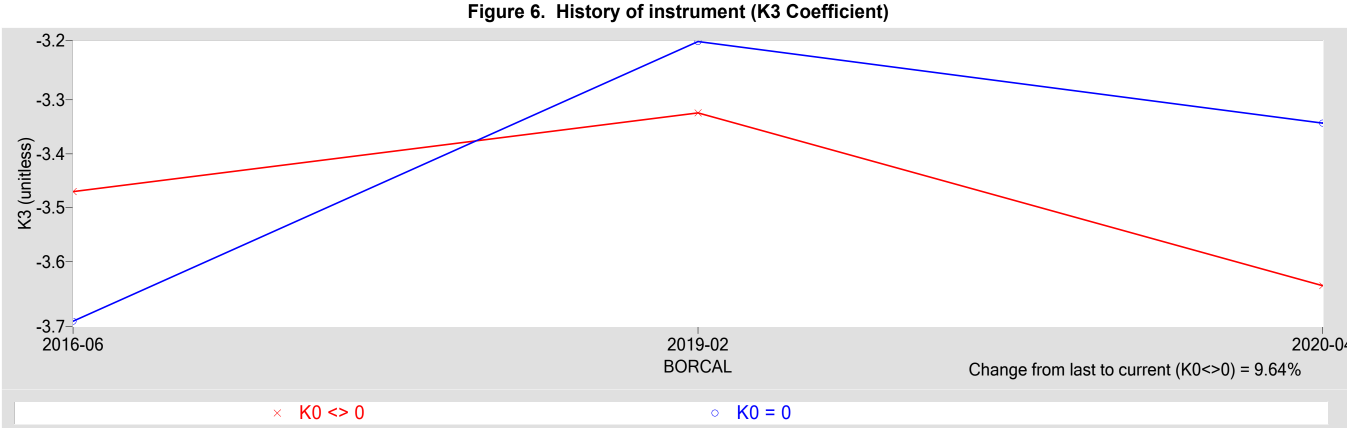


Figure 6. History of instrument (K3 Coefficient)



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:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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
29591F3 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

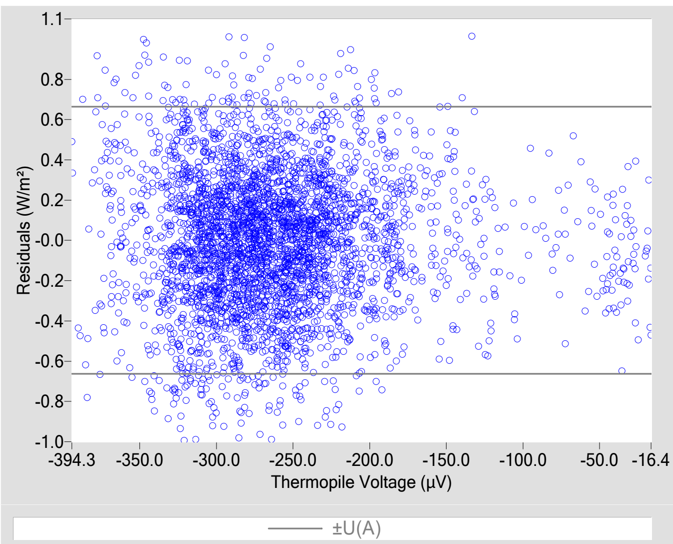


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

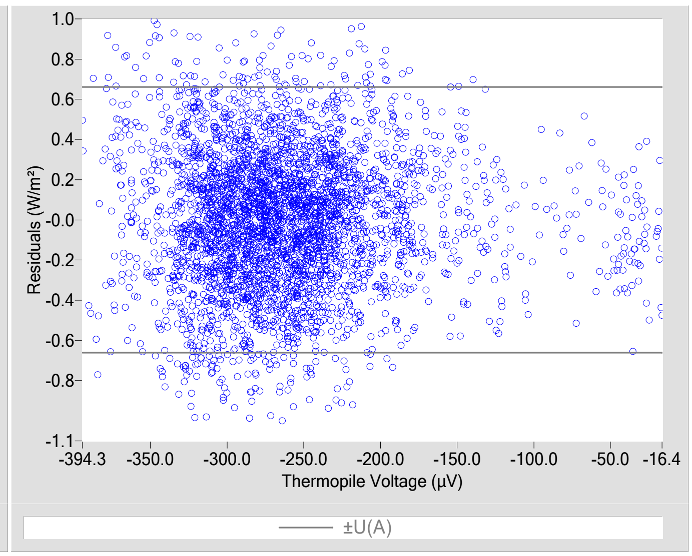


Table 2. Calibration Coefficients for K0<>0

K0	-0.3
K1	0.21856
K2	1.0005
K3	-3.50
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.21857
K2	0.9999
K3	-3.50
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.34
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.34
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)

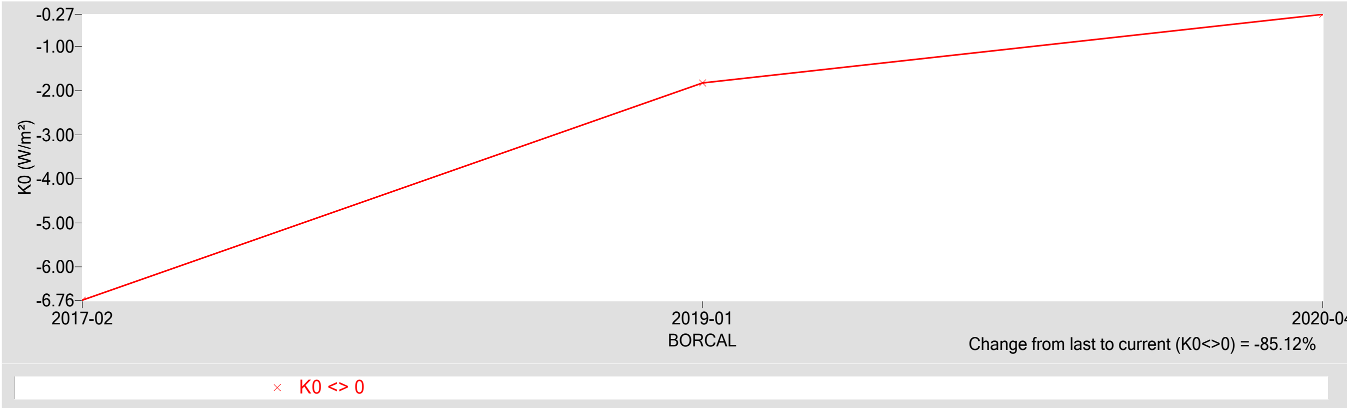


Figure 4. History of instrument (K1 Coefficient)

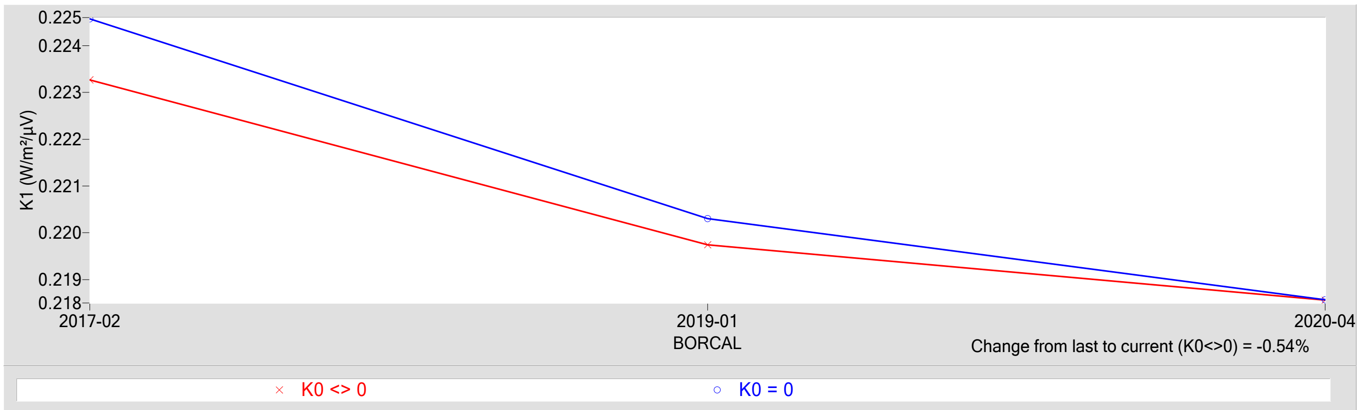


Figure 5. History of instrument (K2 Coefficient)

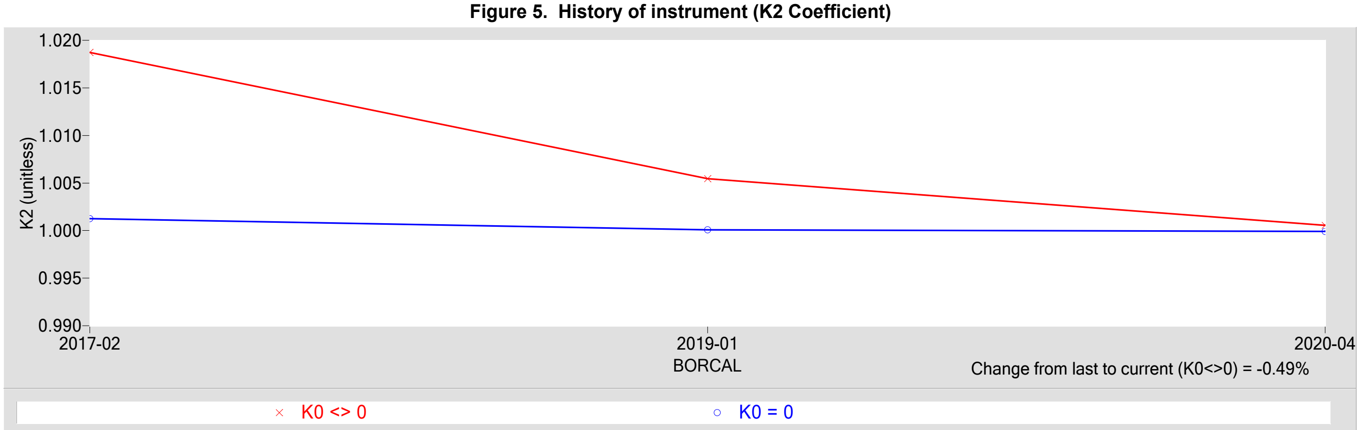
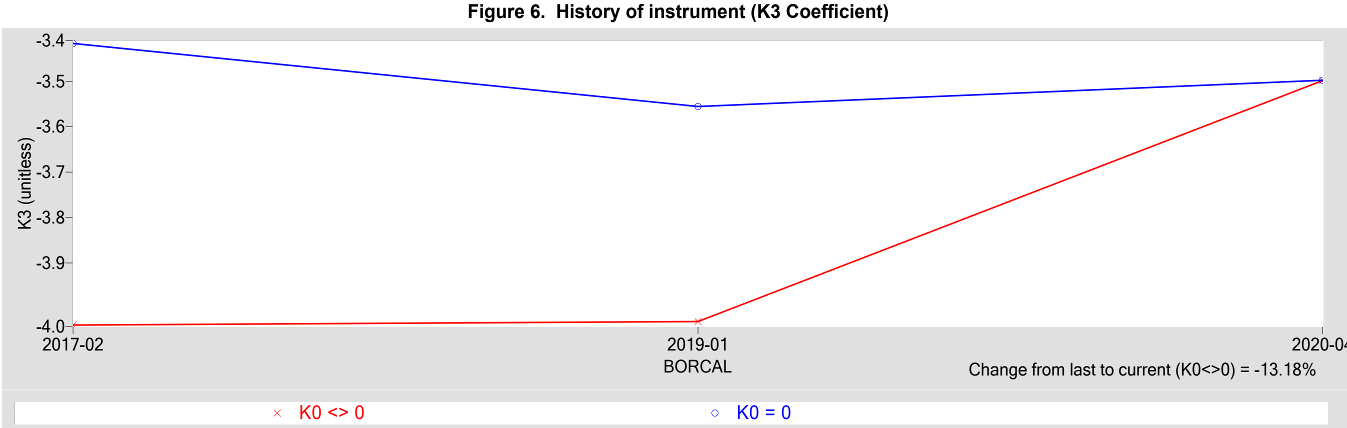


Figure 6. History of instrument (K3 Coefficient)



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:**	30012F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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).

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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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30012F3 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

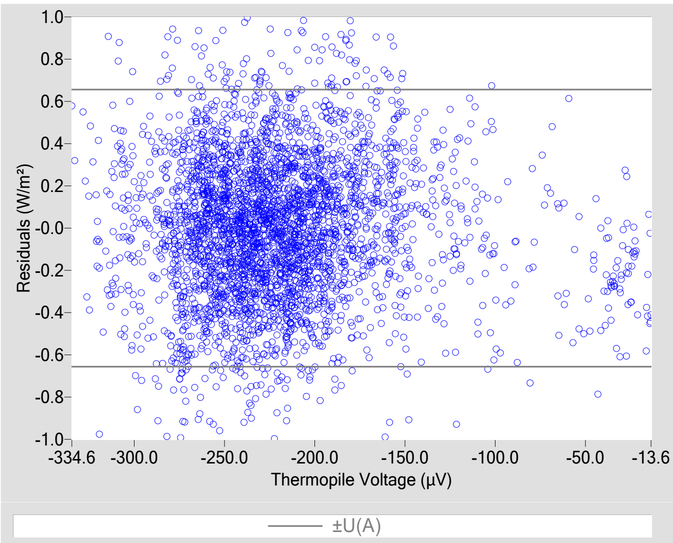


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

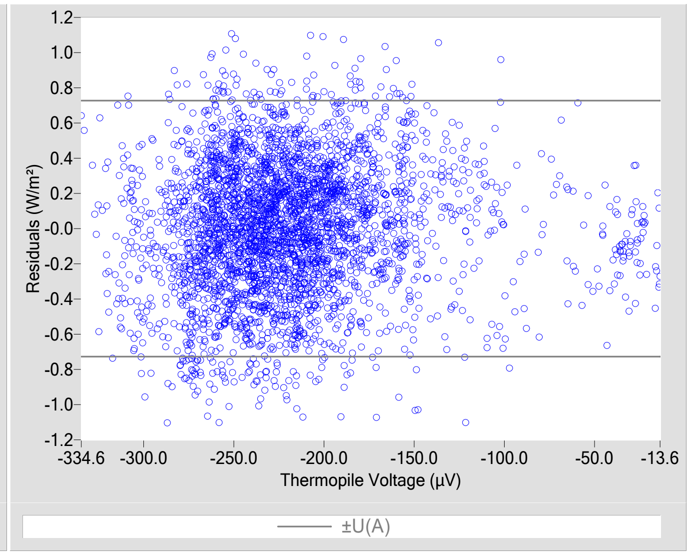


Table 2. Calibration Coefficients for K0<>0

K0	4.1
K1	0.26579
K2	0.9926
K3	-3.43
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.26544
K2	1.0016
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.33
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.37
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)

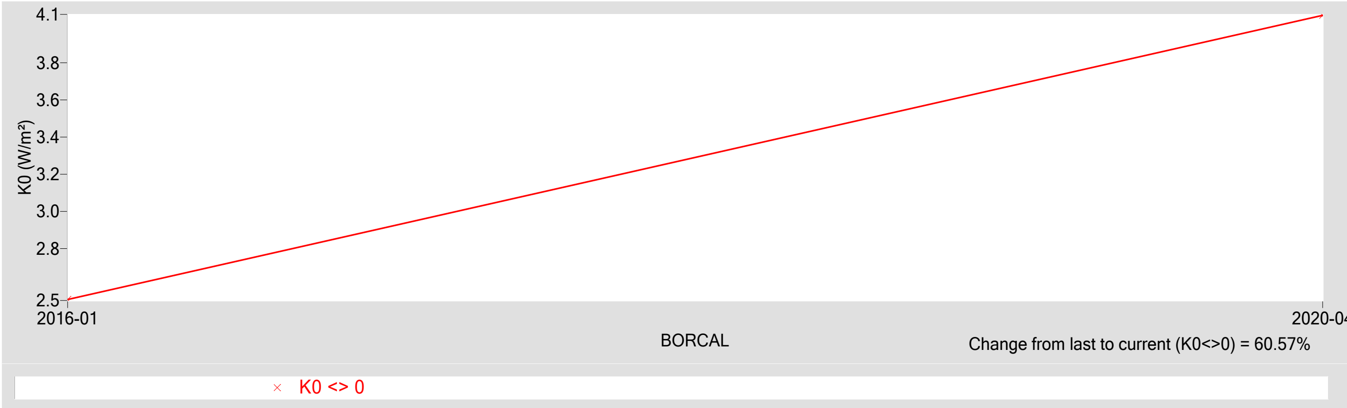


Figure 4. History of instrument (K1 Coefficient)

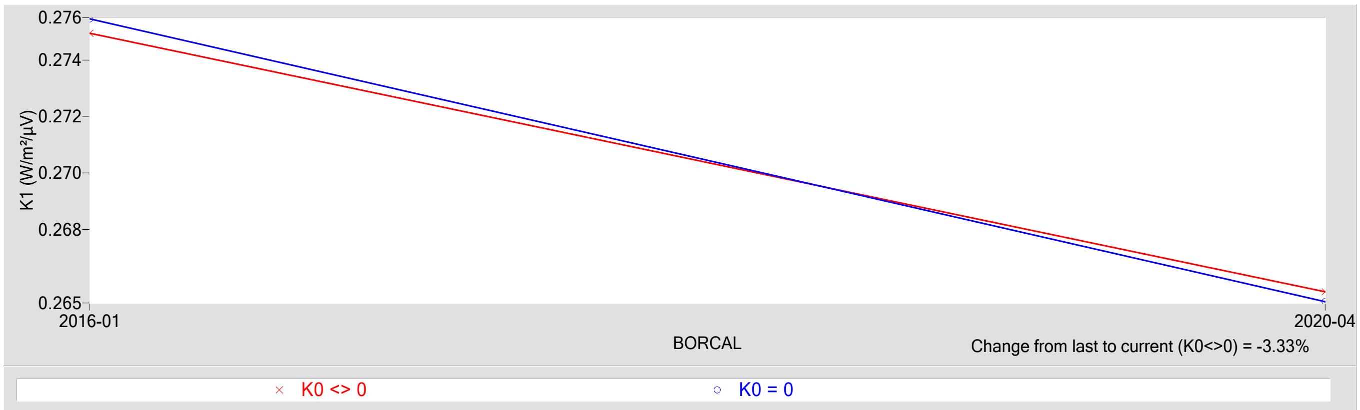


Figure 5. History of instrument (K2 Coefficient)

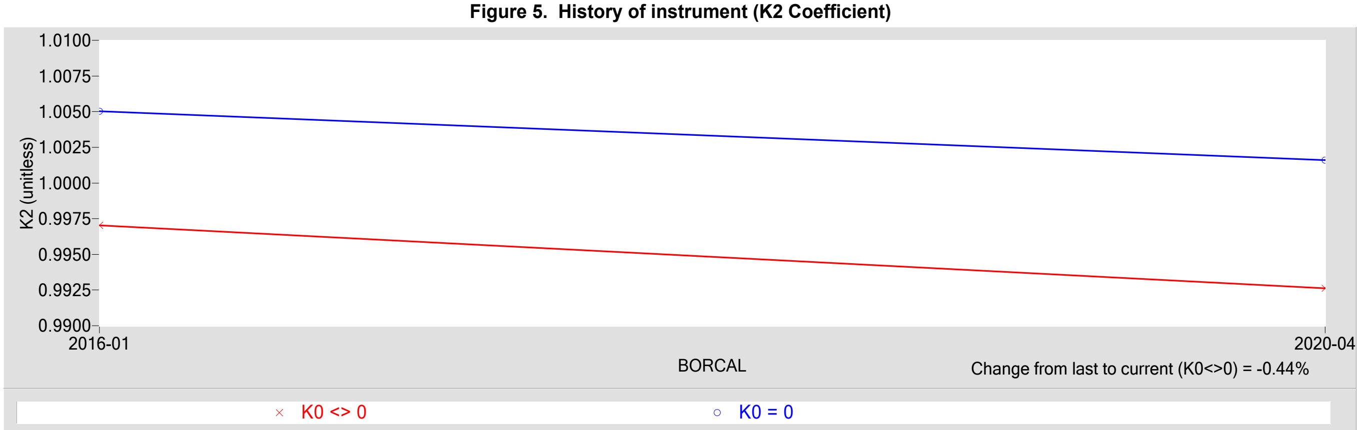
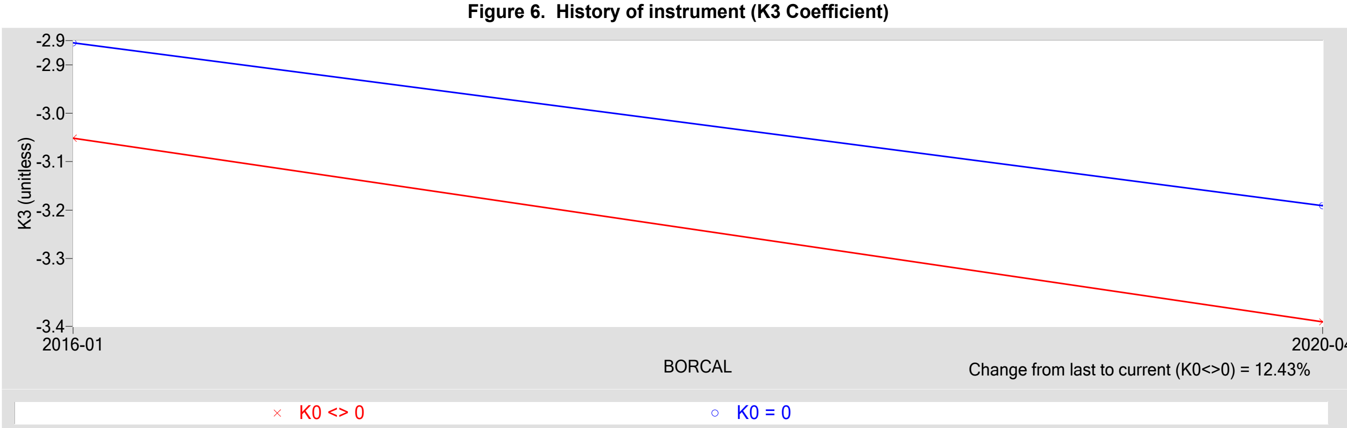


Figure 6. History of instrument (K3 Coefficient)



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:**	30085F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30085F3 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

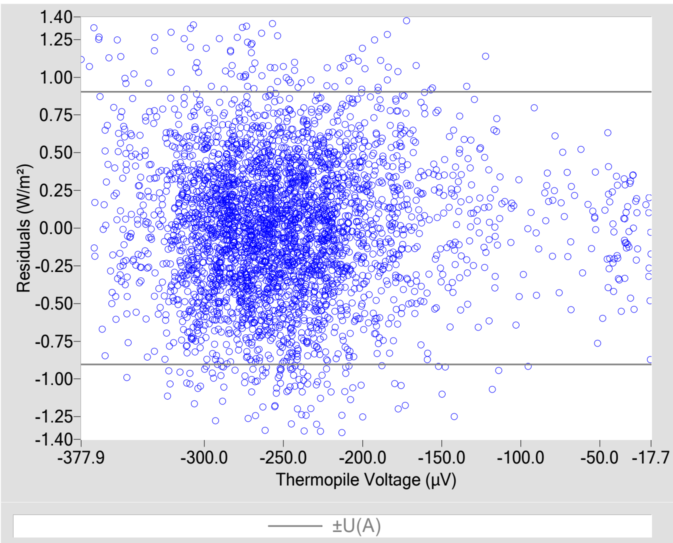


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

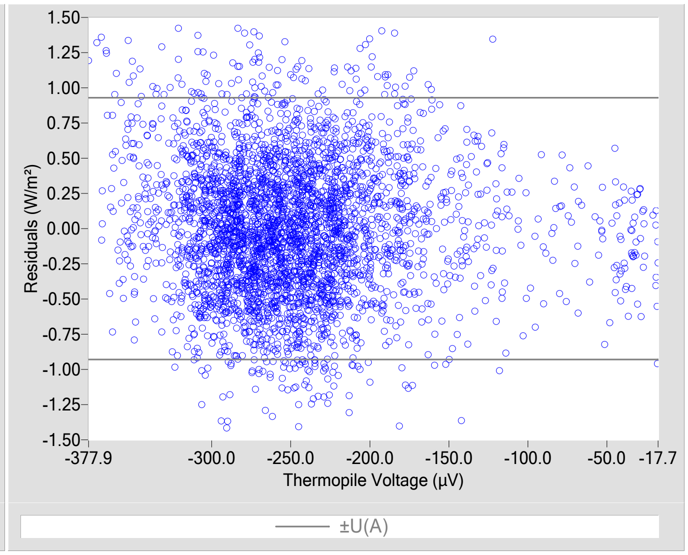


Table 2. Calibration Coefficients for K0<>0

K0	-2.7
K1	0.23128
K2	1.0061
K3	-4.99
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23141
K2	0.9999
K3	-5.09
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.46
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.47
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

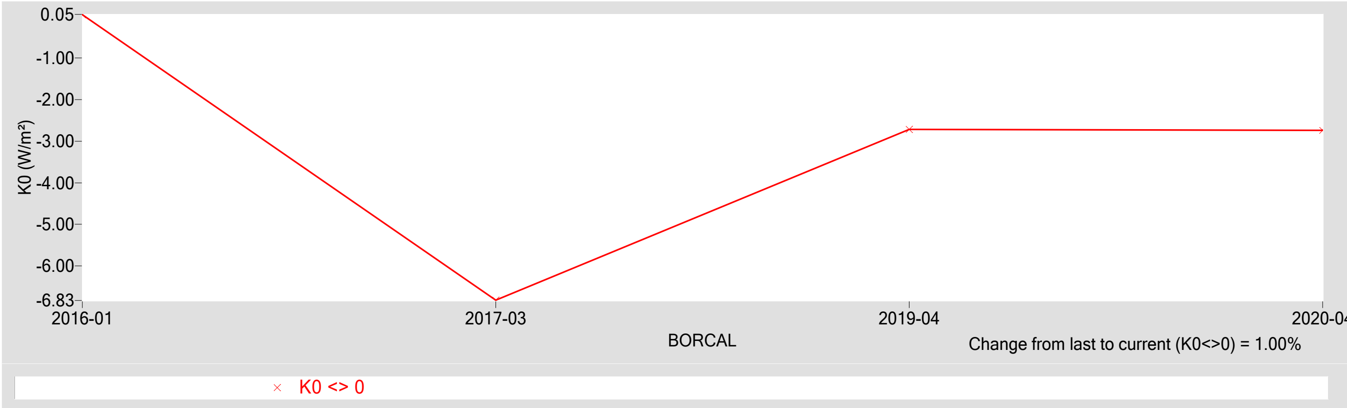


Figure 4. History of instrument (K1 Coefficient)

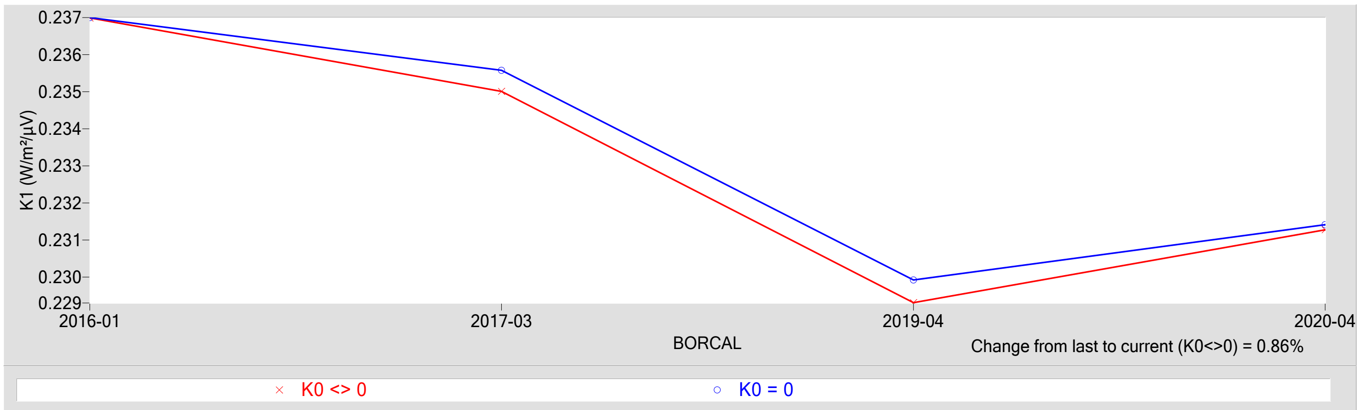


Figure 5. History of instrument (K2 Coefficient)

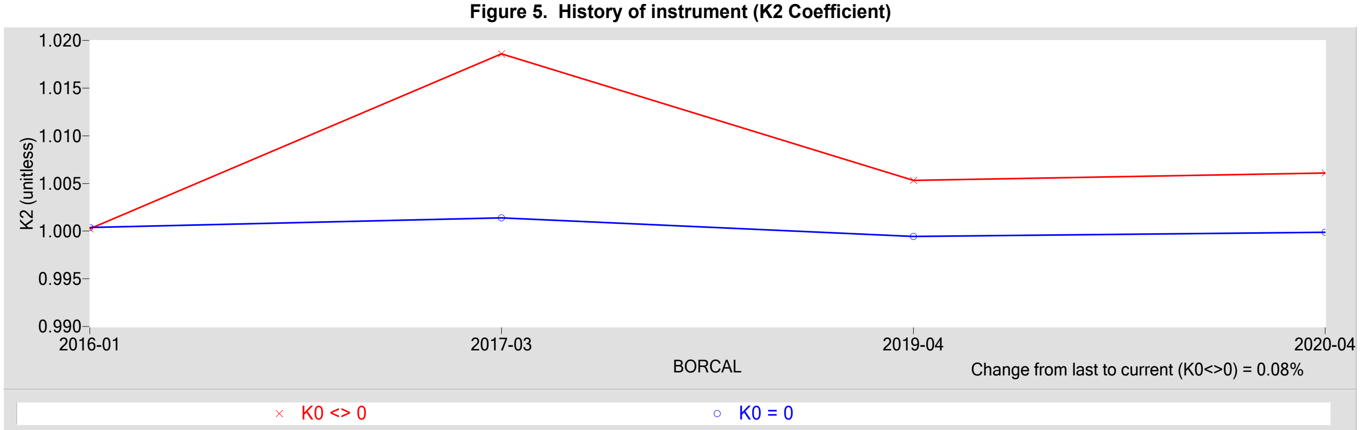
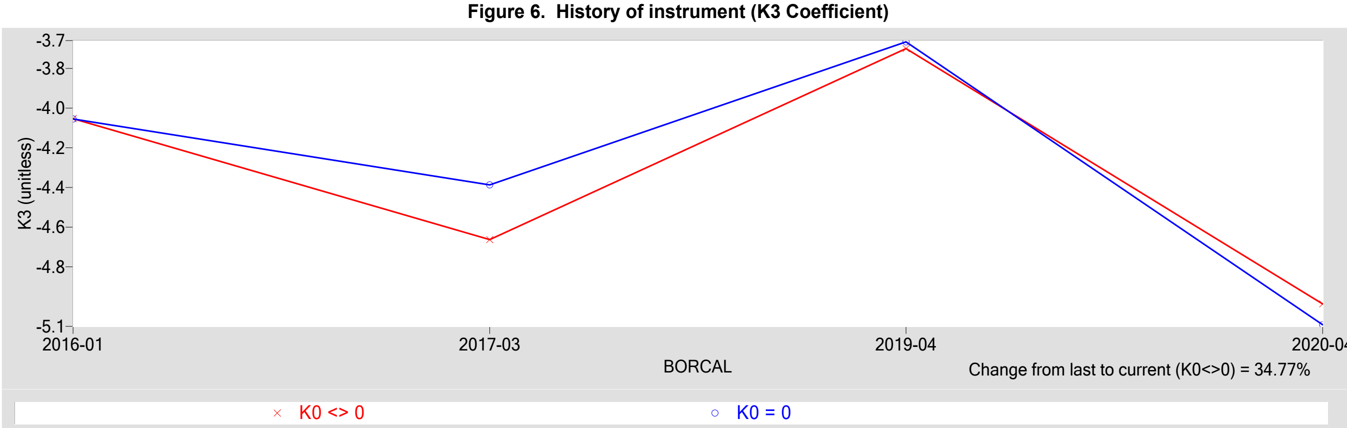


Figure 6. History of instrument (K3 Coefficient)



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:**	30131F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30131F3 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

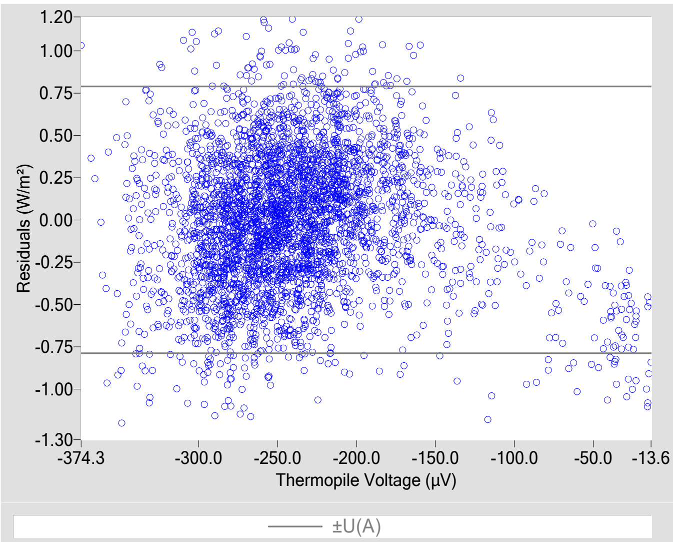


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

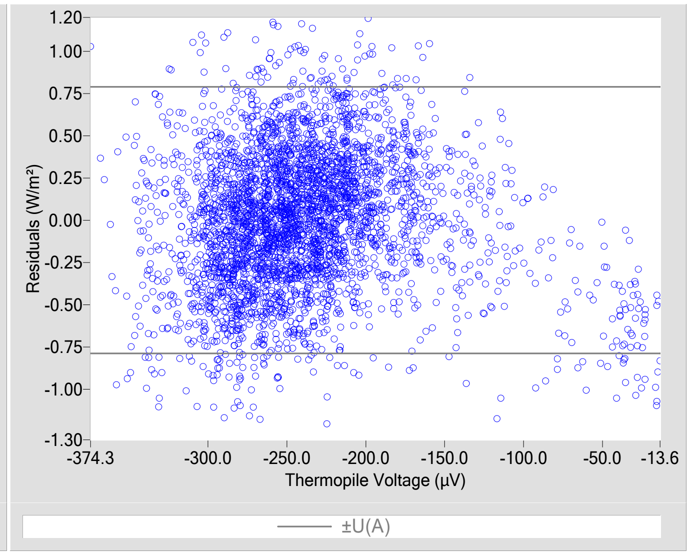


Table 2. Calibration Coefficients for K0<>0

K0	0.3
K1	0.23978
K2	1.0003
K3	-4.20
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23976
K2	1.0008
K3	-4.19
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

