Broadband Outdoor Radiometer Calibration
Longwave

BORCAL-LW
2021-02

Generated by

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
06/23/2021 to 08/11/2021

Report Date
August 11, 2021

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.

Control Instrument History

Figure 1. Eppley PIR Control Instrument (Residual means of current data using historical coefficients)

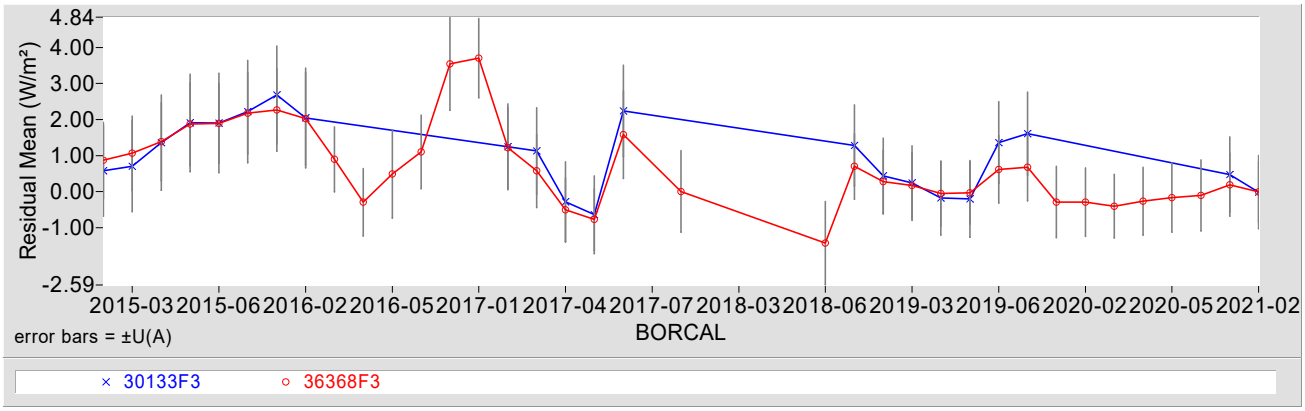


Figure 2. Eppley PIR Control Instrument History (K1 Coefficient)

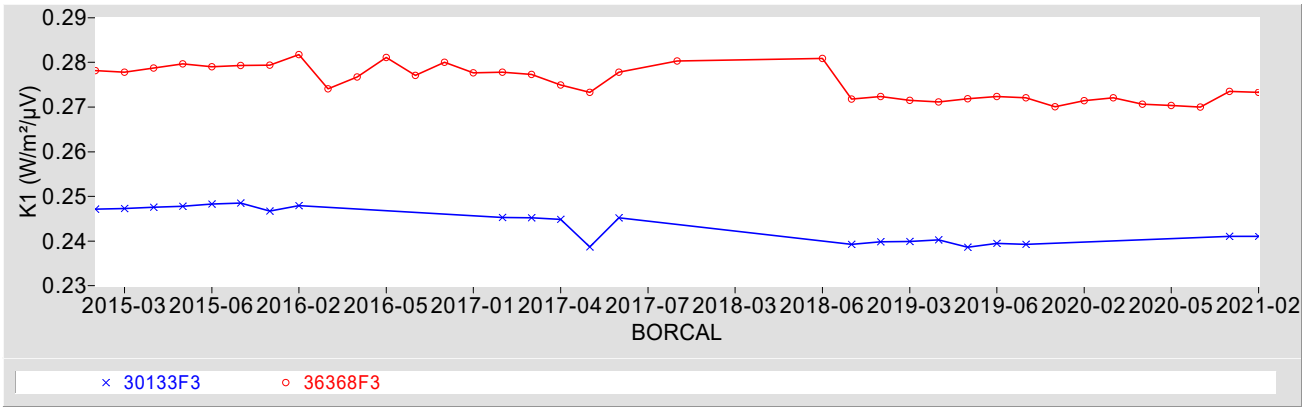


Figure 3. Eppley PIR Control Instrument History (K2 Coefficient)

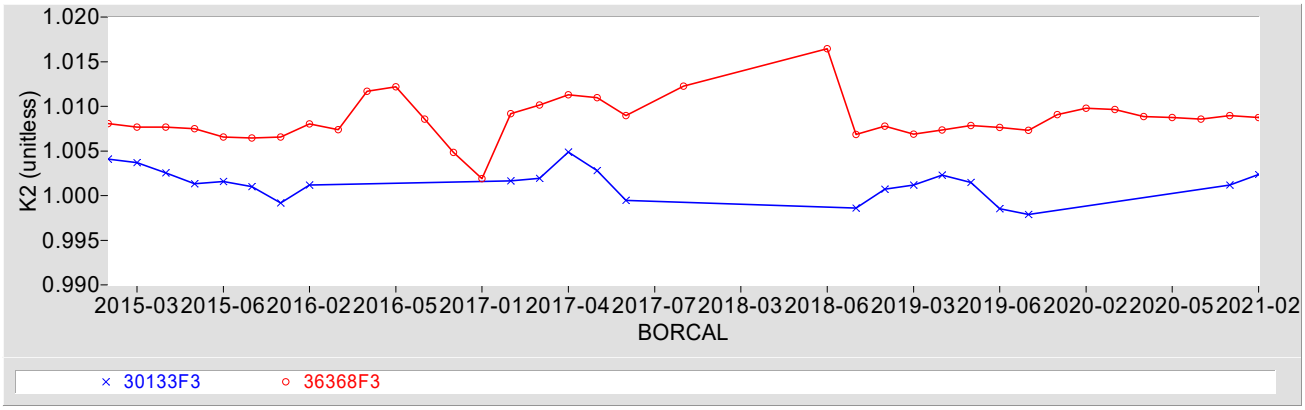
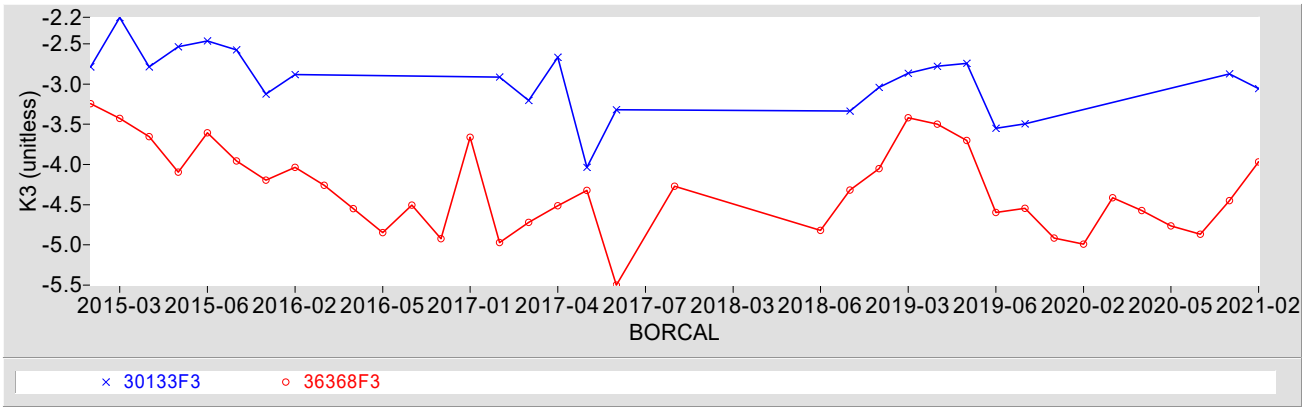


Figure 4. Eppley PIR Control Instrument History (K3 Coefficient)



Results Summary

Table 1. Results Summary

Instrument	Customer	K1 (W/m²/µV)	K2	K3	Kr * (K/µV)	U95 (W/m²)	Page
29148F3	SGP	0.24148	1.0026	-3.08	7.044e-4	±2.7	A1-2
29593F3	SGP	0.22685	1.0012	-3.58	7.044e-4	±2.7	A1-5
29595F3	SGP	0.21131	1.0053	-3.38	7.044e-4	±2.6	A1-8
30133F3	SGP	0.24106	1.0024	-3.06	7.044e-4	±2.7	A1-11
30682F3	SGP	0.23764	1.0012	-3.32	7.044e-4	±2.7	A1-14
30835F3	SGP	0.22723	0.9985	-3.33	7.044e-4	±2.6	A1-17
31391F3	TWP	0.24580	0.9972	-3.13	7.044e-4	±2.6	A1-20
32049F3	SGP	0.23574	1.0026	-3.26	7.044e-4	±2.6	A1-23
33057F3	TWP	0.25021	0.9971	-3.50	7.044e-4	±2.7	A1-26
33058F3	TWP	0.23867	0.9966	-3.03	7.044e-4	±2.6	A1-29
36368F3	SGP	0.27329	1.0087	-3.97	7.044e-4	±2.7	A1-32
37336F3	NSA	0.23325	0.9986	-3.83	7.044e-4	±2.6	A1-35
37339F3	NSA	0.21796	0.9941	-4.83	7.044e-4	±2.7	A1-38

Note: Environmental Conditions for BORCAL starts on page A1-41.

* Kr used to derive coefficients

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:**	29148F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

29148F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

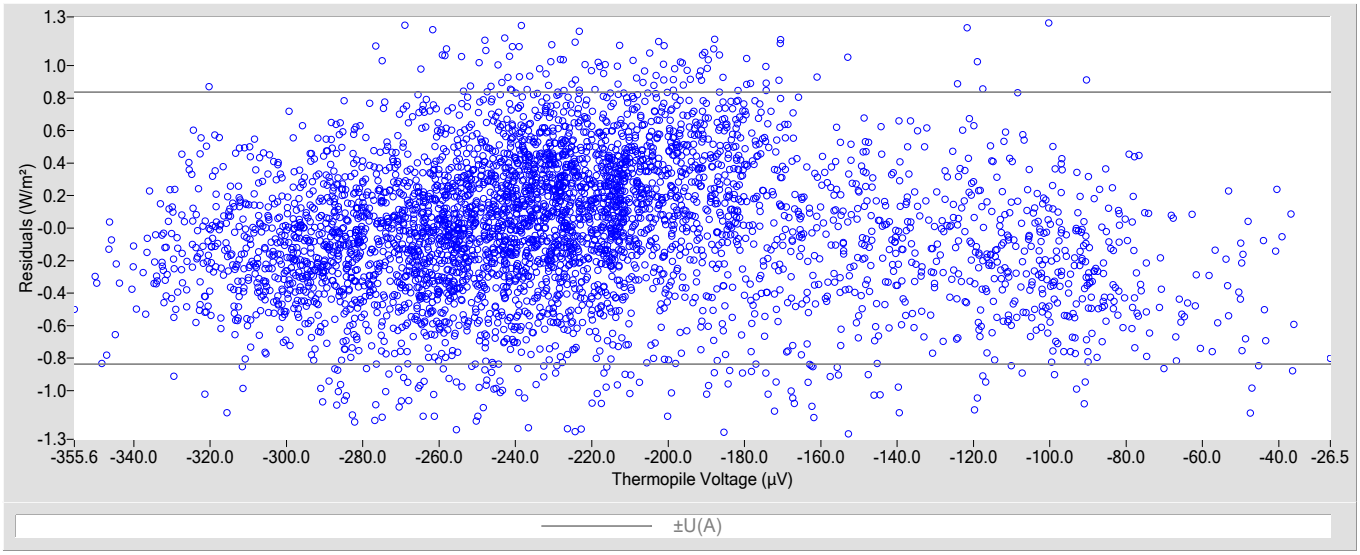


Table 1. Calibration Coefficients

K1	0.24148
K2	1.0026
K3	-3.08
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.43
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.7

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

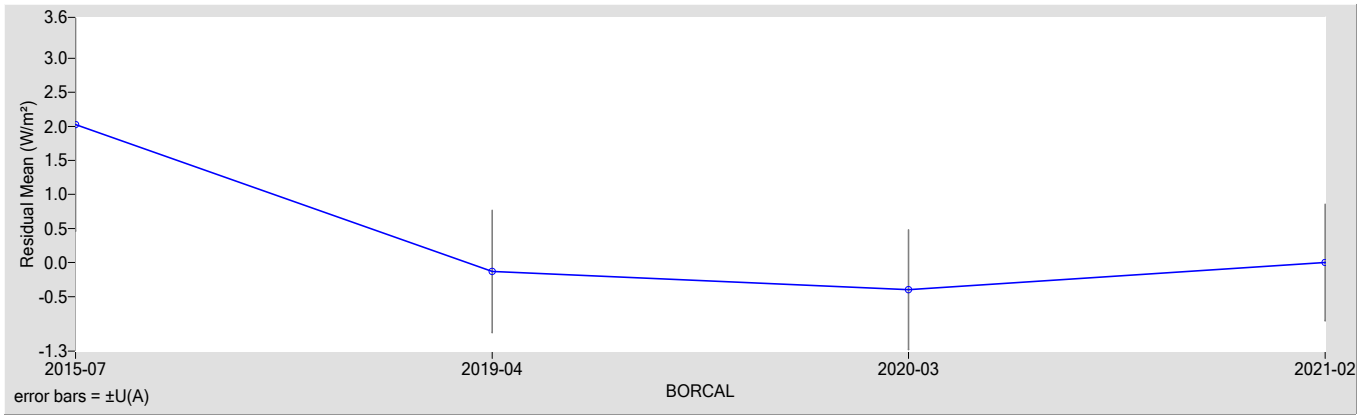


Figure 3. History of instrument (K1 Coefficient)

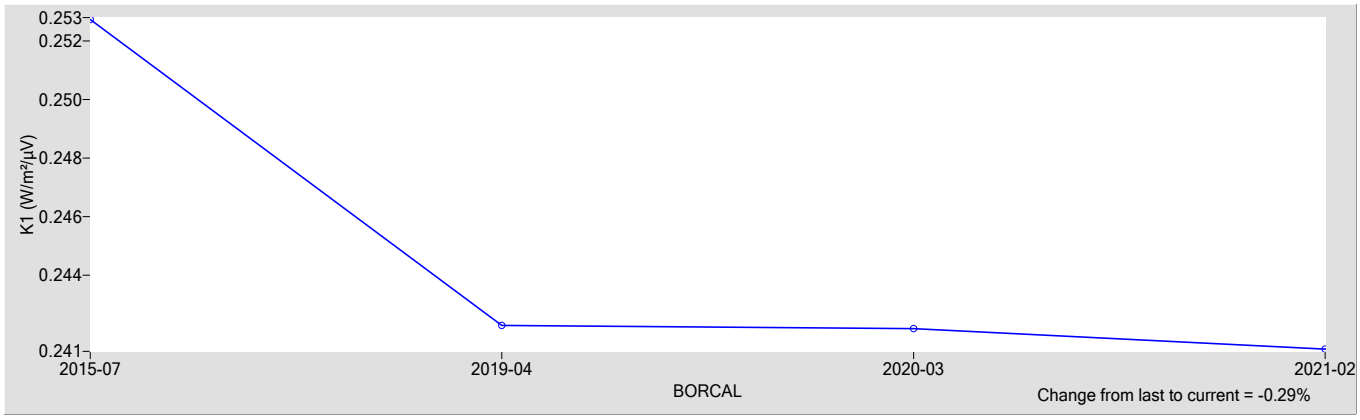


Figure 4. History of instrument (K2 Coefficient)

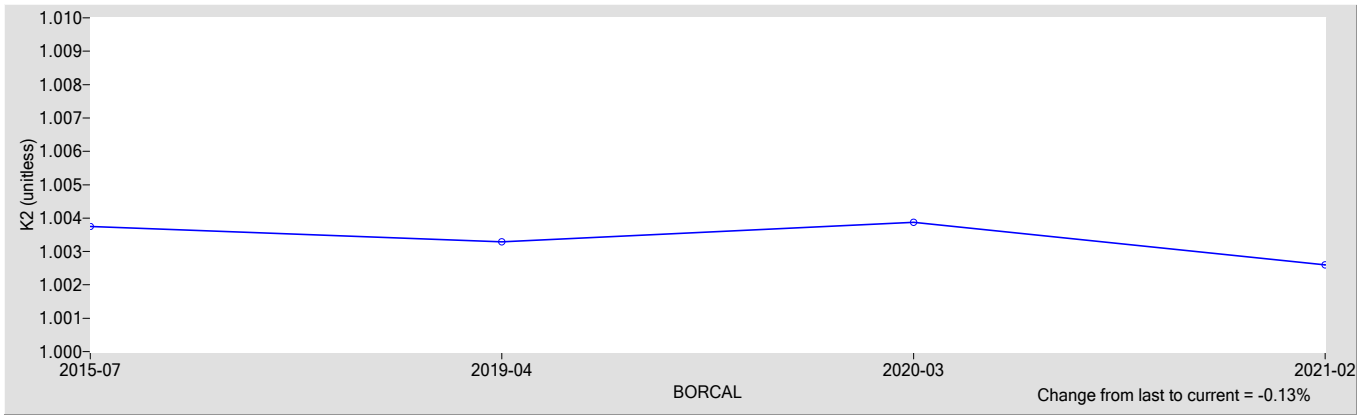
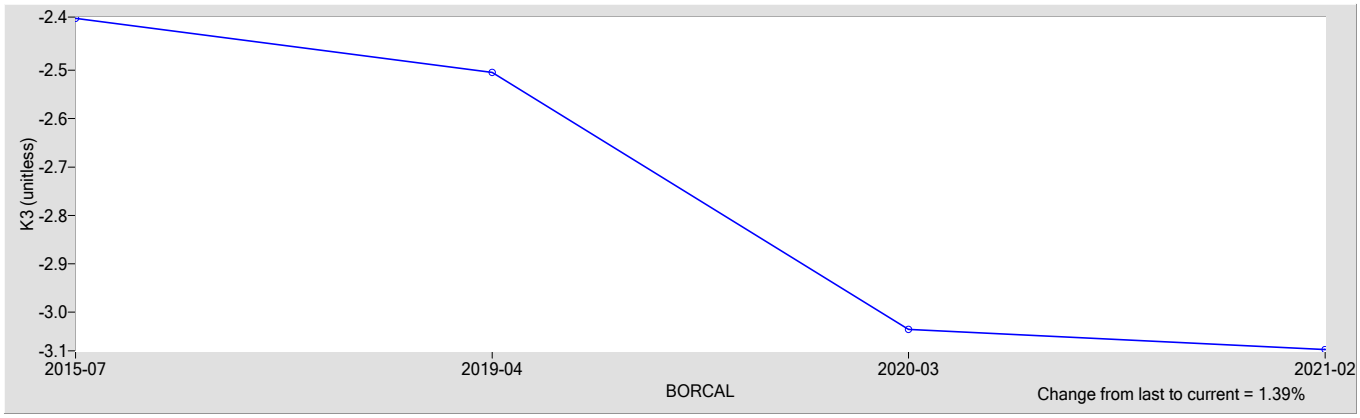


