Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2021-03

Generated by

RCC

Radiometer Calibration and Characterization

<u>Customer</u>

NREL-SRRL-BMS

Organization: NREL
Address: BMS, SRRL, Golden, CO 80401 USA
Phone: 303-384-6326

<u>Calibration Facility</u>

Solar Radiation Research Laboratory

Latitude: 39.742°N
Longitude: 105.180°W
Elevation: 1828.8 meters AMSL
Time Zone: -7.0

Calibration date
05/24/2021 to 05/25/2021

Report Date
December 9, 2021

NREL

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 International System (SI) Units of Measurement.

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

This report has been revised to accommodate updated responsivities given by the calibration provider of the BORCAL reference irradiance instruments. This report replaces the report with an issue date of June 3, 2021. This update affects all responsivities for the devices under test issued in this report by approximately -0.675%. There will also be a very slightly change in reported uncertainties due the reference irradiance instruments' uncertainties changing as well.

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

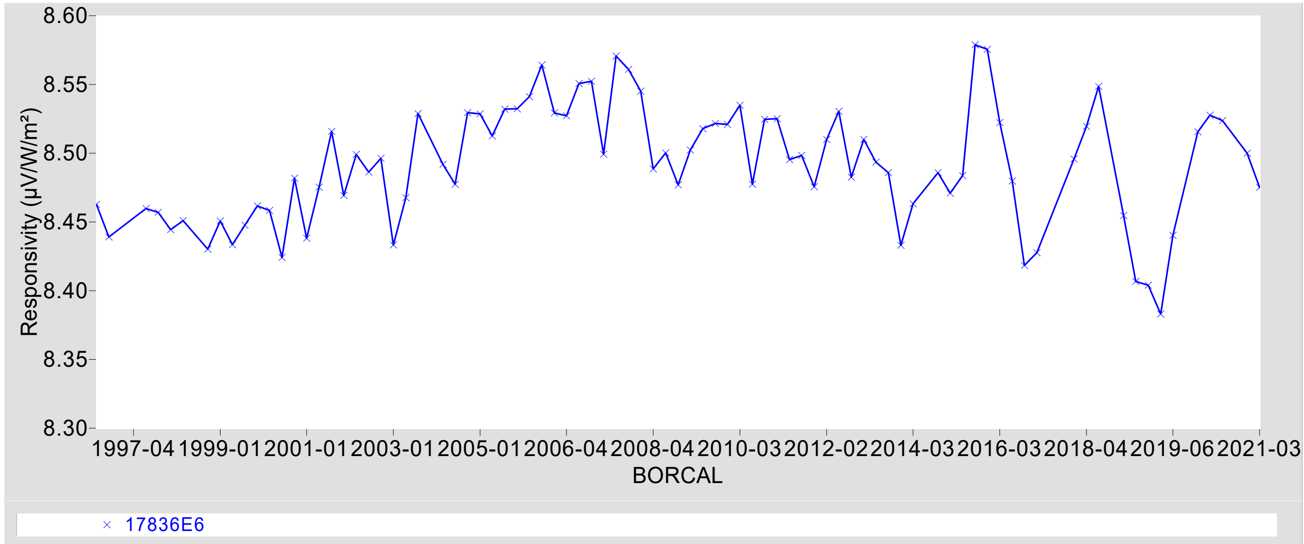


Figure 2. Eppley PSP Control Instrument History

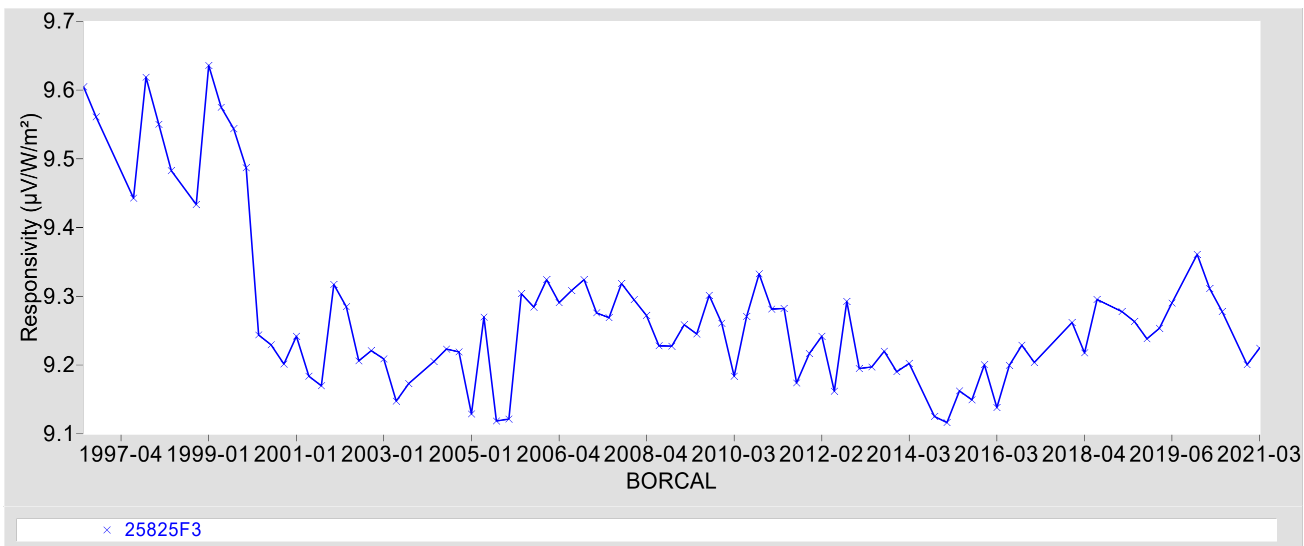
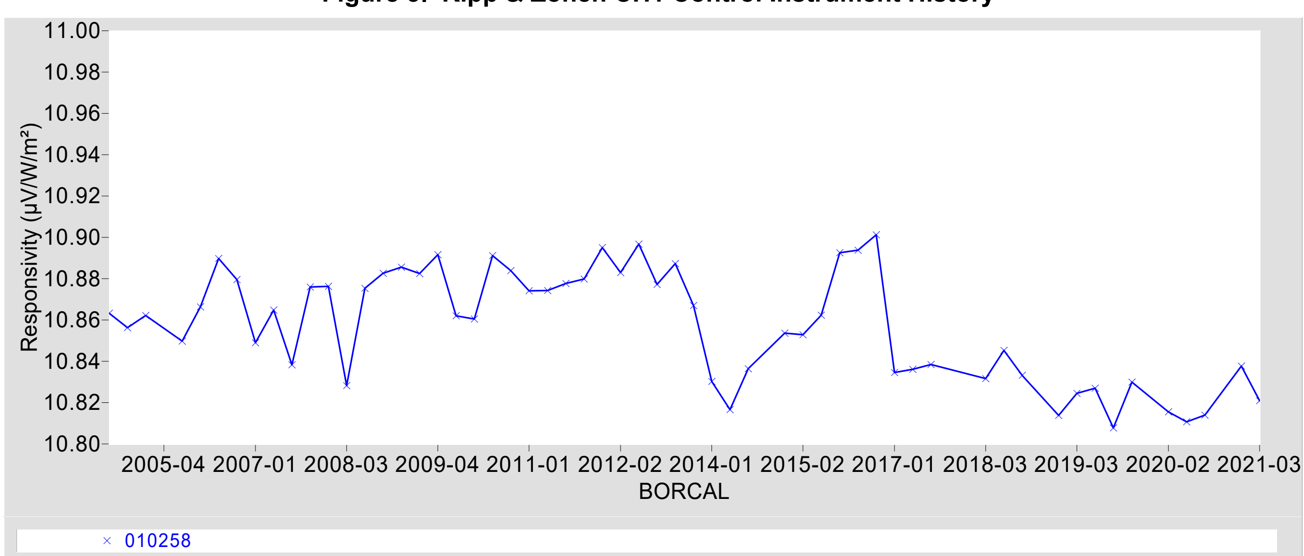


Figure 3. Kipp & Zonen CH1 Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	R@45 ¹ (µV/W/m²)	CF@45 ¹ (W/m²/mV)	U ² (%)	Rnet ³ (µV/W/m²)	Page
010034 Kipp & Zonen CM22	10.910	91.657	+2.1 / -1.5	0.087000	A1-2
010284-UW-CM3 Kipp & Zonen CM3	18.170	55.036	+2.1 / -3.0	0.40000	A1-5