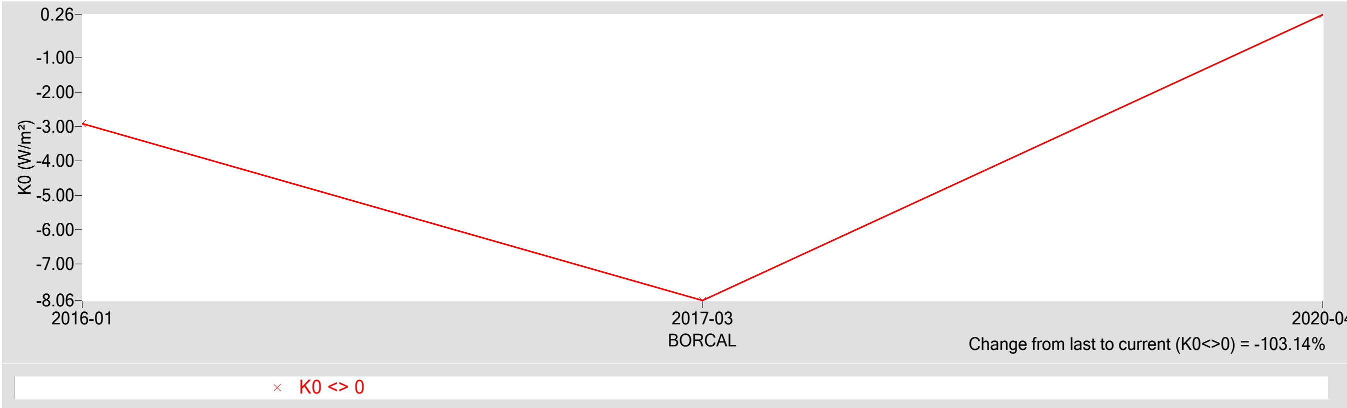


Figure 4. History of instrument (K1 Coefficient)

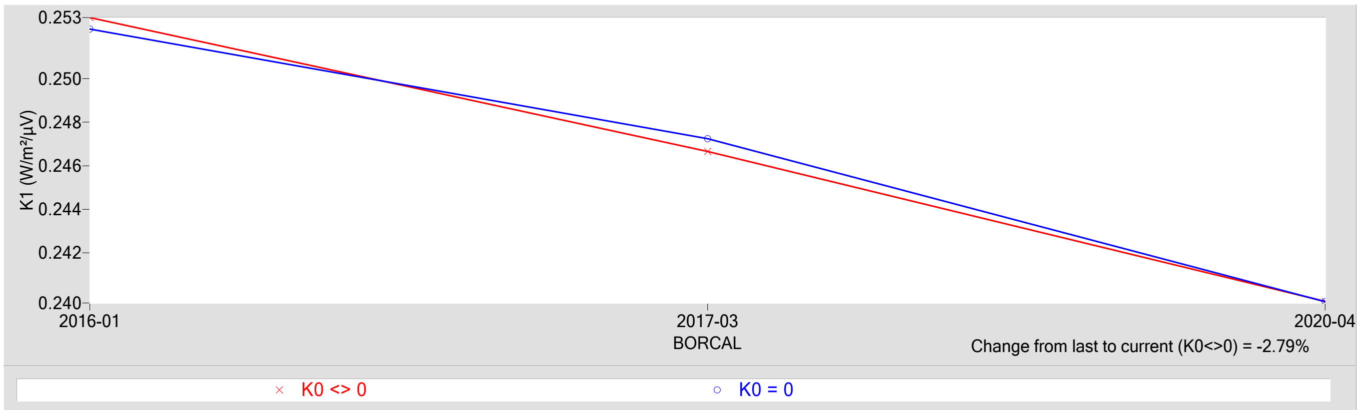


Figure 5. History of instrument (K2 Coefficient)

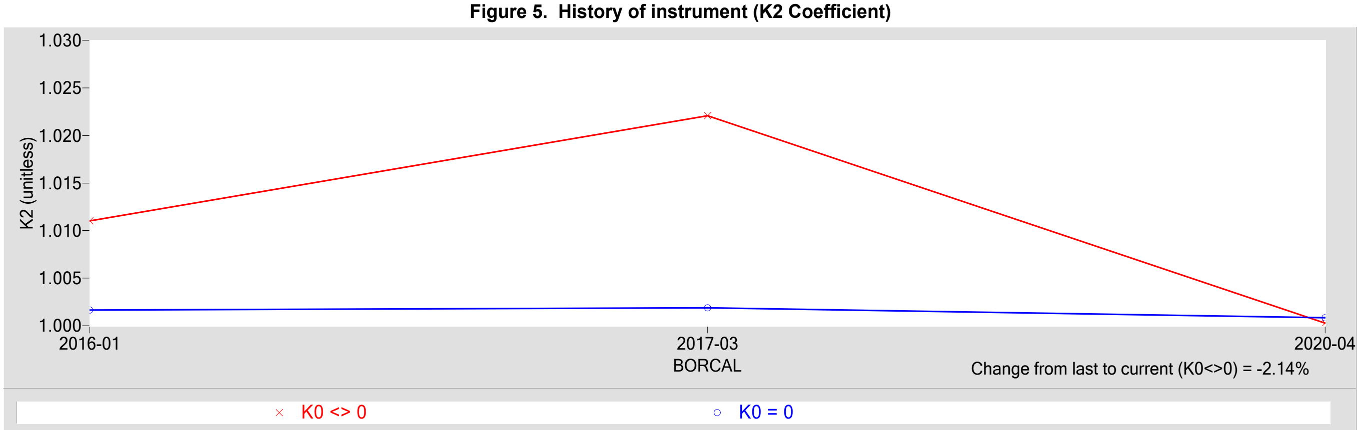
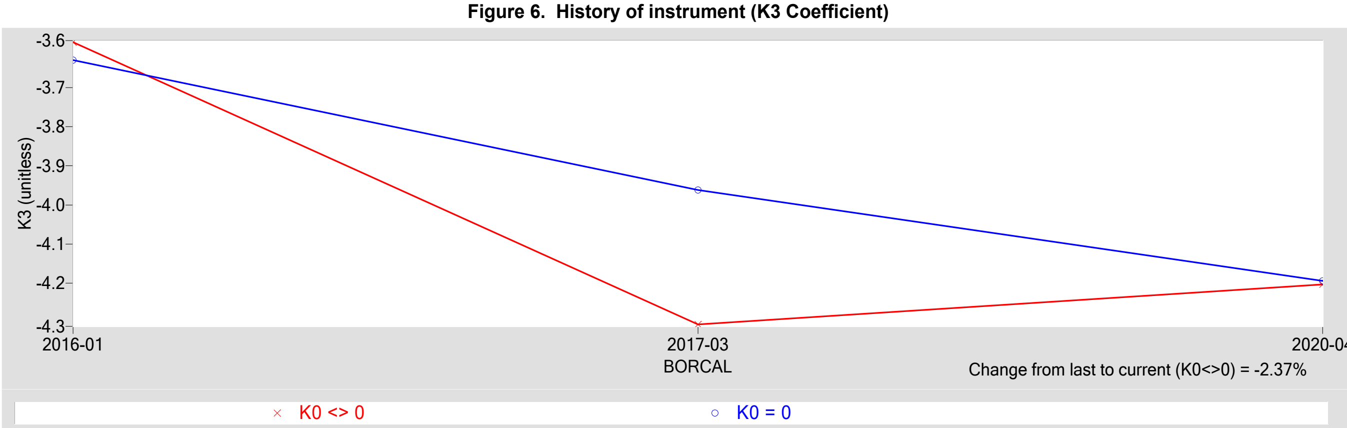


Figure 6. History of instrument (K3 Coefficient)



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:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

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),
$Wd = \sigma * Td^4$ = 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

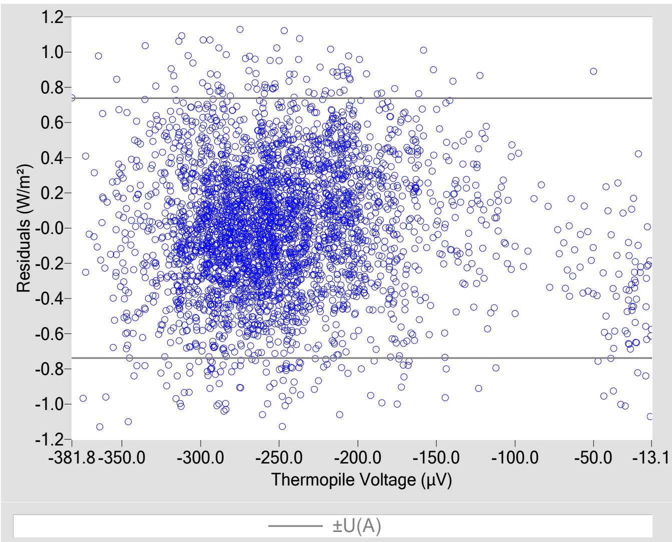


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

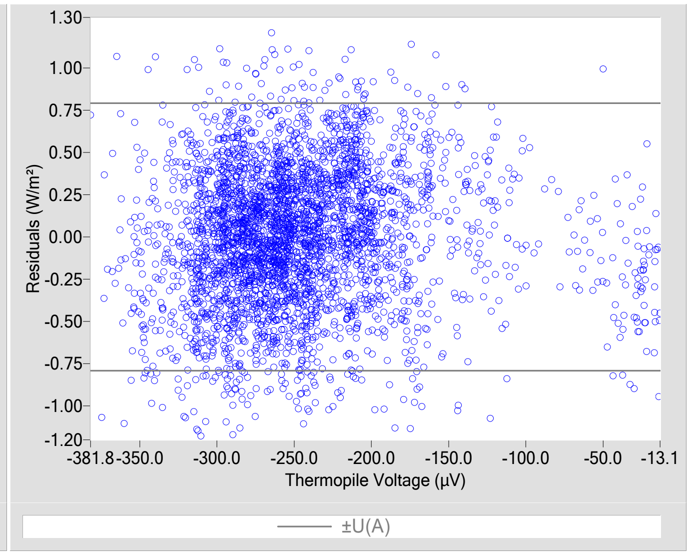


Table 2. Calibration Coefficients for K0<>0

K0	3.6
K1	0.22897
K2	0.9934
K3	-3.53
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.22881
K2	1.0015
K3	-3.36
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)	±1.6
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

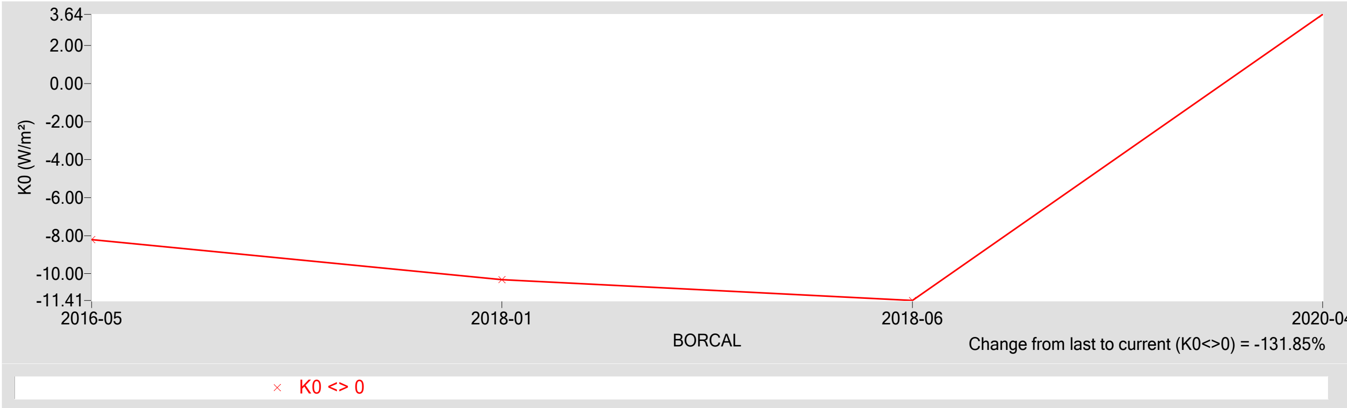


Figure 4. History of instrument (K1 Coefficient)

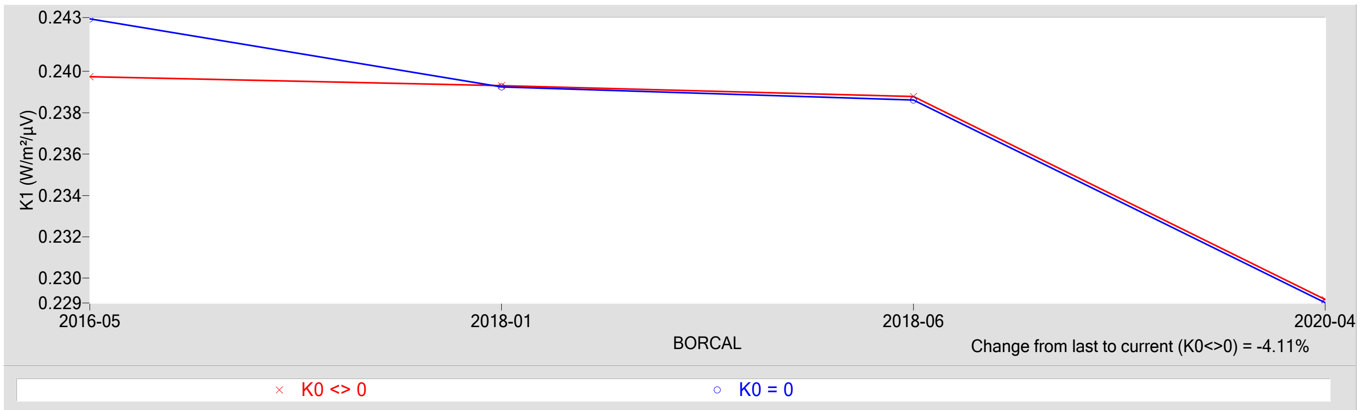


Figure 5. History of instrument (K2 Coefficient)

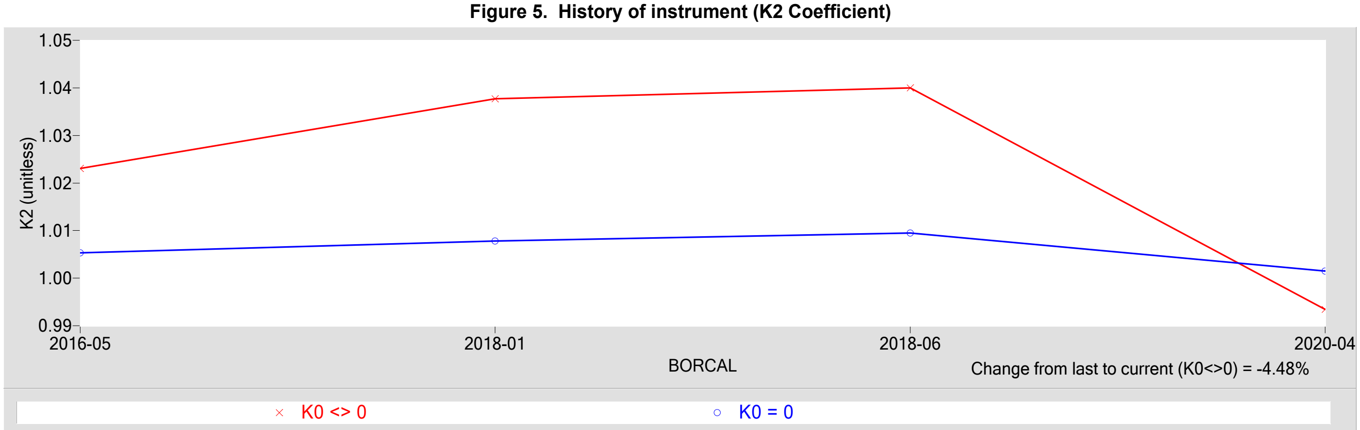
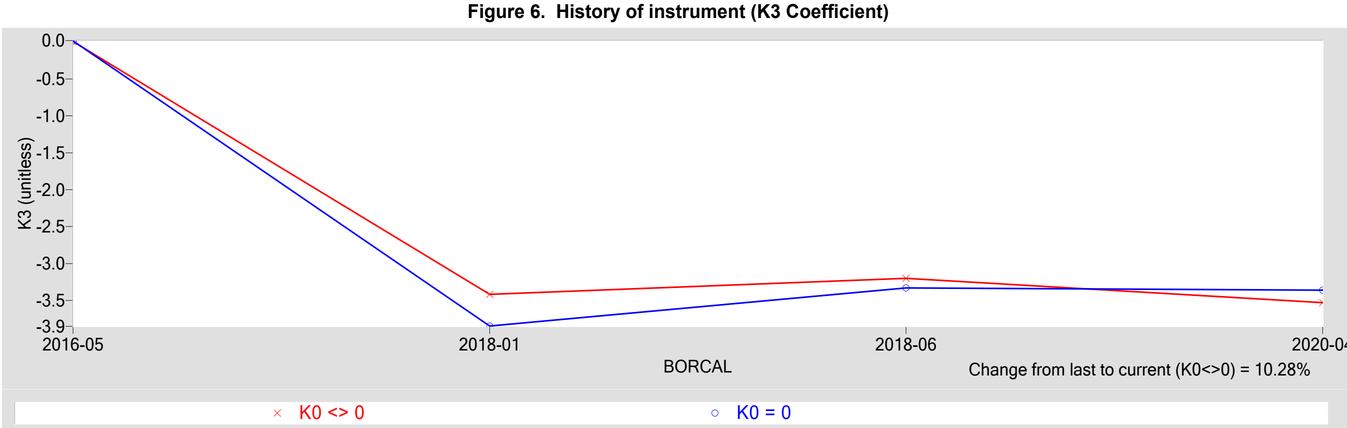


Figure 6. History of instrument (K3 Coefficient)



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:**	30167F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30167F3 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

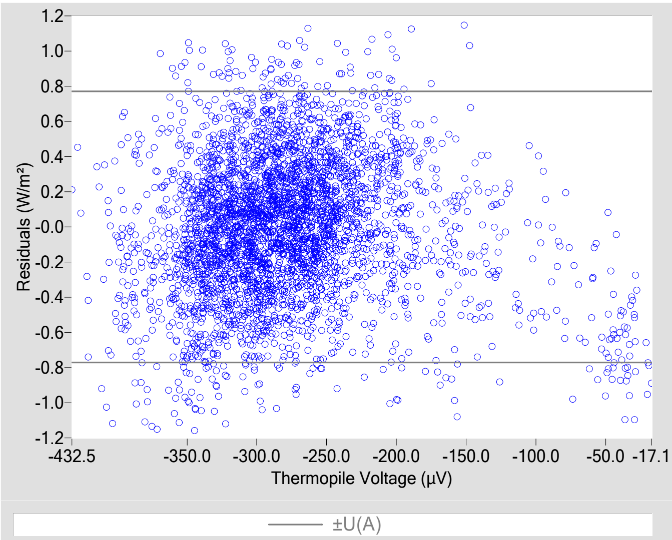


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

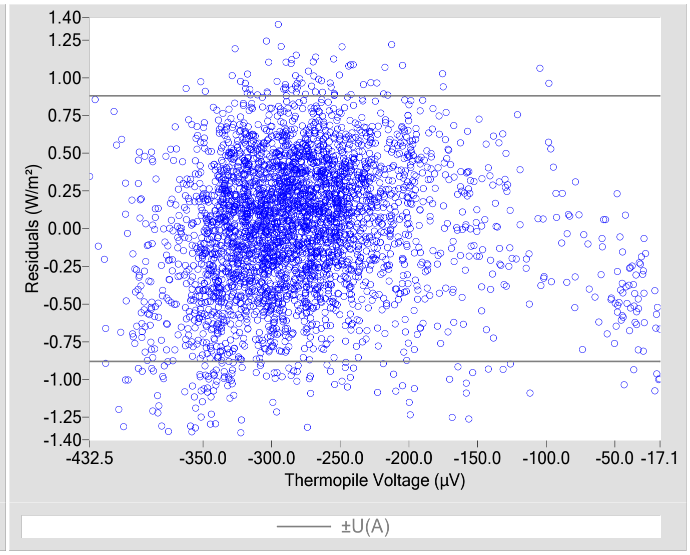


Table 2. Calibration Coefficients for K0<>0

K0	5.6
K1	0.20815
K2	0.9893
K3	-4.10
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.20775
K2	1.0019
K3	-3.60
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

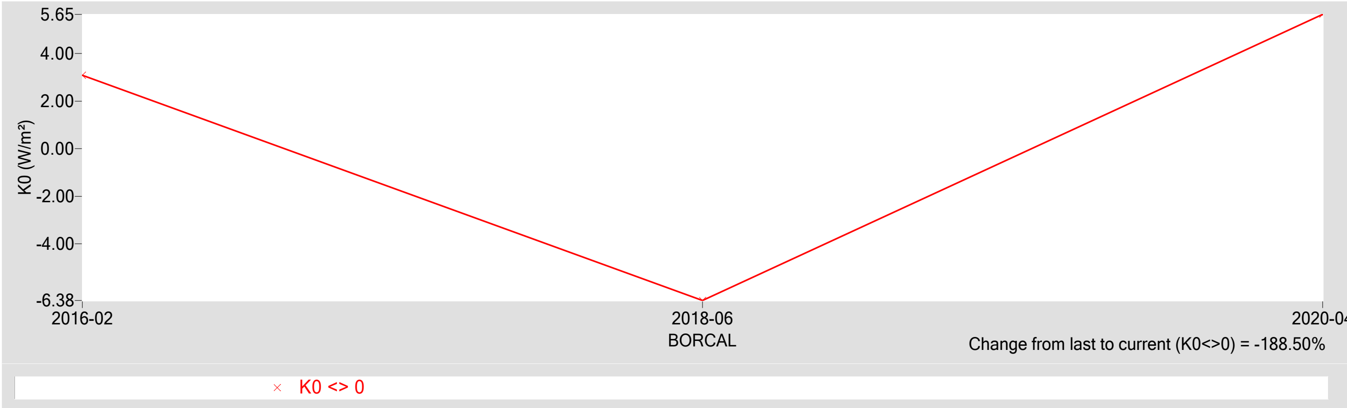


Figure 4. History of instrument (K1 Coefficient)

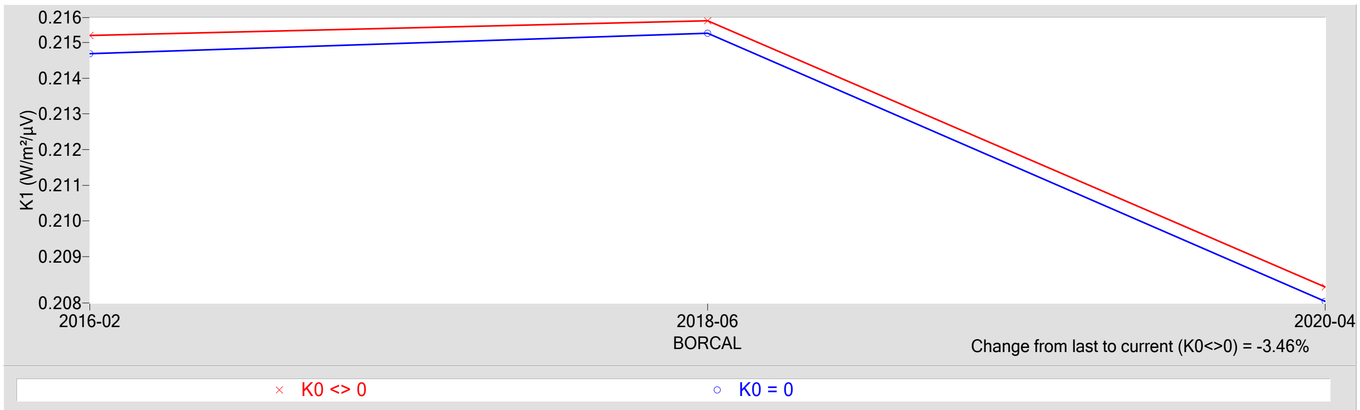


Figure 5. History of instrument (K2 Coefficient)

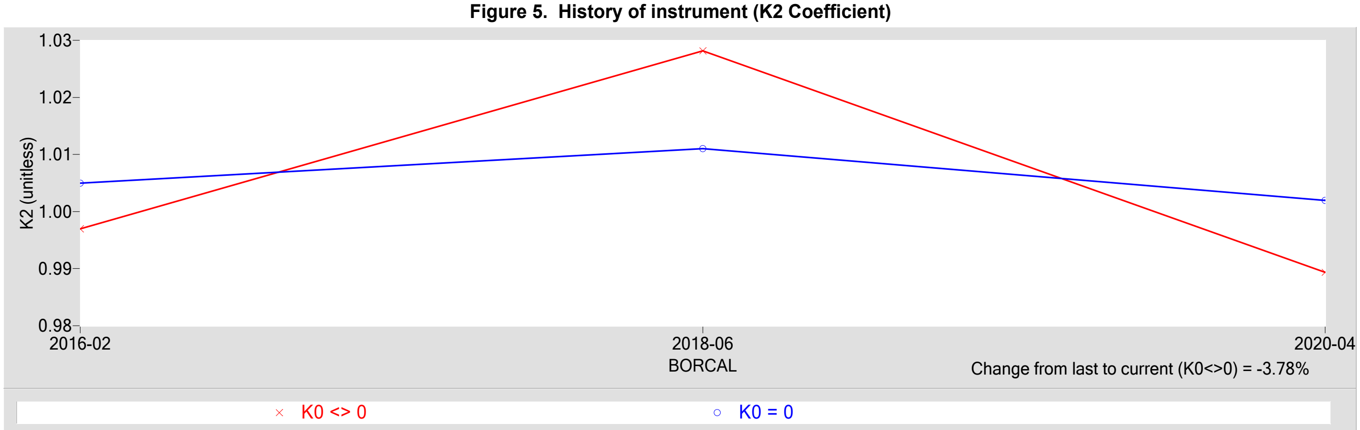
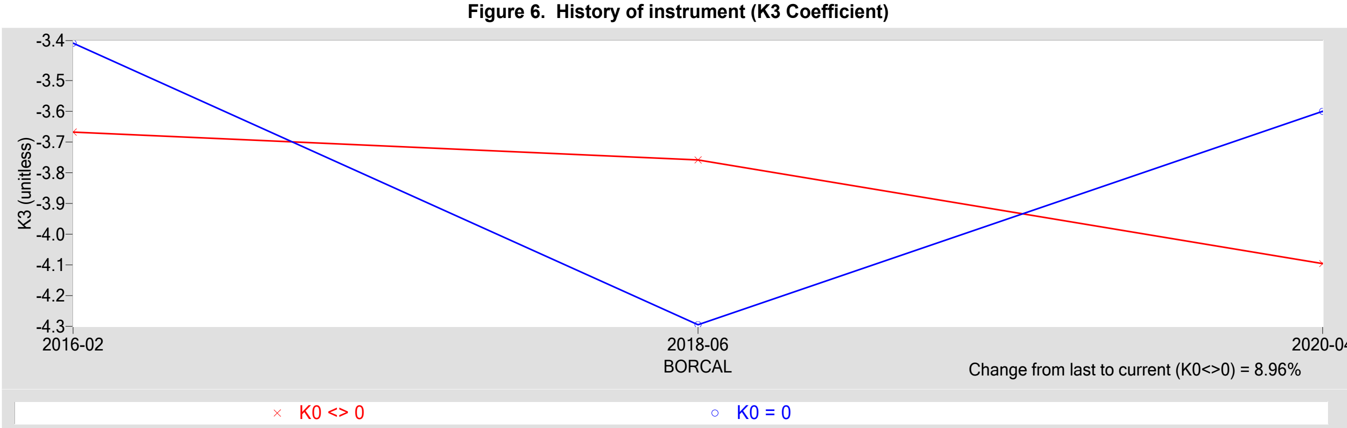


Figure 6. History of instrument (K3 Coefficient)



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:**	30168F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30168F3 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

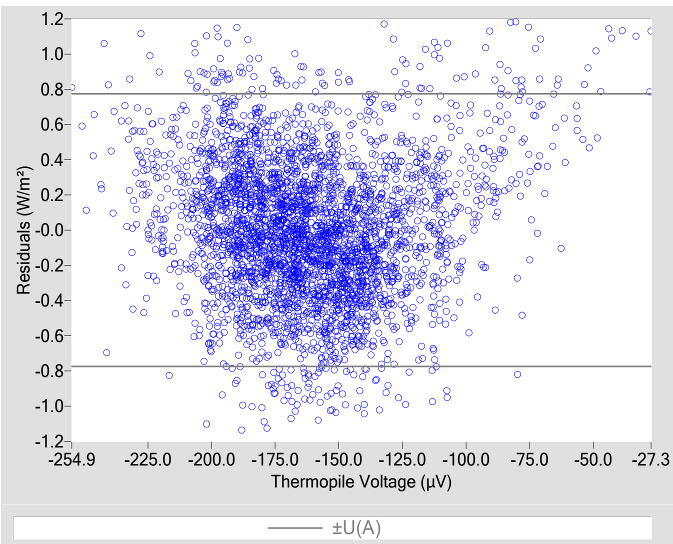


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

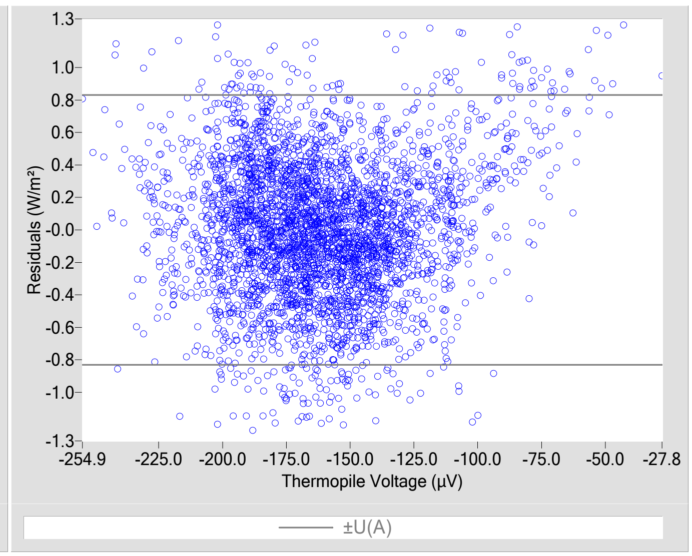


Table 2. Calibration Coefficients for K0<>0

K0	3.5
K1	0.36313
K2	0.9879
K3	-4.14
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.36223
K2	0.9956
K3	-4.06
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

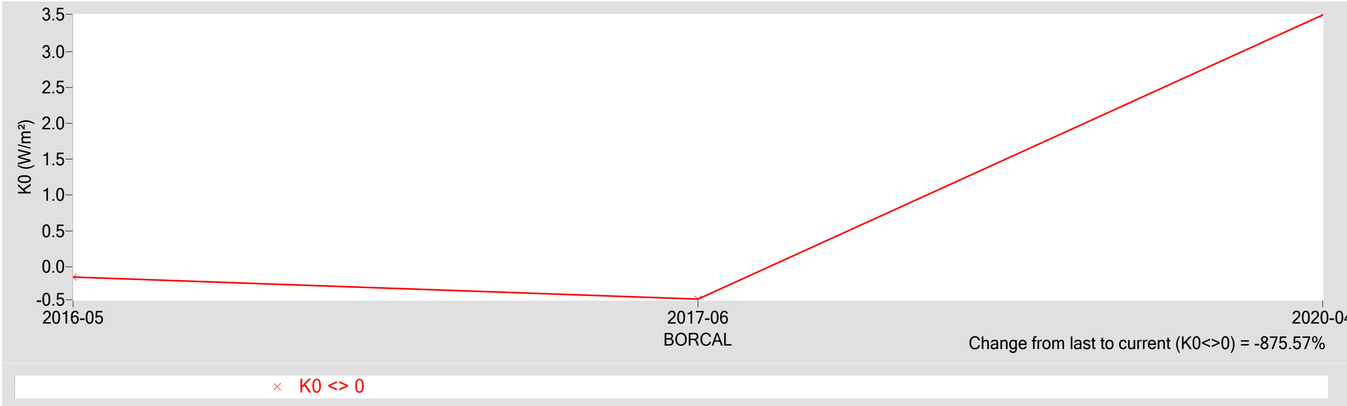


Figure 4. History of instrument (K1 Coefficient)

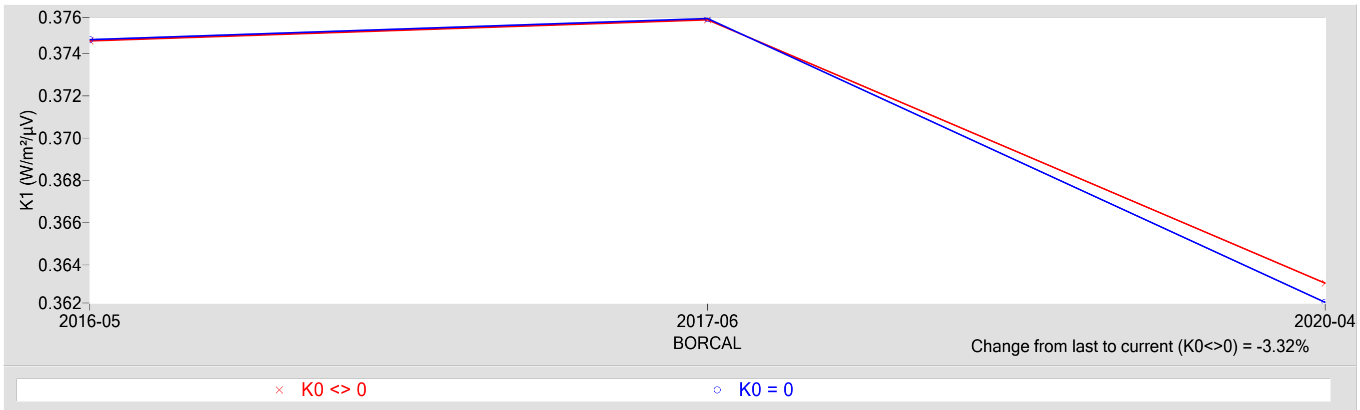


Figure 5. History of instrument (K2 Coefficient)