Figure 5. History of instrument (K3 Coefficient)



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:**	29593F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

29593F3 Eppley PIR

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

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

where,

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),
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Figure 1. Residuals for calculated using coefficients vs reference irradiance

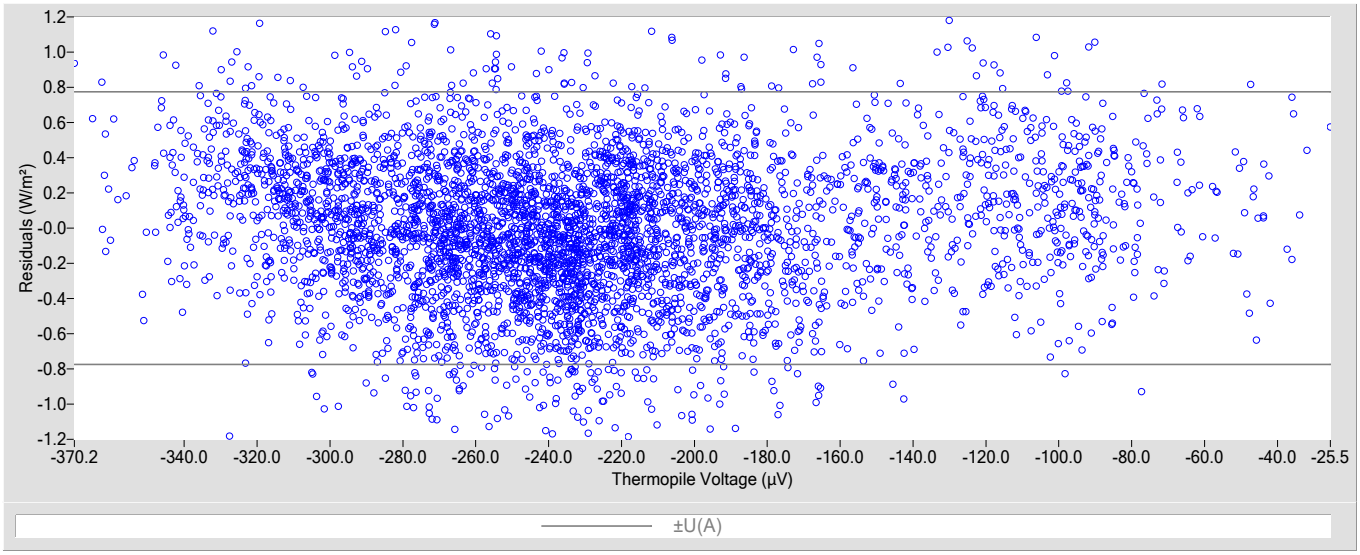


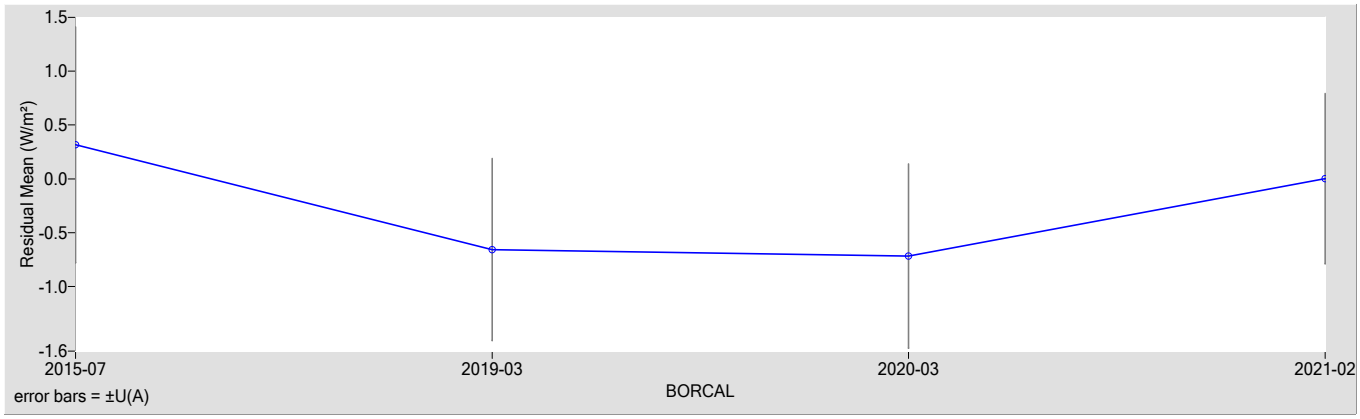
Table 1. Calibration Coefficients

K1	0.22685
K2	1.0012
K3	-3.58
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.40
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.7

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)



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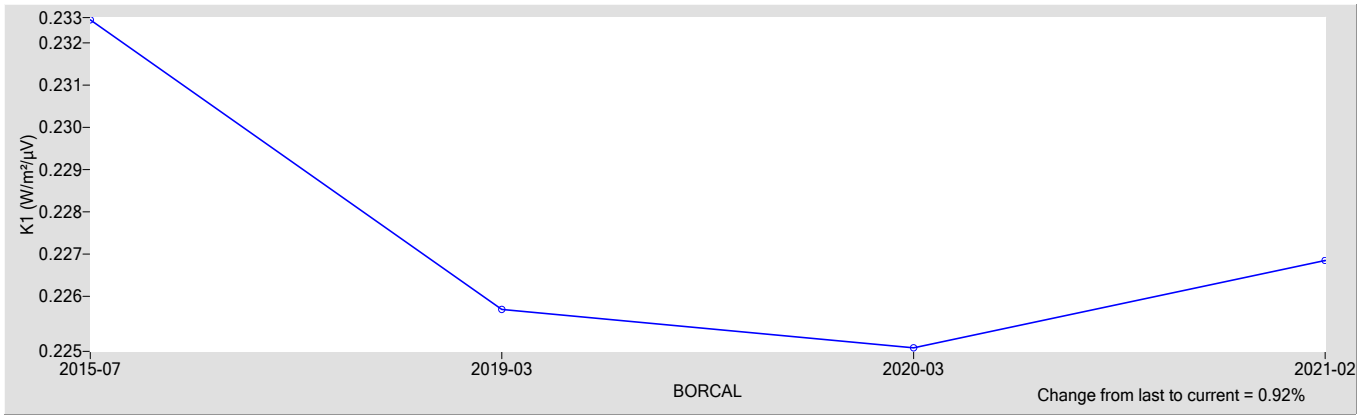


Figure 4. History of instrument (K2 Coefficient)

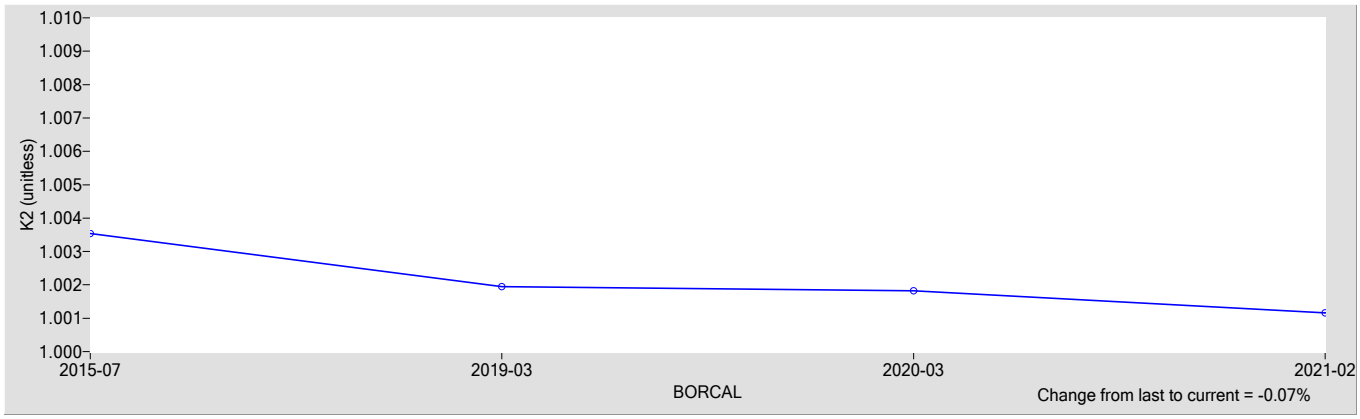
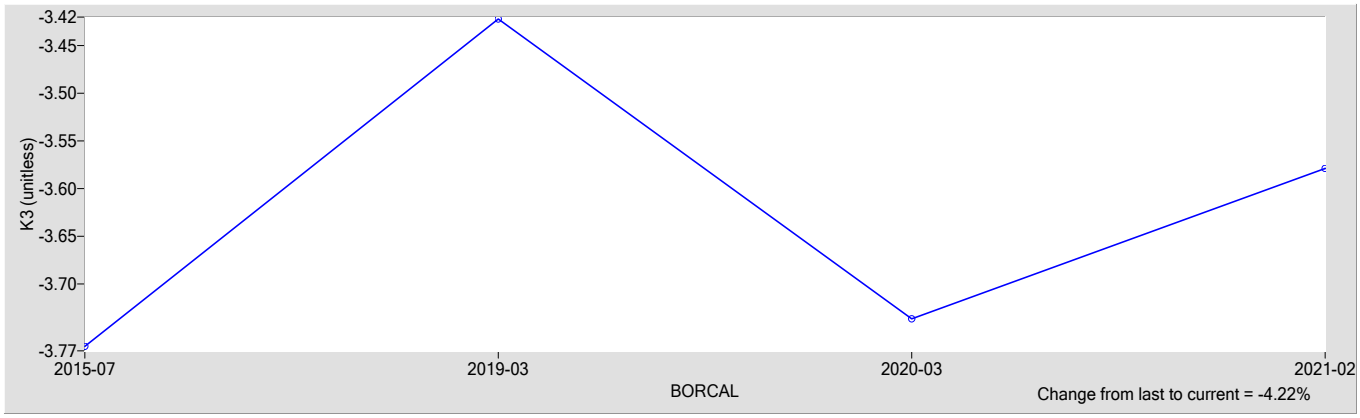


Figure 5. History of instrument (K3 Coefficient)



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Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Downwelling Pyrgeometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PIR	**Serial Number:**	29595F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

29595F3 Eppley PIR

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

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

where,

K1,K2,K3 = calibration coefficeints,
V = thermopile output voltage (μV),
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where, *Td* = dome temperature (K),

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Tc = case temperature (K),
Kr = efficiency coefficient (K/μV).

Figure 1. Residuals for calculated using coefficients vs reference irradiance

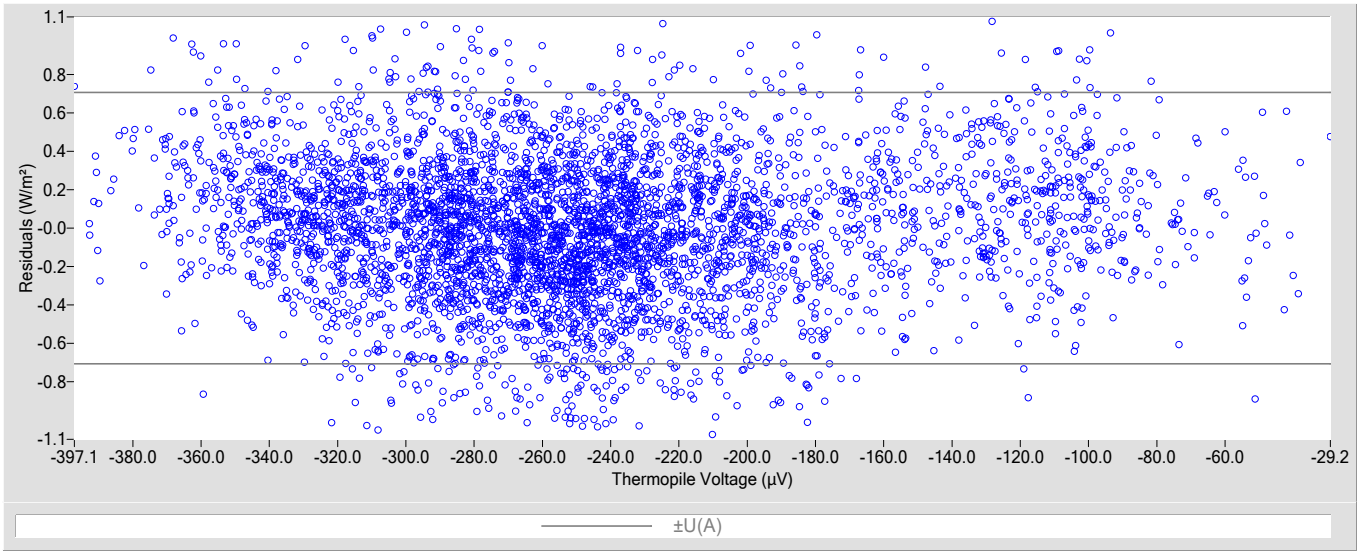


Table 1. Calibration Coefficients

K1	0.21131
K2	1.0053
K3	-3.38
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.36
Combined Standard Uncertainty, u(c) (W/m²)	±1.3
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.6

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

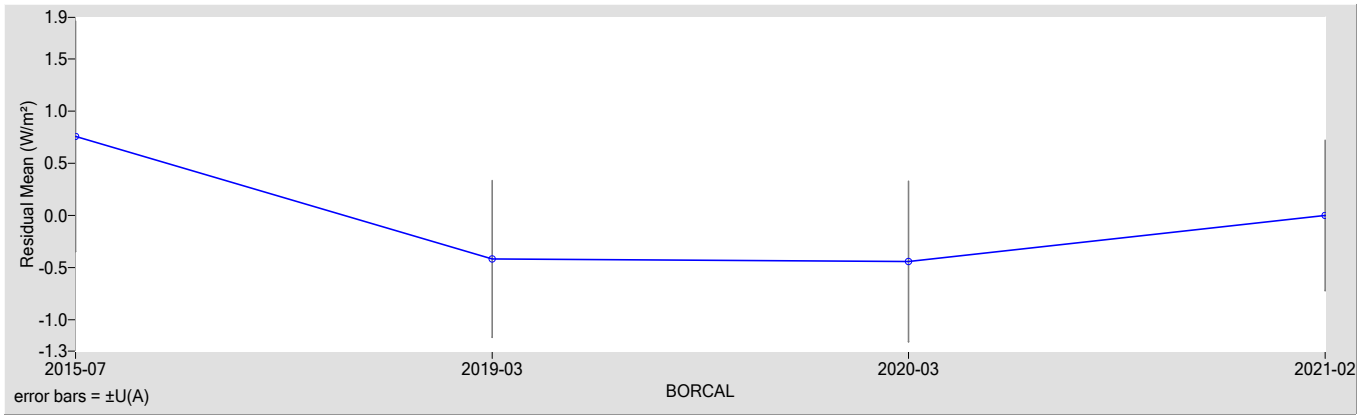


Figure 3. History of instrument (K1 Coefficient)

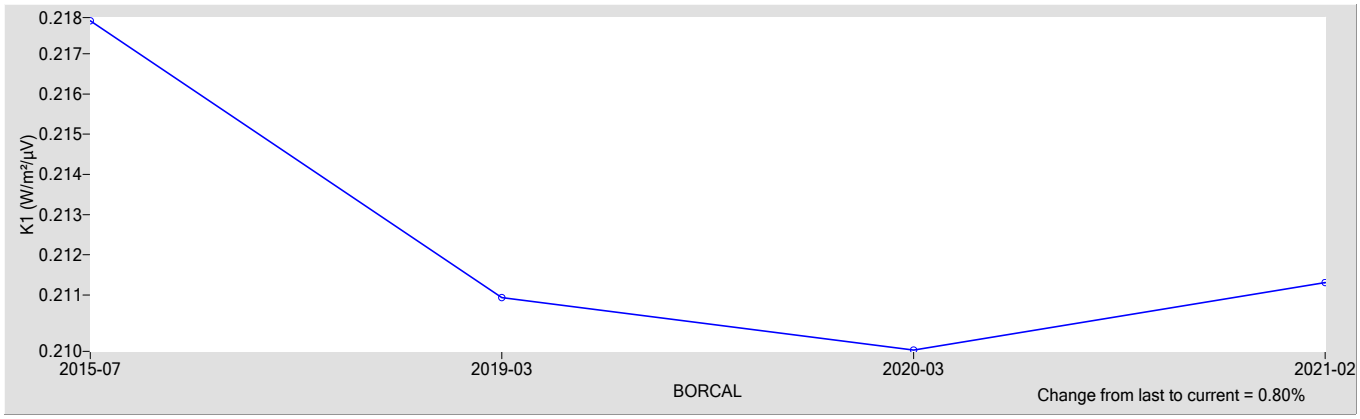


Figure 4. History of instrument (K2 Coefficient)

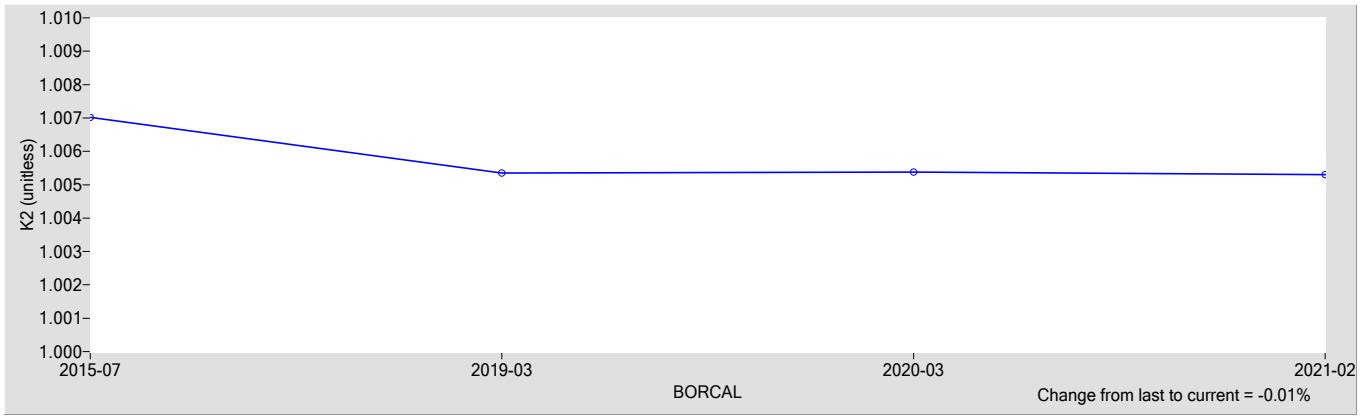
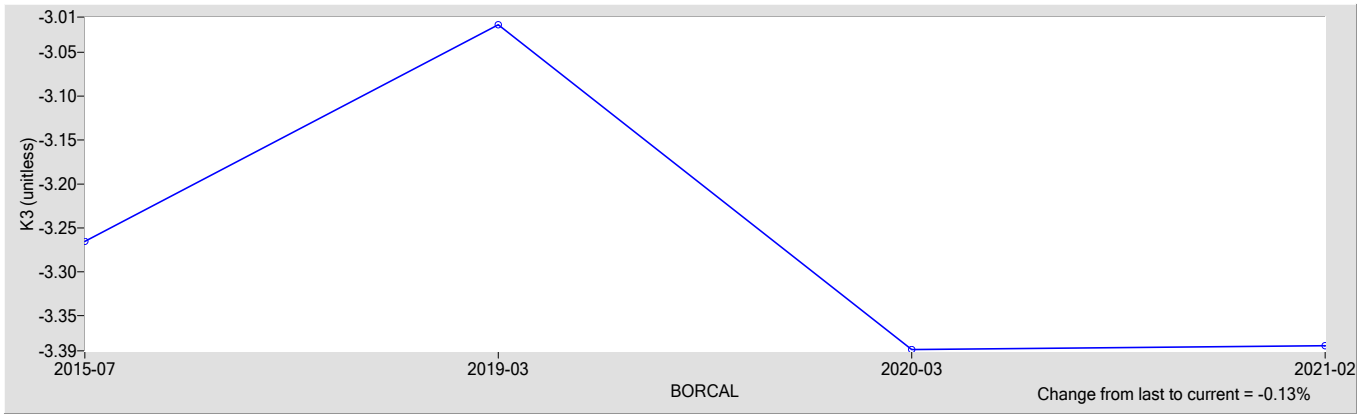


Figure 5. History of instrument (K3 Coefficient)



References:

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Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Downwelling Pyrgeometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PIR	**Serial Number:**	30133F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL-LW Calibration Procedure

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

Calibrated by: Peter Gotseff and Craig Webb

_____ _____

Peter Gotseff, Technical Manager Date

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

Calibration Results

30133F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

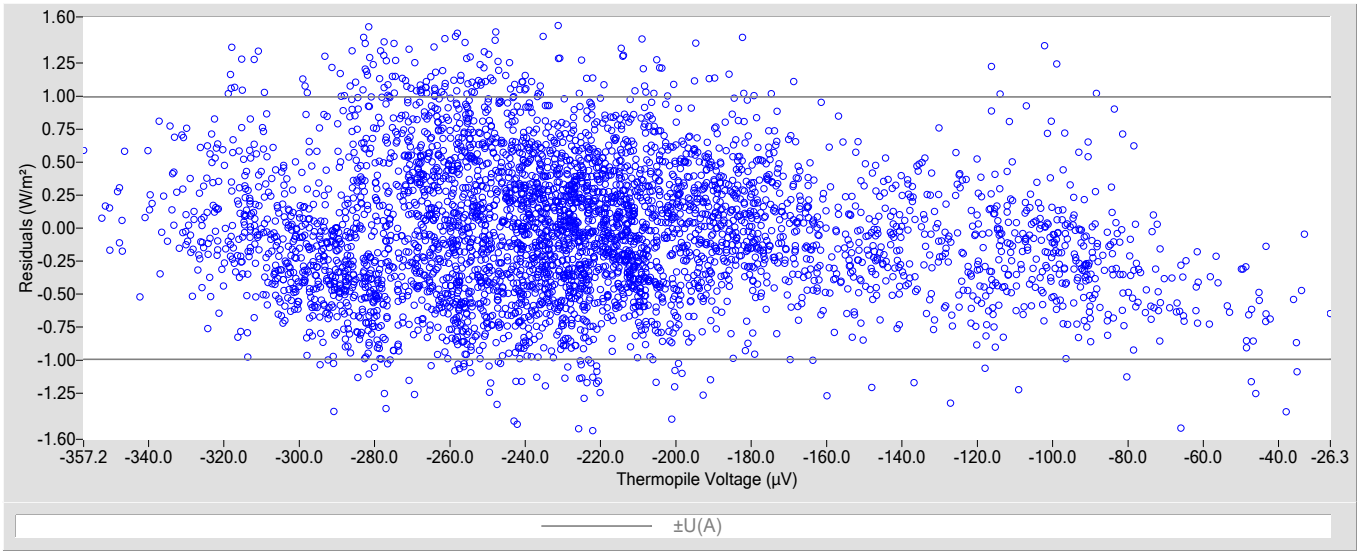


Table 1. Calibration Coefficients

K1	0.24106
K2	1.0024
K3	-3.06
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.51
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.7

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

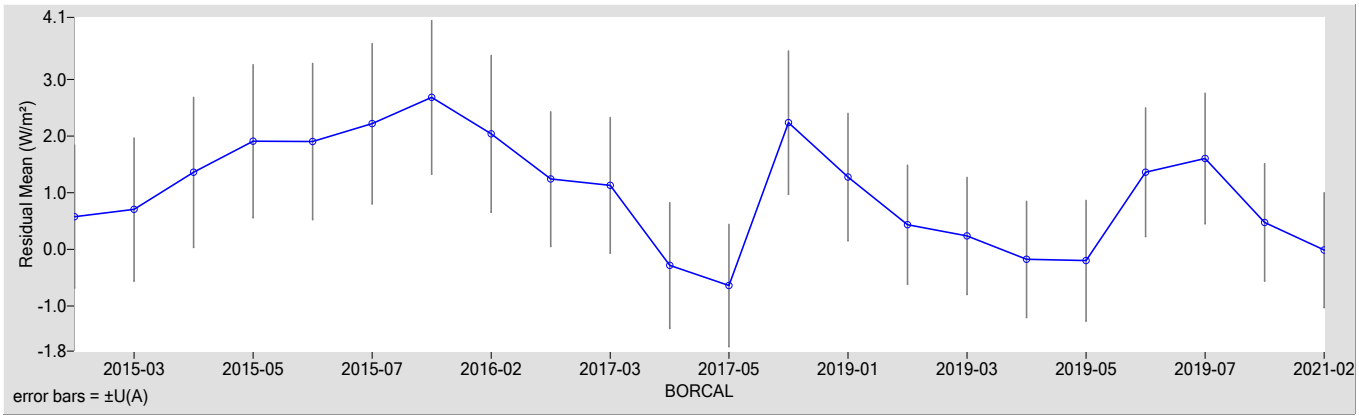


Figure 3. History of instrument (K1 Coefficient)

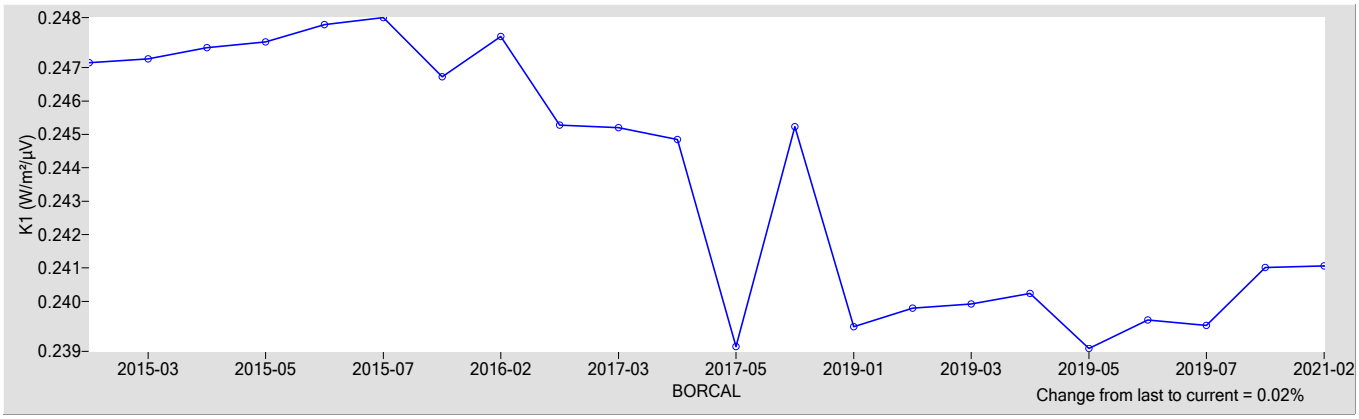


Figure 4. History of instrument (K2 Coefficient)

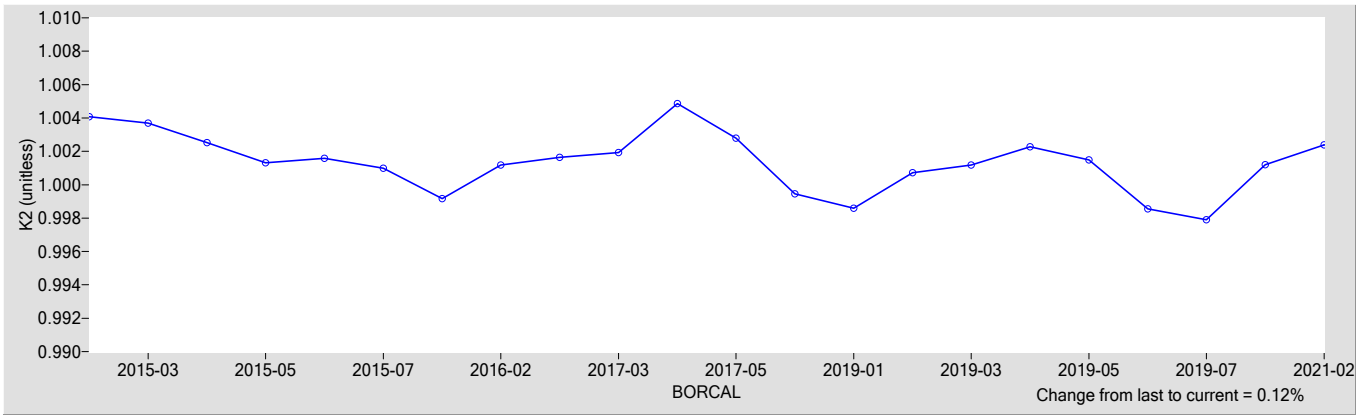
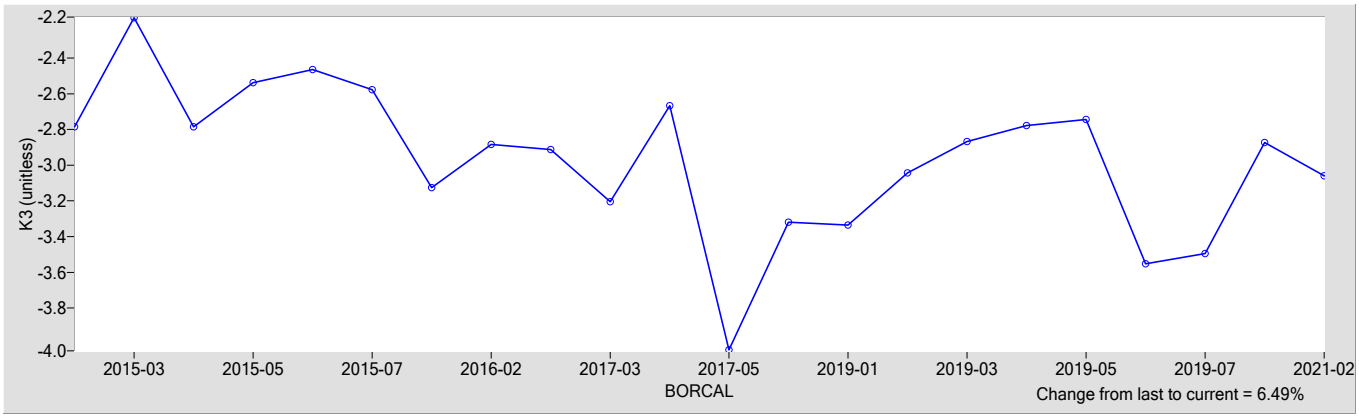


Figure 5. History of instrument (K3 Coefficient)



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:**	30682F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

30682F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

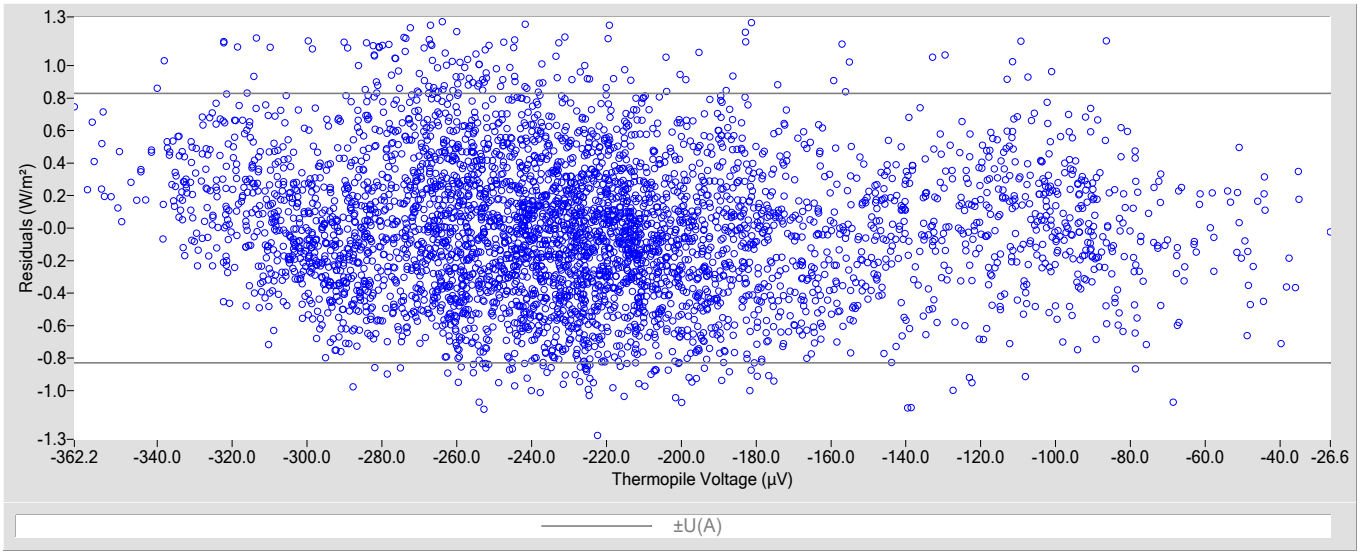


Table 1. Calibration Coefficients

K1	0.23764
K2	1.0012
K3	-3.32
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.7

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

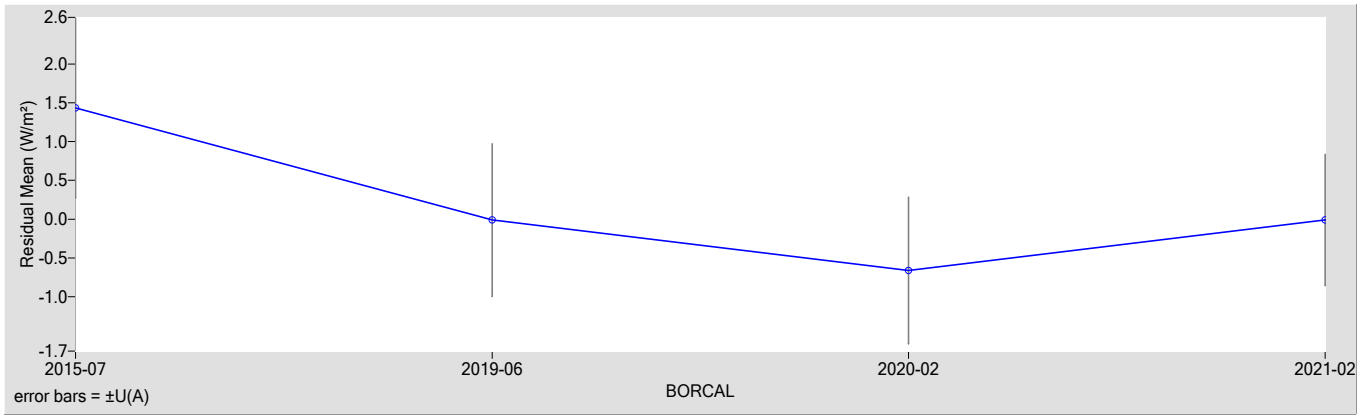


Figure 3. History of instrument (K1 Coefficient)

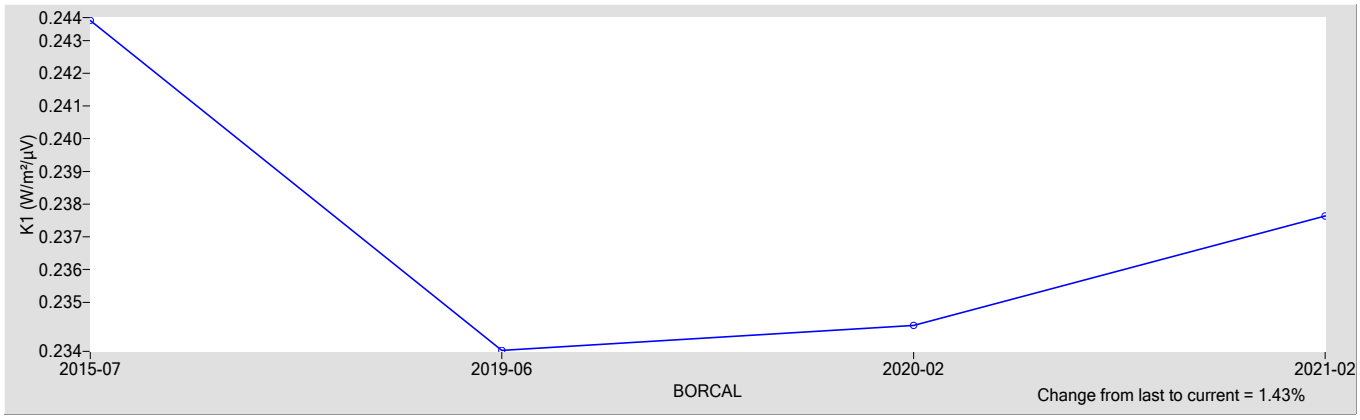


Figure 4. History of instrument (K2 Coefficient)