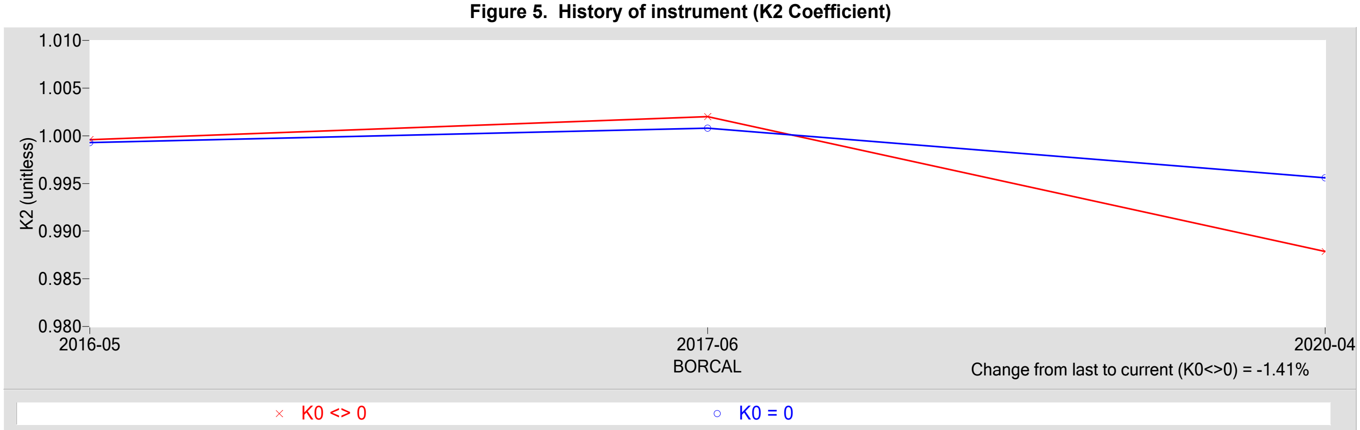
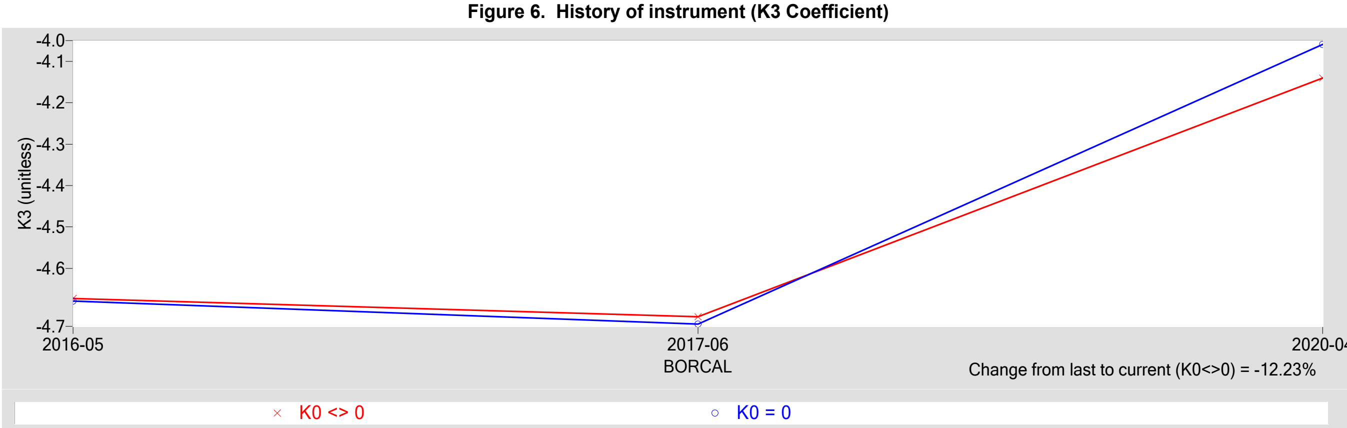


Figure 6. History of instrument (K3 Coefficient)



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:**	30357F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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
30357F3 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

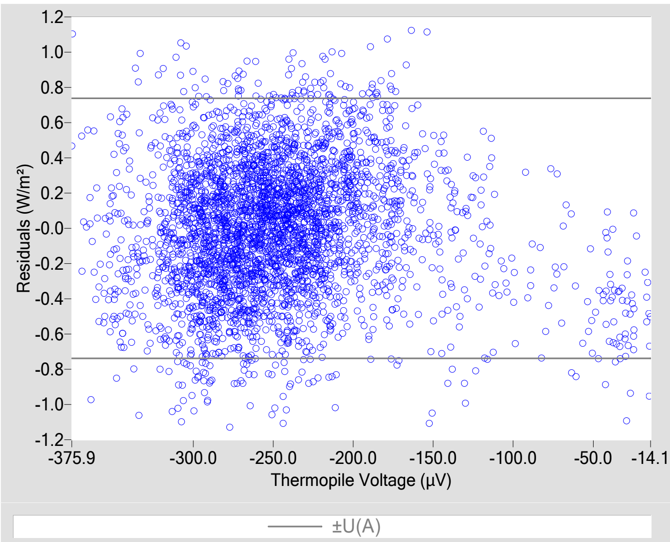


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

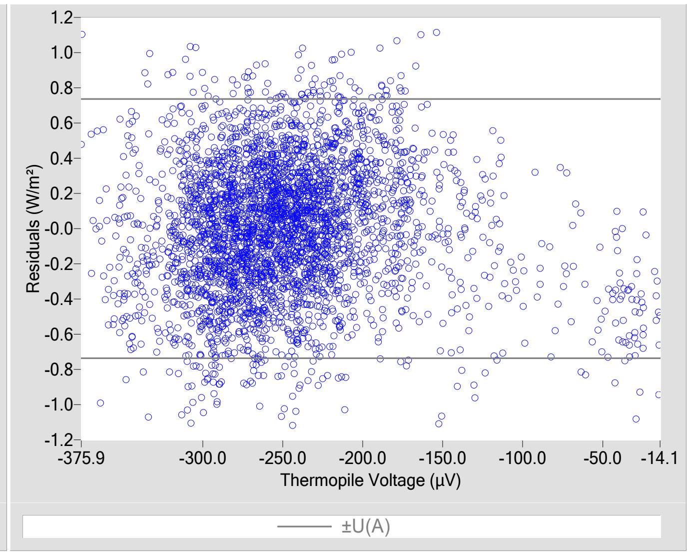


Table 2. Calibration Coefficients for K0<>0

K0	0.3
K1	0.23316
K2	0.9986
K3	-4.06
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23315
K2	0.9991
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)

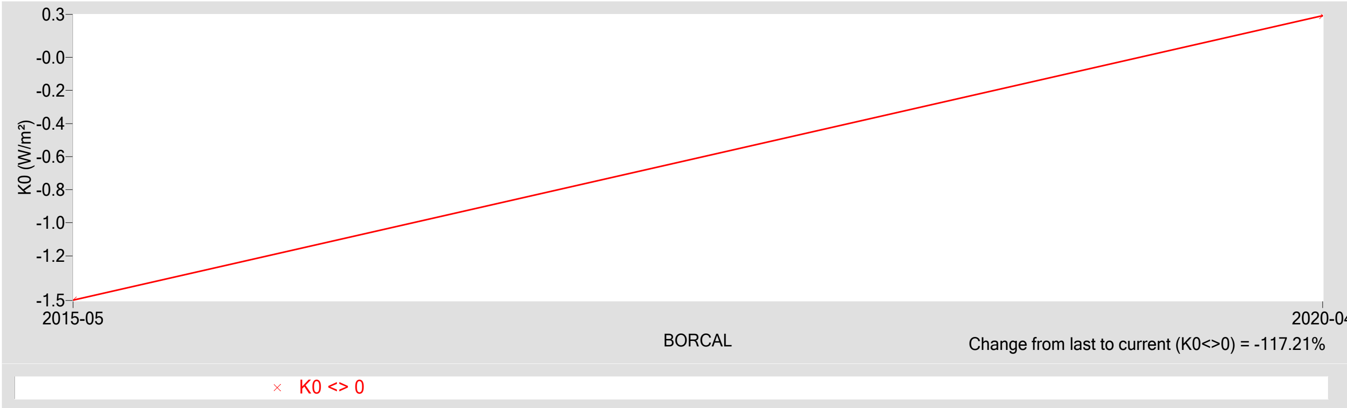


Figure 4. History of instrument (K1 Coefficient)

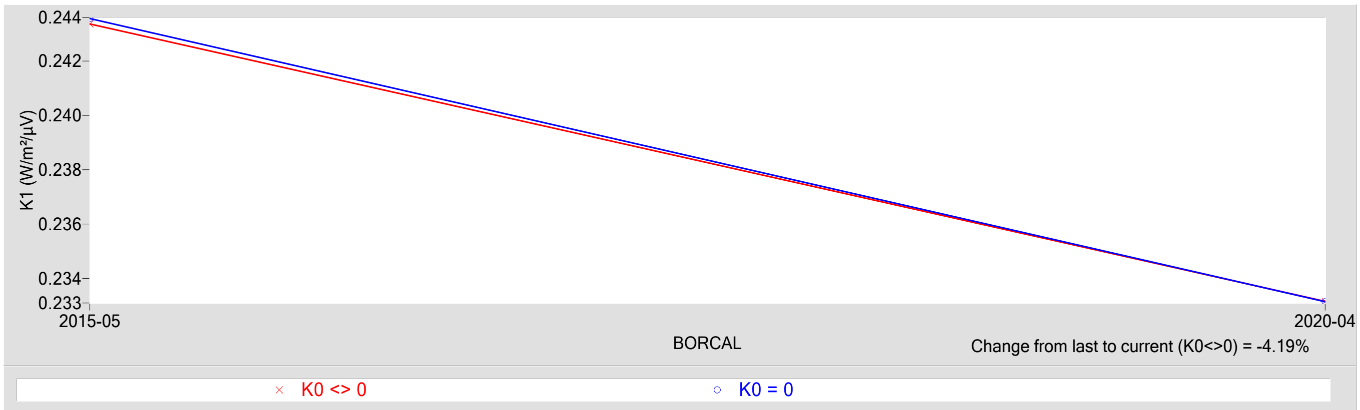


Figure 5. History of instrument (K2 Coefficient)

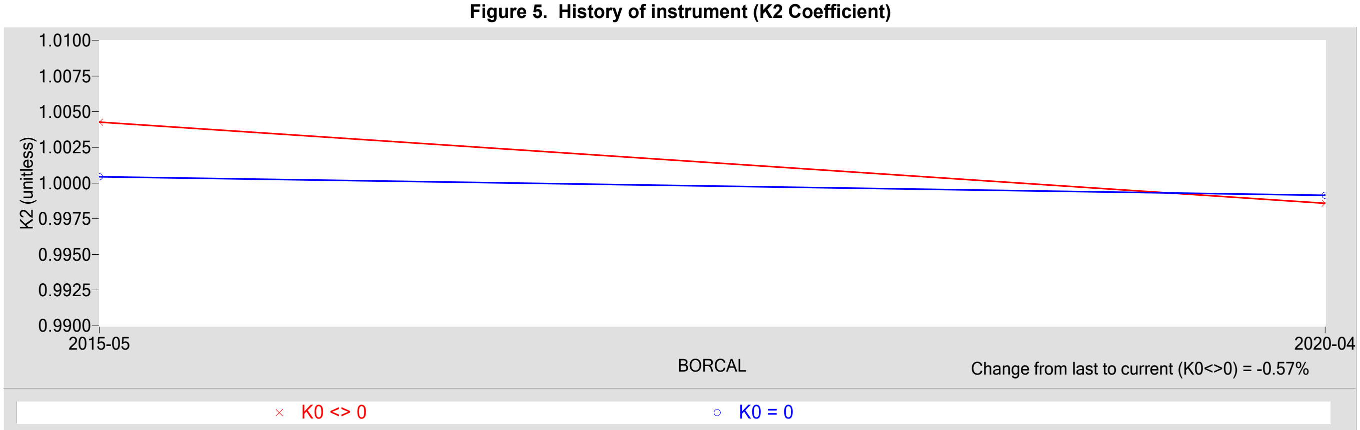
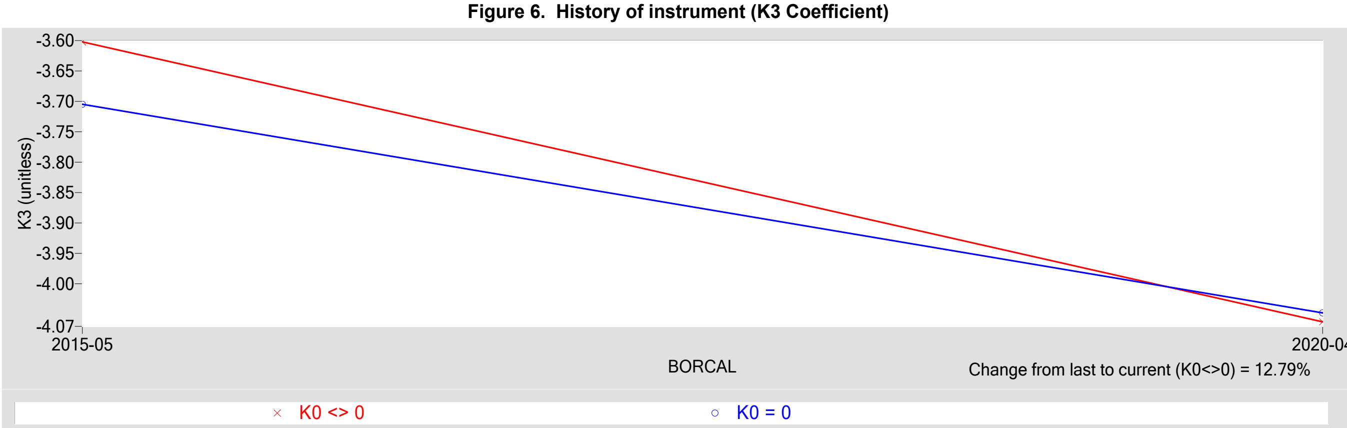


Figure 6. History of instrument (K3 Coefficient)



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:**	30681F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30681F3 Eppley PIR

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

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

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

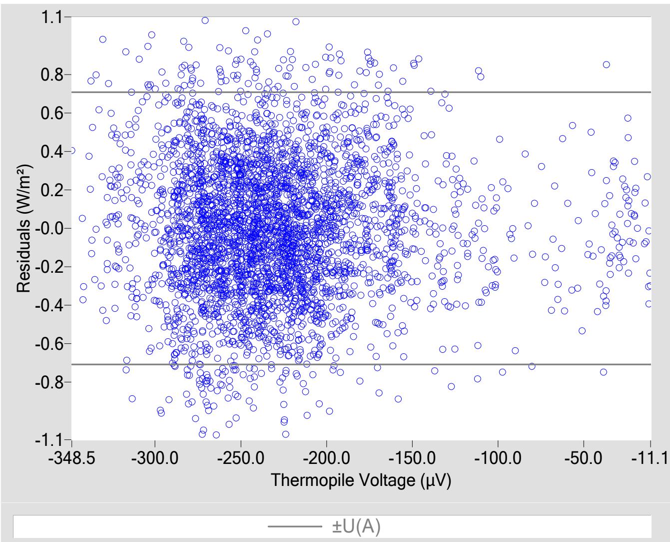


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

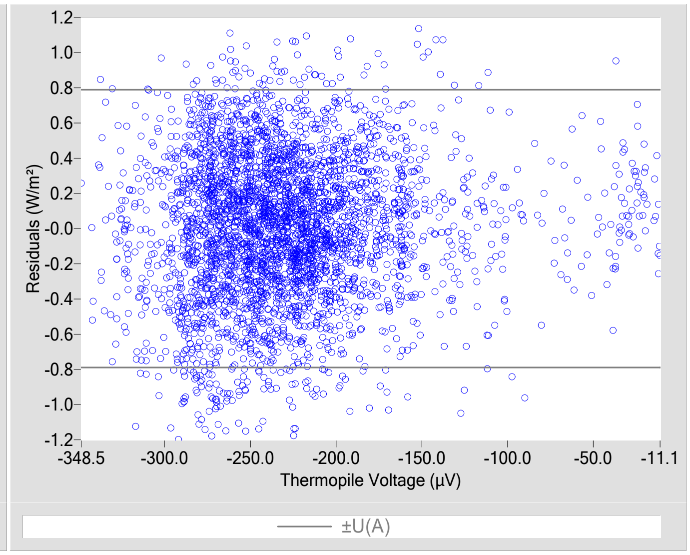


Table 2. Calibration Coefficients for K0<>0

K0	4.3
K1	0.24572
K2	0.9859
K3	-4.03
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24547
K2	0.9958
K3	-3.87
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.36
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)	±1.6
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

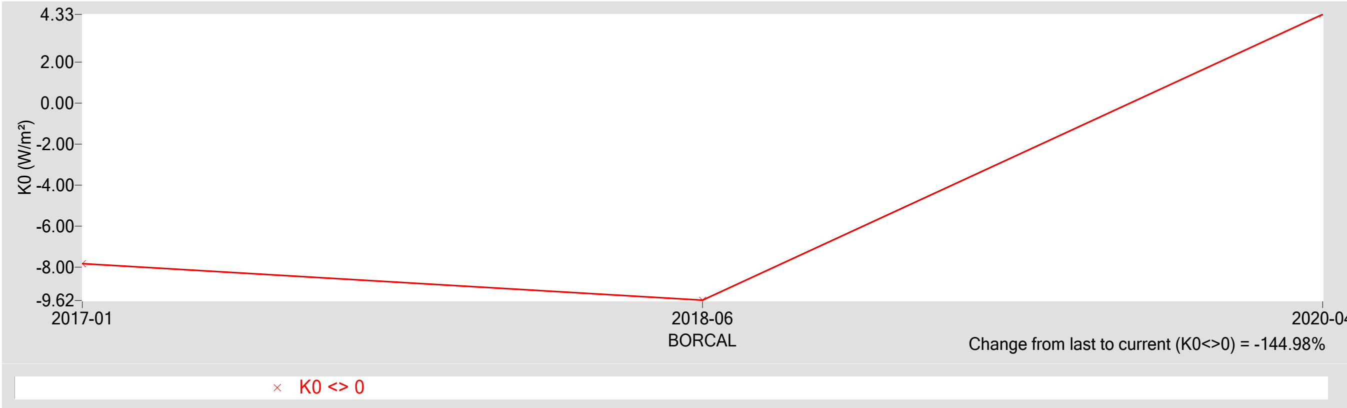


Figure 4. History of instrument (K1 Coefficient)

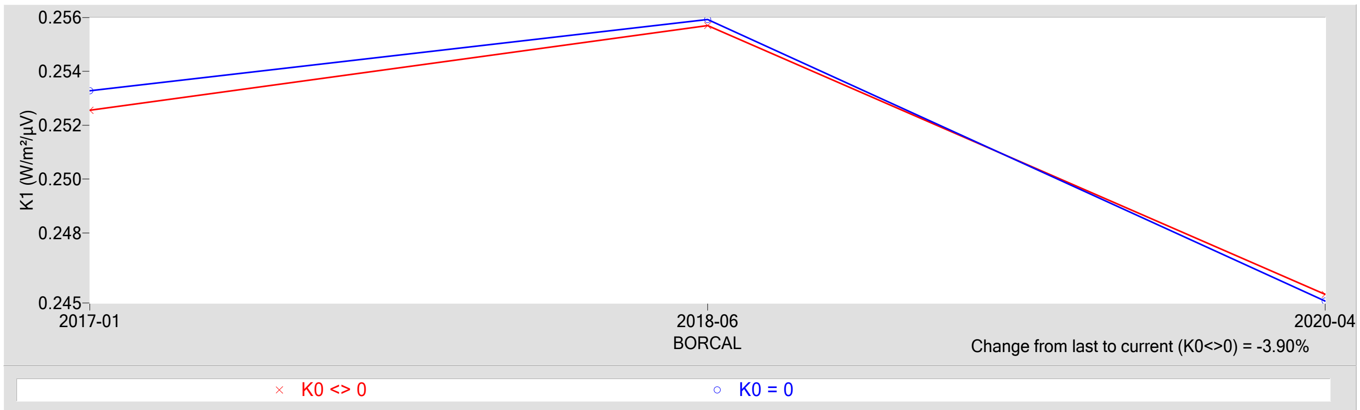


Figure 5. History of instrument (K2 Coefficient)

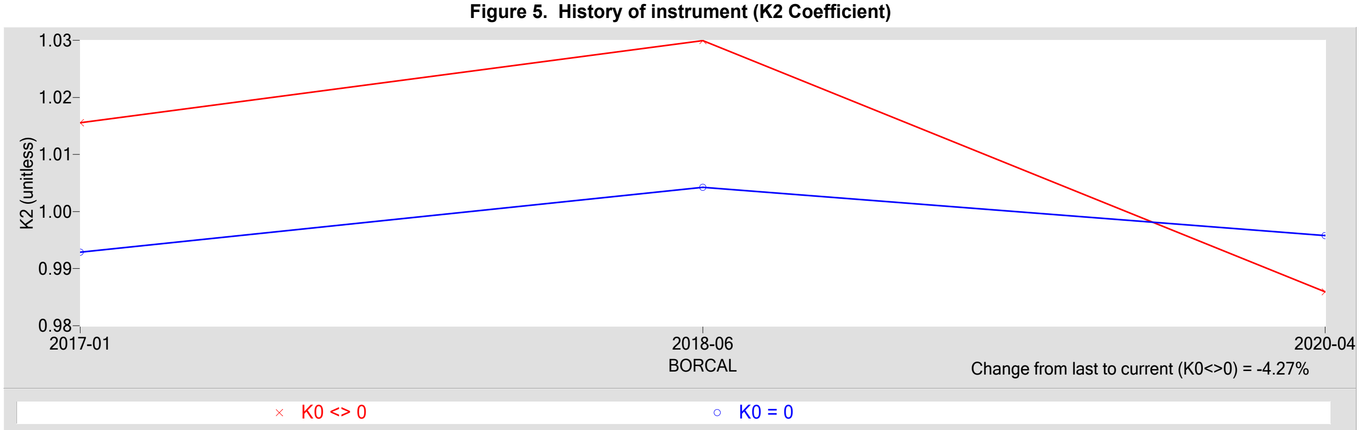
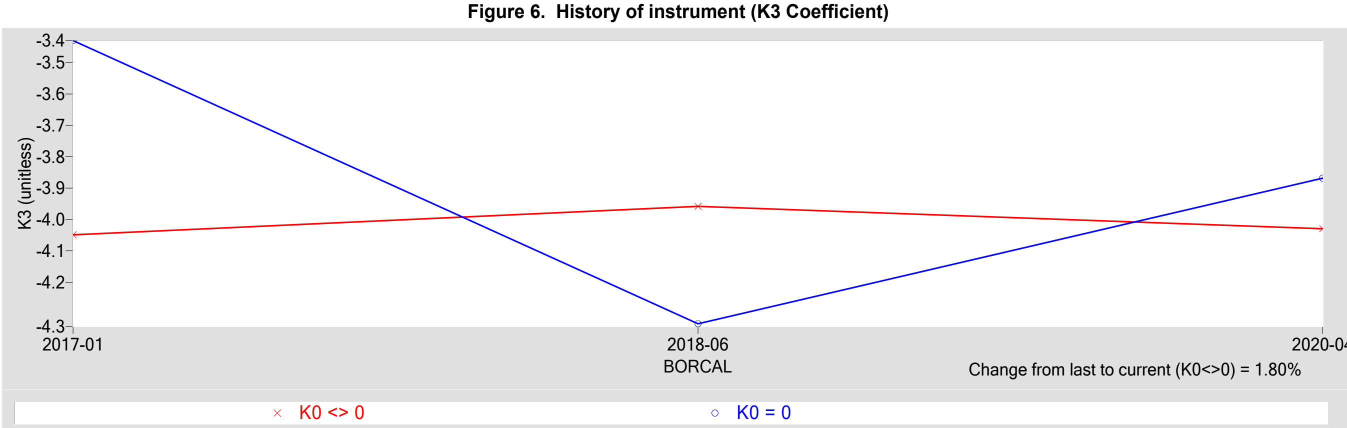


Figure 6. History of instrument (K3 Coefficient)



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:**	30690F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30690F3 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

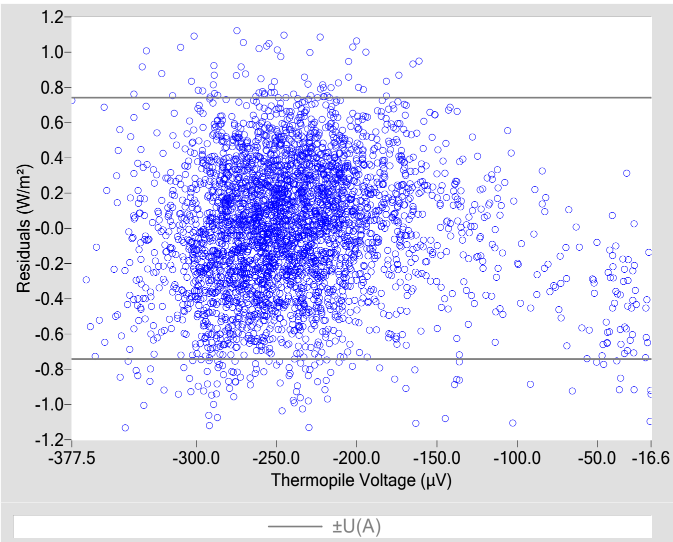


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

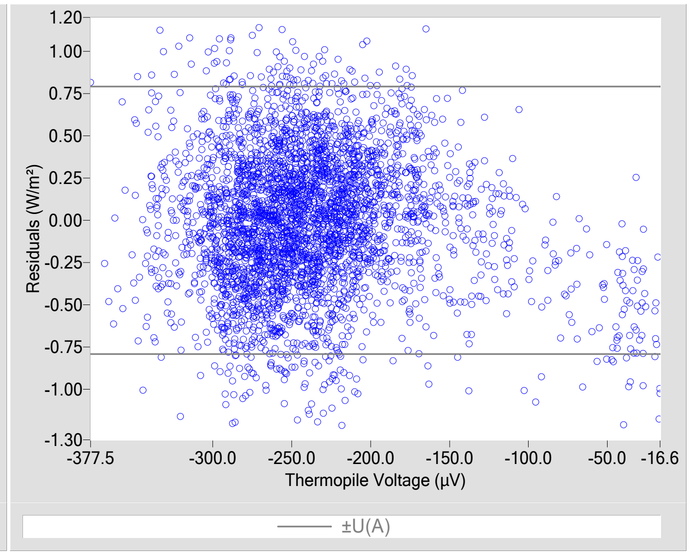


Table 2. Calibration Coefficients for K0<>0

K0	-3.5
K1	0.24469
K2	1.0053
K3	-3.34
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24483
K2	0.9974
K3	-3.36
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)	±1.6
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

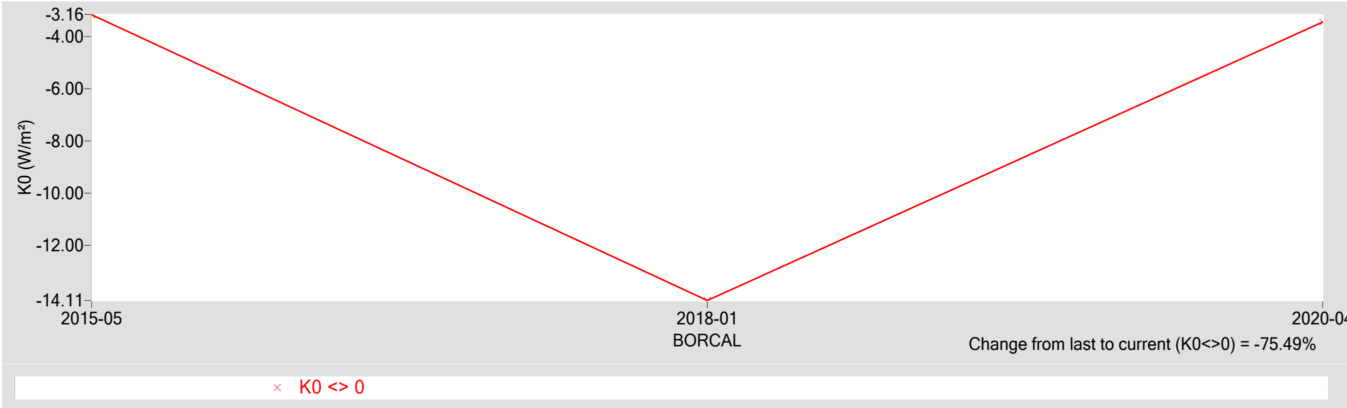


Figure 4. History of instrument (K1 Coefficient)

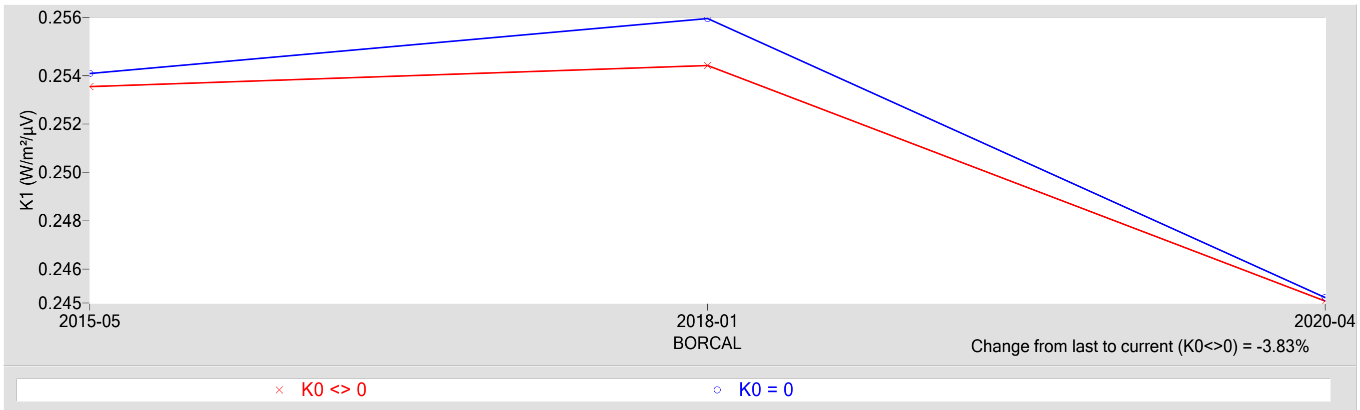


Figure 5. History of instrument (K2 Coefficient)

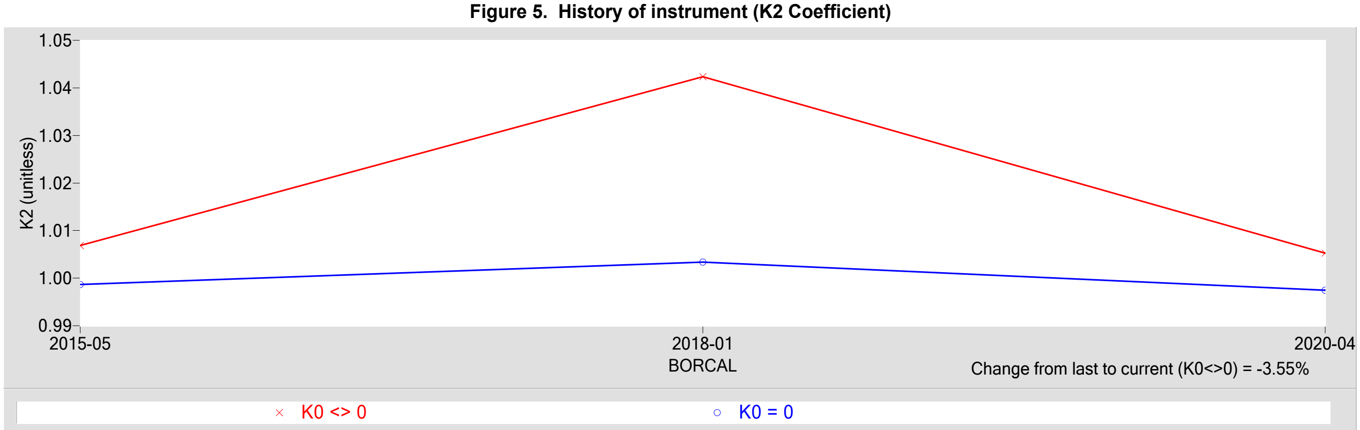
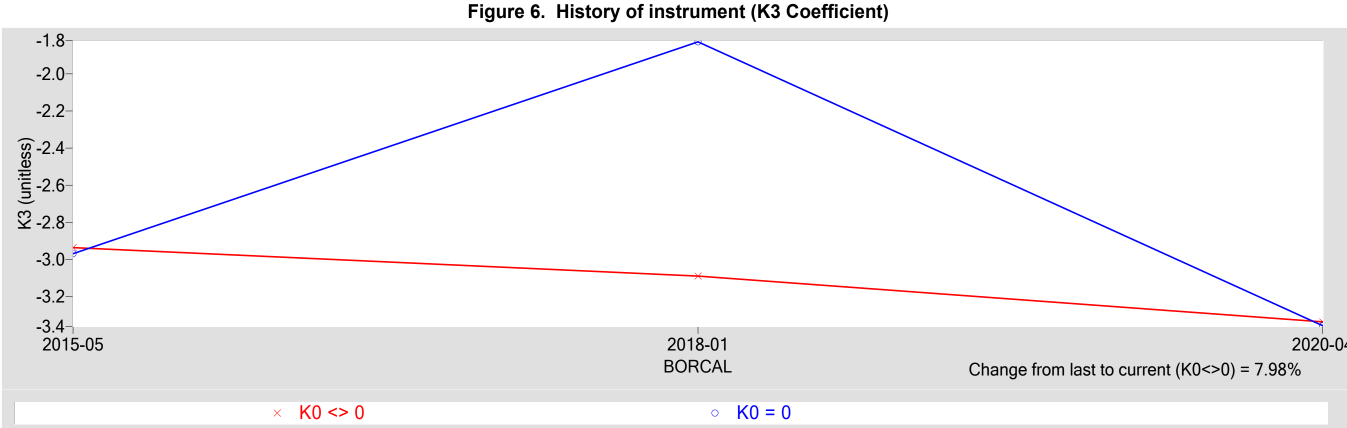


Figure 6. History of instrument (K3 Coefficient)



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:**	30692F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30692F3 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

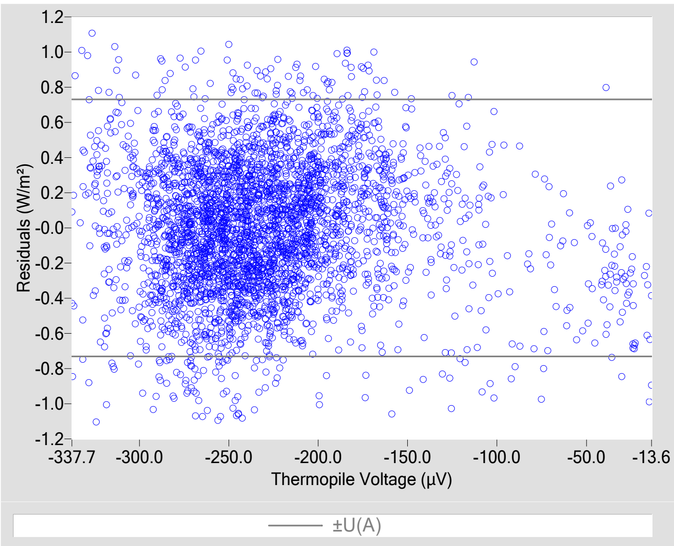


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

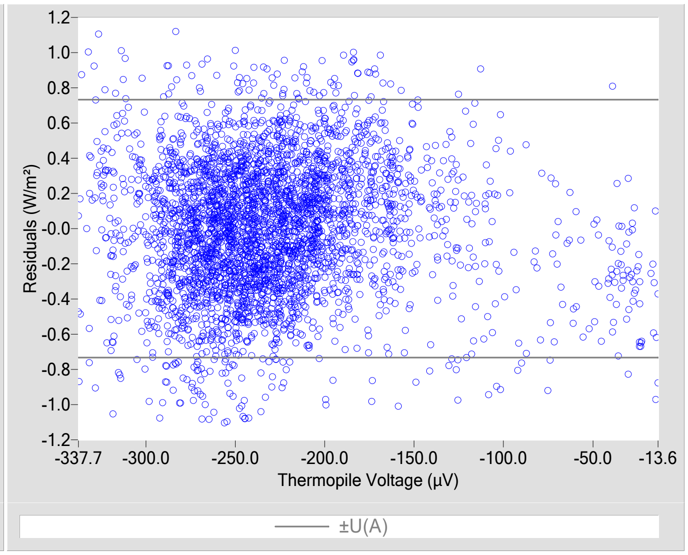


Table 2. Calibration Coefficients for K0<>0

K0	0.5
K1	0.25031
K2	0.9981
K3	-3.59
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.25028
K2	0.9993
K3	-3.58
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.37
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.37
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)

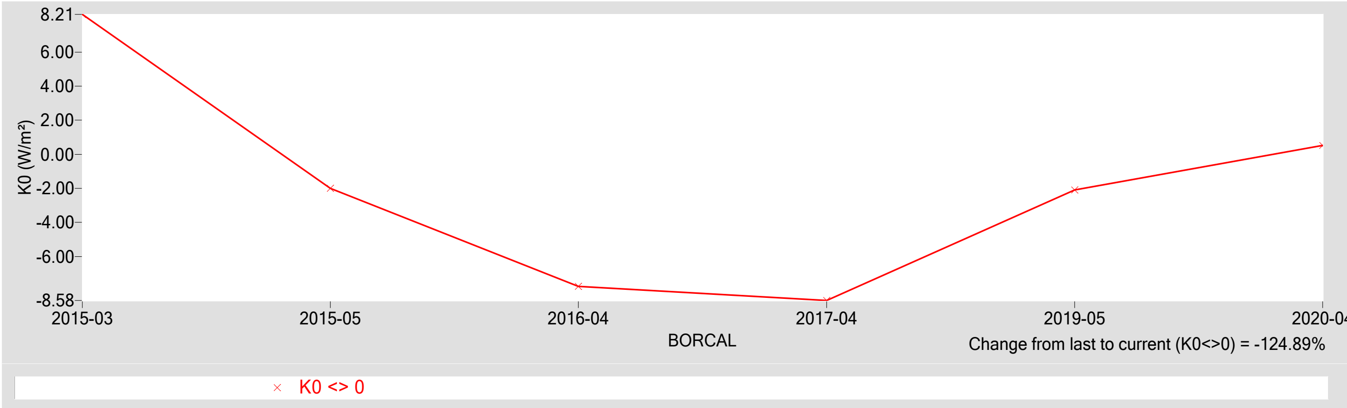


Figure 4. History of instrument (K1 Coefficient)

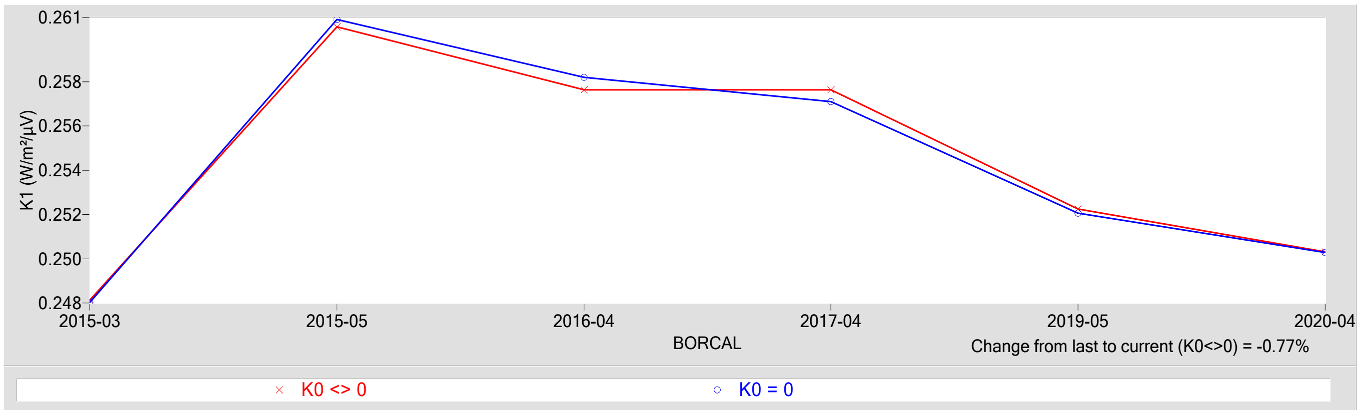


Figure 5. History of instrument (K2 Coefficient)

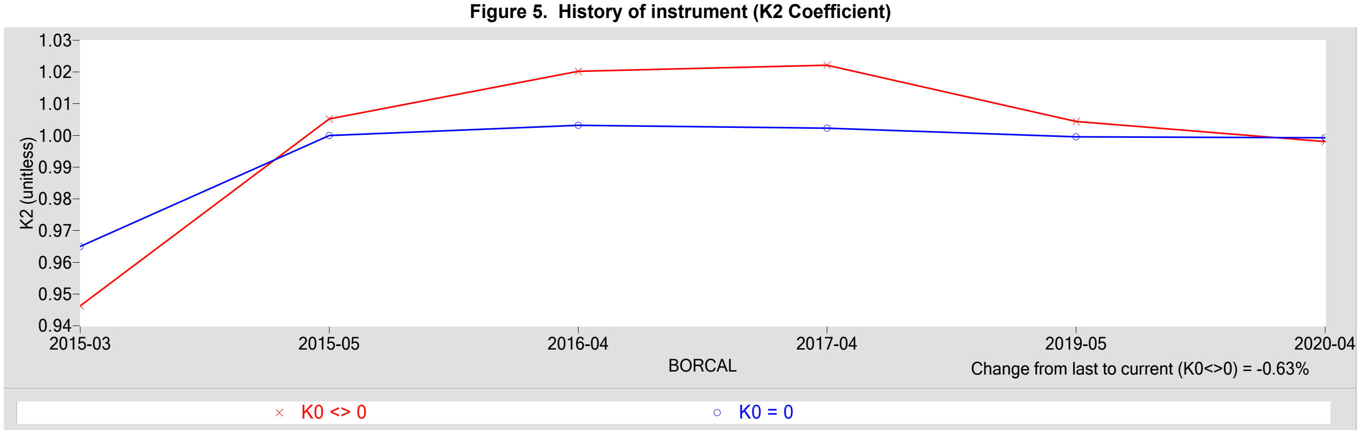
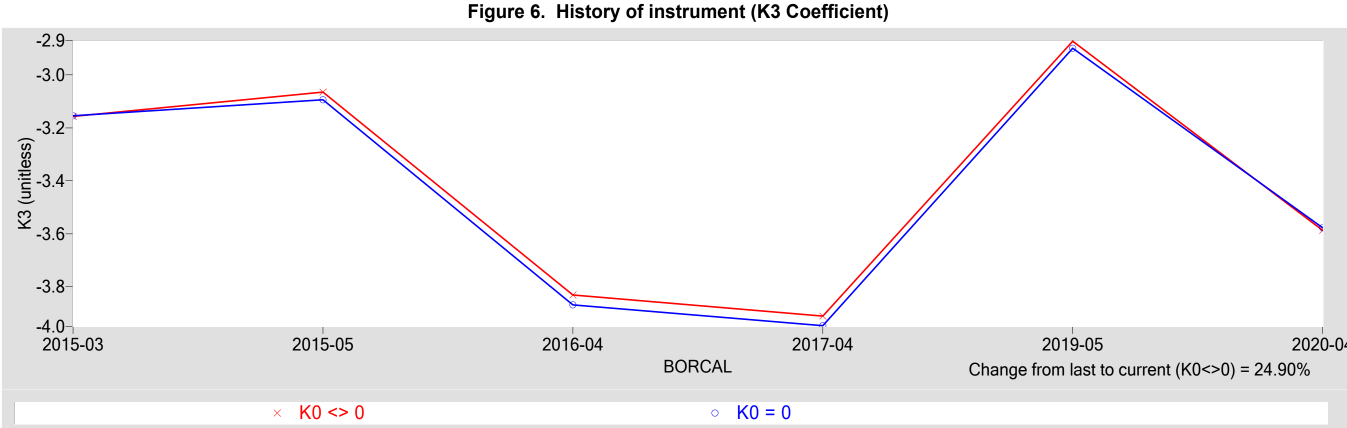


Figure 6. History of instrument (K3 Coefficient)



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:**	30781F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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
30781F3 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

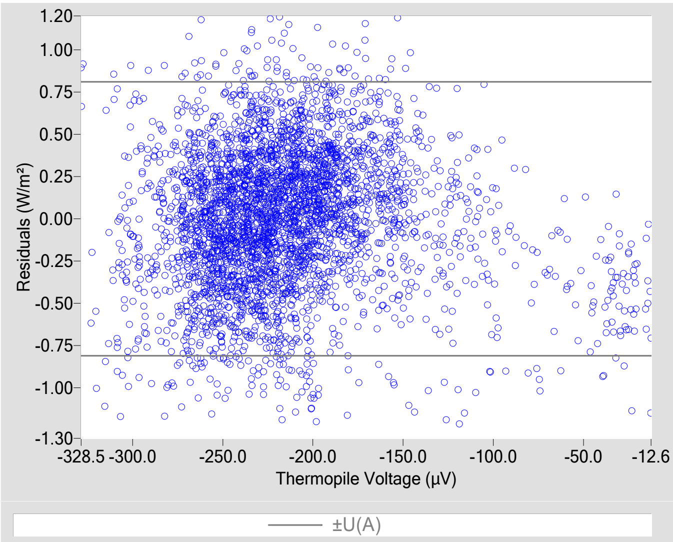


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

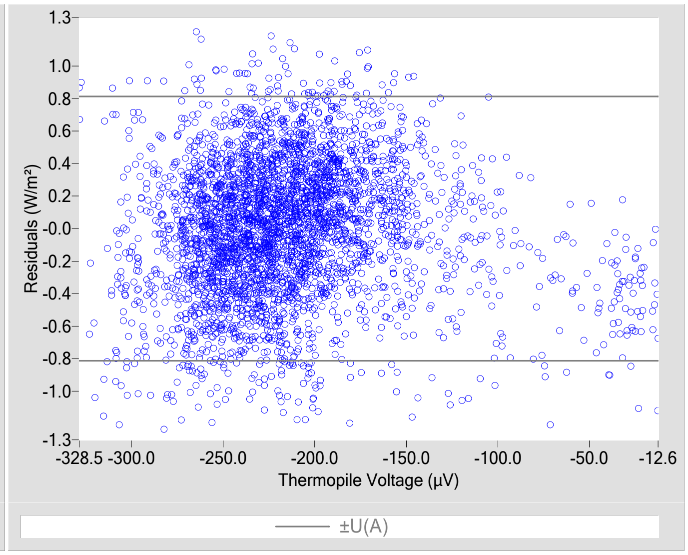


Table 2. Calibration Coefficients for K0<>0

K0	1.0
K1	0.27043
K2	0.9936
K3	-3.51
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.27037
K2	0.9958
K3	-3.49
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.41
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

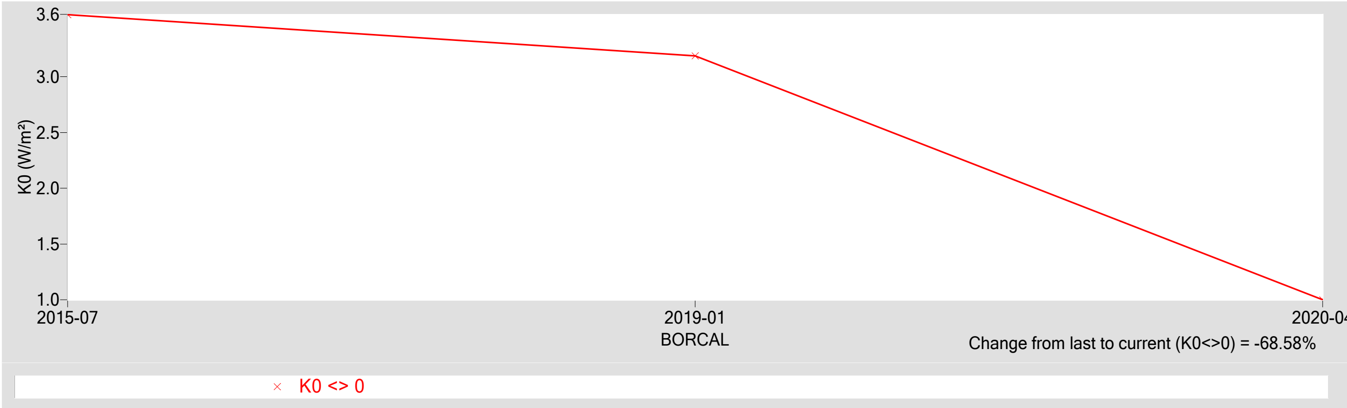


Figure 4. History of instrument (K1 Coefficient)

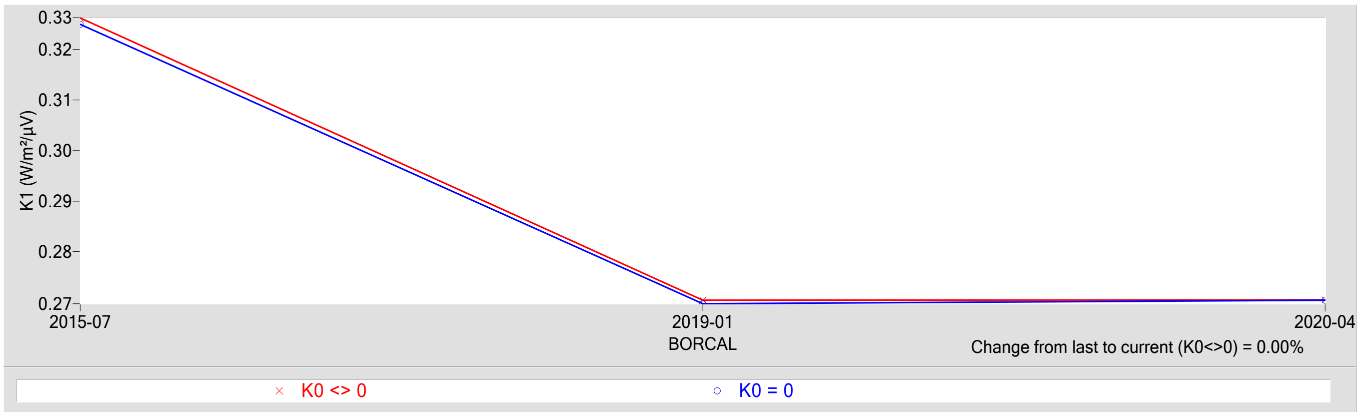


Figure 5. History of instrument (K2 Coefficient)

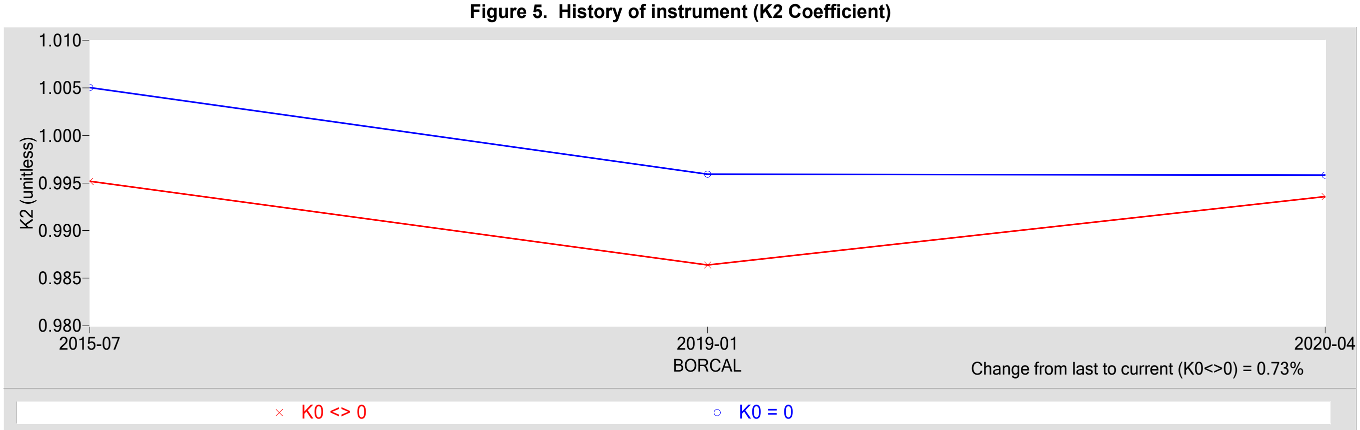
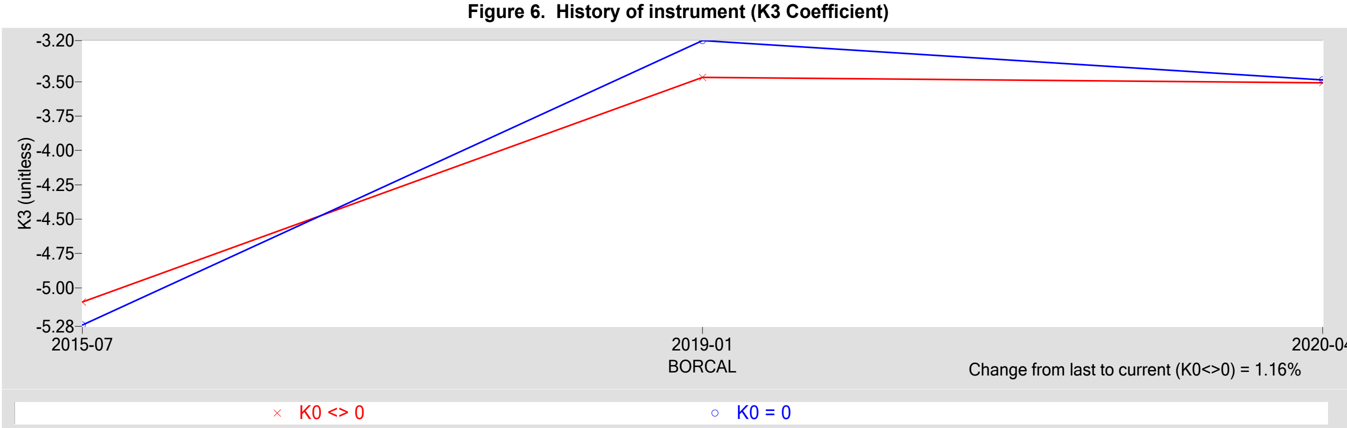


Figure 6. History of instrument (K3 Coefficient)



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:**	30828F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

30828F3 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

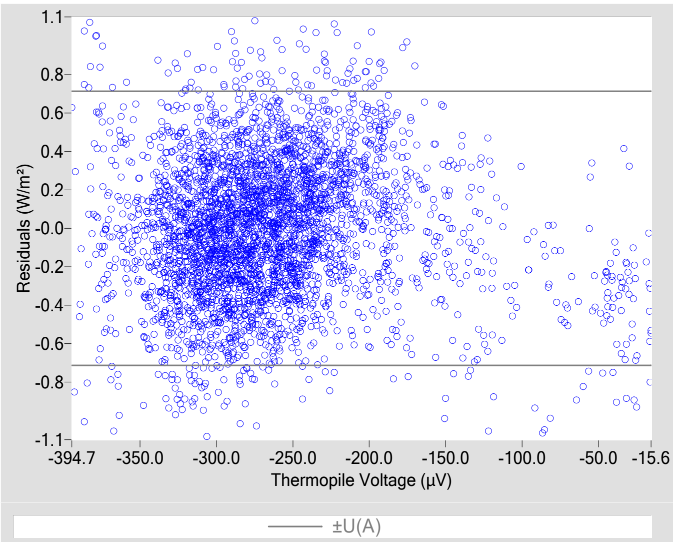


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

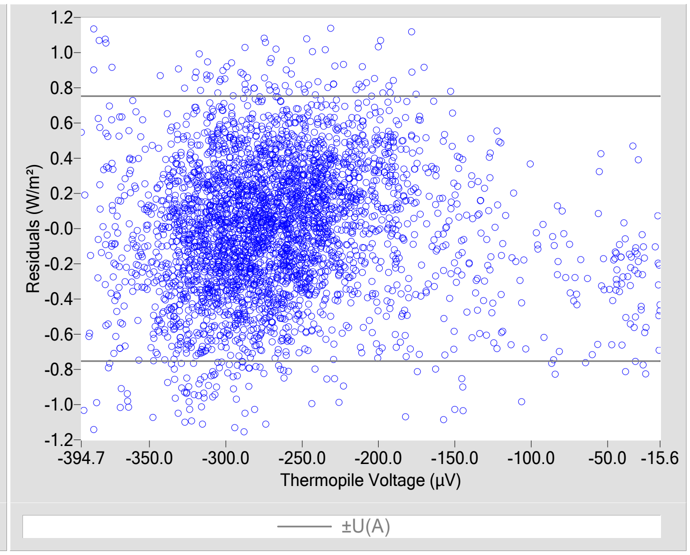


Table 2. Calibration Coefficients for K0<>0

K0	2.9
K1	0.21399
K2	0.9921
K3	-3.32
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.21393
K2	0.9987
K3	-3.13
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.36
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)

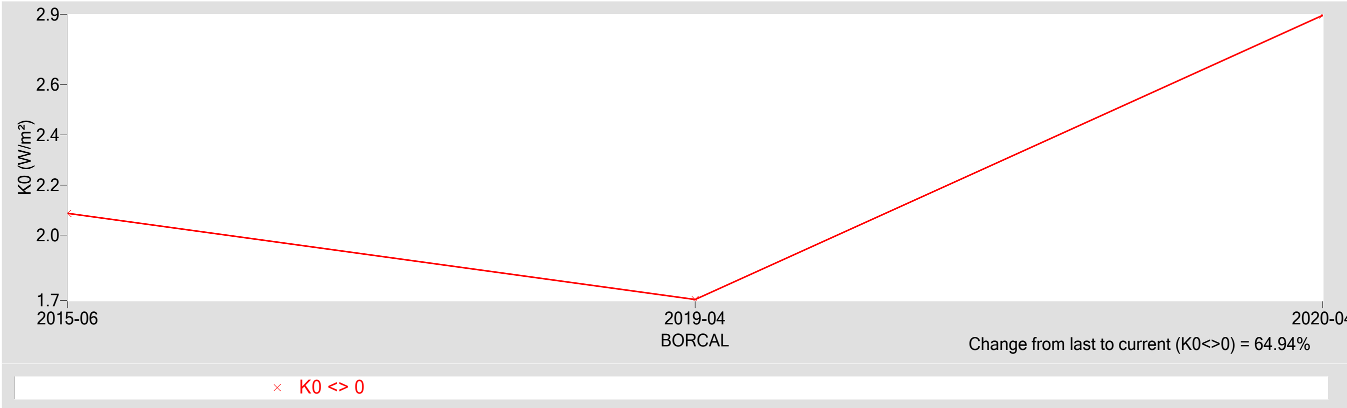


Figure 4. History of instrument (K1 Coefficient)

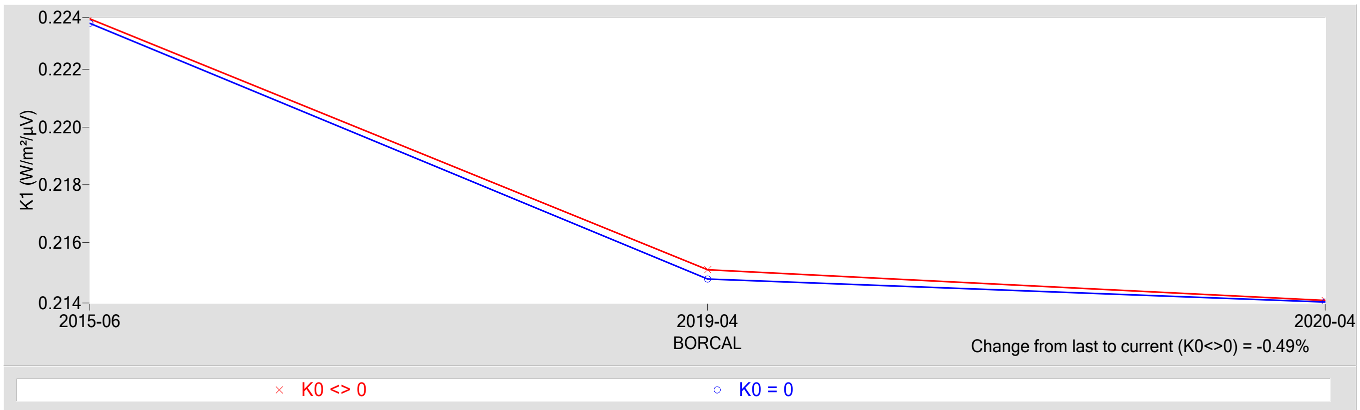


Figure 5. History of instrument (K2 Coefficient)

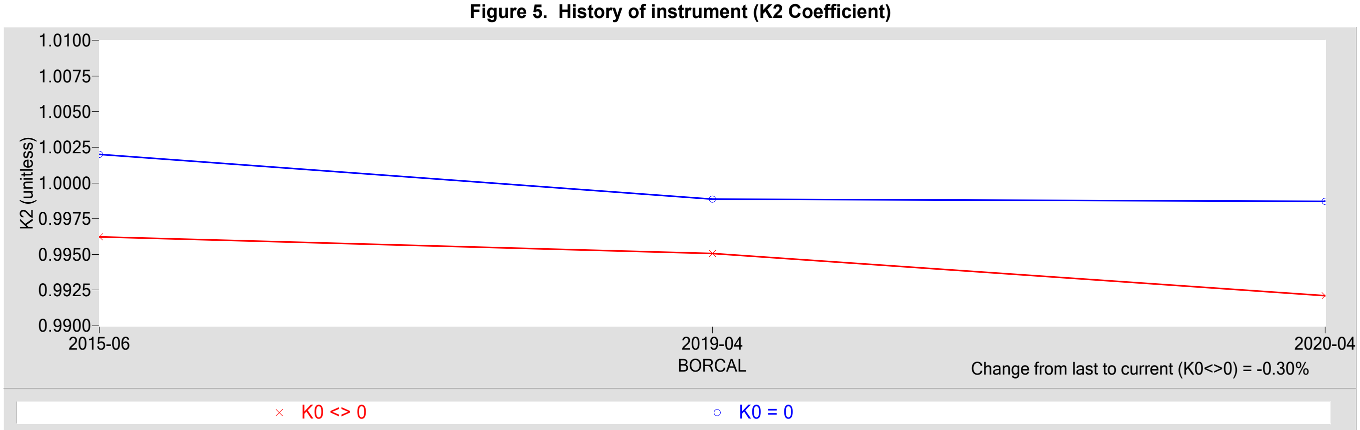
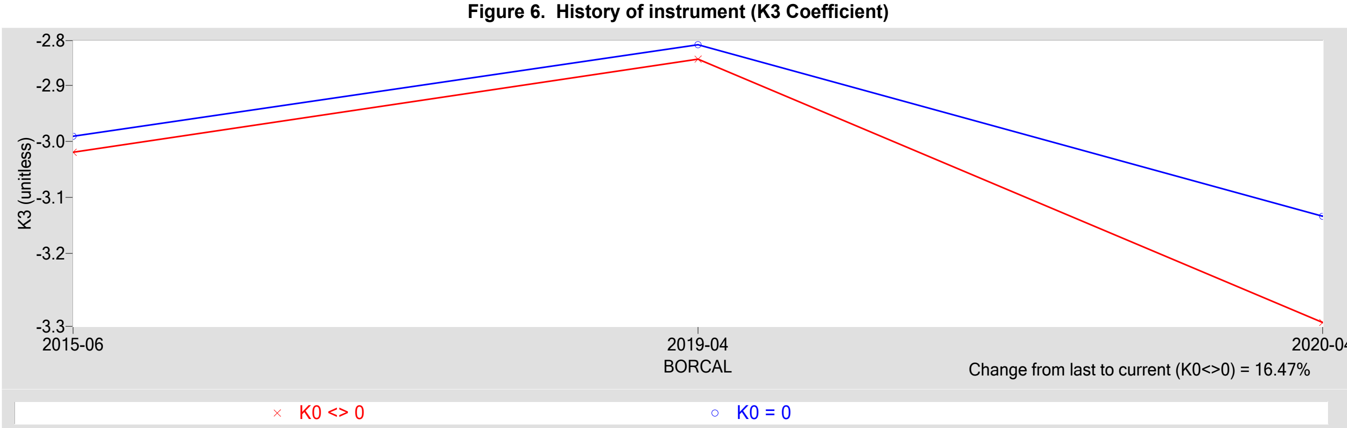


Figure 6. History of instrument (K3 Coefficient)



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:**	30834F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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),
$Wd = \sigma * Td^4$ = 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

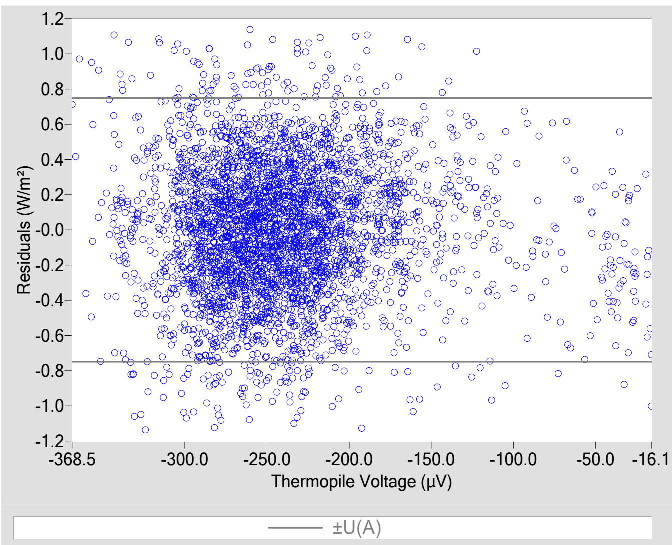


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

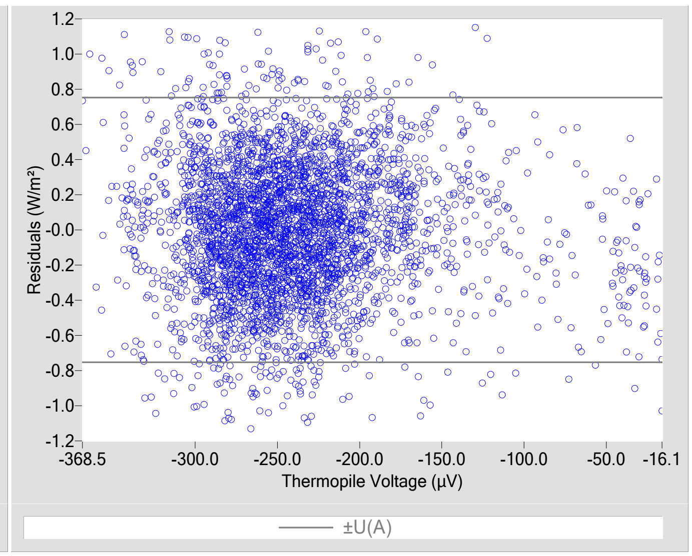


Table 2. Calibration Coefficients for K0<>0

K0	-1.1
K1	0.24175
K2	1.0062
K3	-4.26
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24182
K2	1.0037
K3	-4.25
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)

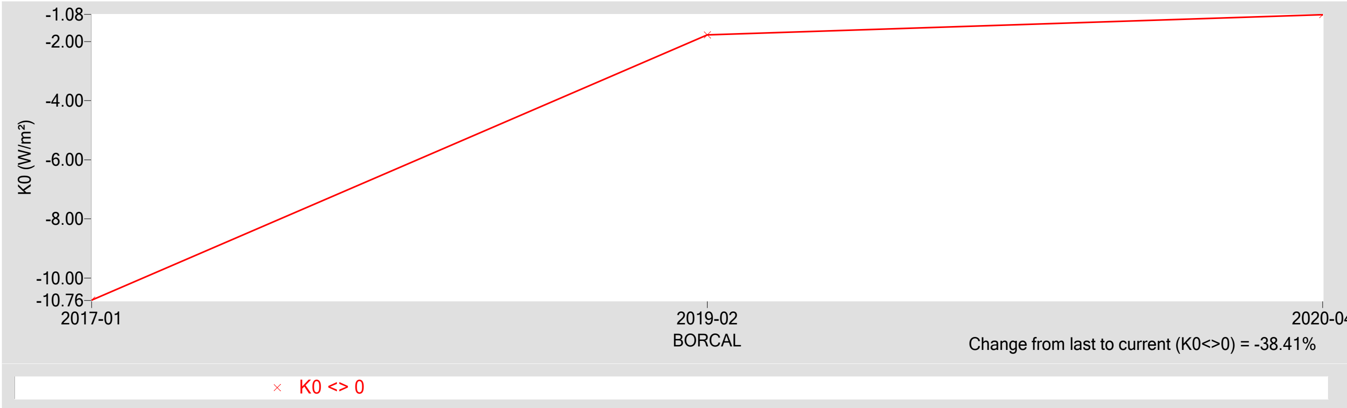


Figure 4. History of instrument (K1 Coefficient)

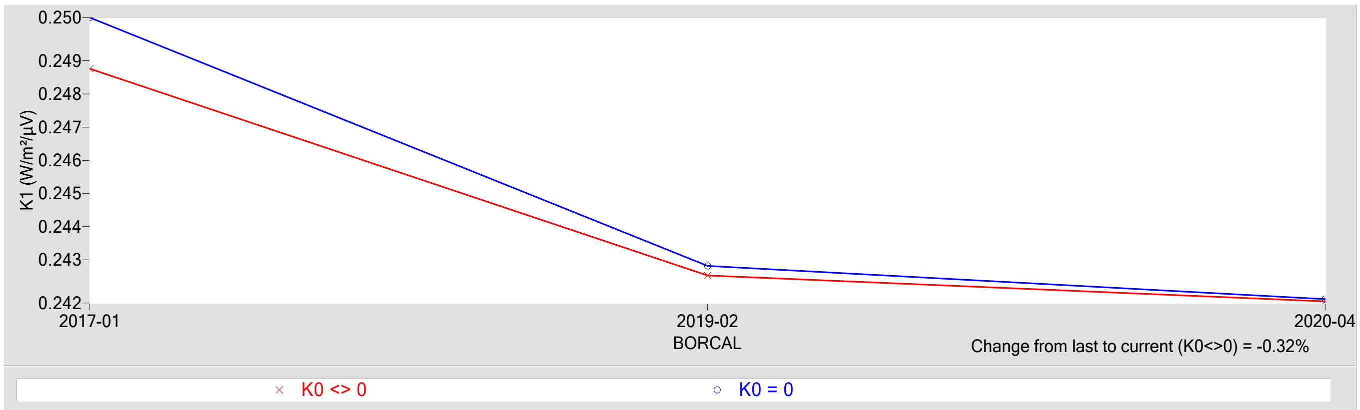


Figure 5. History of instrument (K2 Coefficient)