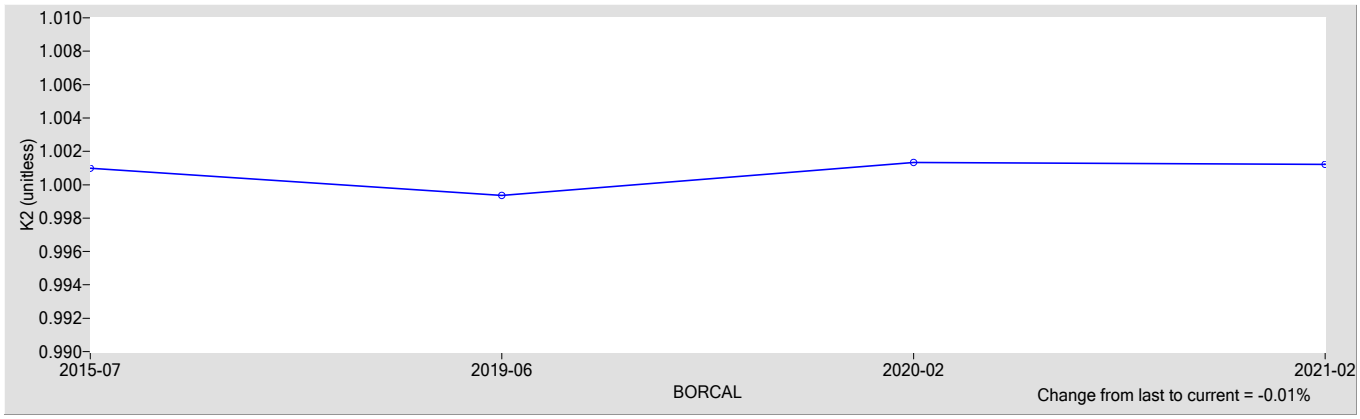
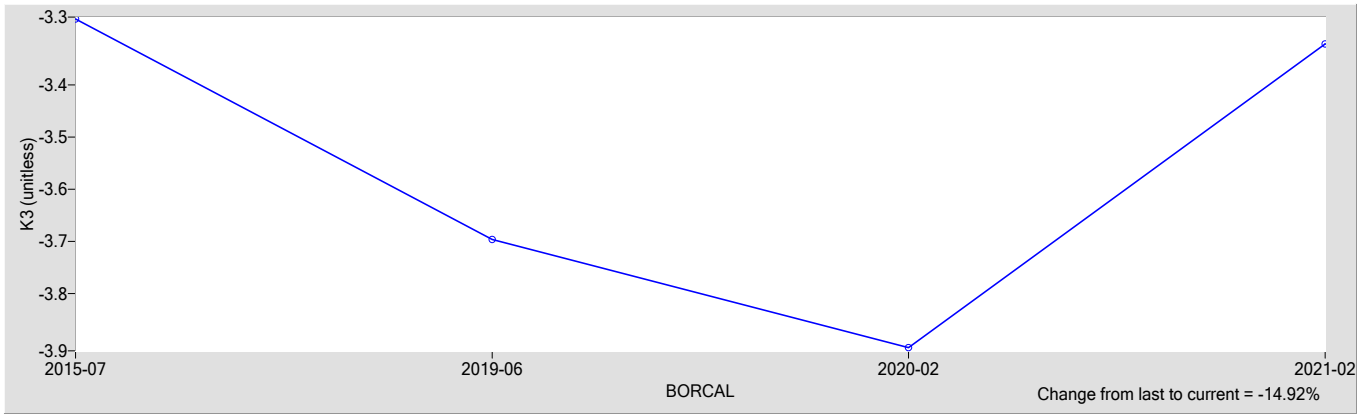


Figure 5. History of instrument (K3 Coefficient)



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:**	30835F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

30835F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

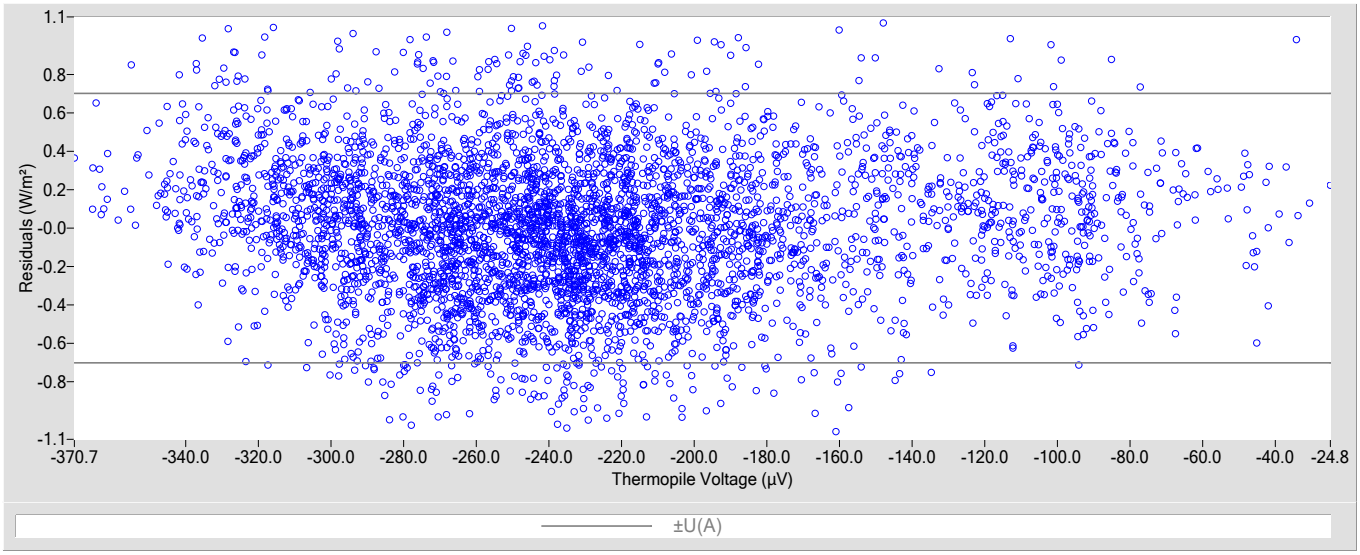


Table 1. Calibration Coefficients

K1	0.22723
K2	0.9985
K3	-3.33
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.36
Combined Standard Uncertainty, u(c) (W/m²)	±1.3
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.6

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

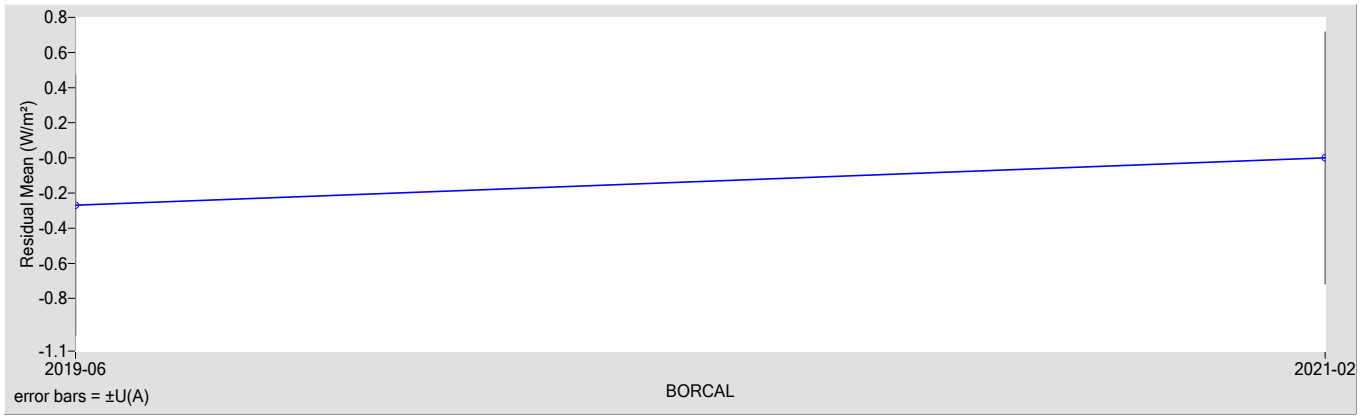


Figure 3. History of instrument (K1 Coefficient)

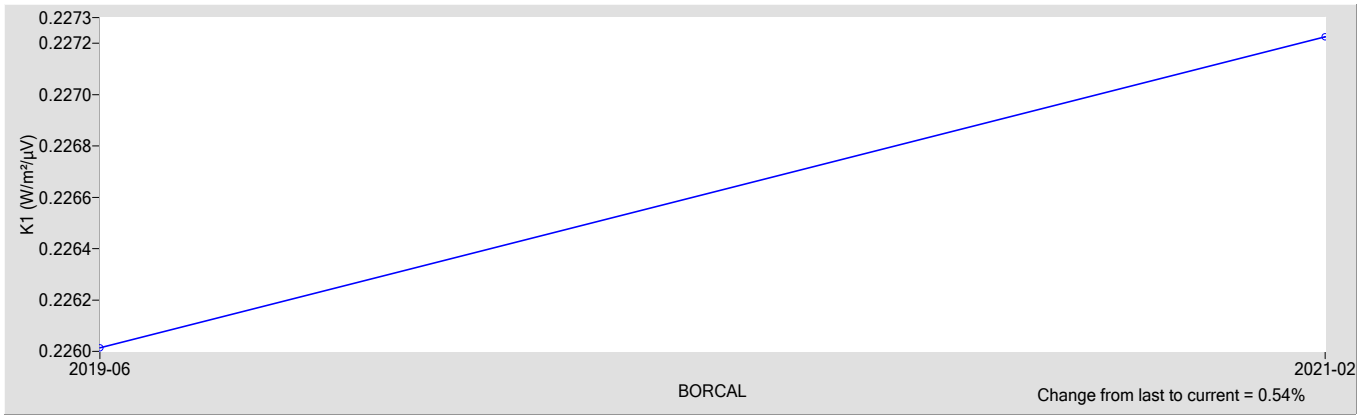


Figure 4. History of instrument (K2 Coefficient)

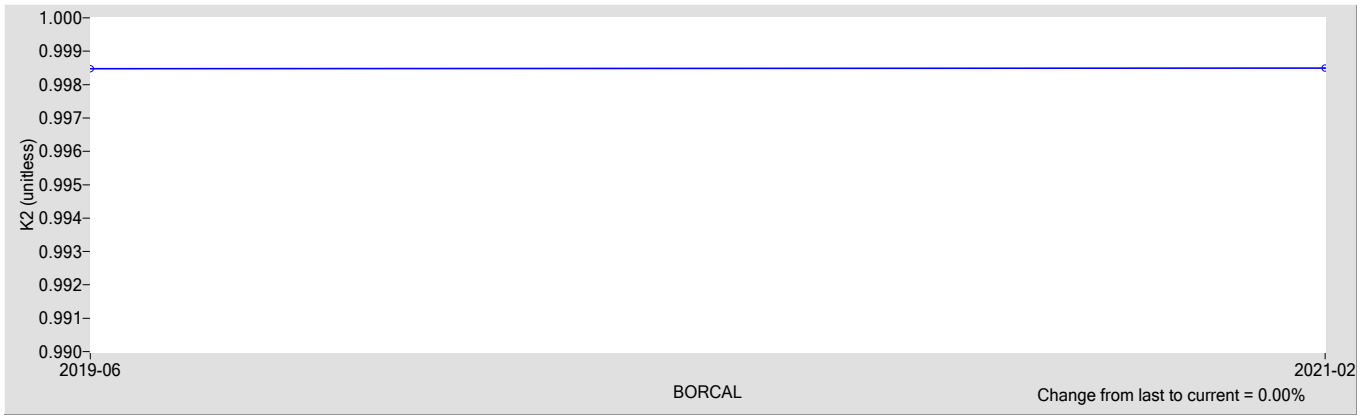
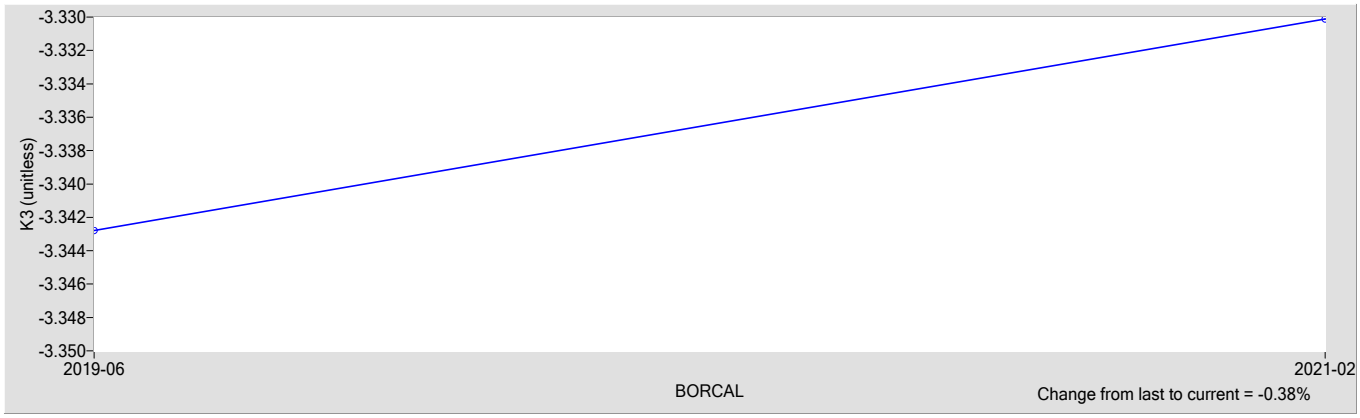


Figure 5. History of instrument (K3 Coefficient)



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:**	31391F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

31391F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

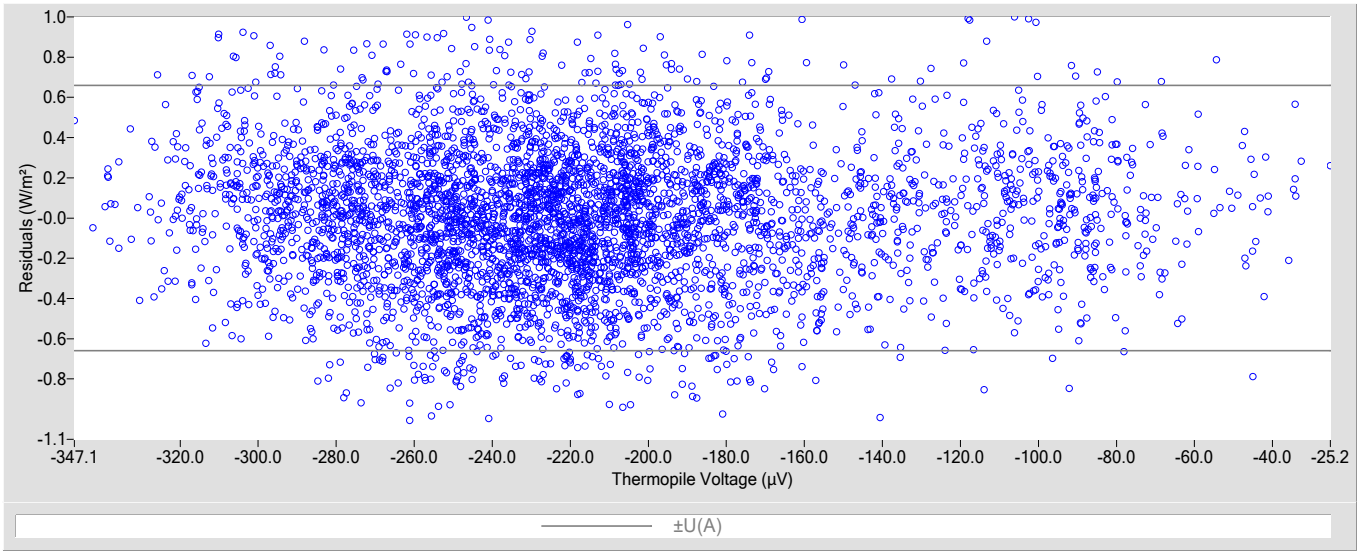


Table 1. Calibration Coefficients

K1	0.24580
K2	0.9972
K3	-3.13
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.34
Combined Standard Uncertainty, u(c) (W/m²)	±1.3
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.6

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

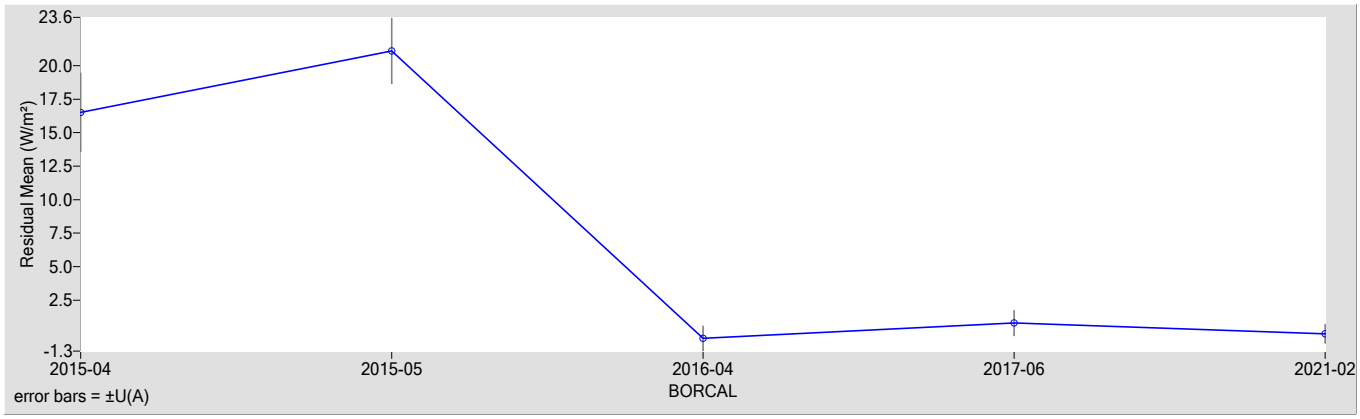


Figure 3. History of instrument (K1 Coefficient)

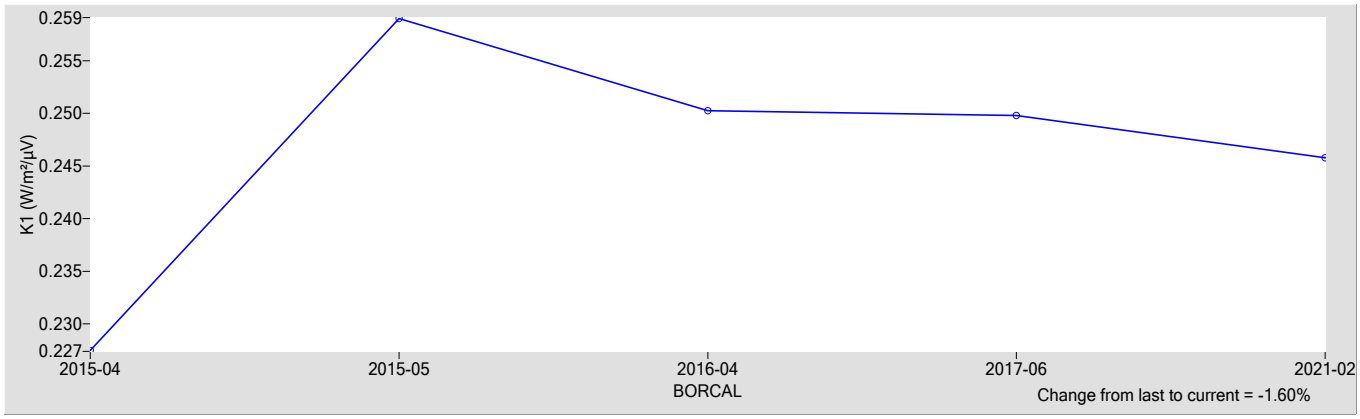


Figure 4. History of instrument (K2 Coefficient)

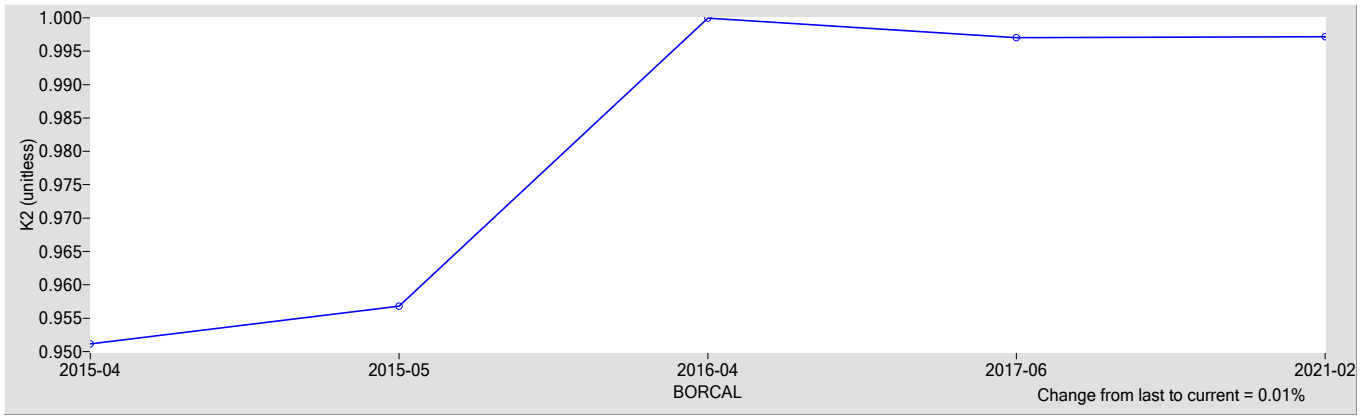
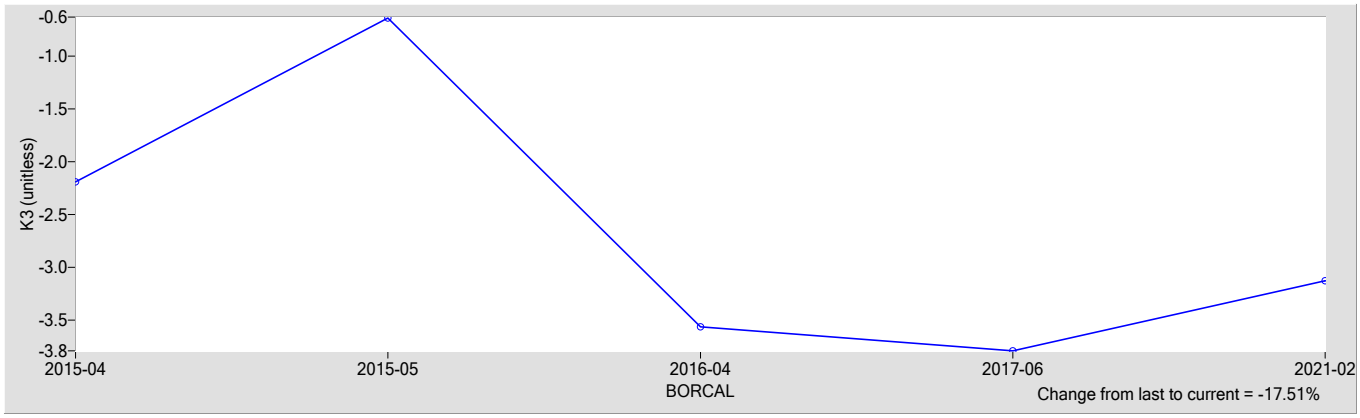


Figure 5. History of instrument (K3 Coefficient)



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:**	32049F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

32049F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

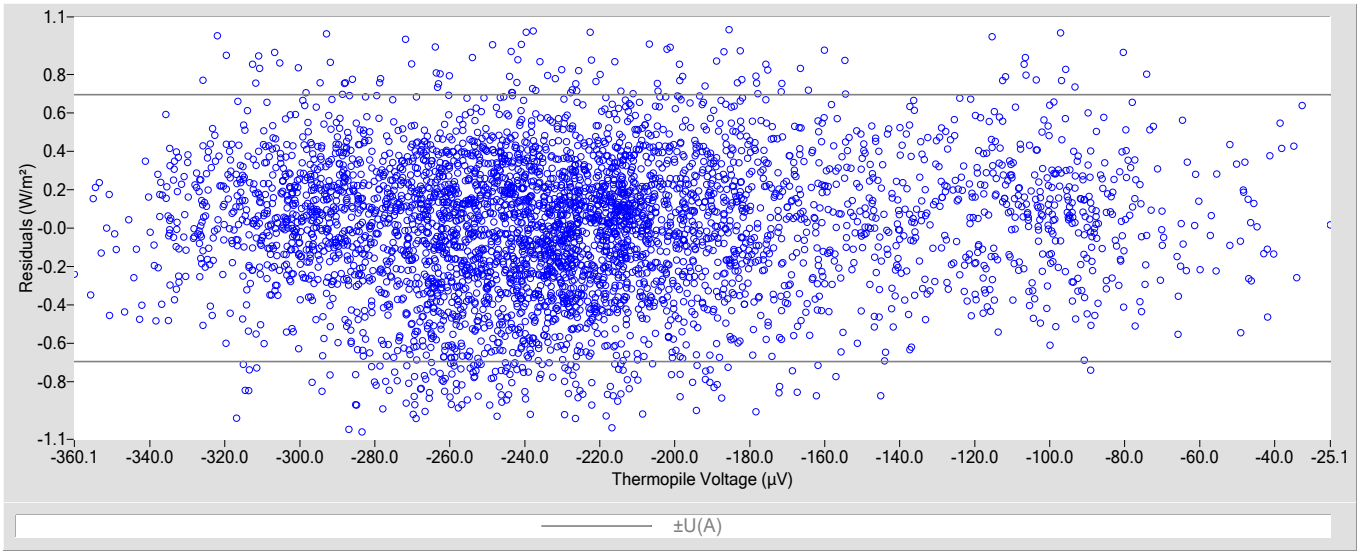


Table 1. Calibration Coefficients

K1	0.23574
K2	1.0026
K3	-3.26
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.35
Combined Standard Uncertainty, u(c) (W/m²)	±1.3
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.6

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

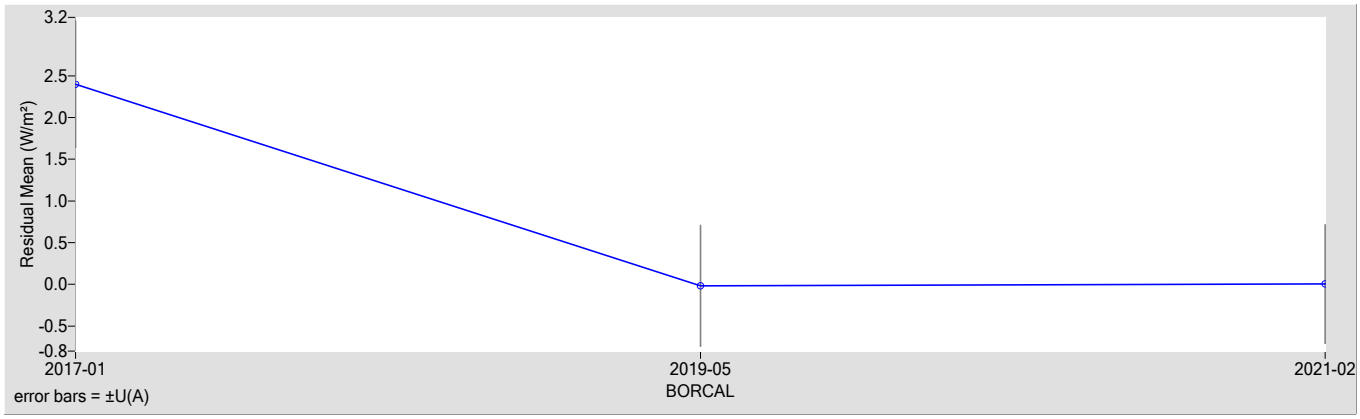


Figure 3. History of instrument (K1 Coefficient)

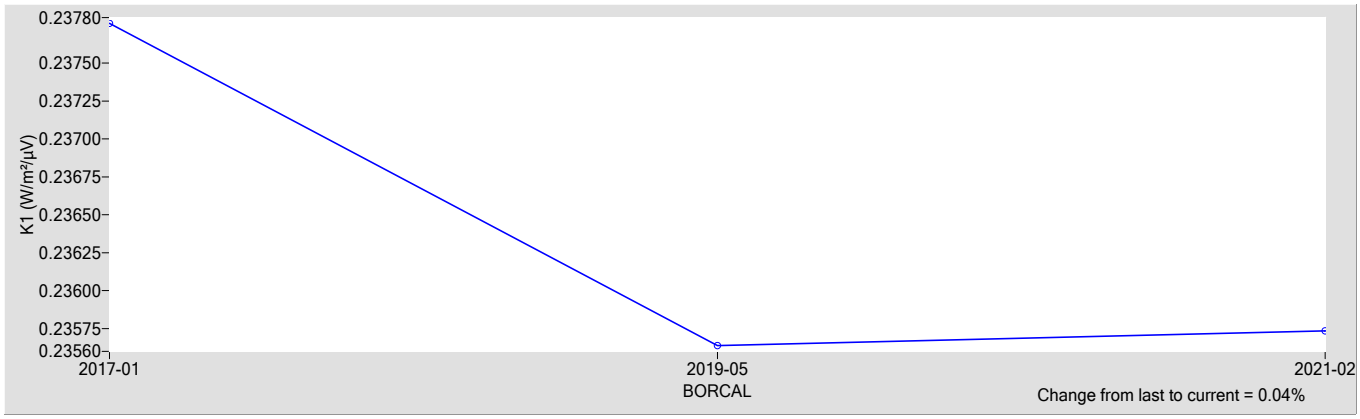


Figure 4. History of instrument (K2 Coefficient)

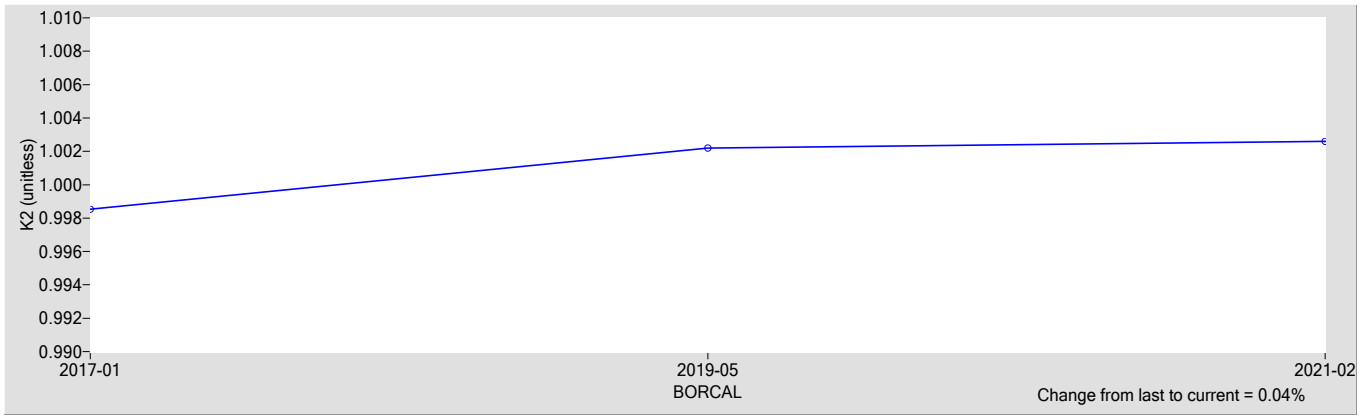
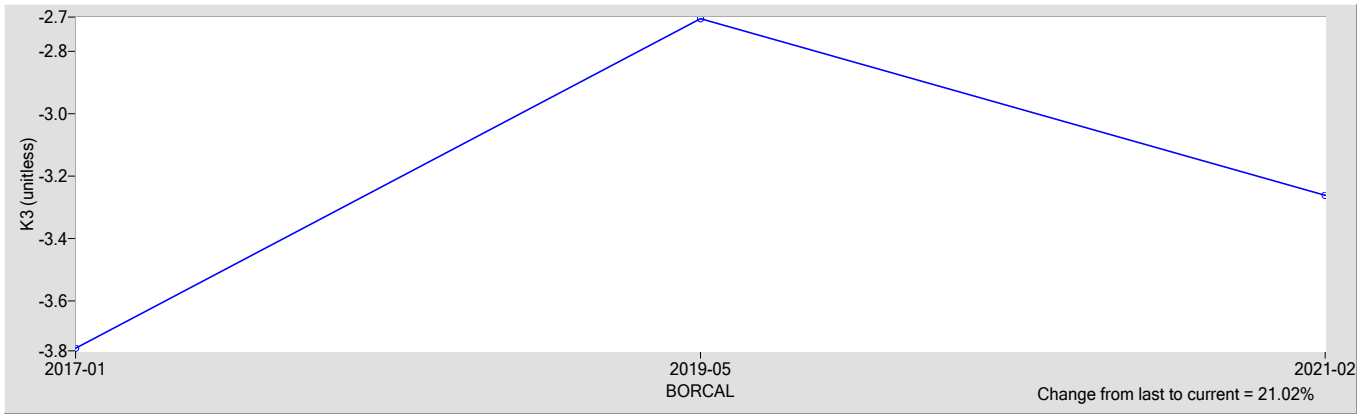


Figure 5. History of instrument (K3 Coefficient)



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:**	33057F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

33057F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

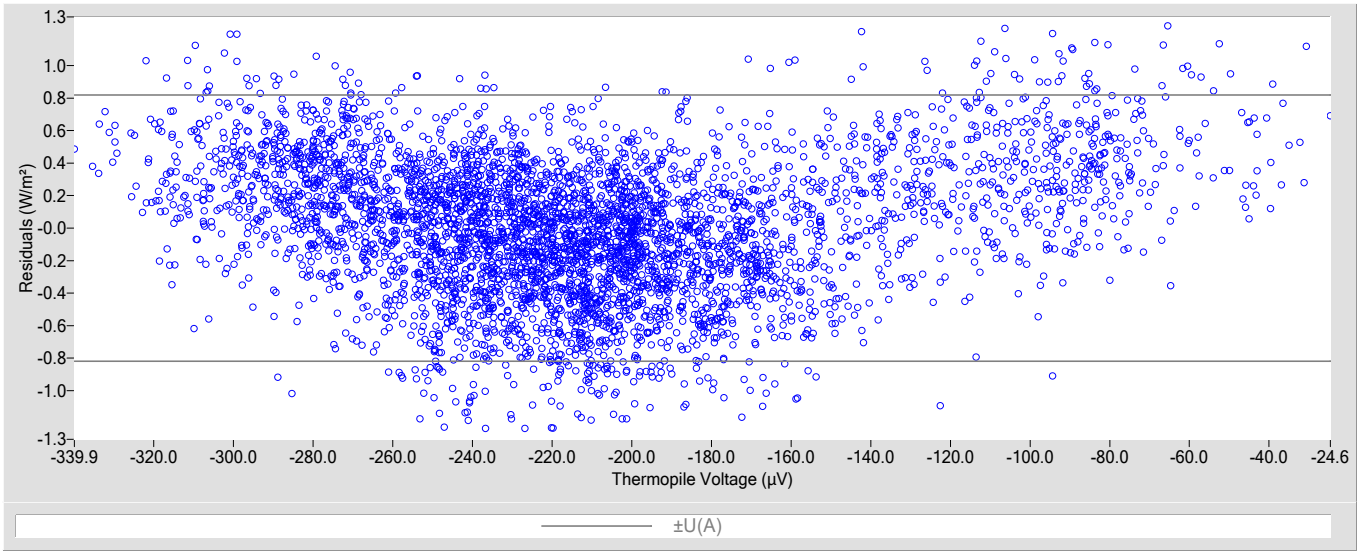


Table 1. Calibration Coefficients

K1	0.25021
K2	0.9971
K3	-3.50
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.7

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

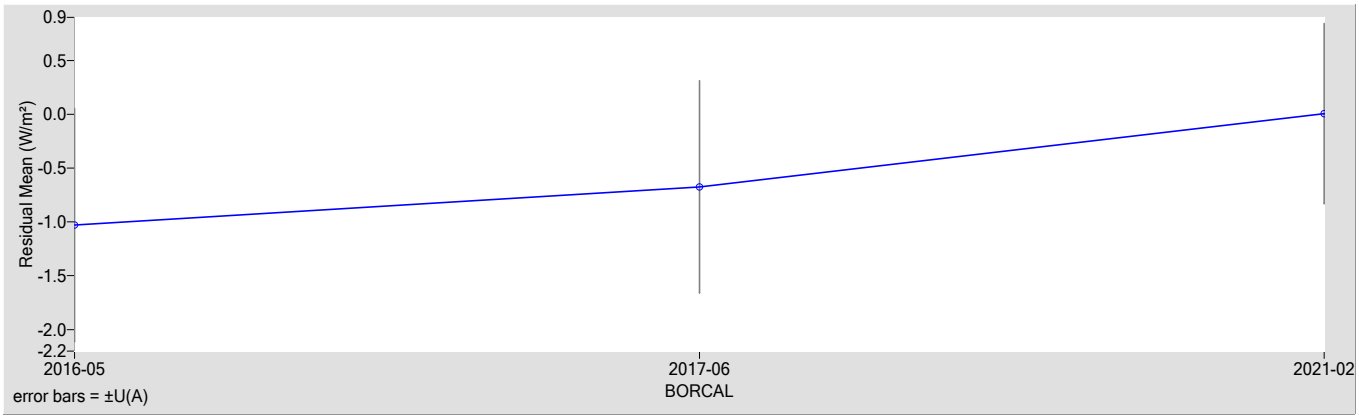


Figure 3. History of instrument (K1 Coefficient)