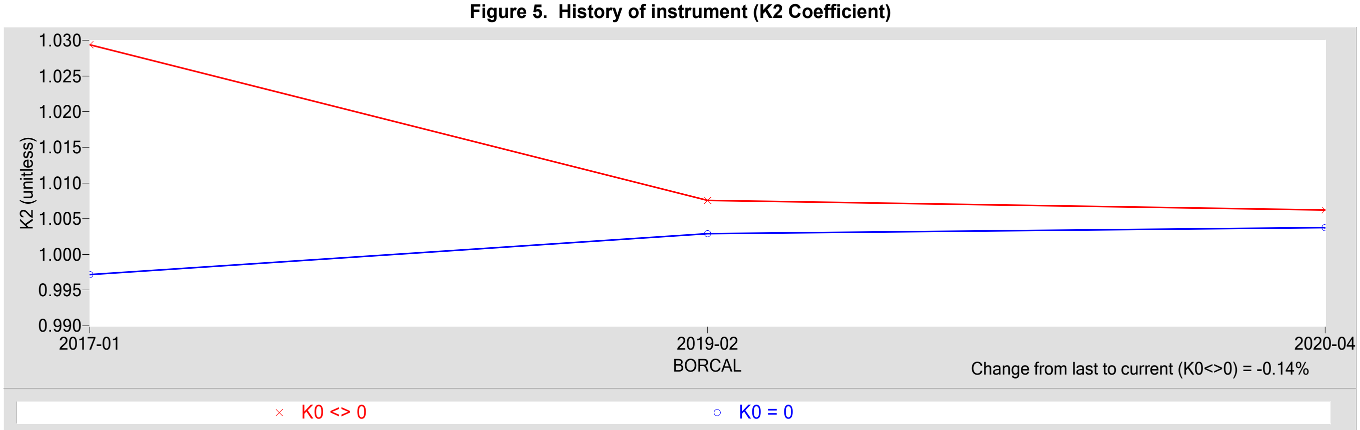
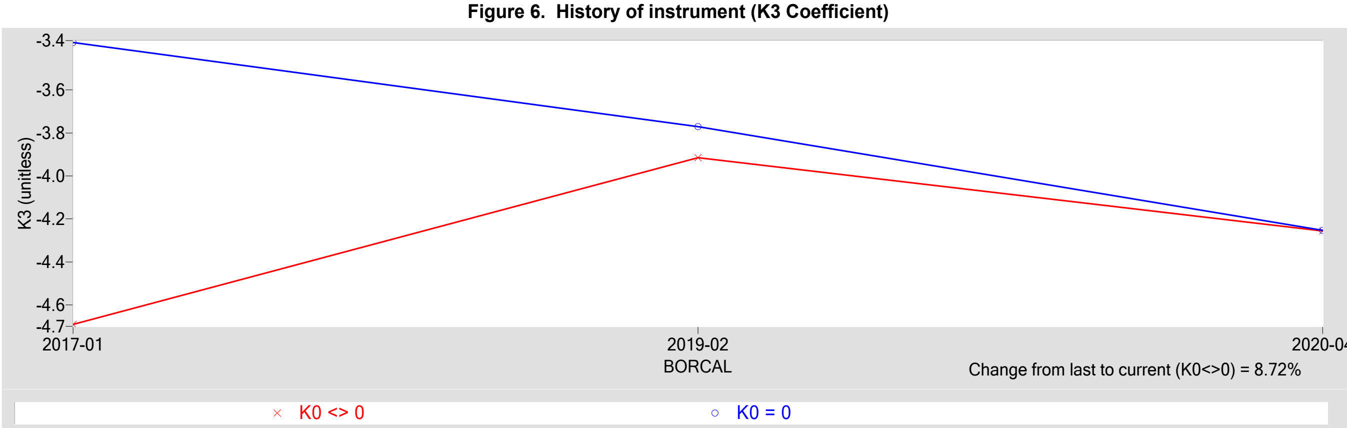


Figure 6. History of instrument (K3 Coefficient)



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:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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:

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

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

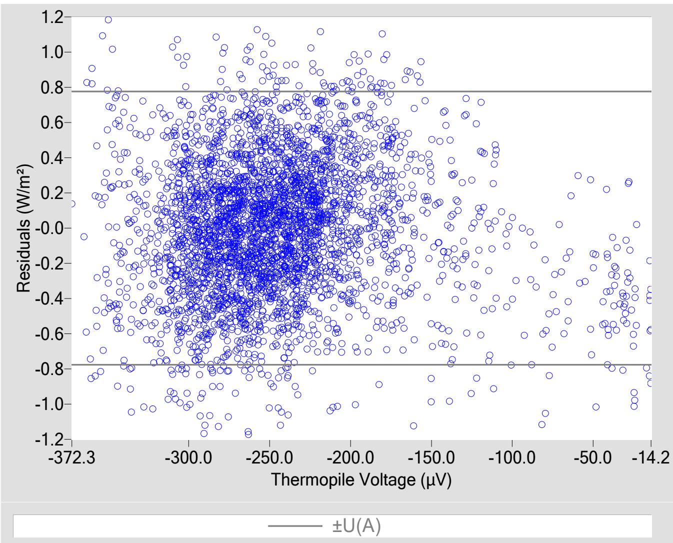


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

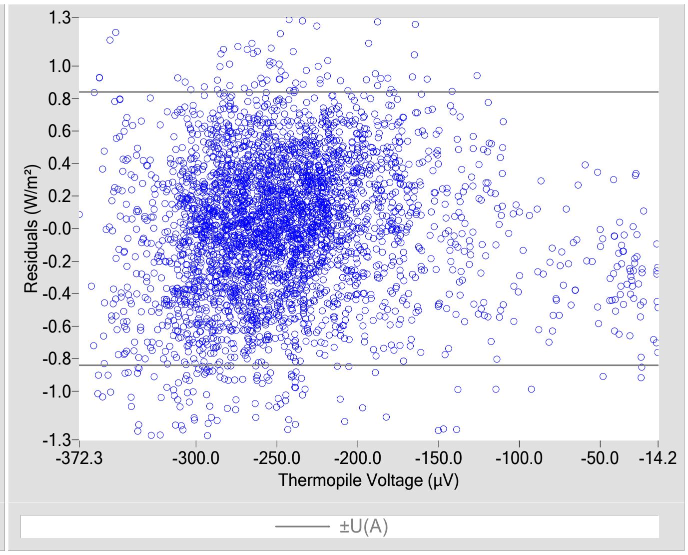


Table 2. Calibration Coefficients for K0<>0

K0	4.0
K1	0.23229
K2	0.9898
K3	-3.42
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23214
K2	0.9988
K3	-3.22
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.43
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

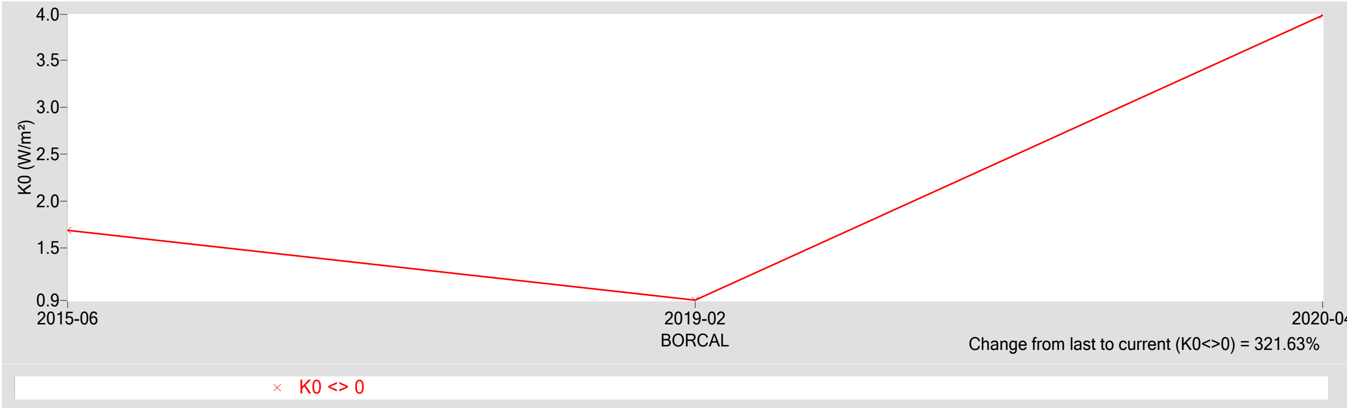


Figure 4. History of instrument (K1 Coefficient)

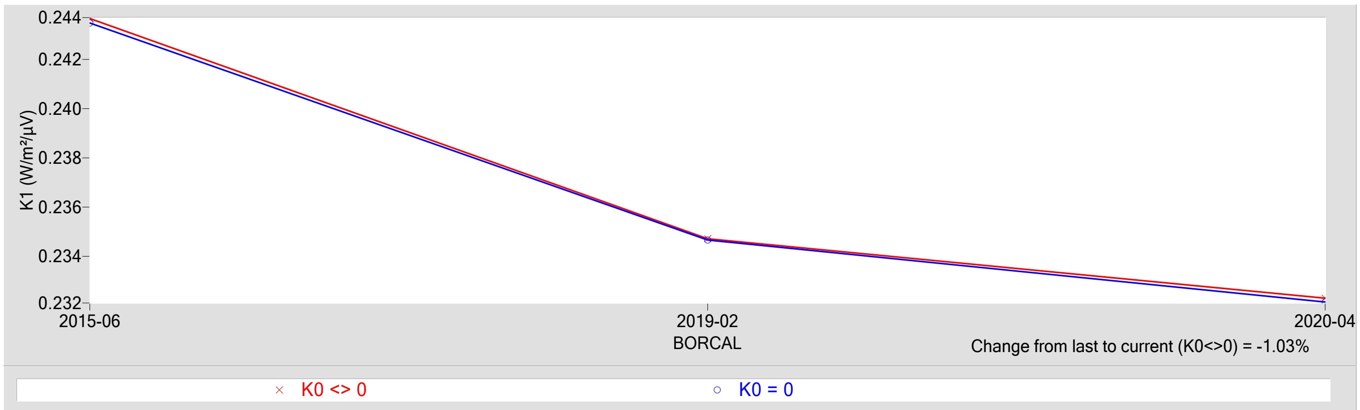


Figure 5. History of instrument (K2 Coefficient)

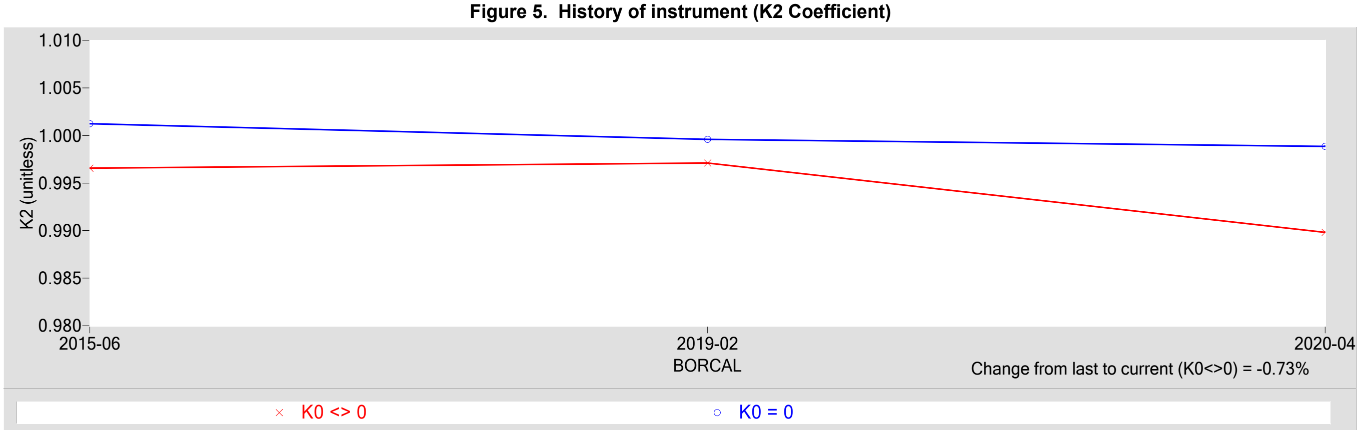
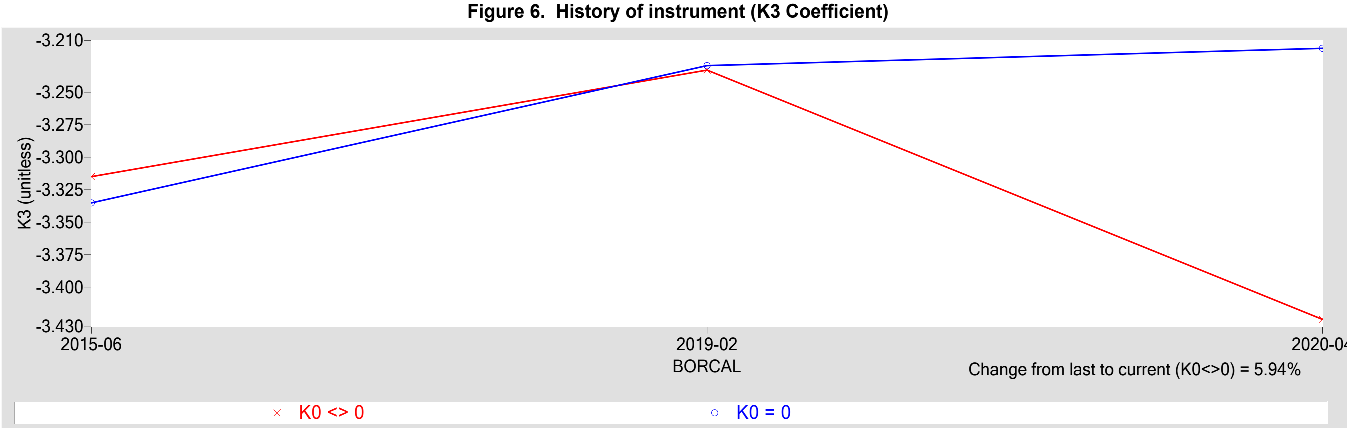


Figure 6. History of instrument (K3 Coefficient)



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:**	31299F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

31299F3 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

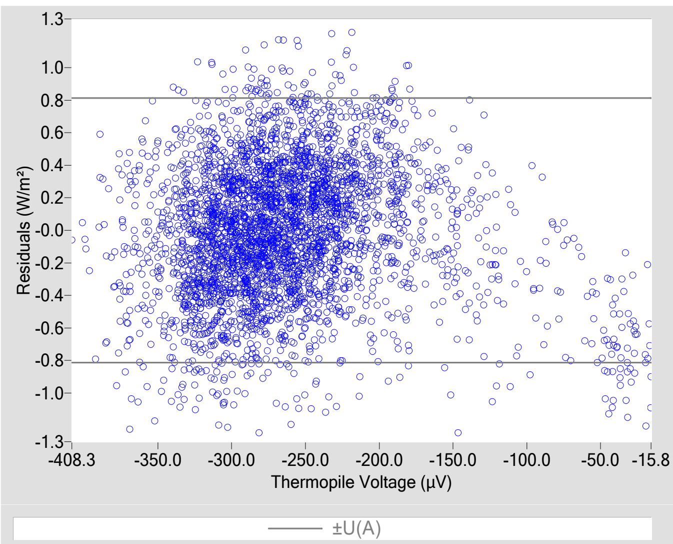


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

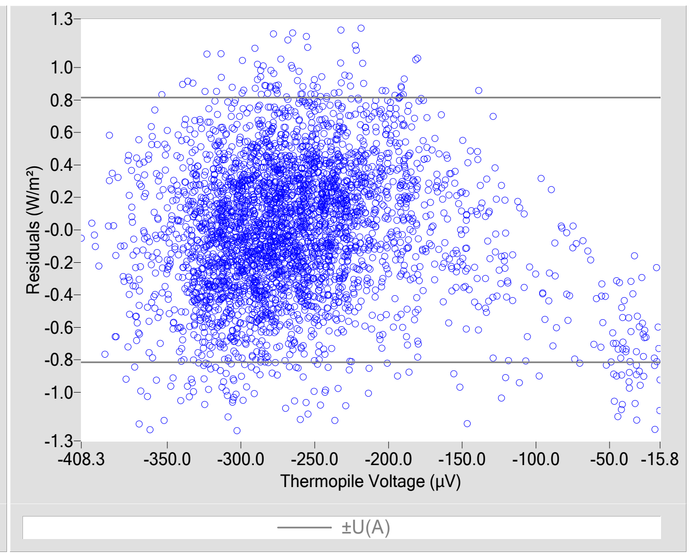


Table 2. Calibration Coefficients for K0<>0

K0	-0.8
K1	0.22366
K2	0.9894
K3	-4.08
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.22372
K2	0.9876
K3	-4.10
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

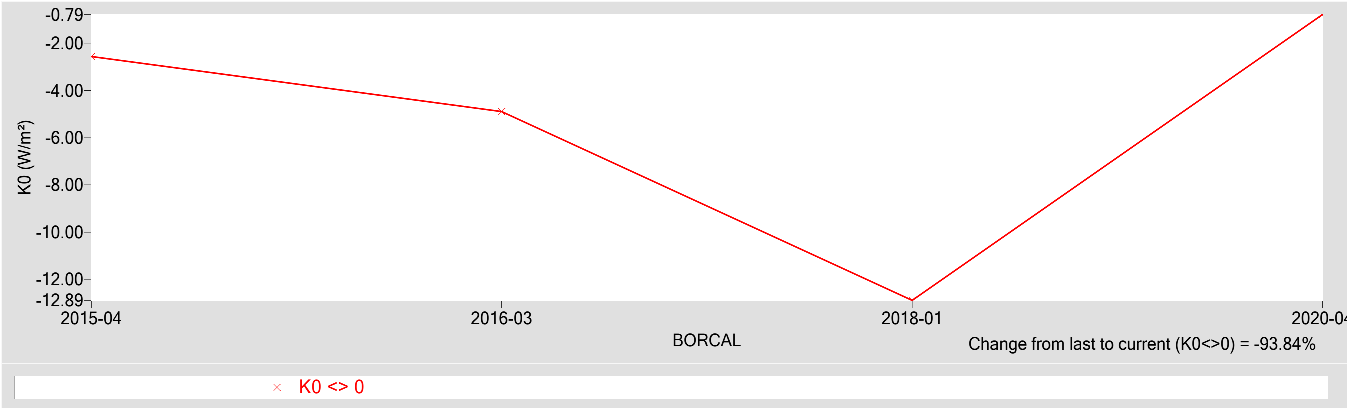


Figure 4. History of instrument (K1 Coefficient)

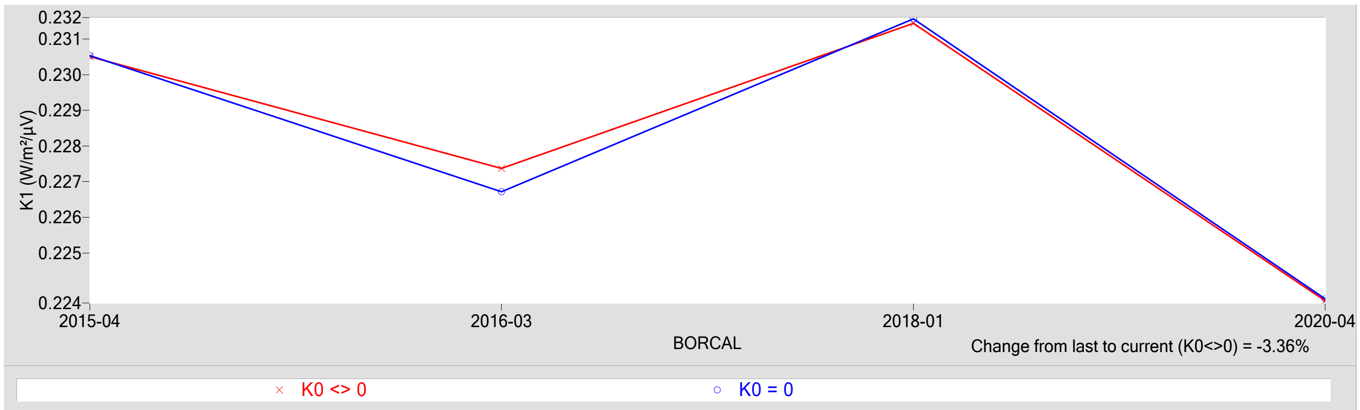


Figure 5. History of instrument (K2 Coefficient)

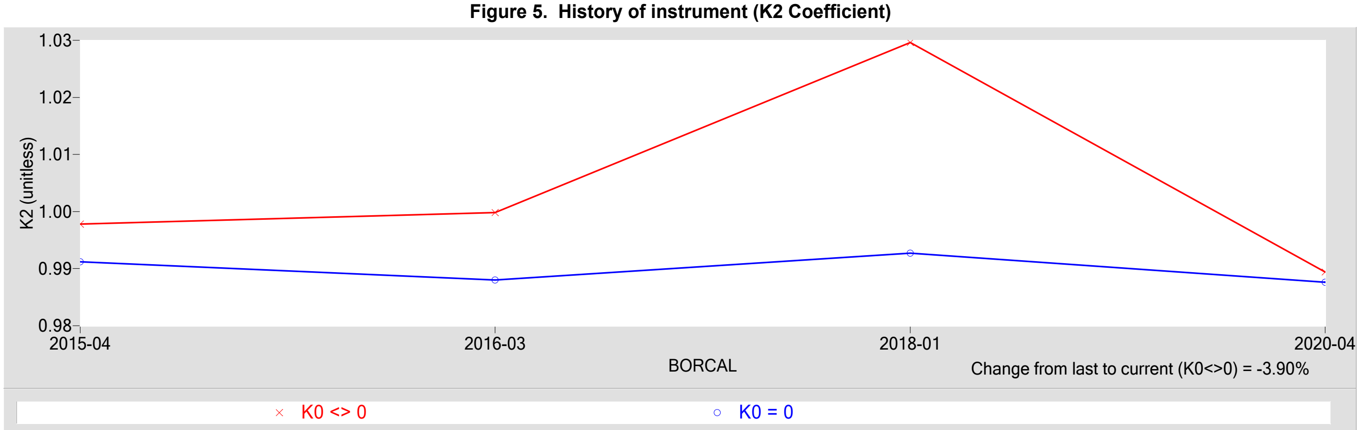
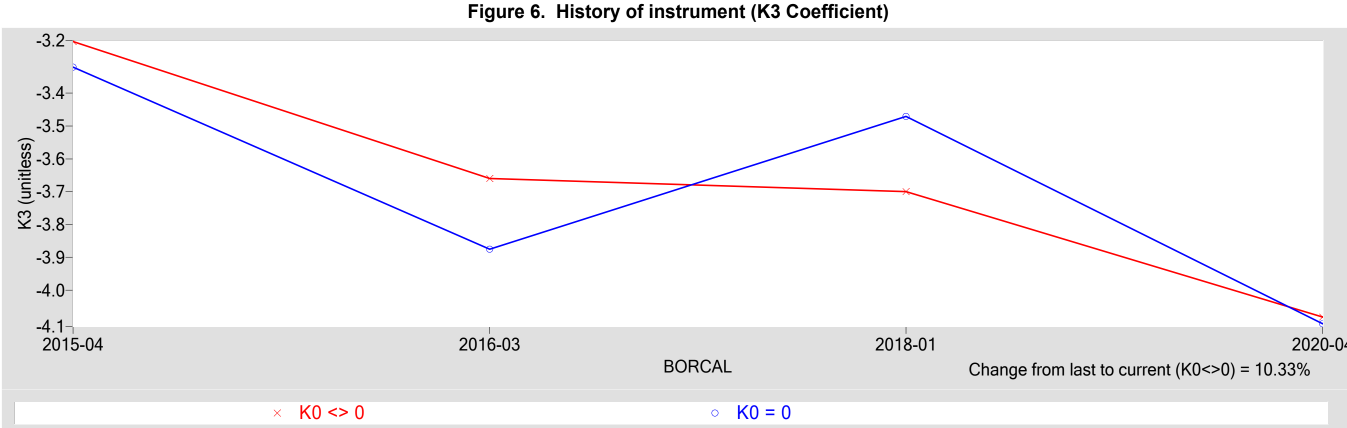


Figure 6. History of instrument (K3 Coefficient)



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:**	31301F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

31301F3 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

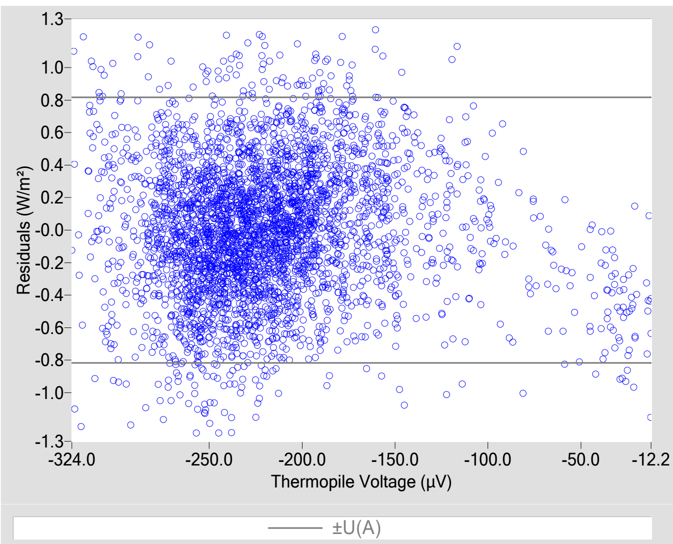


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

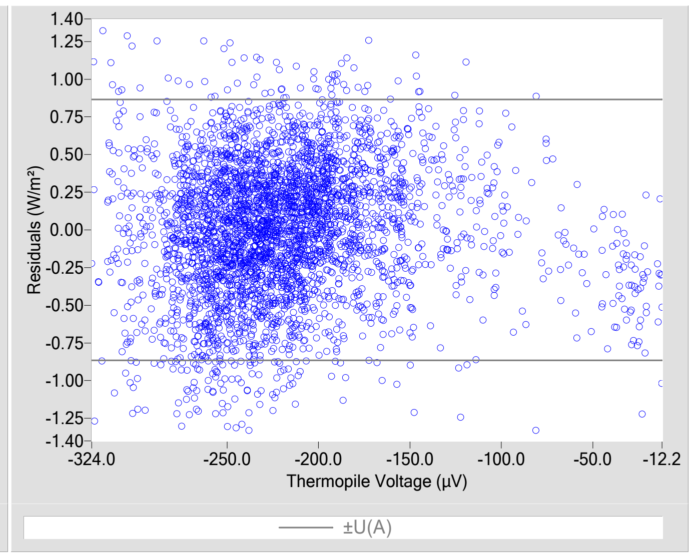


Table 2. Calibration Coefficients for K0<>0

K0	3.9
K1	0.26345
K2	0.9917
K3	-4.02
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.26317
K2	1.0003
K3	-3.81
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.44
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

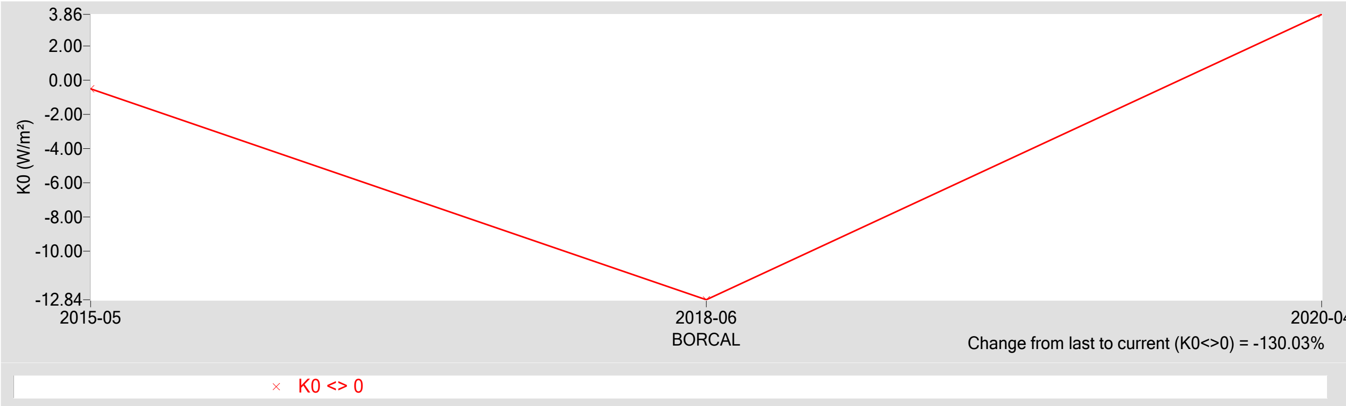


Figure 4. History of instrument (K1 Coefficient)

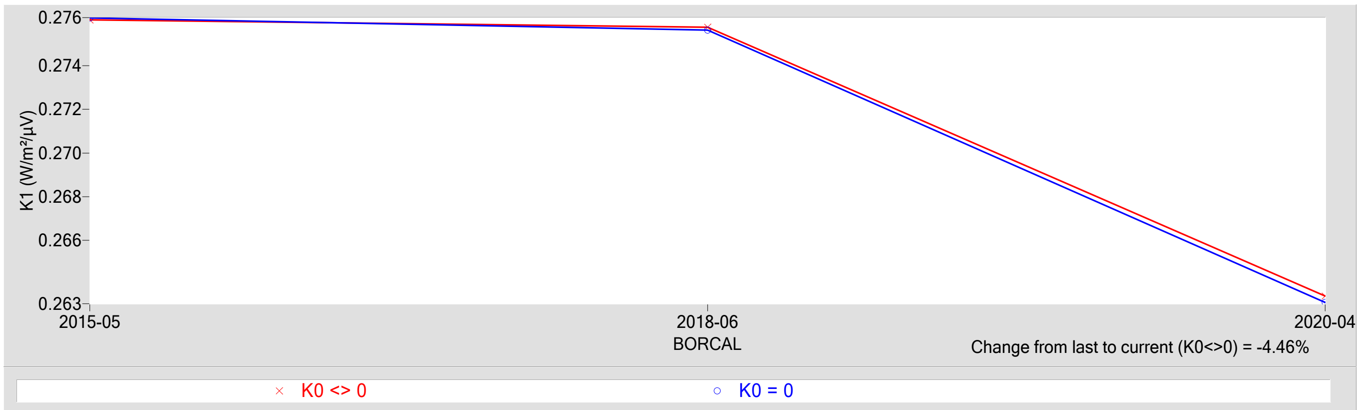


Figure 5. History of instrument (K2 Coefficient)

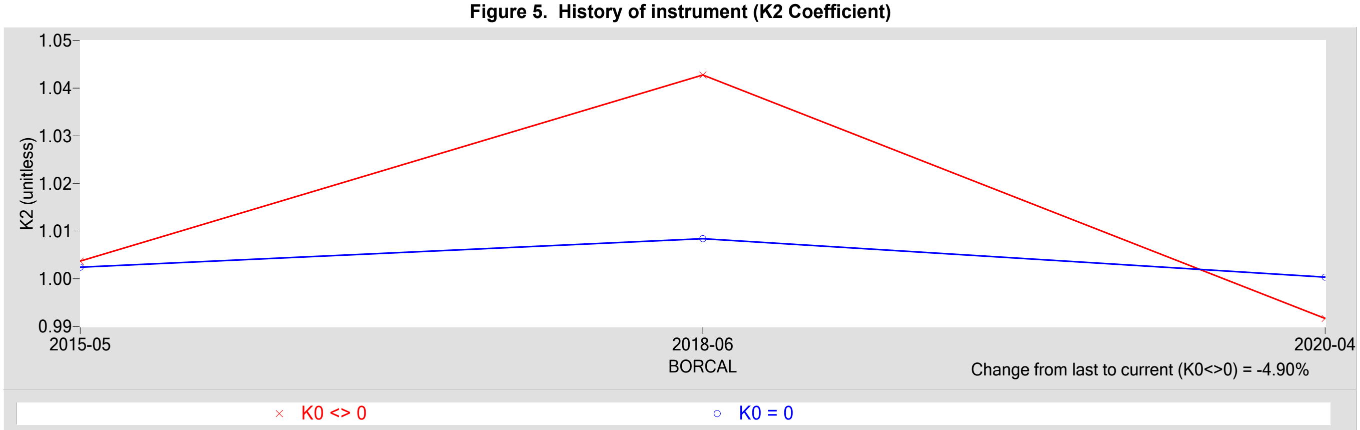
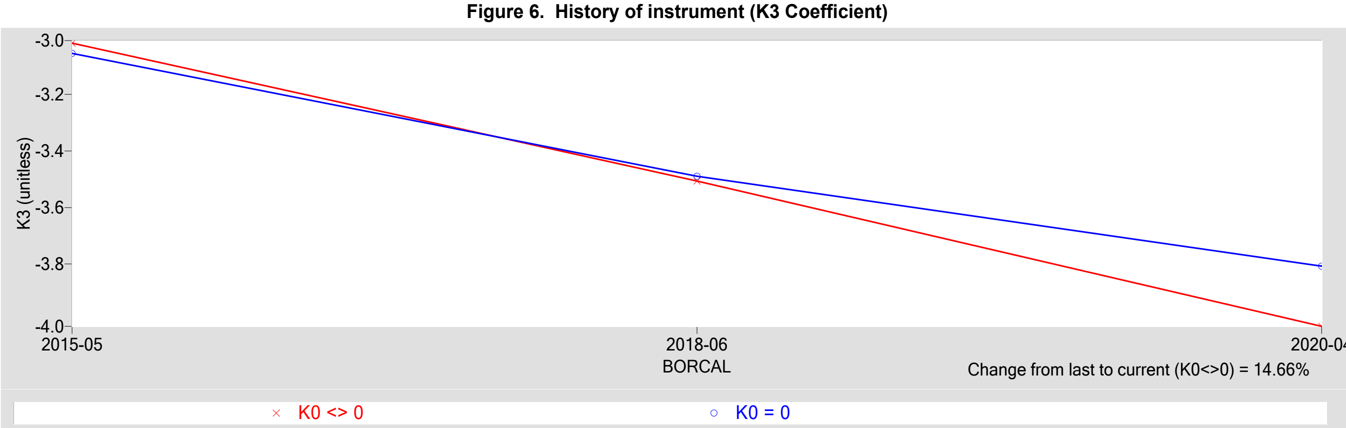


Figure 6. History of instrument (K3 Coefficient)



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: 31302F3

Calibration Date: 9/14/2020

Due Date: 9/14/2022

Customer: TWP

Environmental Conditions: see page 4

Test Dates: 8/5-27, 9/1-8, 9/12-14

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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
31302F3 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