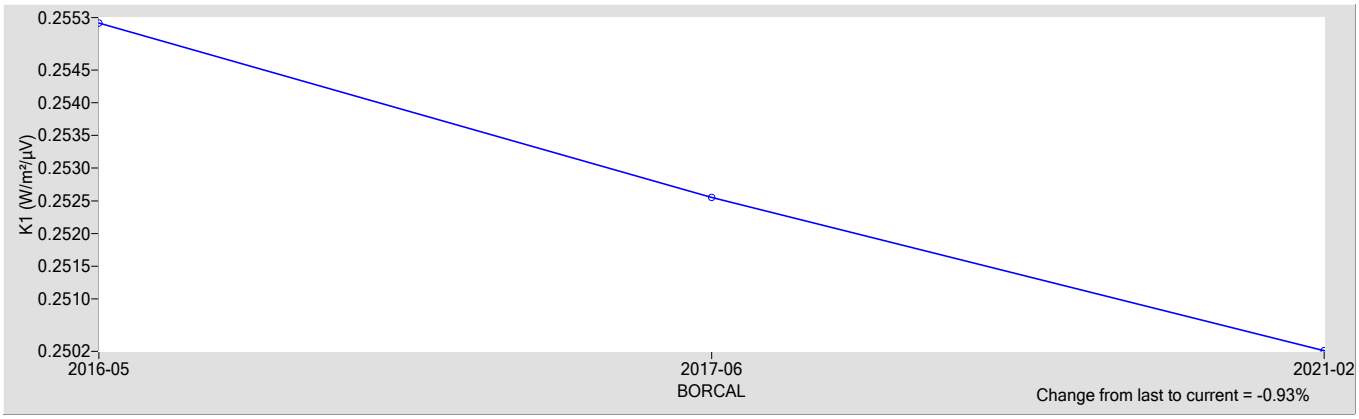


Figure 4. History of instrument (K2 Coefficient)

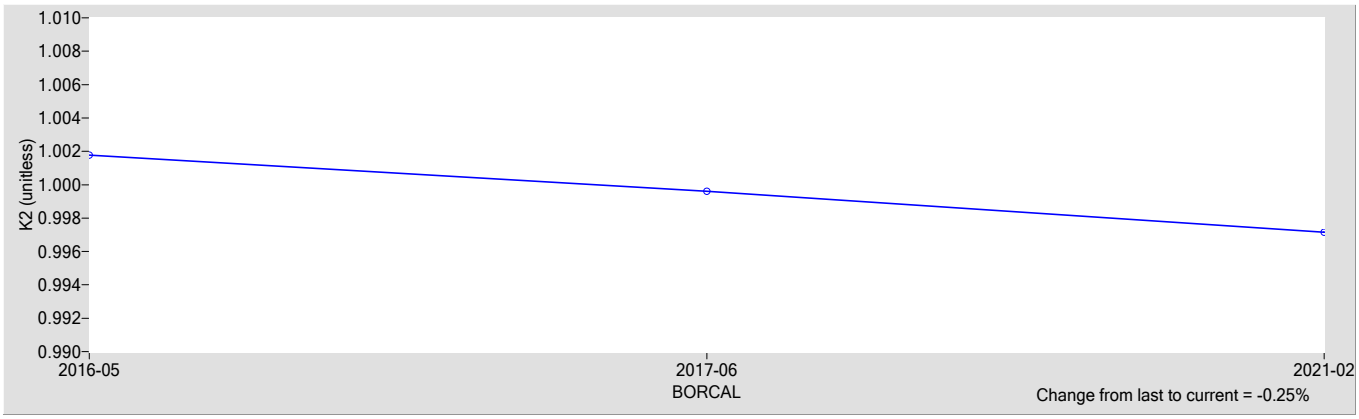
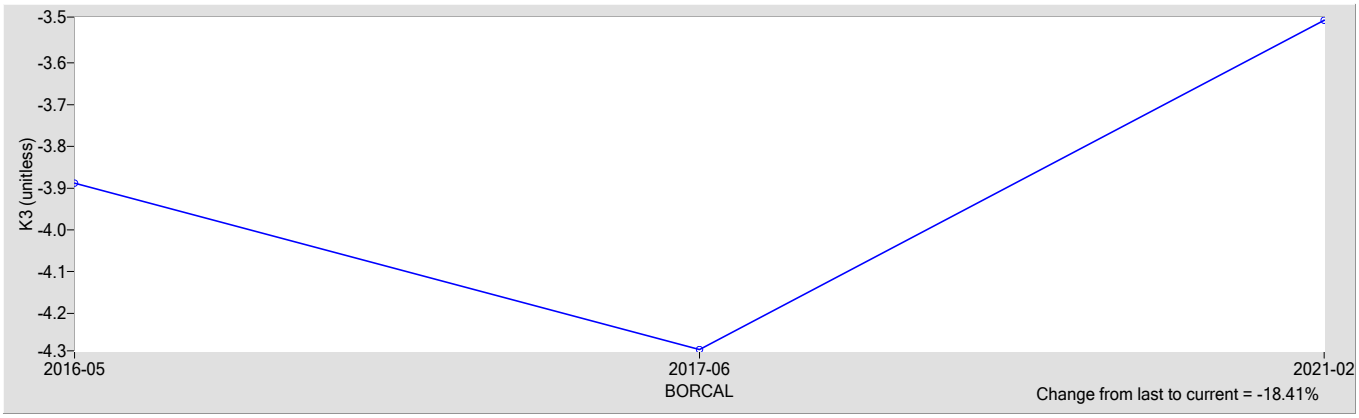


Figure 5. History of instrument (K3 Coefficient)



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:**	33058F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

33058F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

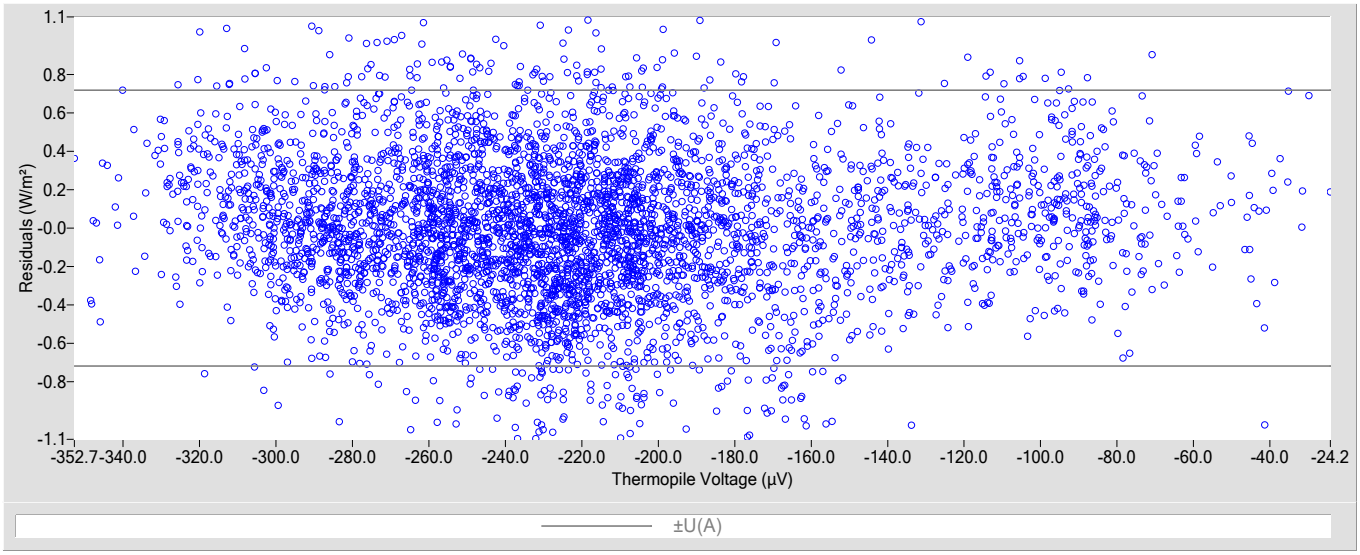


Table 1. Calibration Coefficients

K1	0.23867
K2	0.9966
K3	-3.03
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.37
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.6

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

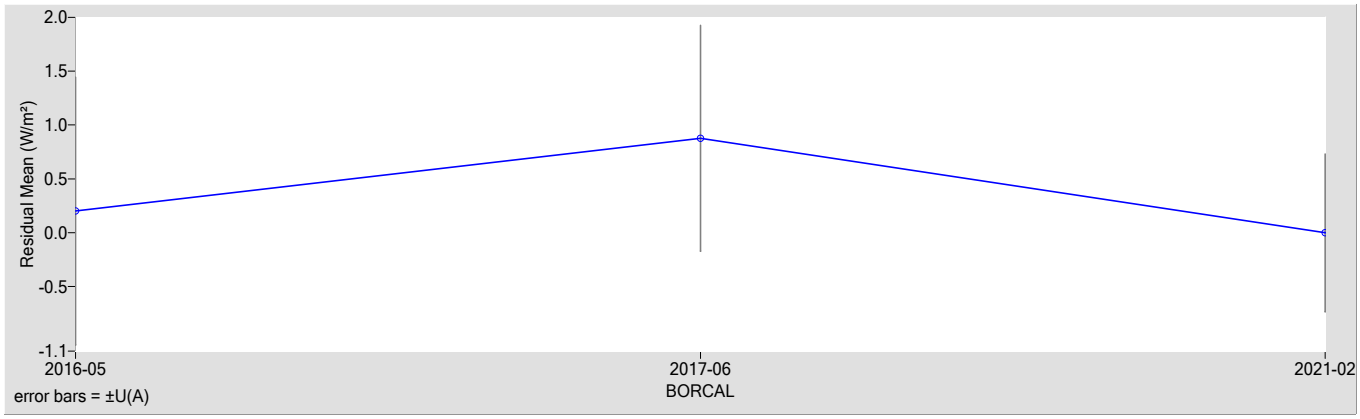


Figure 3. History of instrument (K1 Coefficient)

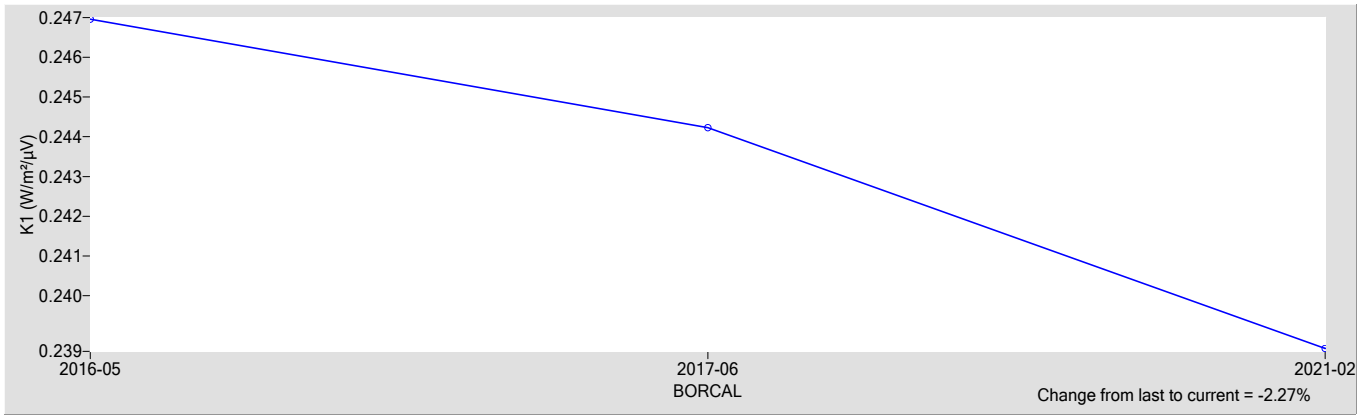


Figure 4. History of instrument (K2 Coefficient)

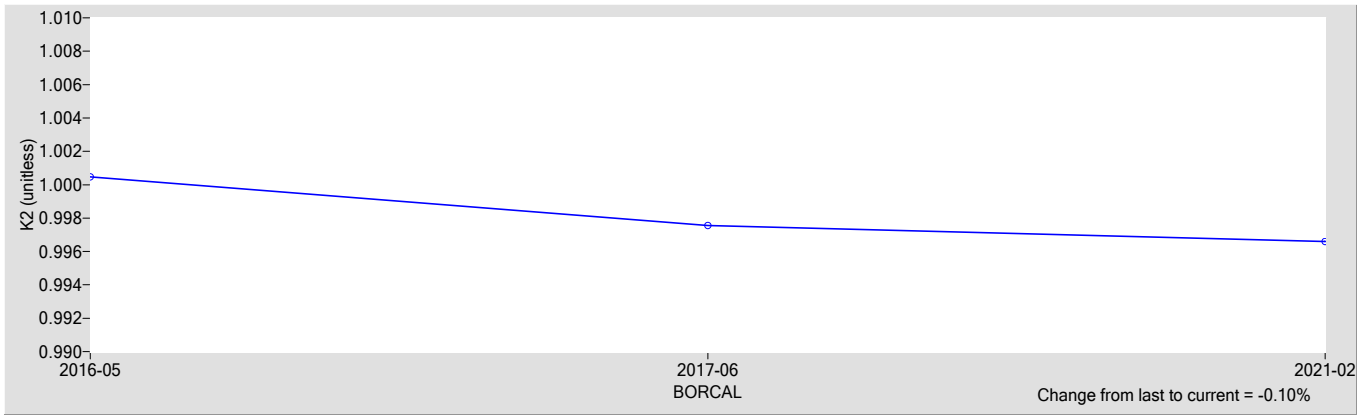
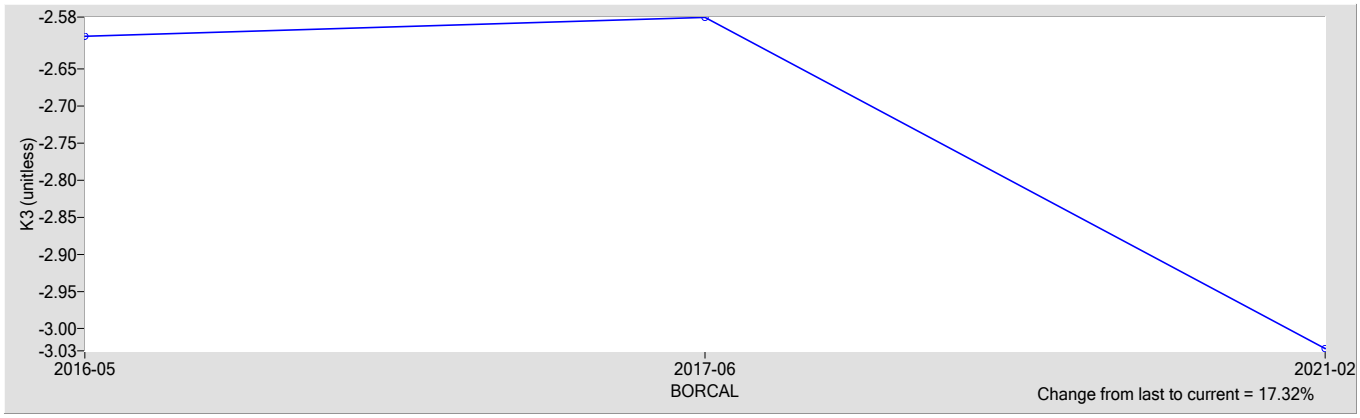


Figure 5. History of instrument (K3 Coefficient)



References:

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Downwelling Pyrgeometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PIR	**Serial Number:**	36368F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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 = K1*V + K2*Wr + K3*(Wd - Wr)* [1]

where,

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 calculated using coefficients vs reference irradiance

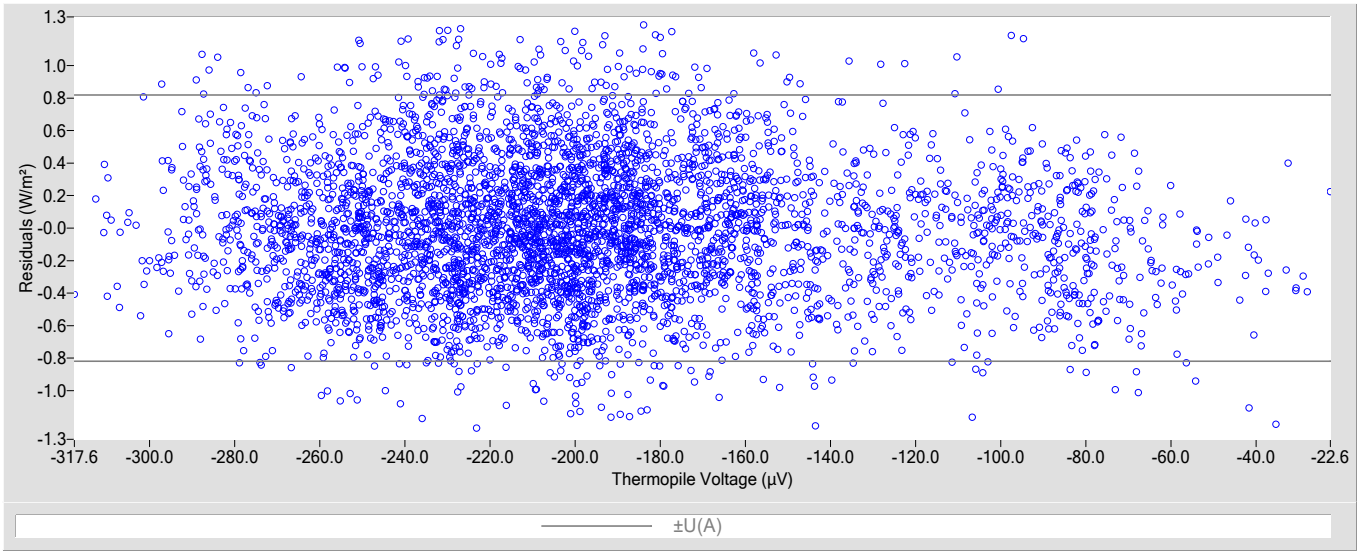


Table 1. Calibration Coefficients

K1	0.27329
K2	1.0087
K3	-3.97
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.42
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.7