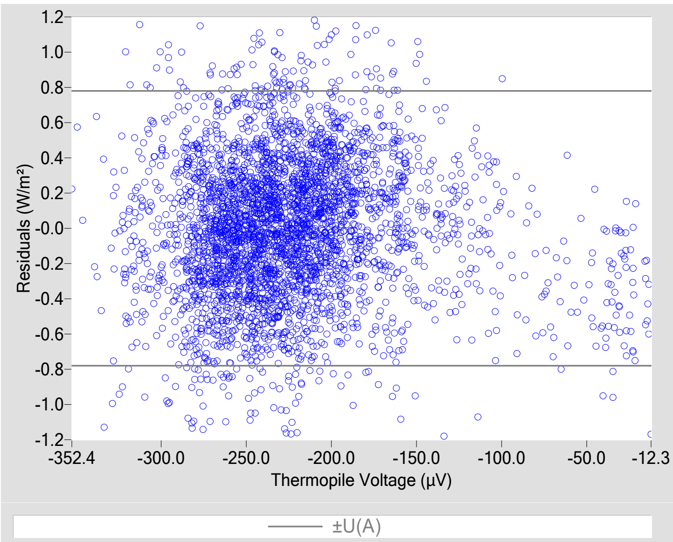


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

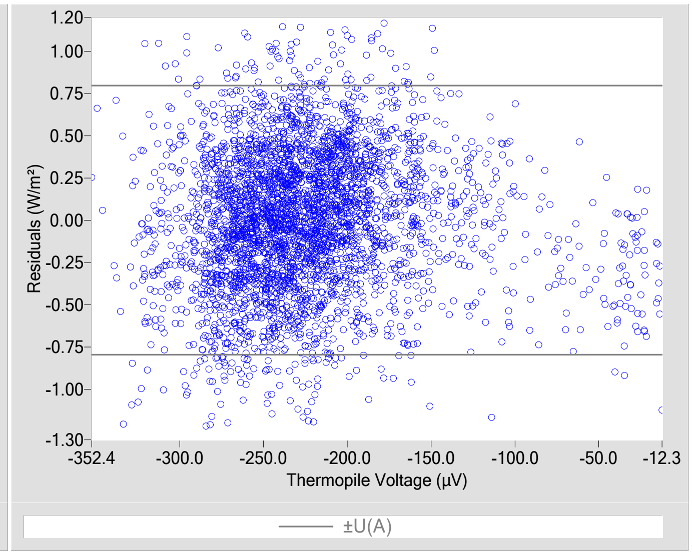


Table 2. Calibration Coefficients for K0<>0

K0	2.1
K1	0.25715
K2	0.9947
K3	-3.99
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.25707
K2	0.9994
K3	-3.89
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.41
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

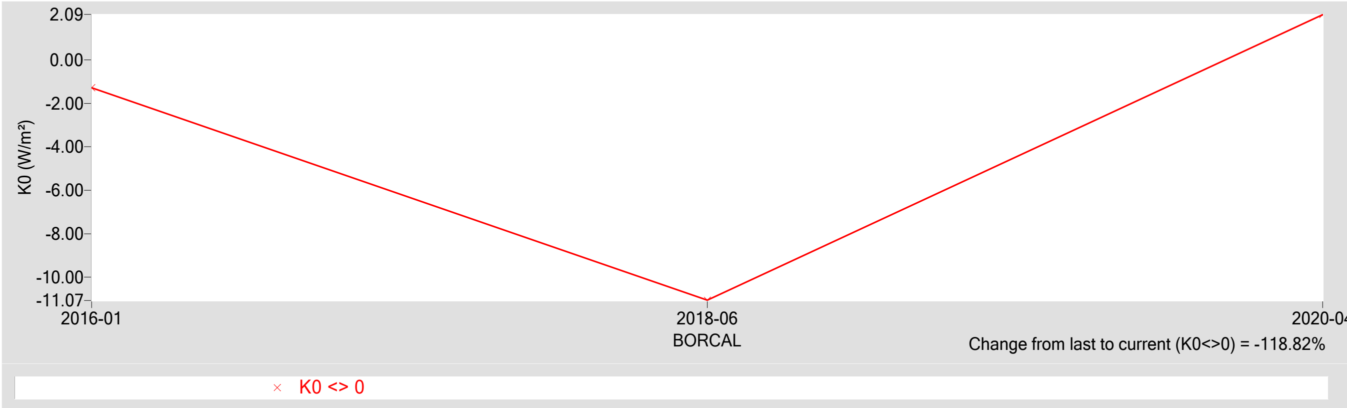


Figure 4. History of instrument (K1 Coefficient)

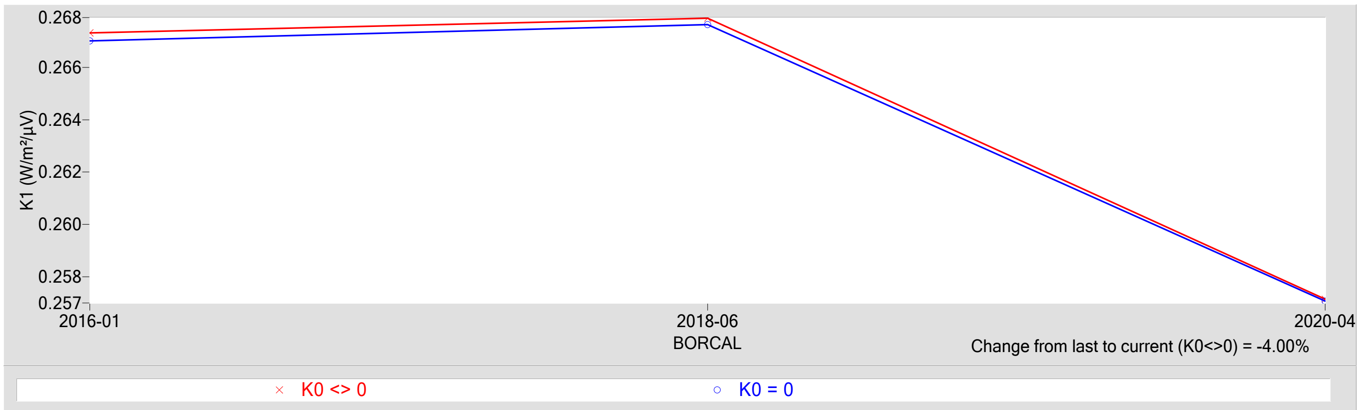


Figure 5. History of instrument (K2 Coefficient)

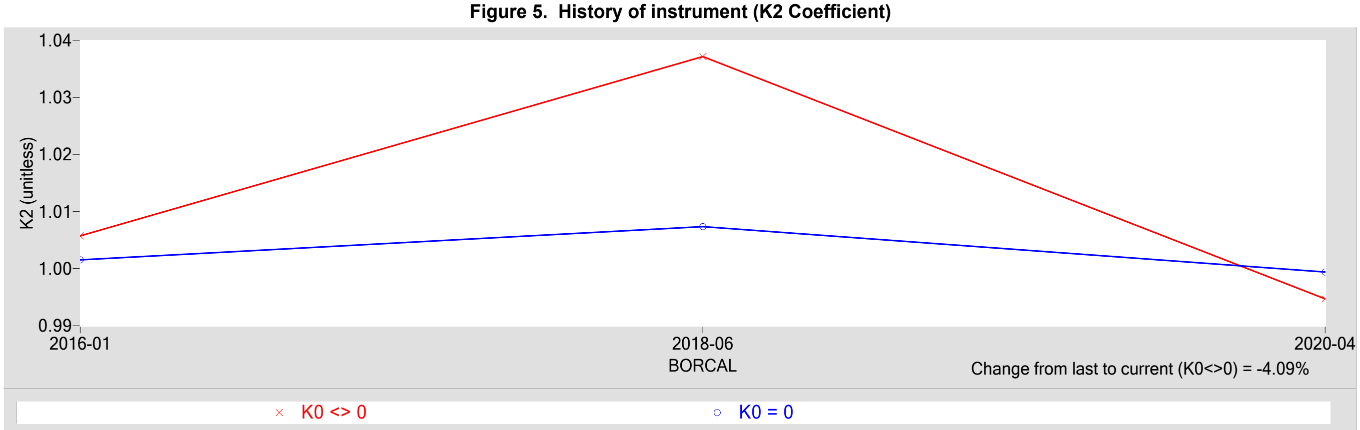
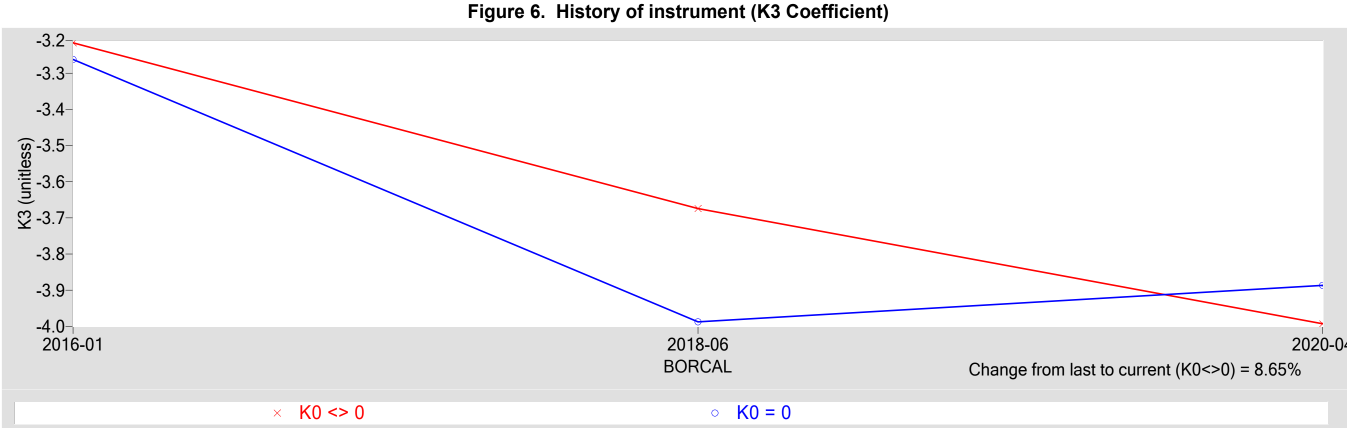


Figure 6. History of instrument (K3 Coefficient)



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:**	31308F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

31308F3 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

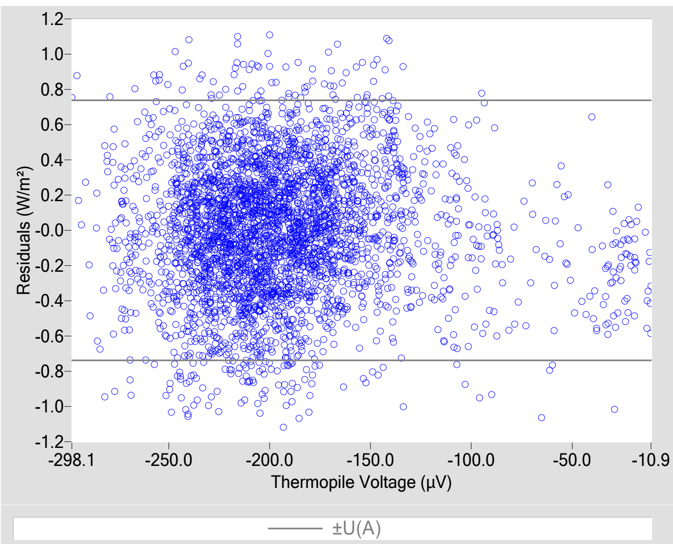


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

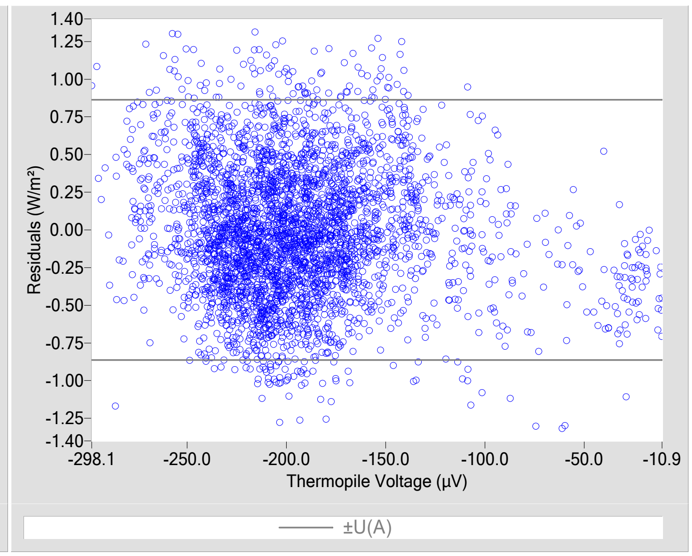


Table 2. Calibration Coefficients for K0<>0

K0	-5.6
K1	0.29830
K2	1.0093
K3	-3.51
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.29855
K2	0.9968
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.44
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

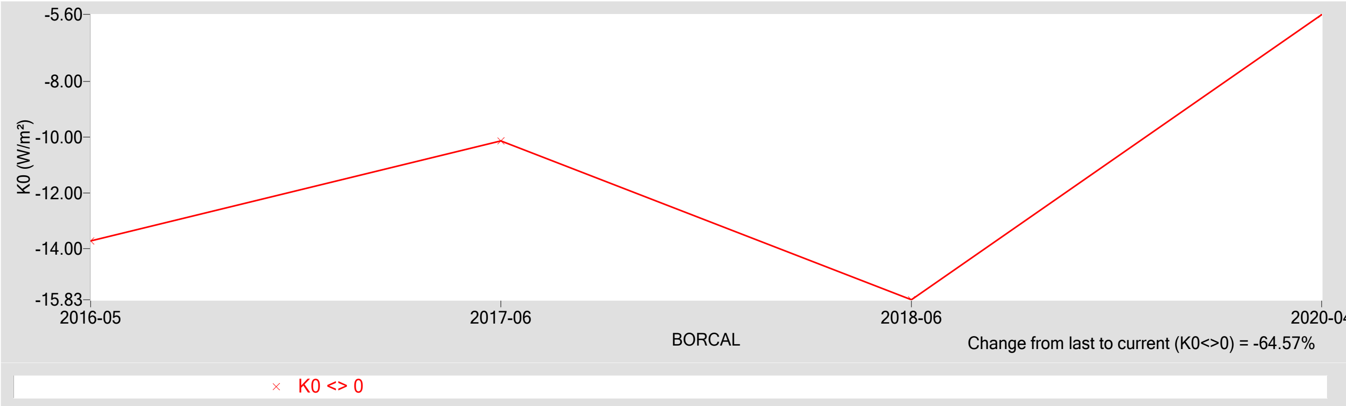


Figure 4. History of instrument (K1 Coefficient)

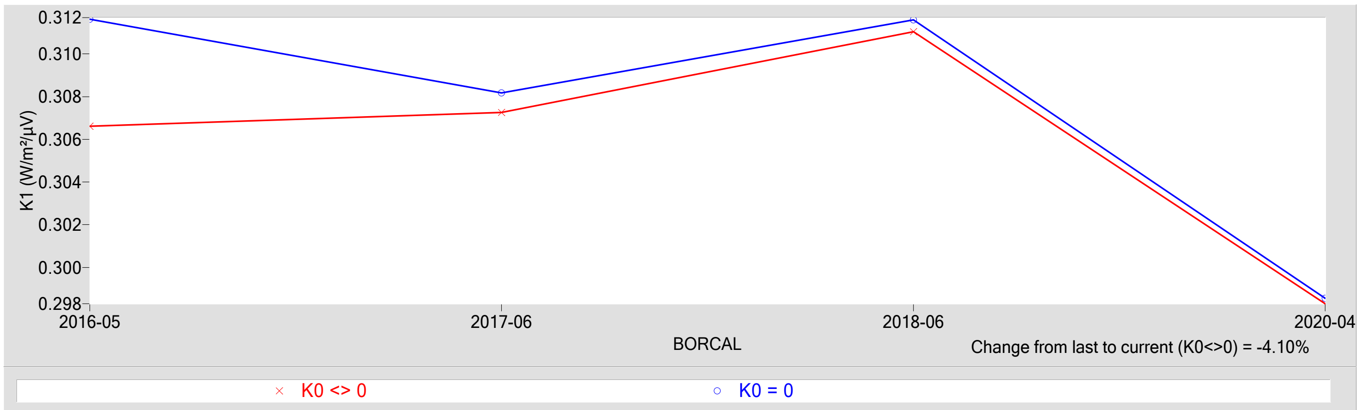


Figure 5. History of instrument (K2 Coefficient)

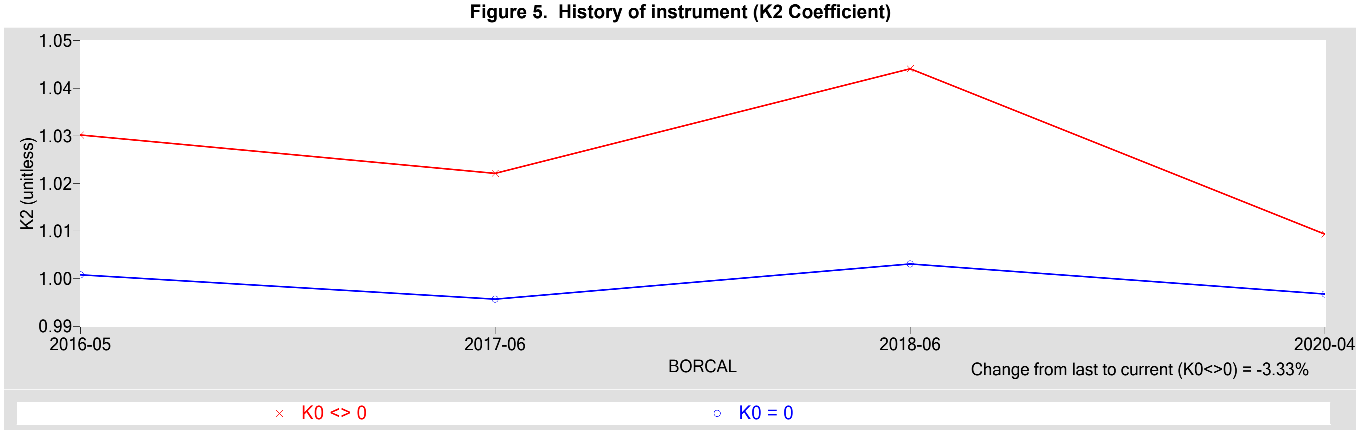
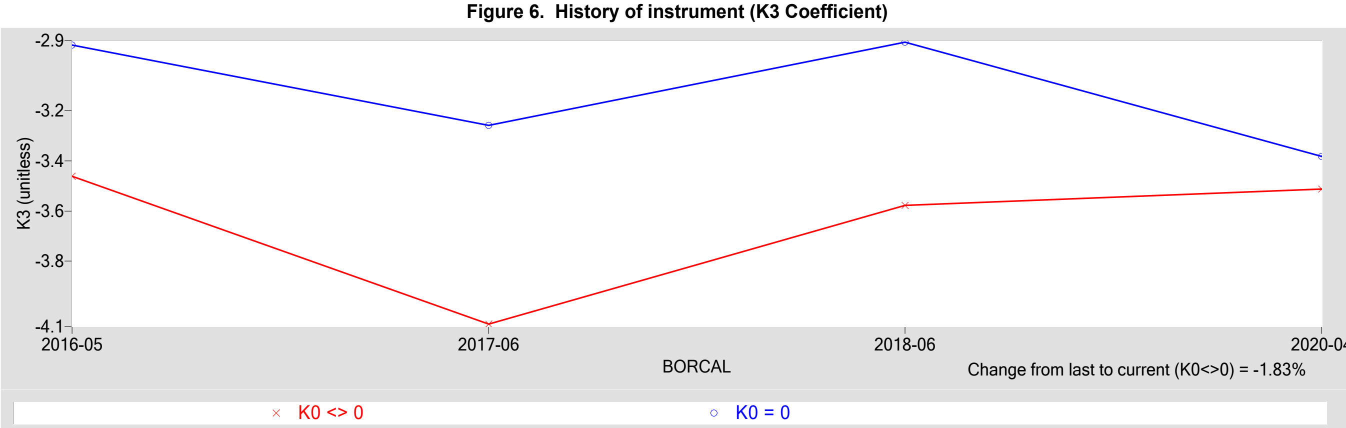


Figure 6. History of instrument (K3 Coefficient)



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: 31311F3

Calibration Date: 9/14/2020

Due Date: 9/14/2022

Customer: TWP

Environmental Conditions: see page 4

Test Dates: 8/5-27, 9/1-8, 9/12-14

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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
31311F3 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

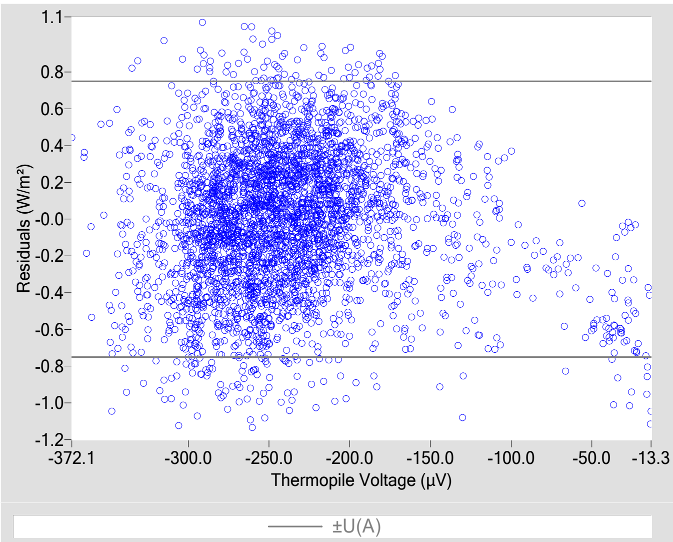


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

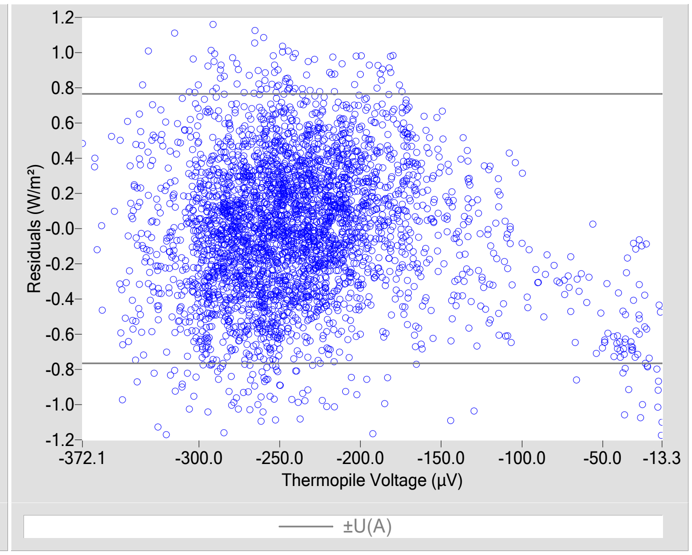


Table 2. Calibration Coefficients for K0<>0

K0	-1.8
K1	0.24196
K2	1.0006
K3	-3.30
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24210
K2	0.9966
K3	-3.32
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)	±1.6
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)	±3.1

Figure 3. History of instrument (K0 Coefficient)

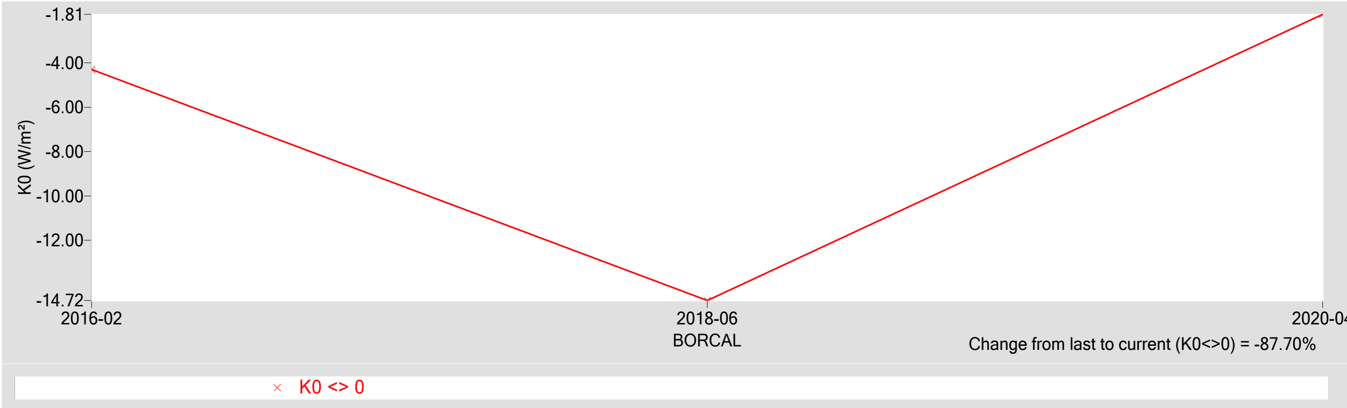


Figure 4. History of instrument (K1 Coefficient)

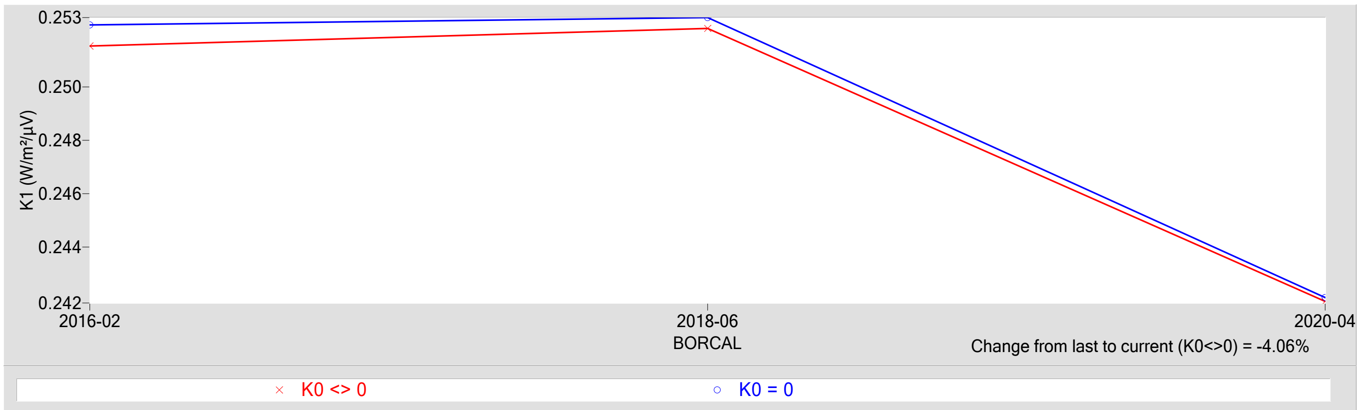


Figure 5. History of instrument (K2 Coefficient)

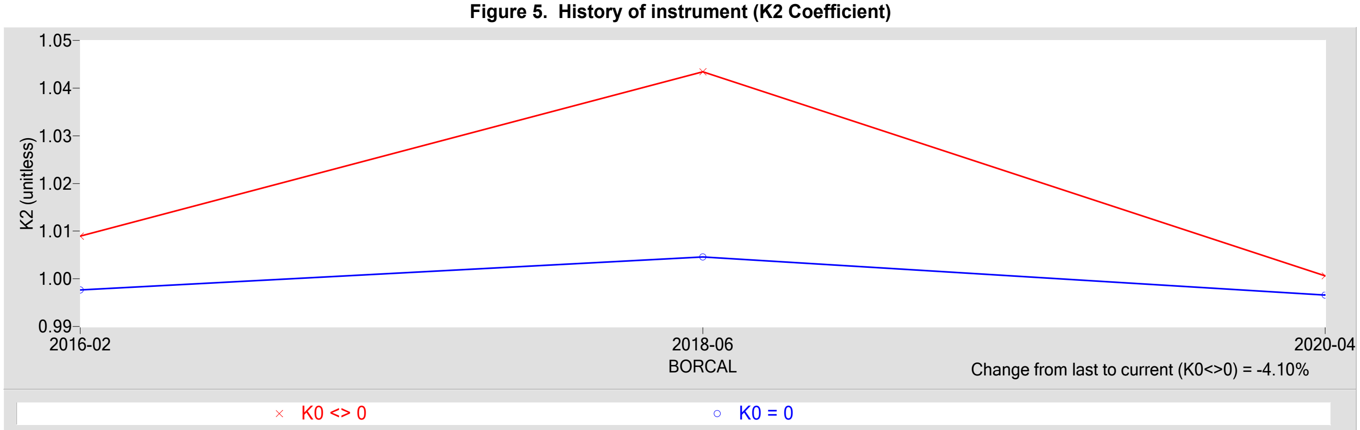
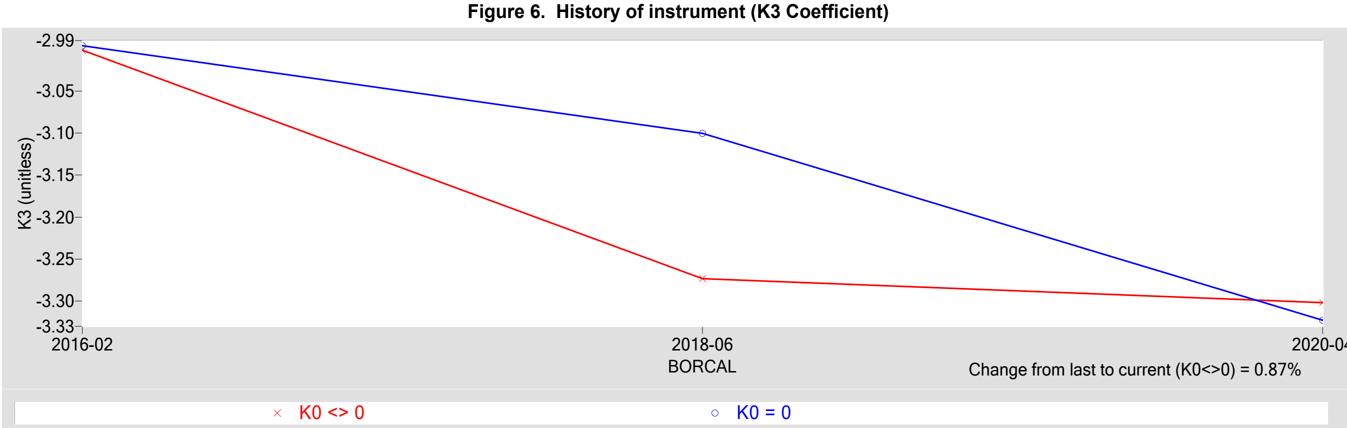


Figure 6. History of instrument (K3 Coefficient)



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:**	31640F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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
31640F3 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

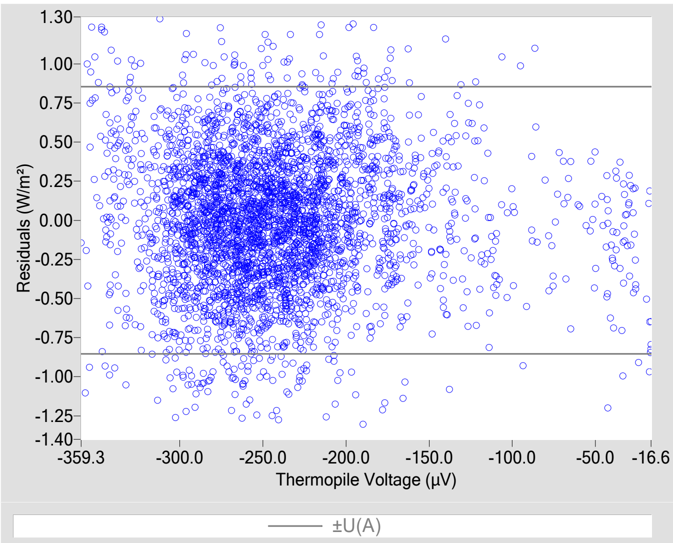


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

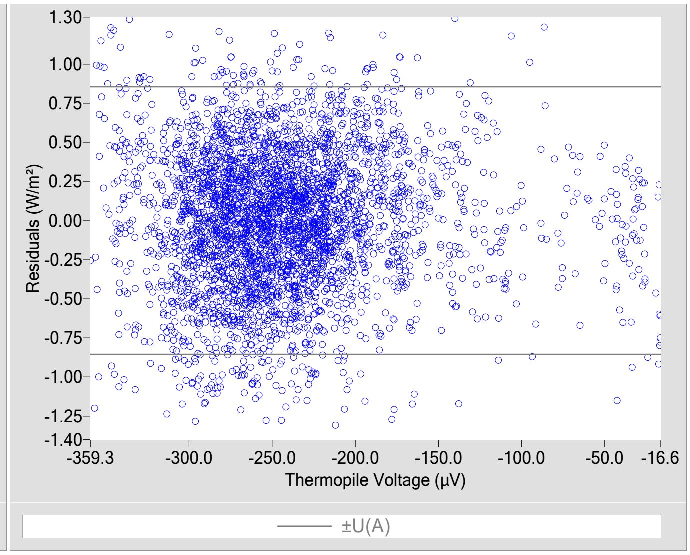


Table 2. Calibration Coefficients for K0<>0

K0	1.4
K1	0.24029
K2	0.9952
K3	-3.84
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24017
K2	0.9983
K3	-3.78
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.44
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.44
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

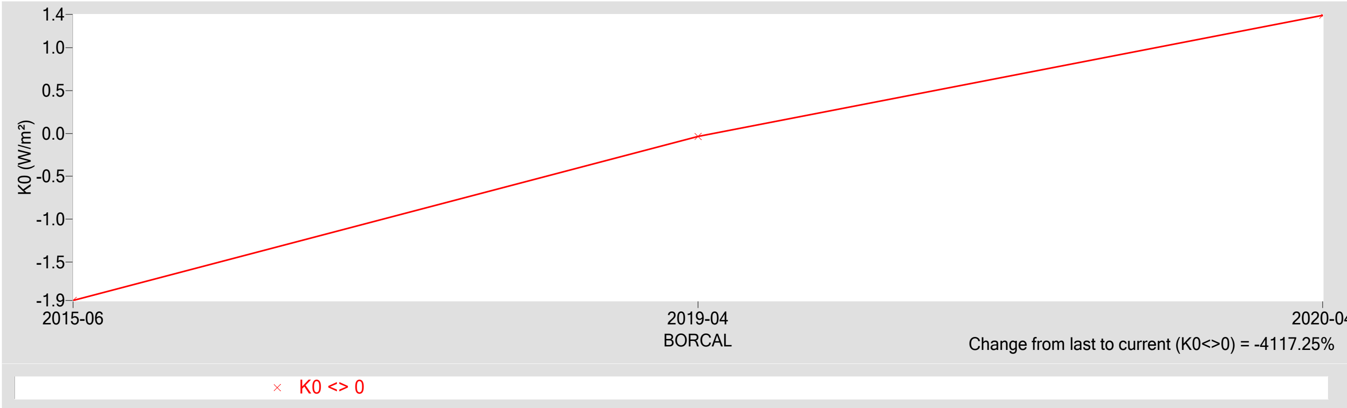


Figure 4. History of instrument (K1 Coefficient)