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

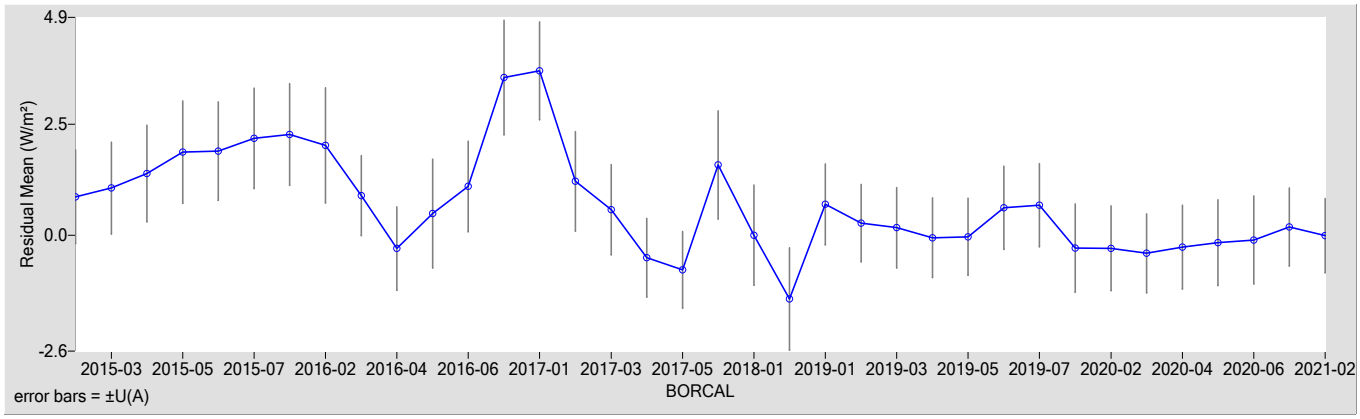


Figure 3. History of instrument (K1 Coefficient)

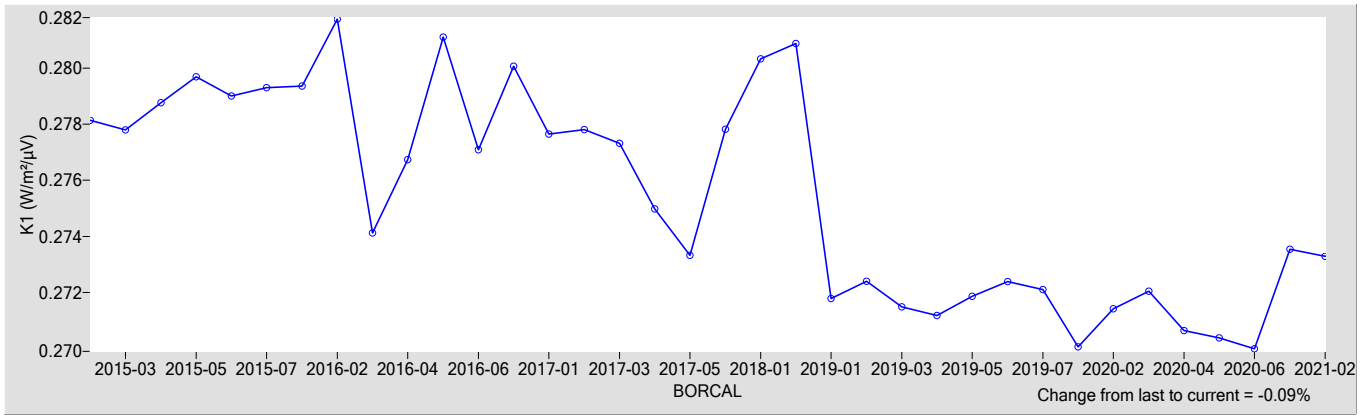


Figure 4. History of instrument (K2 Coefficient)

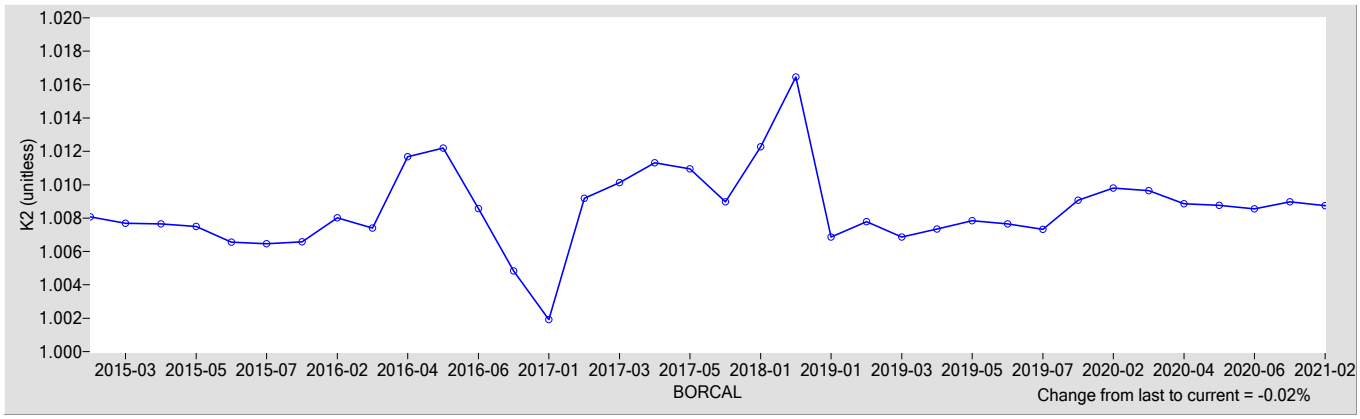
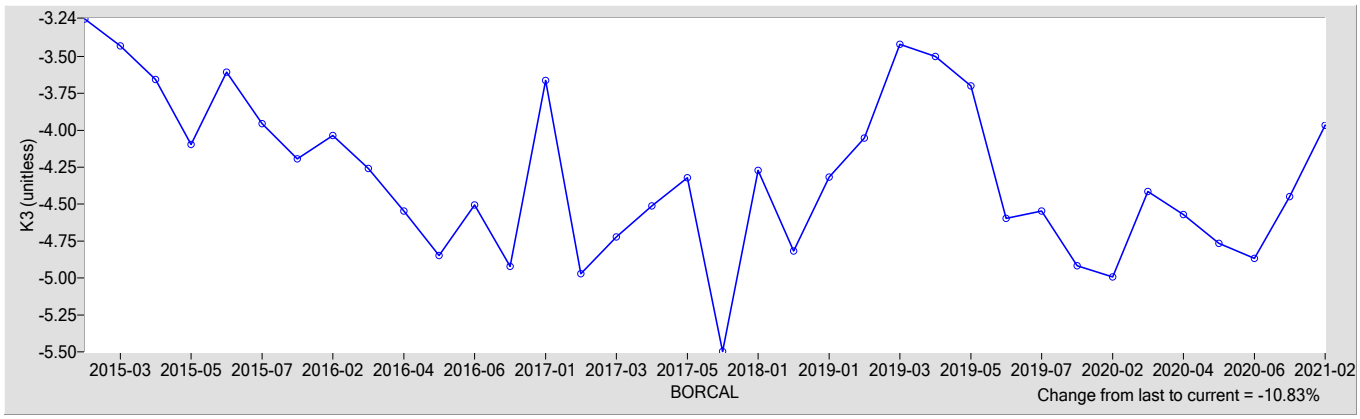


Figure 5. History of instrument (K3 Coefficient)



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:**	37336F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

37336F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

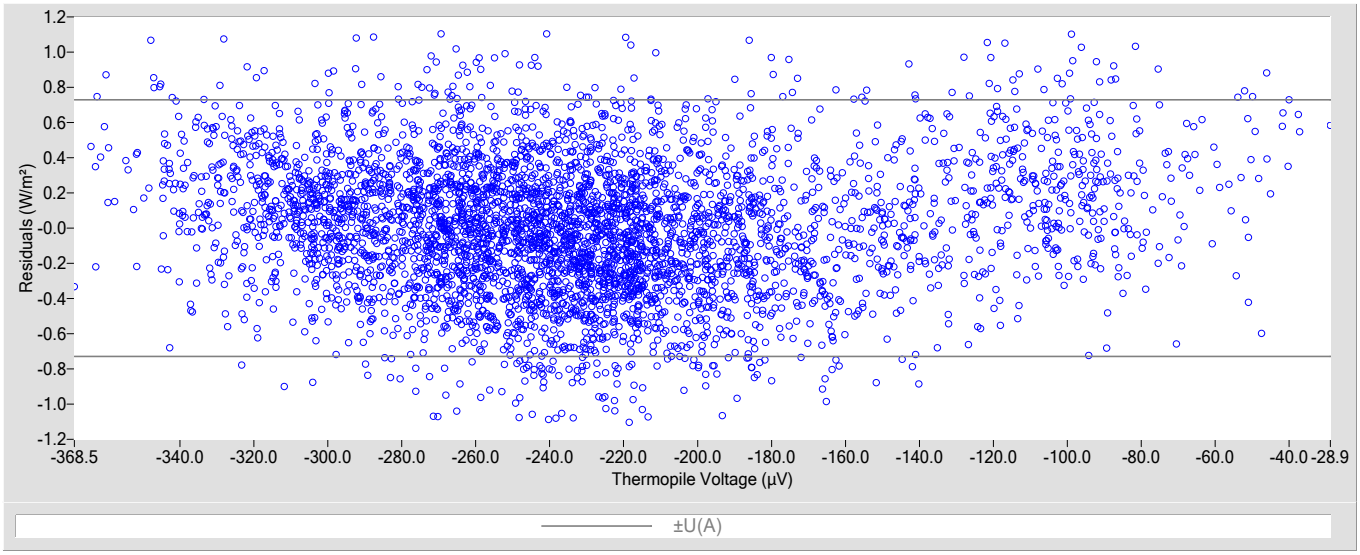


Table 1. Calibration Coefficients

K1	0.23325
K2	0.9986
K3	-3.83
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.37
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.6

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

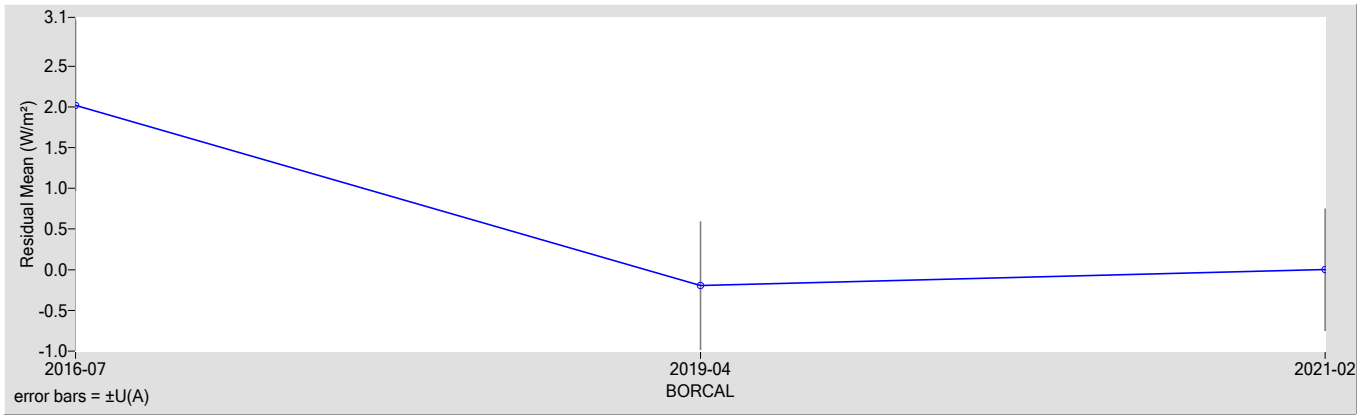


Figure 3. History of instrument (K1 Coefficient)

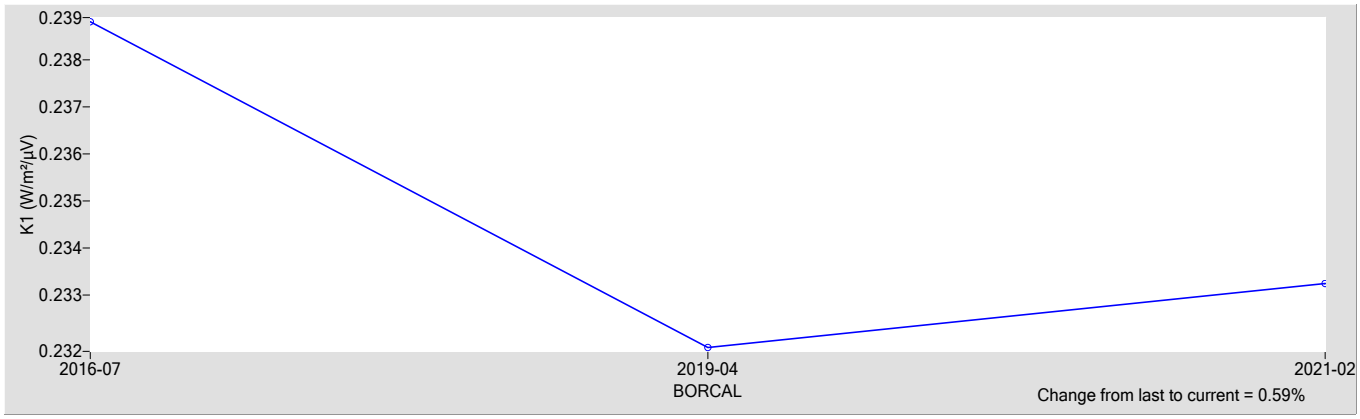


Figure 4. History of instrument (K2 Coefficient)

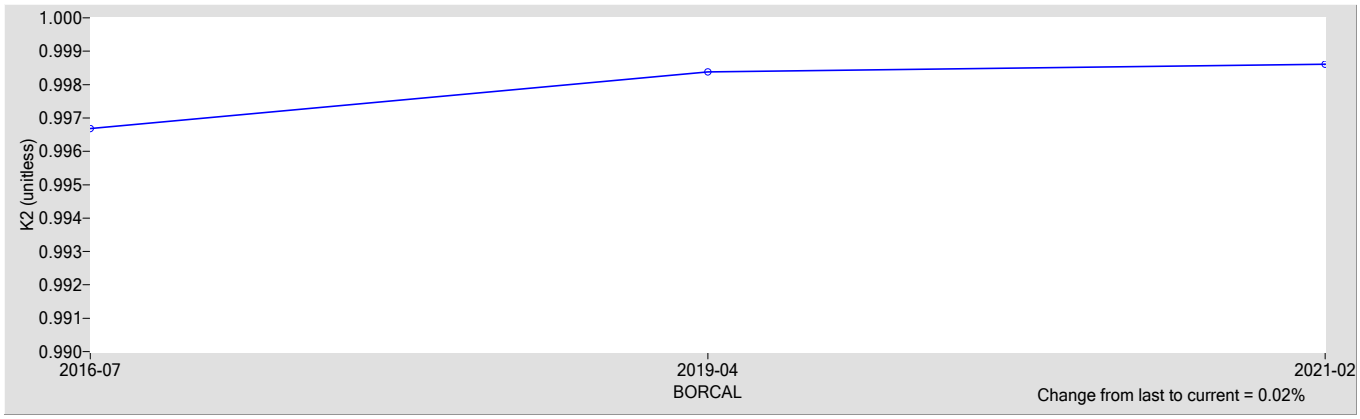
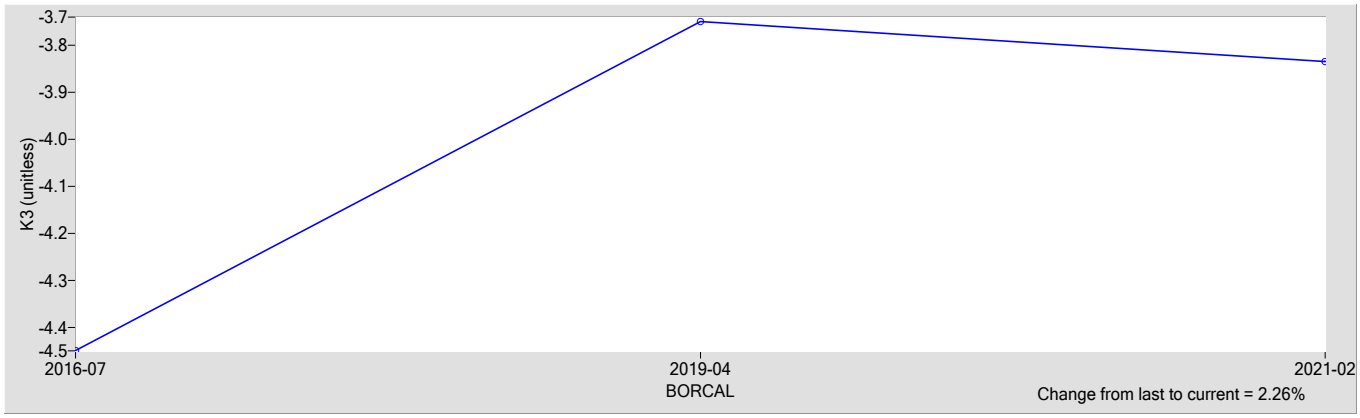


Figure 5. History of instrument (K3 Coefficient)



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:**	37339F3
Calibration Date:	8/11/2021	**Due Date:**	8/11/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	6/23-25, 6/27-28, 6/30, 7/1-31, 8/1-11		

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	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/27/2021	04/27/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/27/2021	04/27/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31206F3	02/19/2020	02/19/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31237F3	02/19/2020	02/19/2022

‡ 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

37339F3 Eppley PIR

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

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

where,

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 calculated using coefficients vs reference irradiance