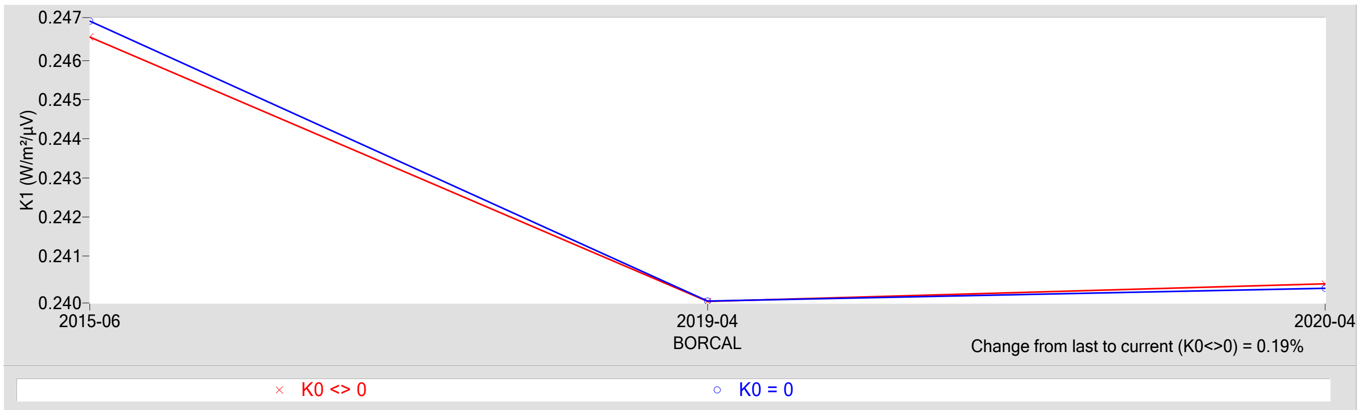


Figure 5. History of instrument (K2 Coefficient)

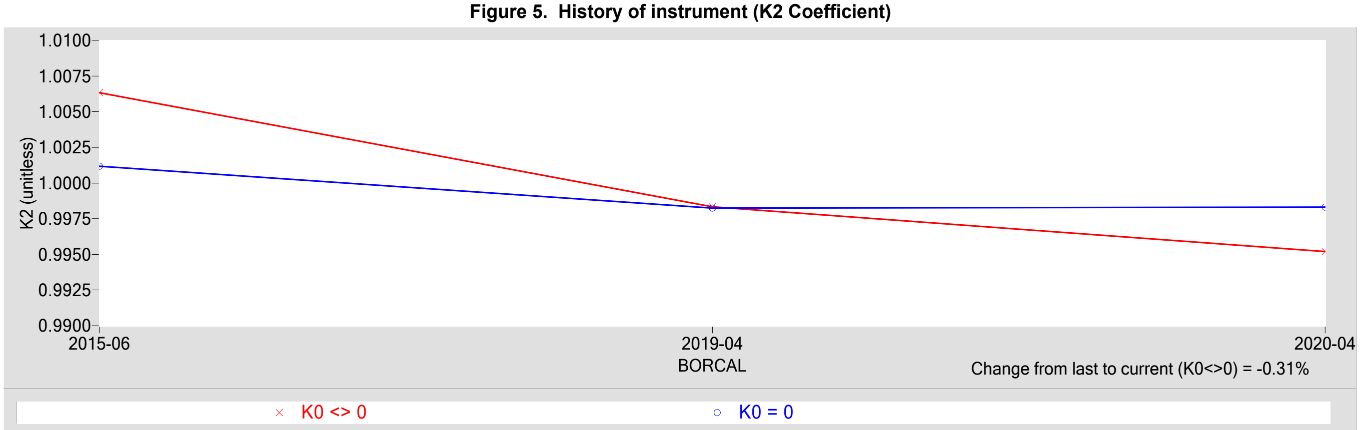
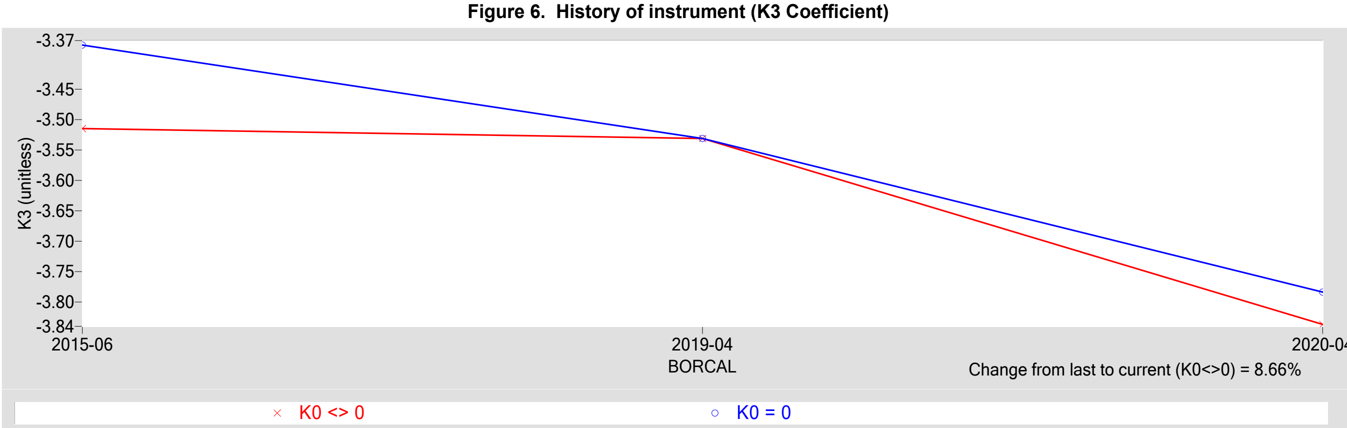


Figure 6. History of instrument (K3 Coefficient)



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:**	32040F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

32040F3 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

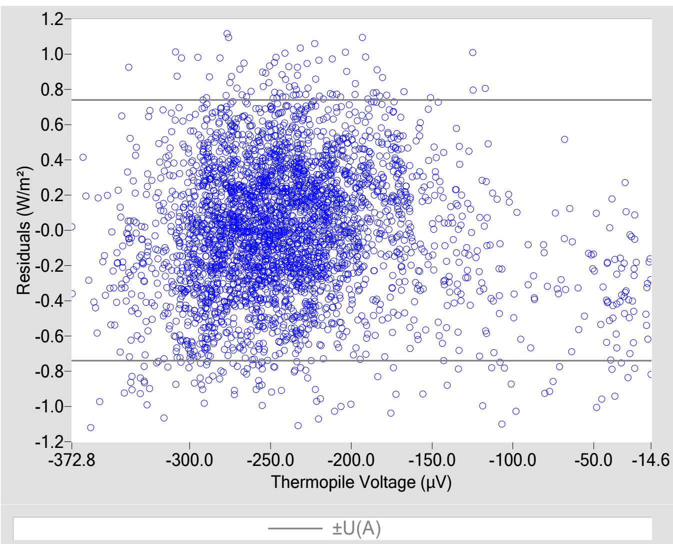


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

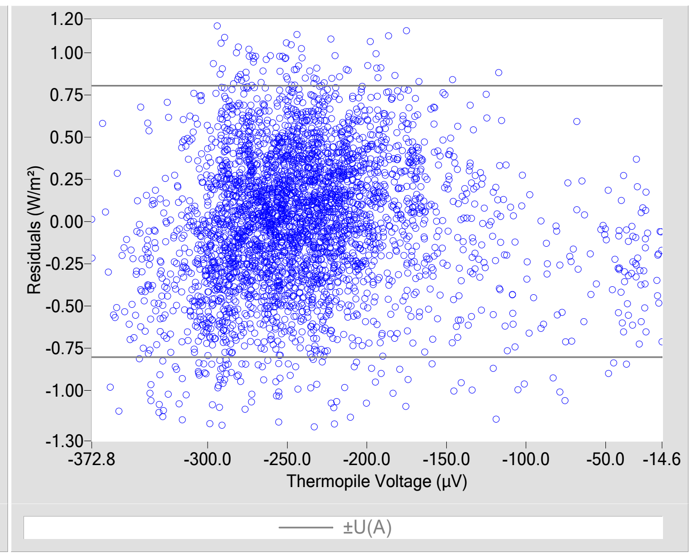


Table 2. Calibration Coefficients for K0<>0

K0	3.6
K1	0.24167
K2	0.9904
K3	-3.86
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.24144
K2	0.9985
K3	-3.74
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.38
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.41
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

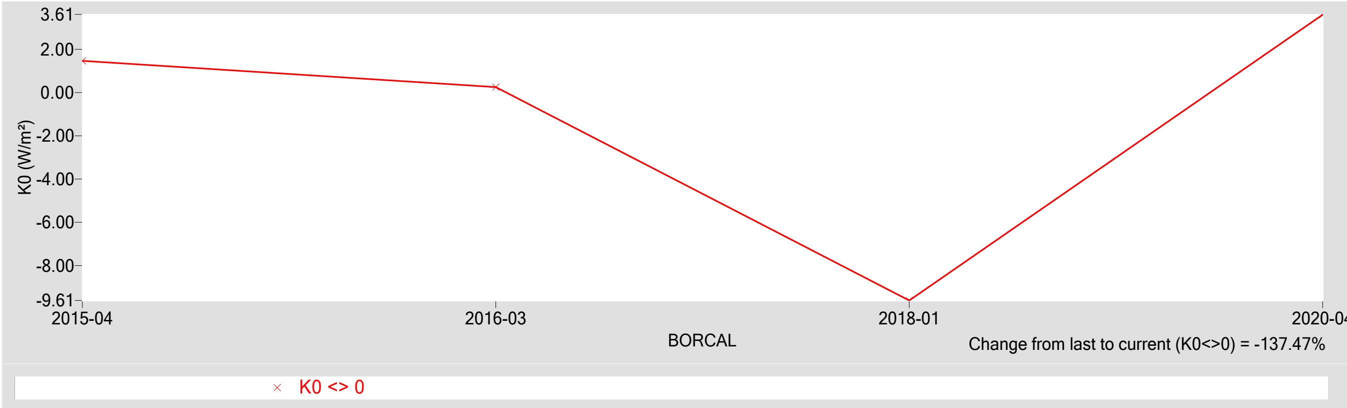


Figure 4. History of instrument (K1 Coefficient)

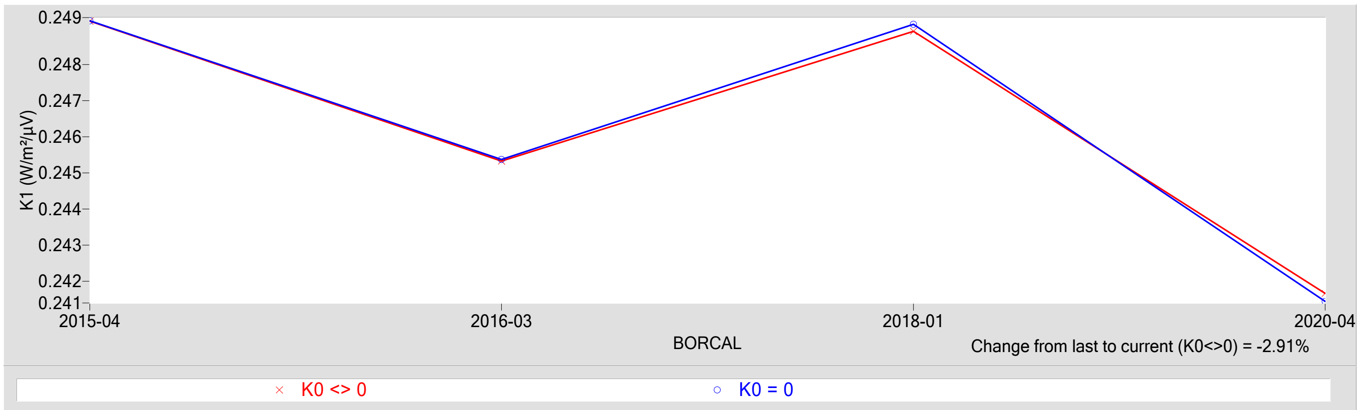


Figure 5. History of instrument (K2 Coefficient)

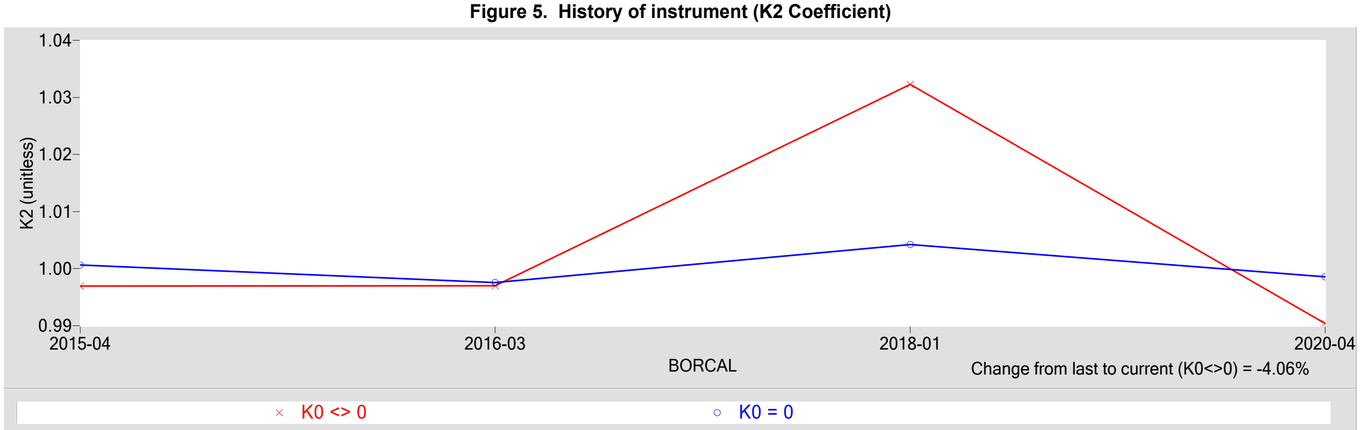
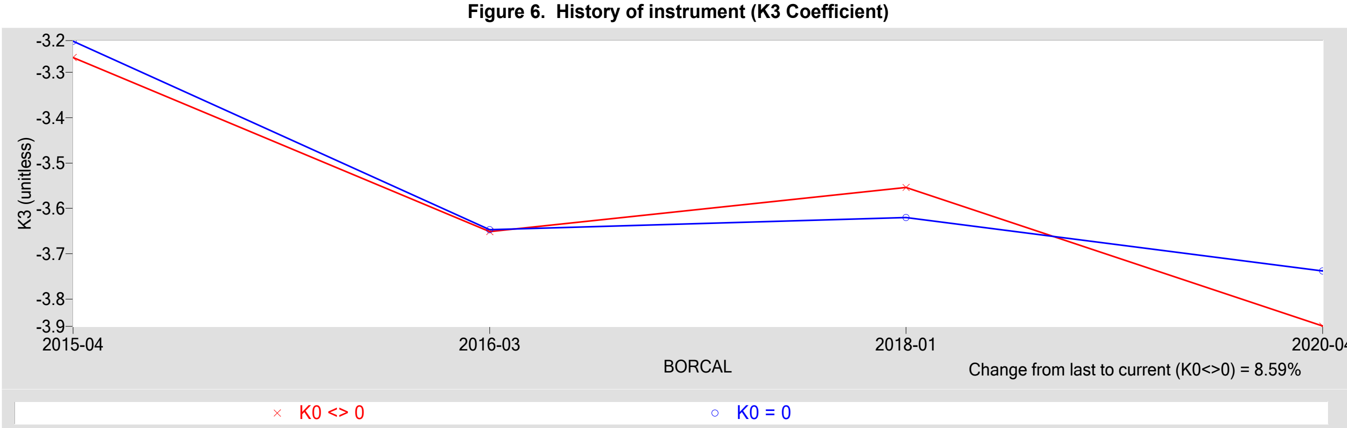


Figure 6. History of instrument (K3 Coefficient)



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:**	32050F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

32050F3 Eppley PIR

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

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

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

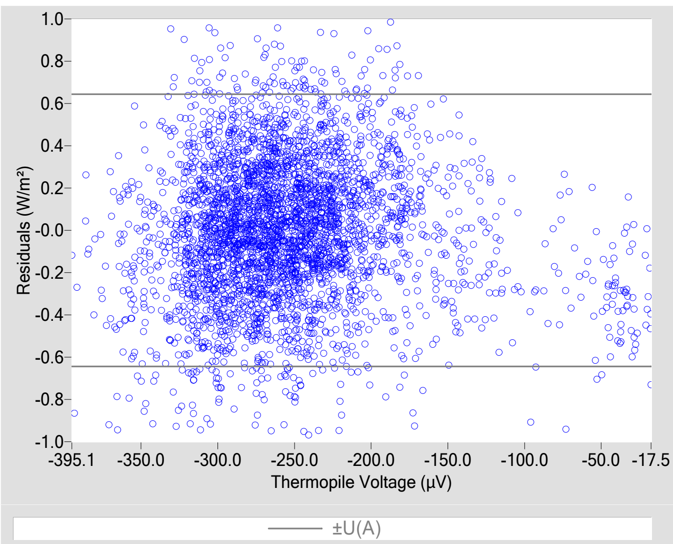


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

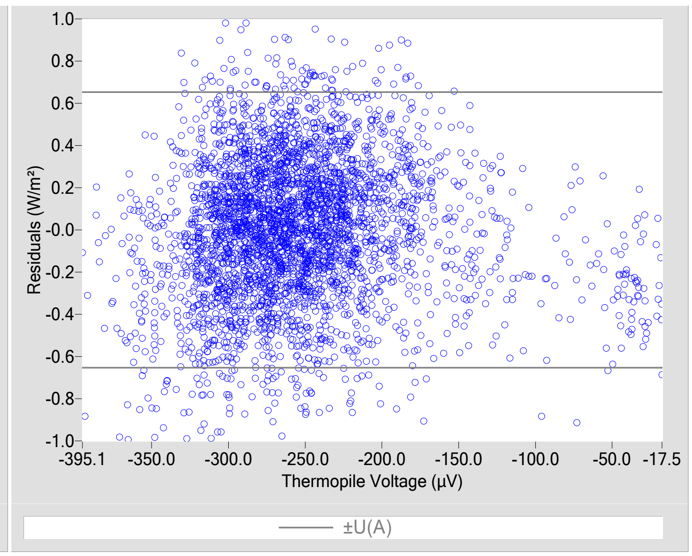


Table 2. Calibration Coefficients for K0<>0

K0	1.5
K1	0.22987
K2	0.9948
K3	-3.39
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.22979
K2	0.9982
K3	-3.35
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.33
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.33
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)

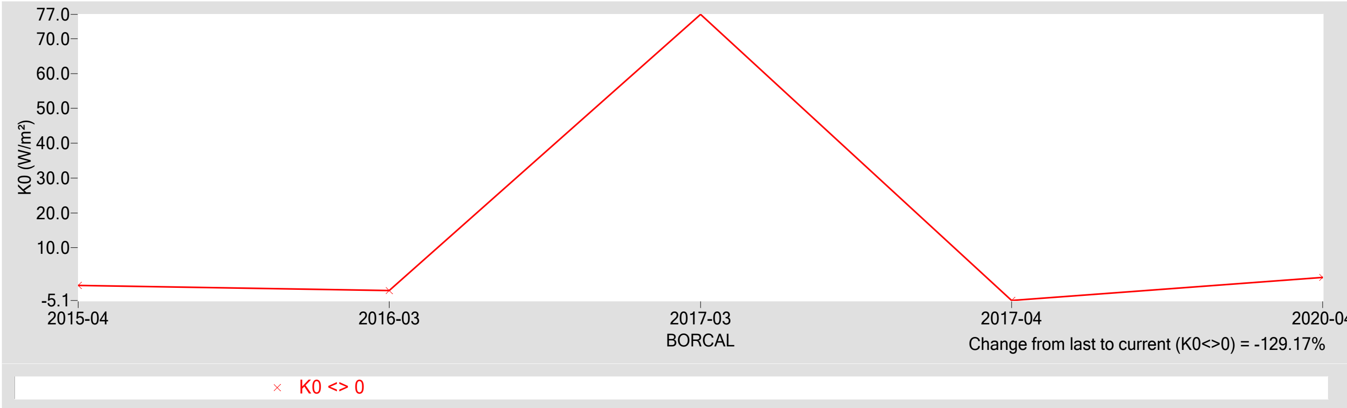


Figure 4. History of instrument (K1 Coefficient)

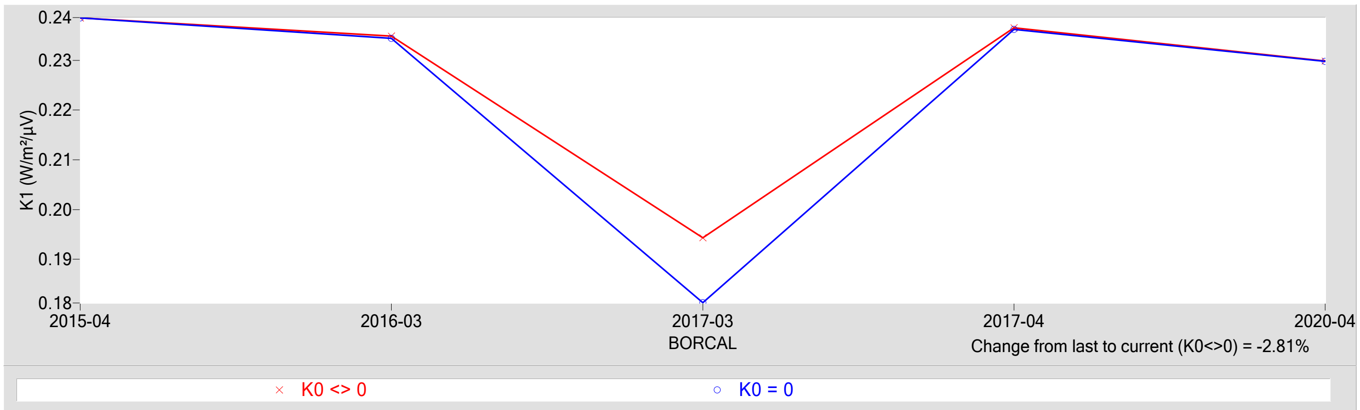


Figure 5. History of instrument (K2 Coefficient)

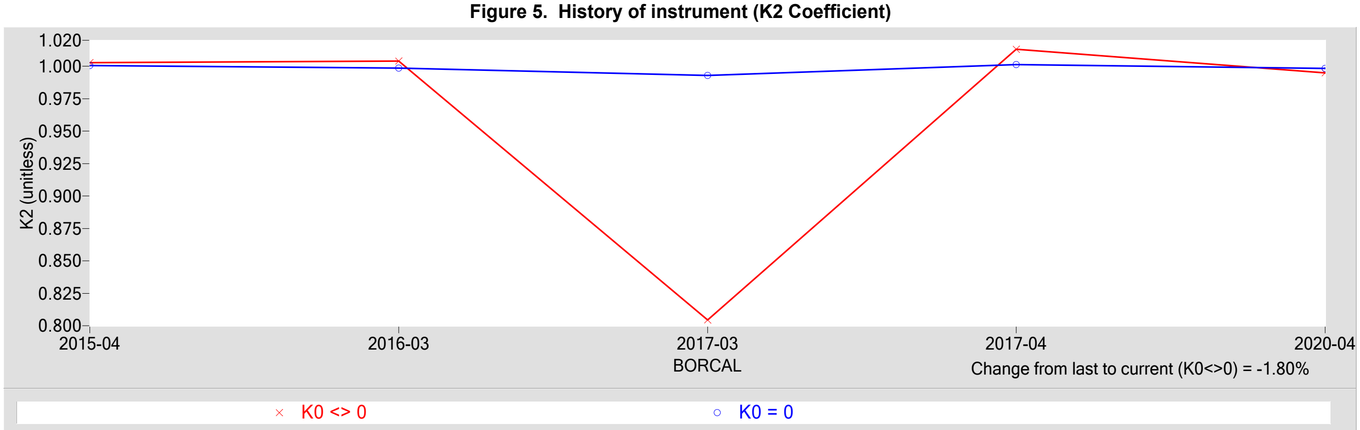
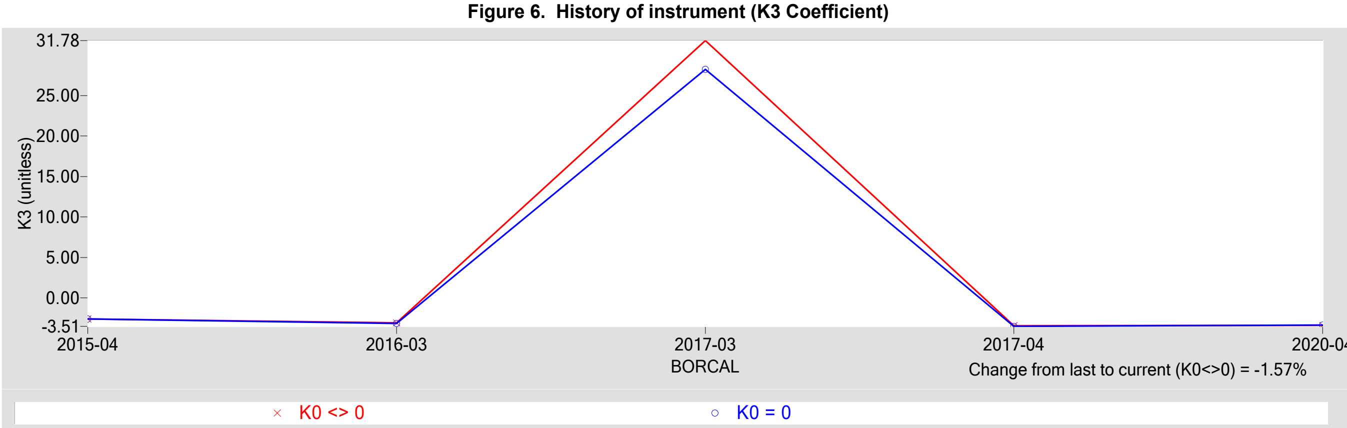


Figure 6. History of instrument (K3 Coefficient)



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:**	36363F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

36363F3 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

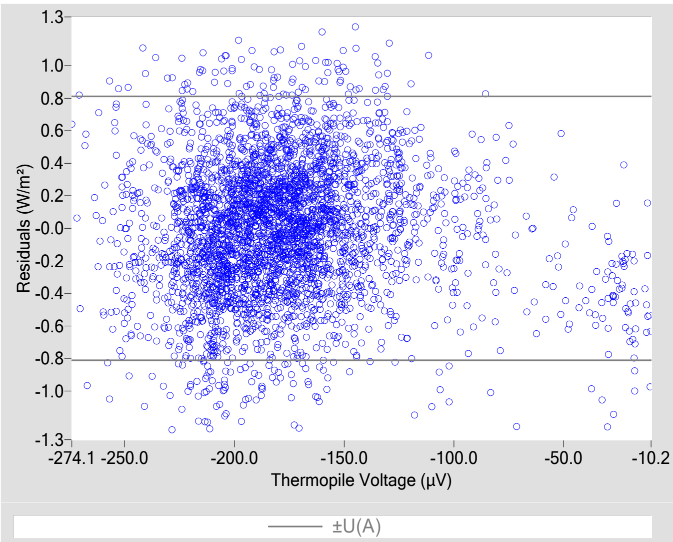


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

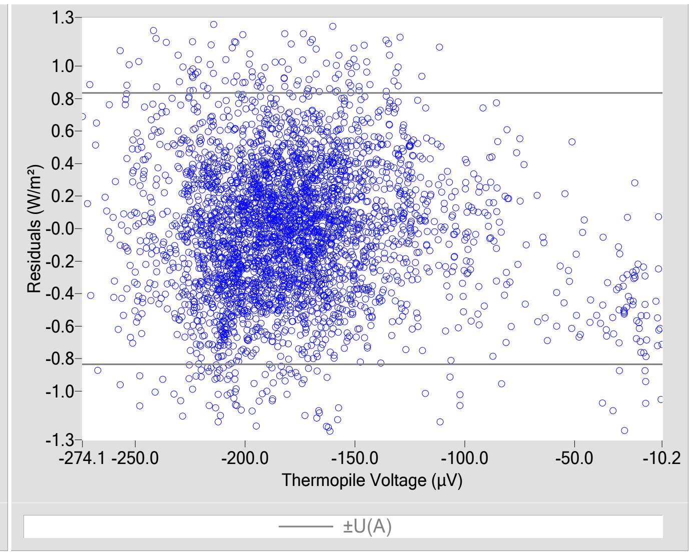


Table 2. Calibration Coefficients for K0<>0

K0	-2.5
K1	0.33042
K2	1.0098
K3	-4.60
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.33068
K2	1.0042
K3	-4.59
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.41
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.43
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

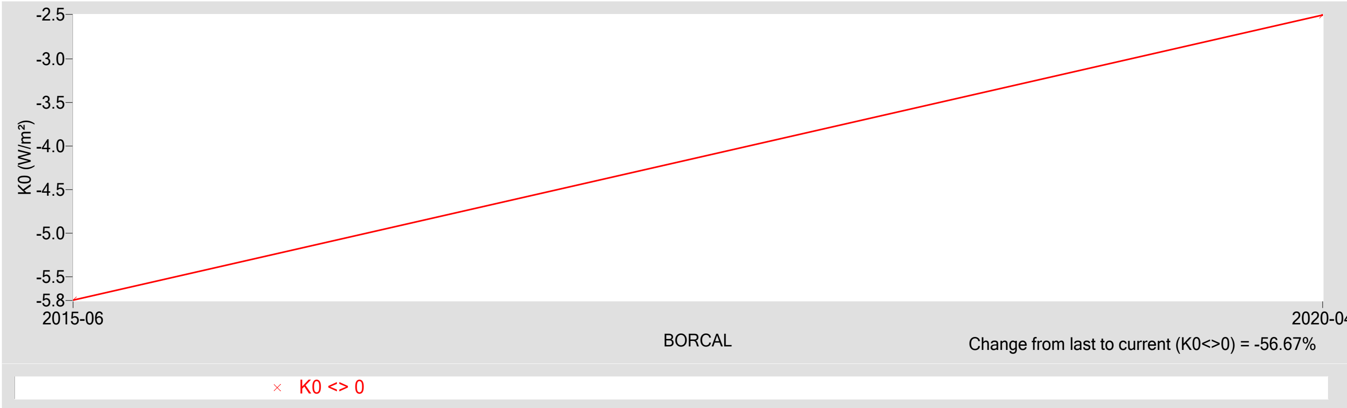


Figure 4. History of instrument (K1 Coefficient)

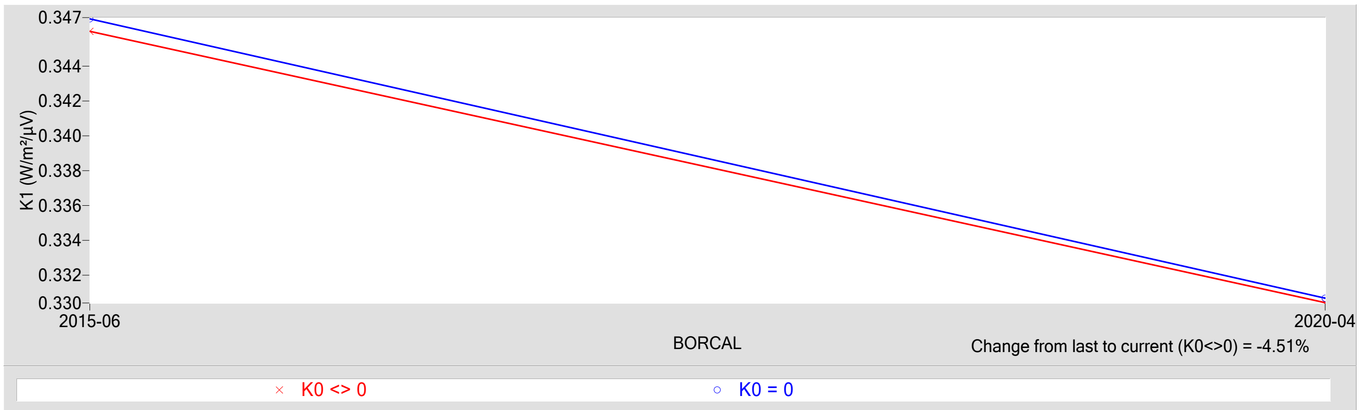


Figure 5. History of instrument (K2 Coefficient)

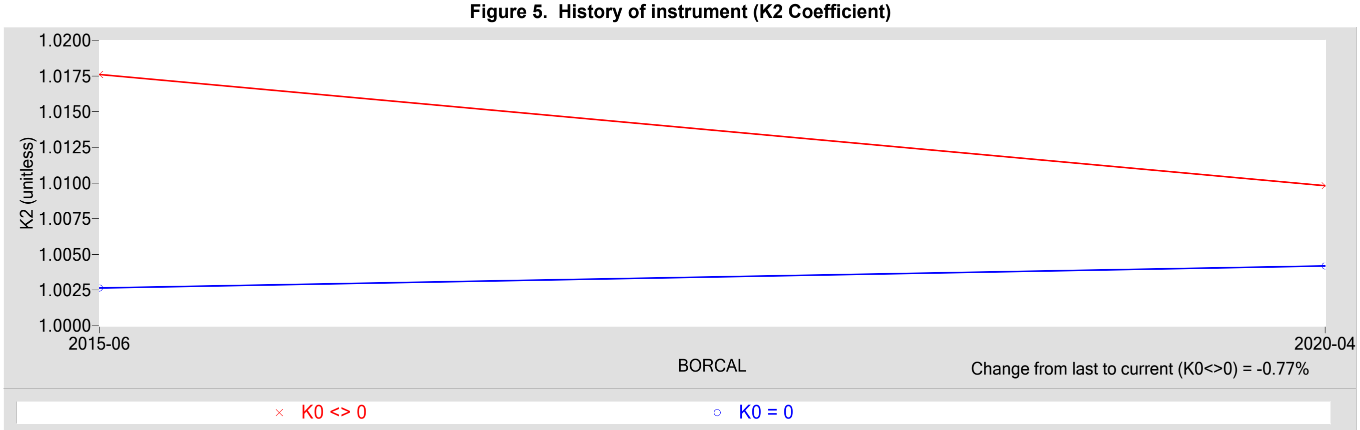
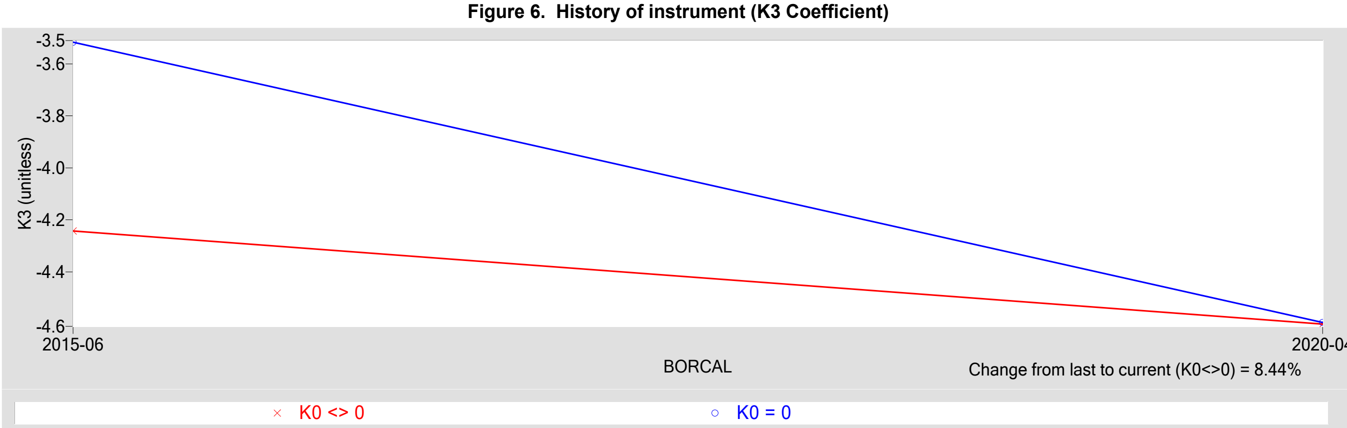


Figure 6. History of instrument (K3 Coefficient)



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: 9/14/2020
Due Date: 9/14/2022
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 8/5-27, 9/1-8, 9/12-14

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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 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

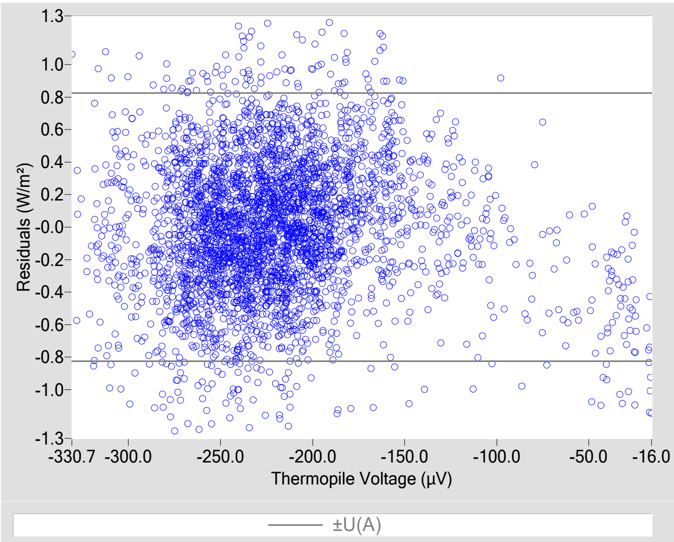


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

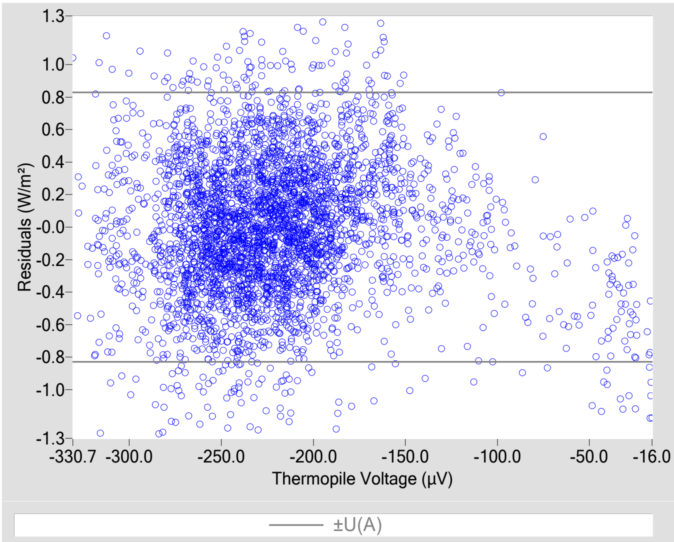


Table 2. Calibration Coefficients for K0<>0

K0	-0.9
K1	0.27052
K2	1.0109
K3	-4.52
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.27064
K2	1.0089
K3	-4.57
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
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)	±3.2

Table 5. Uncertainty using K0=0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
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)	±3.2

Figure 3. History of instrument (K0 Coefficient)

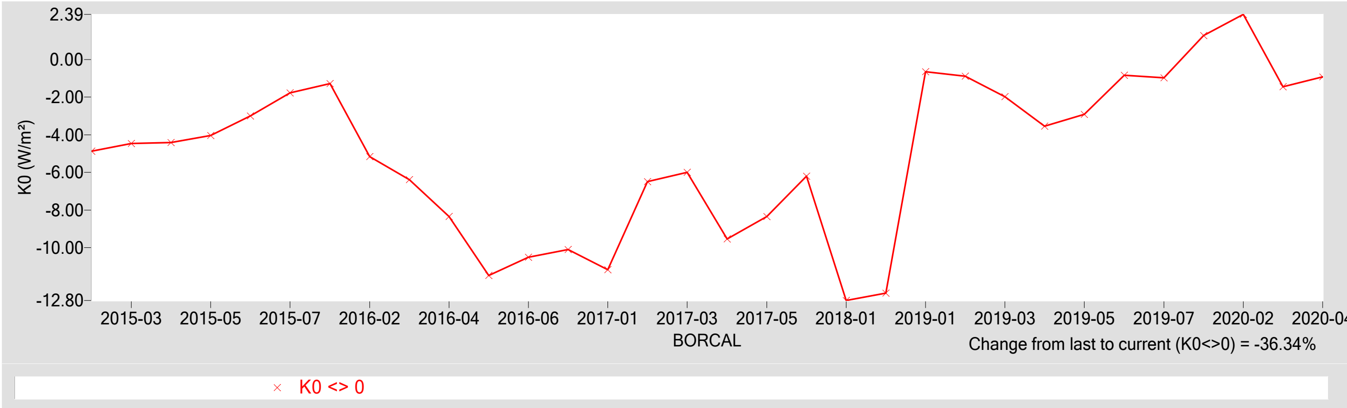


Figure 4. History of instrument (K1 Coefficient)

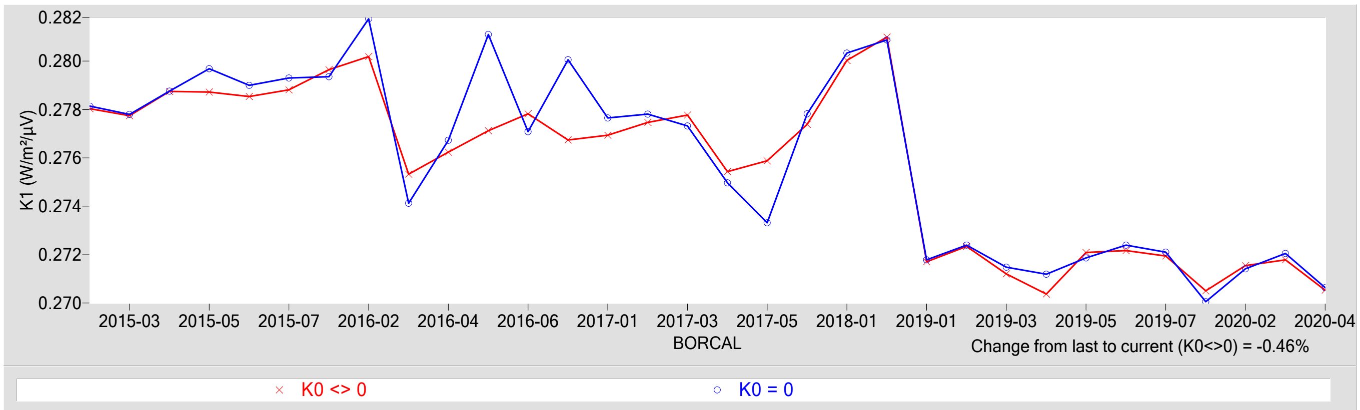


Figure 5. History of instrument (K2 Coefficient)

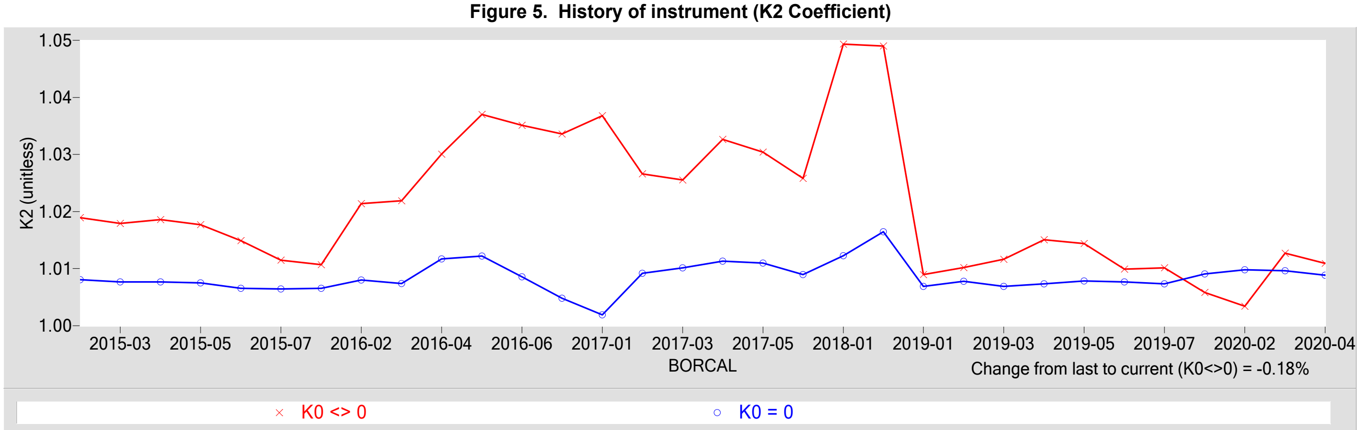
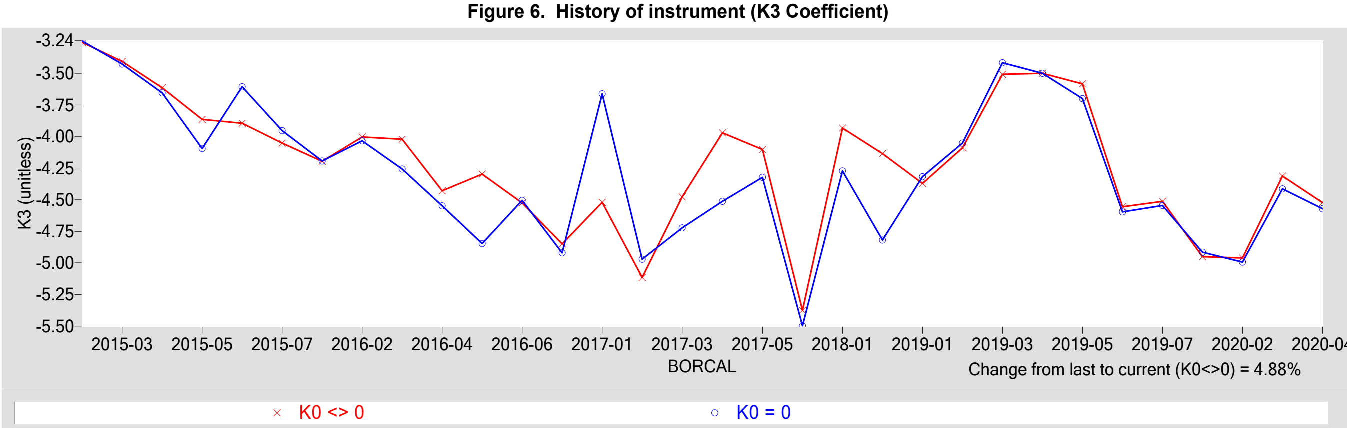


Figure 6. History of instrument (K3 Coefficient)



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:**	36370F3
Calibration Date:	9/14/2020	**Due Date:**	9/14/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/5-27, 9/1-8, 9/12-14		

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	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	01/03/2020	01/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	01/03/2020	01/03/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29590F3	04/02/2019	04/02/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29927F3	04/02/2019	04/02/2021

‡ 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

36370F3 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

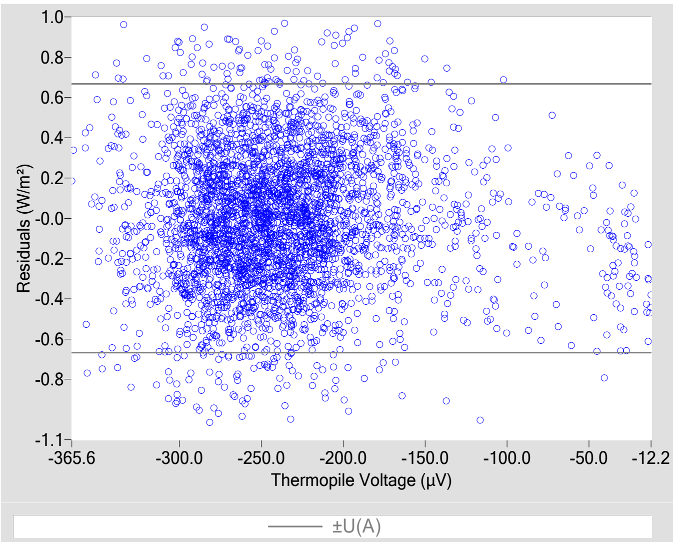


Figure 2. Residuals for calc. vs ref. irradiance using K0=0 Coefficients

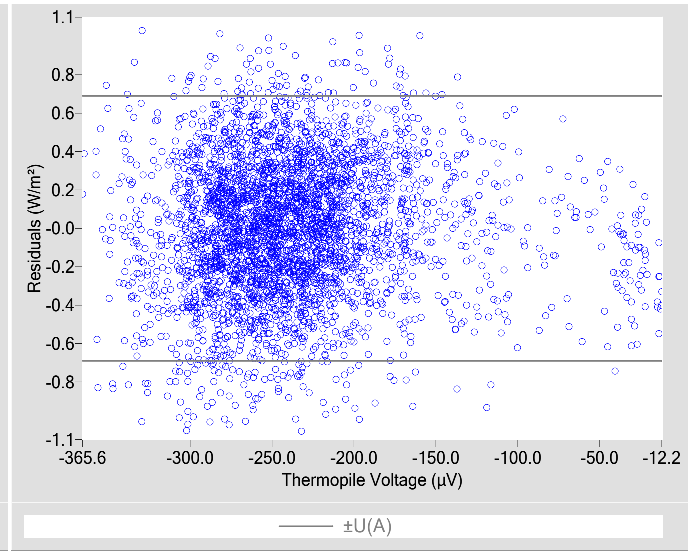


Table 2. Calibration Coefficients for K0<>0

K0	1.9
K1	0.23899
K2	0.9962
K3	-3.91
Kr used to derive coefficients	7.044e-4

Table 3. Calibration Coefficients for K0=0

K0	0.0
K1	0.23893
K2	1.0005
K3	-3.84
Kr used to derive coefficients	7.044e-4

Table 4. Uncertainty using K0<>0 Coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.34
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)	±1.6
Type-A Standard Uncertainty, u(A) (W/m²)	±0.35
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)

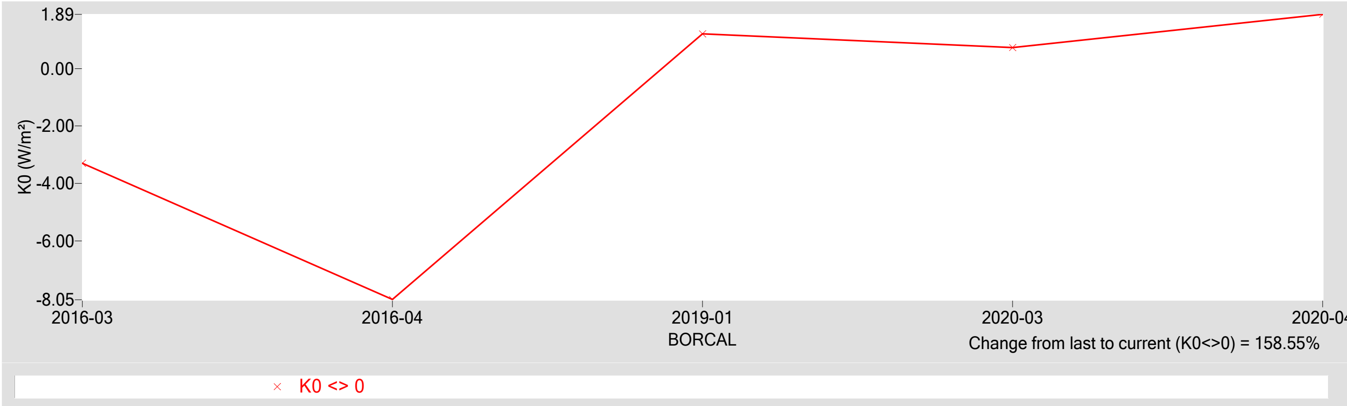


Figure 4. History of instrument (K1 Coefficient)

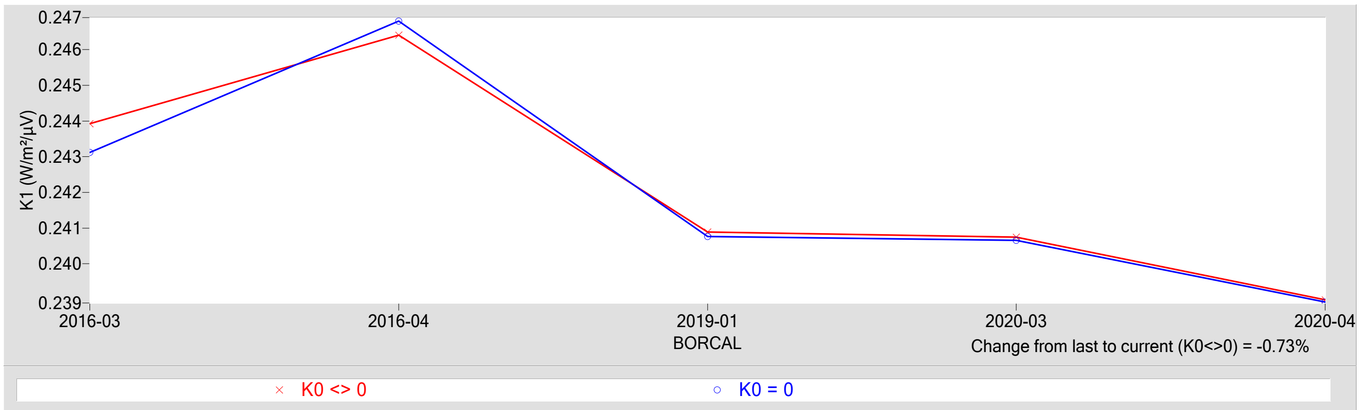


Figure 5. History of instrument (K2 Coefficient)

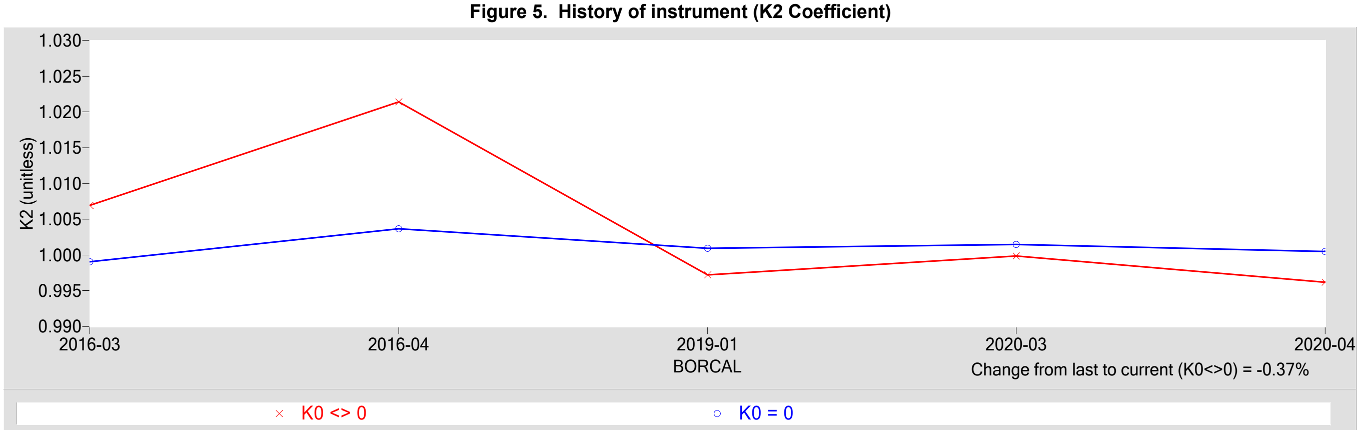
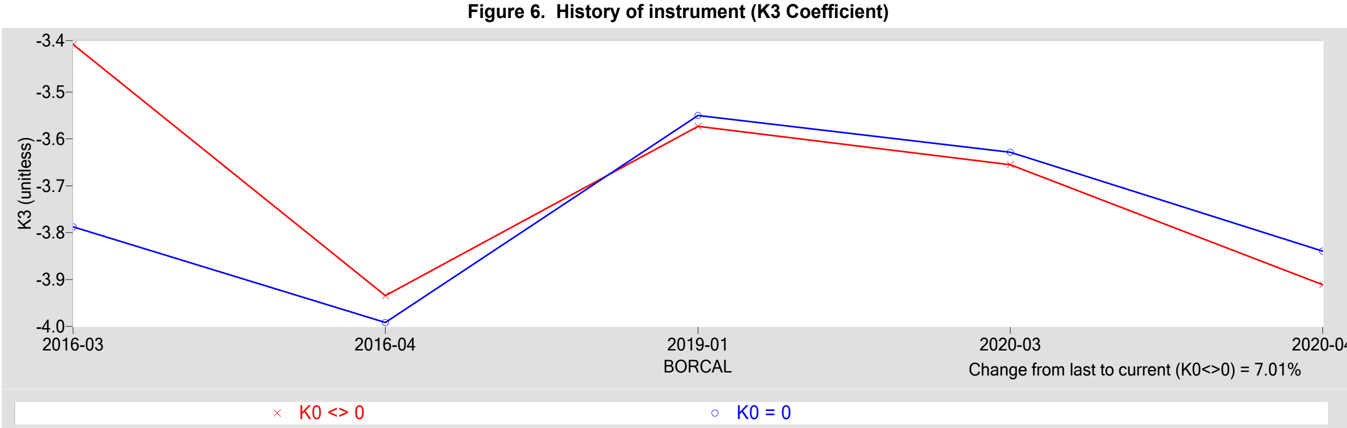


Figure 6. History of instrument (K3 Coefficient)



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.

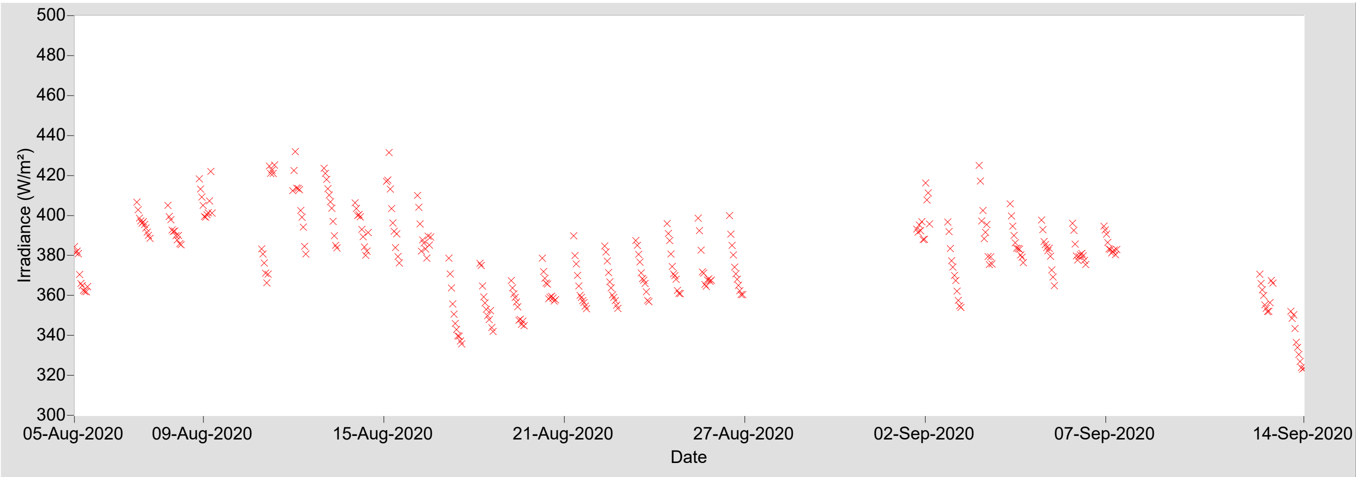
Environmental and Sky Conditions for BORCAL-LW 2020-04

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

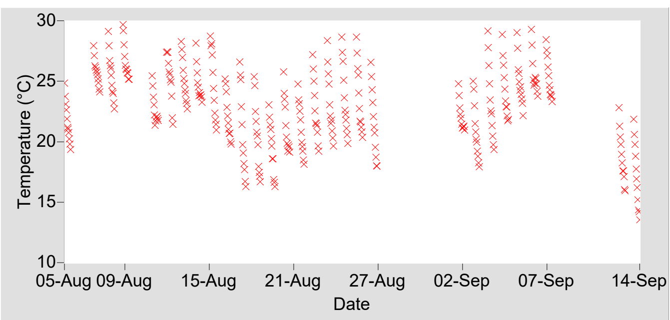


Figure 8. Humidity

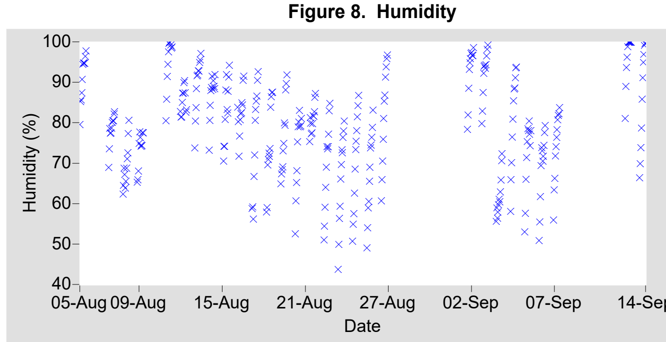


Figure 9. Pressure

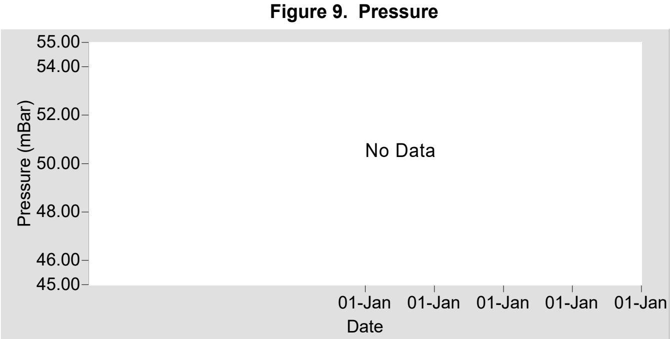


Figure 10. Estimated Precipitable Water Vapor (PWV)

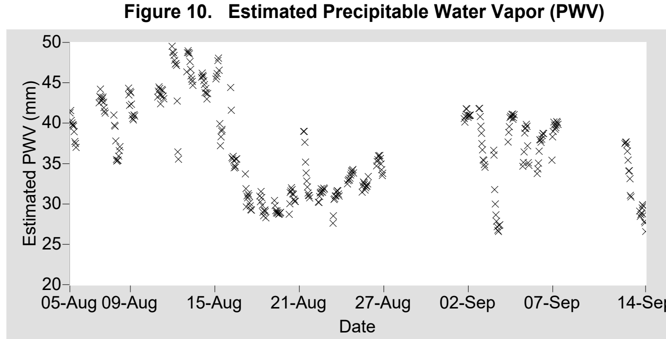


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	22.79	13.19	30.14
Humidity (%)	79.51	42.07	100.05
Pressure (mBar)	N/A	N/A	N/A
Est. Precipitable Water Vapor (mm)	36.6	26.1	49.7

For other information about the calibration facility visit: https://www.arm.gov/capabilities/observatories/sgp

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 2020-04 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): 30
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: E0710025T Vaisala HMP155 T	239			Temp	100	-40
Humidity: E0710025H Vaisala HMP155 H	255			Hum	100	0
Pressure: None					0	0

GPS TIME RECIEVER

SGP Symmetricom NTP

Type	Port	Baud	Parity	Stop bits	Data bits
RS232	0	115200	0	1	8

DATALOGGER

	Logger/Relay	DMM
Unit 1	2009-1207 NREL RAP-DAQ	MY42002864 Agilent 34420A
Unit 0	2009-1206 NREL RAP-DAQ	MY42002863 Agilent 34420A
Unit 3	2014-1302 NREL RAP-DAQ	SG42000596 Agilent 34420A
Unit 2	2009-1208 NREL RAP-DAQ	MY42002866 Agilent 34420A

		Unit 1	Unit 0	Unit 3	Unit 2
	Cal Date	01/03/2020	01/03/2020	01/03/2020	01/03/2020
	Cal Due Date	01/03/2021	01/03/2021	01/03/2021	01/03/2021
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	1	GPIB	22	0	0	0	0
Relay	1	GPIB	25	1	0	0	0
DMM	0	GPIB	21	0	0	0	0
Relay	0	GPIB	24	1	0	0	0
DMM	3	GPIB	1	0	0	0	0
Relay	3	GPIB	4	1	0	0	0
DMM	2	GPIB	23	0	0	0	0
Relay	2	GPIB	26	1	0	0	0

BORCAL/LW 2020-04 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: 29590F3 Eppley PIR-V (Ventilated)													
04/02/2019	04/02/2021	9.70000	0.25424	0.97400	-4.07000	7.04400E-4	2.70	9	71		2	T6-2	✔
Pyrgeometer 1: Case 10K Temperature									67		2		
Pyrgeometer 1: Dome 10K Temperature									75		2		
Pyrgeometer 2: 29927F3 Eppley PIR-V (Ventilated)													
04/02/2019	04/02/2021	5.20000	0.26417	0.99030	-3.94000	7.04400E-4	2.70	9	23		2	T5-2	✔
Pyrgeometer 2: Case 10K Temperature									19		2		
Pyrgeometer 2: Dome 10K Temperature									27		2		

BORCAL/LW 2020-04 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	98		37	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	37/43	24
PIR	(Case 10K Temperature)		106		37									
	(Dome 10K Temperature)		24		43									
29591F3	SGP	4.1900	208		30	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	30	24
PIR	(Case 10K Temperature)		216		30									
	(Dome 10K Temperature)		224		30									
29665F3	SGP	3.9200	113		55	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	55/61	24
PIR	(Case 10K Temperature)		121		55									
	(Dome 10K Temperature)		40		61									
29924F3	SGP	3.8600	114		56	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	56/62	24
PIR	(Case 10K Temperature)		122		56									
	(Dome 10K Temperature)		41		62									
30011F3	SGP	3.5900	82		29	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	29/18	24
PIR	(Case 10K Temperature)		90		29									
	(Dome 10K Temperature)		18		18									
30012F3	TWP	3.4300	135		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-3	24
PIR	(Case 10K Temperature)		131		3									
	(Dome 10K Temperature)		139		3									
30032F3	SGP	4.0400	128		57	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	57/58	24
PIR	(Case 10K Temperature)		136		57									
	(Dome 10K Temperature)		137		58									
30085F3	SGP	4.0800	144		65	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	65/45	24
PIR	(Case 10K Temperature)		152		65									
	(Dome 10K Temperature)		26		45									
30131F3	TWP	3.7700	61		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	3/5/7	24
PIR	(Case 10K Temperature)		1		5									
	(Dome 10K Temperature)		8		7									
30132F3 ‡	SGP	3.9000	231		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-3	24
PIR	(Case 10K Temperature)		227		3									
	(Dome 10K Temperature)		235		3									
30167F3	TWP	4.5100	199		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-1	24
PIR	(Case 10K Temperature)		195		1									
	(Dome 10K Temperature)		203		1									
30168F3	NSA	2.6100	39		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T5-3	24
PIR	(Case 10K Temperature)		35		3									
	(Dome 10K Temperature)		43		3									
30357F3	SGP	3.8800	119		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-2	24
PIR	(Case 10K Temperature)		115		2									
	(Dome 10K Temperature)		123		2									
30681F3	SGP	3.8100	183		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-3	24
PIR	(Case 10K Temperature)		179		3									
	(Dome 10K Temperature)		187		3									
30690F3	SGP	3.6200	55		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T6-1	24
PIR	(Case 10K Temperature)		51		1									
	(Dome 10K Temperature)		59		1									
30692F3	SGP	3.4800	232		83	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	83	24
PIR	(Case 10K Temperature)		240		83									
	(Dome 10K Temperature)		248		83									

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Serial Number / Model	Customer	Mfg RS	Ch	Box	Cable	Act	ISO	AIM	Stickr	Vent	Use	Kr	Location	Due
30781F3	SGP	3.7300	96		31	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	31/32	24
PIR	(Case 10K Temperature)		104		31									
	(Dome 10K Temperature)		105		32									
30828F3	SGP	4.2400	145		73	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	73/53	24
PIR	(Case 10K Temperature)		153		73									
	(Dome 10K Temperature)		33		53									
30830F3	SGP	3.7900	112		46	No	No	Yes	K0=0	Yes	PYG	7.044e-4	46/52	24
PIR	(Case 10K Temperature)		120		46									
	(Dome 10K Temperature)		32		52									
30834F3	SGP	3.7500	81		28	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	28/17	24
PIR	(Case 10K Temperature)		89		28									
	(Dome 10K Temperature)		17		17									
30836F3	SGP	3.9300	130		64	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	64/44	24
PIR	(Case 10K Temperature)		138		64									
	(Dome 10K Temperature)		25		44									
31236F3	SGP	3.6500	161		84	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	84/85	24
PIR	(Case 10K Temperature)		169		84									
	(Dome 10K Temperature)		170		85									
31298F3	TWP	3.8500	49		10	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	10/16	24
PIR	(Case 10K Temperature)		57		10									
	(Dome 10K Temperature)		16		16									
31299F3	NSA	4.2000	87		3	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T6-3	24
PIR	(Case 10K Temperature)		83		3									
	(Dome 10K Temperature)		91		3									
31301F3	TWP	3.3400	160		82	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	82/63	24
PIR	(Case 10K Temperature)		168		82									
	(Dome 10K Temperature)		42		63									
31302F3	TWP	3.5900	60		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	2/4/6	24
PIR	(Case 10K Temperature)		0		4									
	(Dome 10K Temperature)		2		6									
31303F3	TWP	3.4800	48		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	1/8	24
PIR	(Case 10K Temperature)		56		1									
	(Dome 10K Temperature)		9		8									
31308F3	TWP	3.1400	50		11	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	11/12	24
PIR	(Case 10K Temperature)		58		11									
	(Dome 10K Temperature)		72		12									
31309F3	TWP	3.8700	65		13	No	No	Yes	K0=0	Yes	PYG	7.044e-4	13/14	12
PIR	(Case 10K Temperature)		73		13									
	(Dome 10K Temperature)		74		14									
31311F3	TWP	3.8200	80		19	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	19/9	24
PIR	(Case 10K Temperature)		88		19									
	(Dome 10K Temperature)		10		9									
31640F3	SGP	4.0500	146		74	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	74/54	24
PIR	(Case 10K Temperature)		154		74									
	(Dome 10K Temperature)		34		54									
32040F3	NSA	3.8000	103		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T7-1	24
PIR	(Case 10K Temperature)		99		1									
	(Dome 10K Temperature)		107		1									

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Serial Number / Model	Customer	Mfg RS	Ch	Box	Cable	Act	ISO	AIM	Stickr	Vent	Use	Kr	Location	Due
32050F3	NSA	3.7700	7		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T5-1	24
PIR	(Case 10K Temperature)		3		1									
	(Dome 10K Temperature)		11		1									
36363F3	SGP	2.7500	151		1	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-1	24
PIR	(Case 10K Temperature)		147		1									
	(Dome 10K Temperature)		155		1									
36368F3 ‡	SGP	3.0200	167		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T8-2	24
PIR	(Case 10K Temperature)		163		2									
	(Dome 10K Temperature)		171		2									
36370F3 ‡	SGP	3.8300	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									

‡ Control Instrument