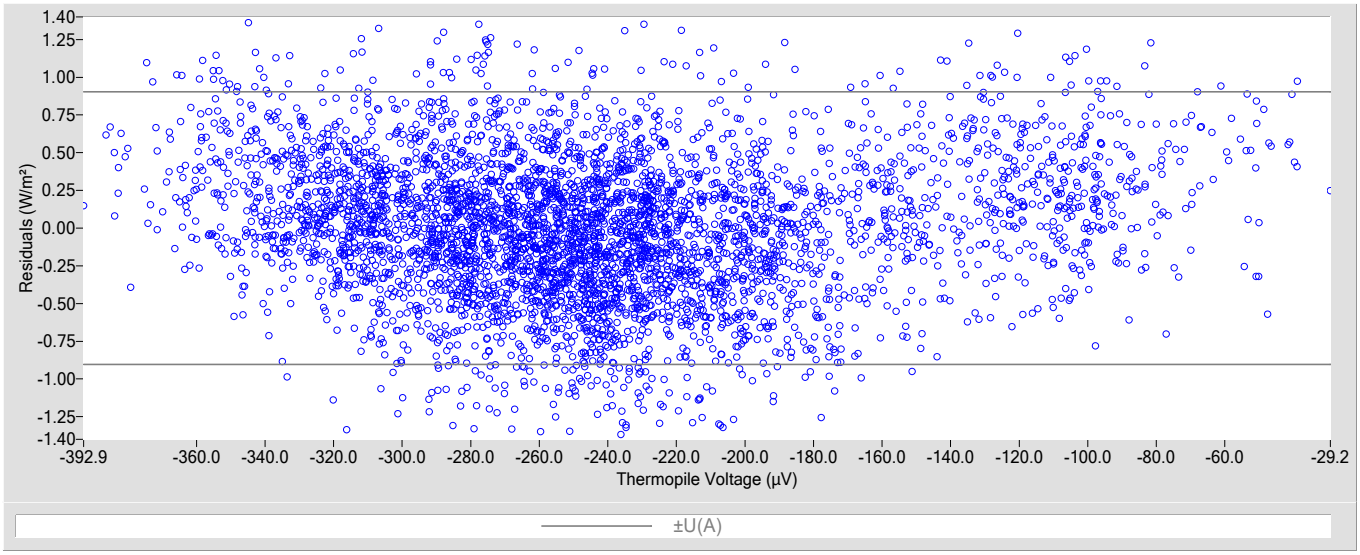


Table 1. Calibration Coefficients

K1	0.21796
K2	0.9941
K3	-4.83
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, u(B) (W/m²)	±1.3
Type-A Standard Uncertainty, u(A) (W/m²)	±0.46
Combined Standard Uncertainty, u(c) (W/m²)	±1.4
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (W/m²)	±2.7

Figure 2. History of instrument (Residual means of current data using historical BORCAL coefficients)

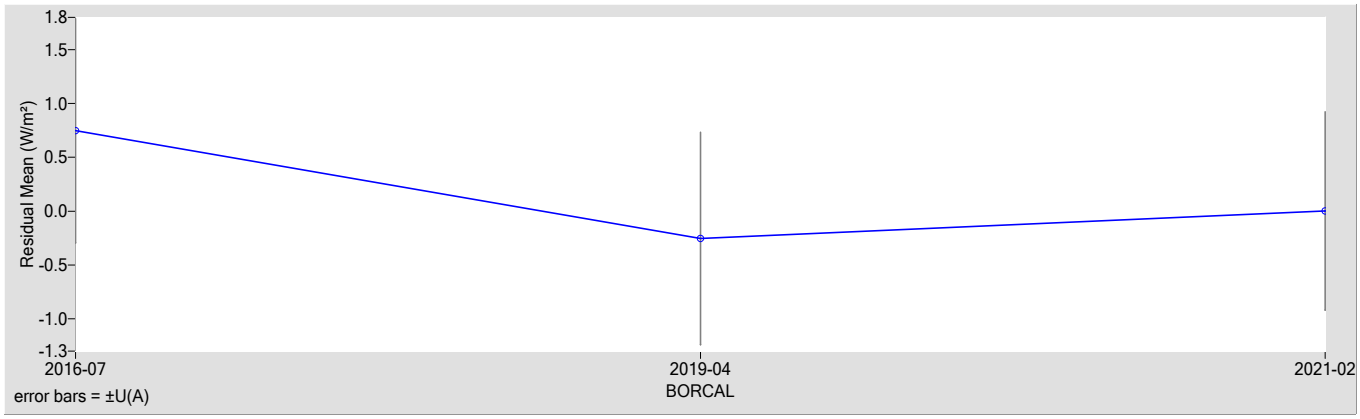


Figure 3. History of instrument (K1 Coefficient)

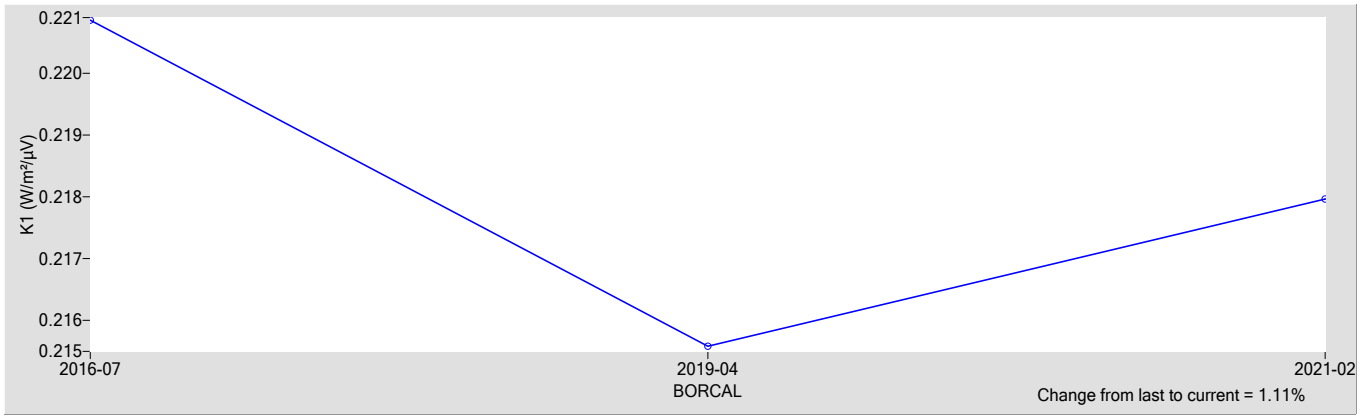


Figure 4. History of instrument (K2 Coefficient)

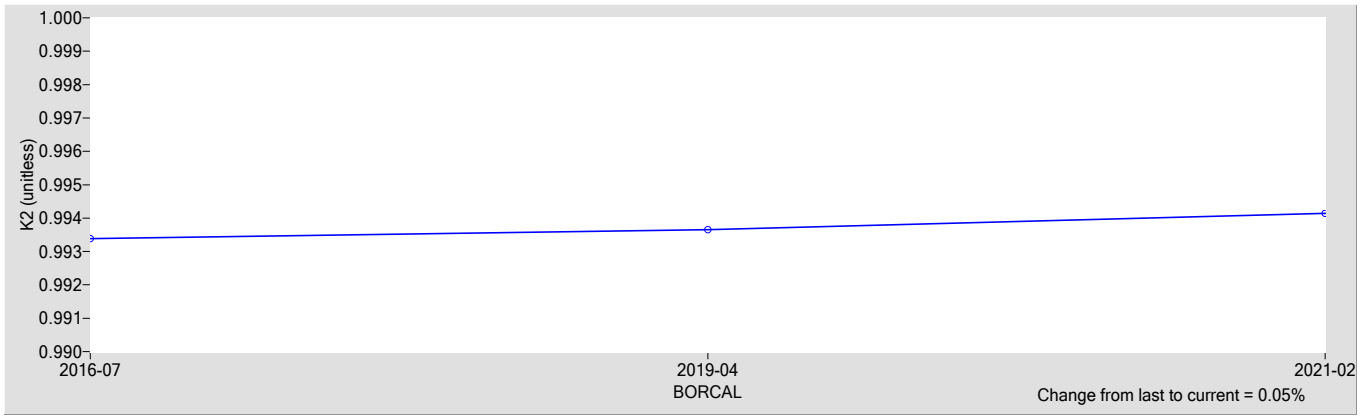
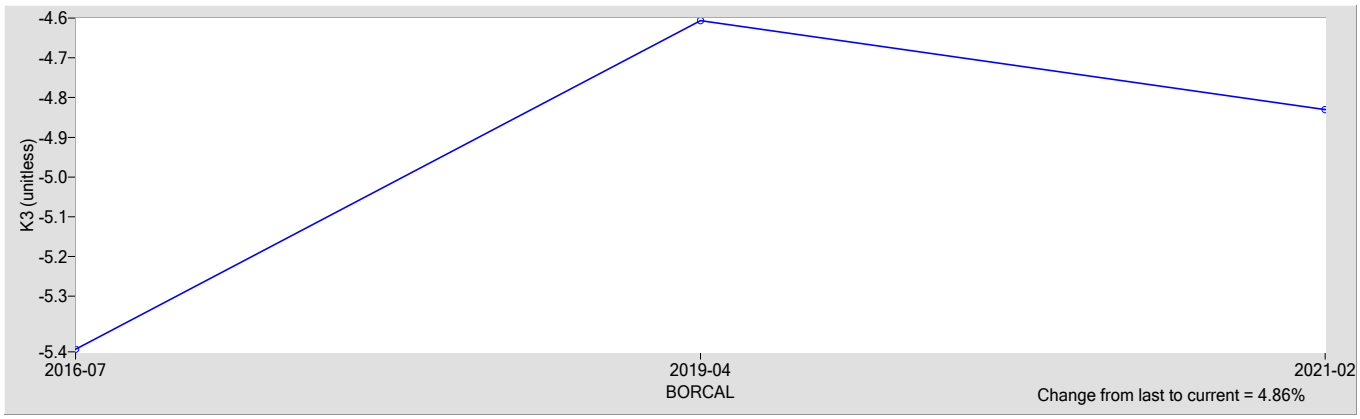


Figure 5. History of instrument (K3 Coefficient)



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.

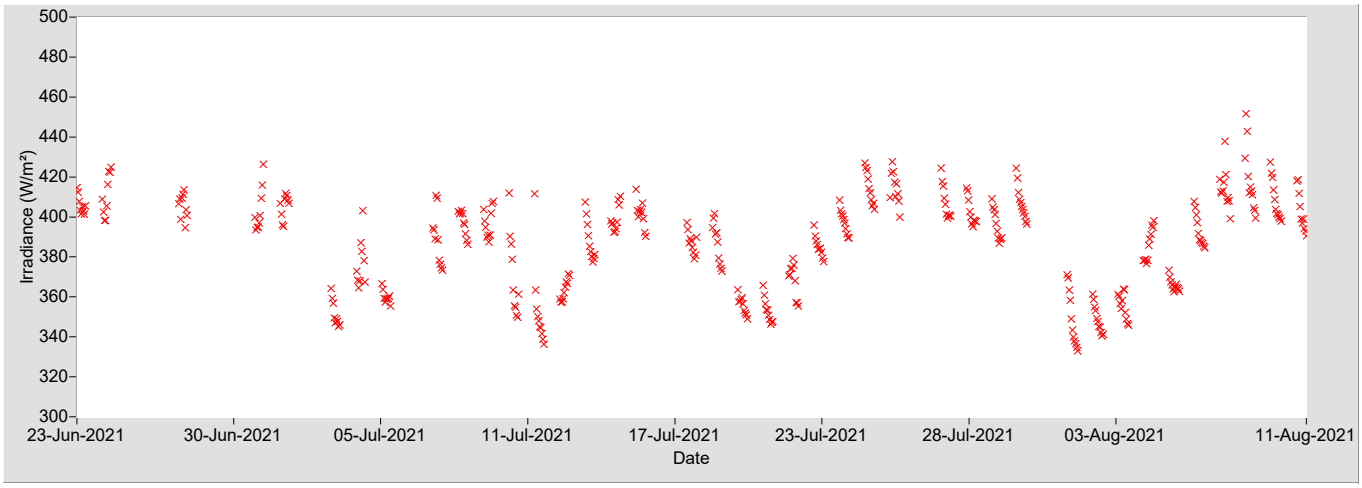
Environmental and Sky Conditions for BORCAL-LW 2021-02

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

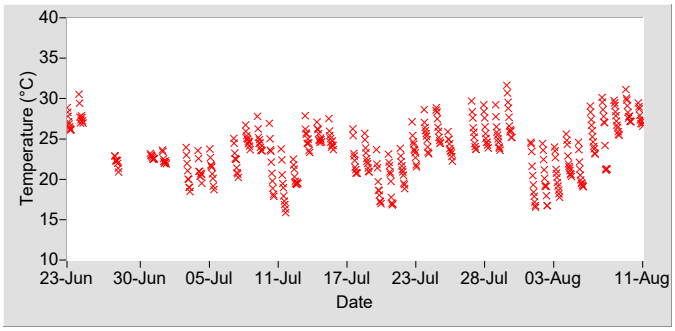


Figure 8. Humidity

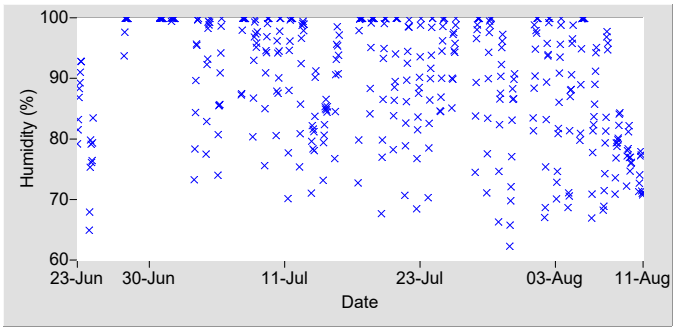


Figure 9. Pressure

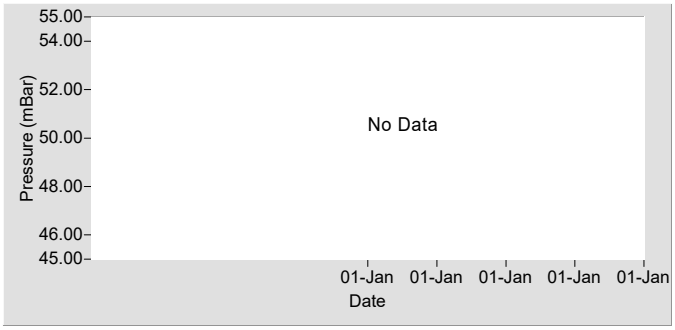


Figure 10. Estimated Precipitable Water Vapor (PWV)

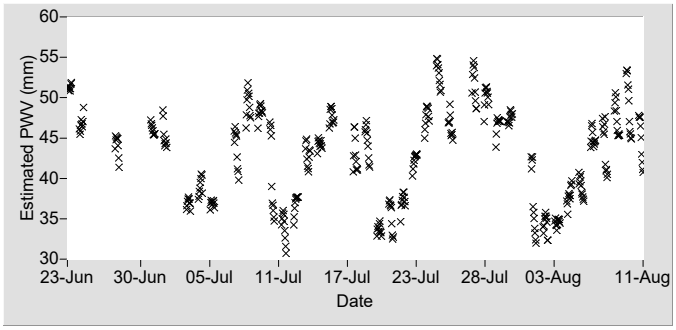


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	23.58	15.88	31.65
Humidity (%)	89.33	62.25	100.04
Pressure (mBar)	N/A	N/A	N/A
Est. Precipitable Water Vapor (mm)	43.2	30.7	55.3

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 2021-02 Session Configuration Audit Report

LOCATION

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

SYSTEM

% Error Thresholds

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

Delta Thresholds

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

Analysis Rejection

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

Clock

Reset Interval (m)	30
Warning Threshold (s)	0
Delta UT1	-0.200

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)	69.384
Atmos. Refraction (deg)	0.5667

METEOROLOGICAL INSTRUMENTS

Channel	Junction Box	Cable	Location
Temperature: E0710026T Vaisala HMP155 T			
239			Temp
		Scale 100	Offset -40
Humidity: E0710026H Vaisala HMP155 H			
255			Hum
		Scale 100	Offset 0
Pressure: None			
		Scale 0	Offset 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 0	2009-1206 NREL RAP-DAQ	MY42002863 Agilent 34420A
Unit 1	2009-1207 NREL RAP-DAQ	MY42002864 Agilent 34420A
Unit 2	2009-1208 NREL RAP-DAQ	MY42002866 Agilent 34420A
Unit 3	2014-1302 NREL RAP-DAQ	SG42000596 Agilent 34420A

		Unit 0	Unit 1	Unit 2	Unit 3
	Cal Date	04/27/2021	04/27/2021	04/27/2021	04/27/2021
	Cal Due Date	04/27/2022	04/27/2022	04/27/2022	04/27/2022
System Offsets:	Volts DC (µV)	0.93	0.93	0.93	0.93
	2-Wire Res. (mOhms)	2680.00	2680.00	2680.00	2680.00
	4-Wire Res. (mOhms)	0.00	0.00	0.00	0.00

Communications

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

BORCAL/LW 2021-02 Session Configuration Audit Report

PYRGEOMETER REFERENCE INSTRUMENTS

		Calibration Coefficients					Uncert.	Max Out					
Cal Date	Cal Due Date	K0	K1	K2	K3	Kr	(W/m^2)	(mV)	Channel	Junction Box	Cable	Location	Active
Pyrgeometer 1: 31206F3 Eppley PIR (Ventilated)													
02/19/2020	02/19/2022	0.00000	0.26576	0.99910	-3.67000	7.04400E-4	2.20	9	23		2	T5-2	☑
Pyrgeometer 1: Case 10K Temperature									19		2		
Pyrgeometer 1: Dome 10K Temperature									27		2		
Pyrgeometer 2: 31237F3 Eppley PIR (Ventilated)													
02/19/2020	02/19/2022	3.80000	0.22978	0.99080	-4.34000	7.04400E-4	2.30	9	71		2	T6-2	☑
Pyrgeometer 2: Case 10K Temperature									67		2		
Pyrgeometer 2: Dome 10K Temperature									75		2		

BORCAL/LW 2021-02 Session Configuration Audit Report

INSTRUMENTS

Serial Number / Model	Customer	Mfg RS	Ch	Box	Cable	Act	ISO	AIM	Stickr	Vent	Use	Kr	Location	Due
29148F3	SGP	3.6000	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									
29593F3	SGP	4.1600	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									
29595F3	SGP	4.4300	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									
30133F3 ‡	SGP	3.9000	215		2	Yes	No	Yes	K0=0	Yes	PYG	7.044e-4	T9-2	24
PIR	(Case 10K Temperature)		211		2									
	(Dome 10K Temperature)		219		2									
30682F3	SGP	3.9300	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									
30835F3	SGP	4.0700	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									
31391F3	TWP	3.7800	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									
32049F3	SGP	3.8400	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									
33057F3	TWP	3.8400	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									
33058F3	TWP	3.8300	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									
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									
37336F3	NSA	3.9600	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									
37339F3	NSA	4.4500	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									

‡ Control Instrument