140910 Kipp & Zonen CMP11	9.2241	108.41	+1.4 / -1.9	0.20500	A1-8
160430 Kipp & Zonen CMP22	9.7438	102.63	+1.2 / -1.1	0.087000	A1-11
194362 Kipp & Zonen SP-LITE2	72.408	13.811	+2.7 / -2.1	0	A1-14
19621F3 Eppley PSP	7.6001	131.58	+2.4 / -2.2	0.60000	A1-17
25782F3 Eppley PSP	8.7083	114.83	+3.5 / -5.4	0.76000	A1-20
28400F3 Eppley PSP	7.3515	136.03	+2.8 / -3.4	0.60000	A1-23
31394F3 Eppley PSP	7.9993	125.01	+3.0 / -5.2	0.60000	A1-26
PY108623 Licor LI200R	10.001	99.994	+2.1 / -1.7	0	A1-29
PY1711 Licor LI200	12.241	81.692	+1.6 / -1.3	0	A1-32
PY1744 Licor LI200	14.525	68.848	+1.7 / -1.3	0	A1-35
PY25070 Licor LI200	14.372	69.581	+3.2 / -1.8	0	A1-38
PY28246 Licor LI200	12.214	81.874	+1.4 / -1.5	0	A1-41
PY28262 Licor LI200	11.451	87.329	+1.3 / -1.9	0	A1-44

¹ CF = 1000 / R ² See certificate for valid zenith angle range ³ Instrument's Effective Net IR Response

Note: Environmental Conditions for BORCAL starts on page A1-47.

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.

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CM22	**Serial Number:**	010034
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CGR4, S/N 140021	04/02/2019	04/02/2023

† Through the World Radiometric Reference (WRR)　　‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

________________________________ ______________

Afshín M. Andreas, Deputy Technical Manager　　Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

010034 Kipp & Zonen CM22

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \quad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

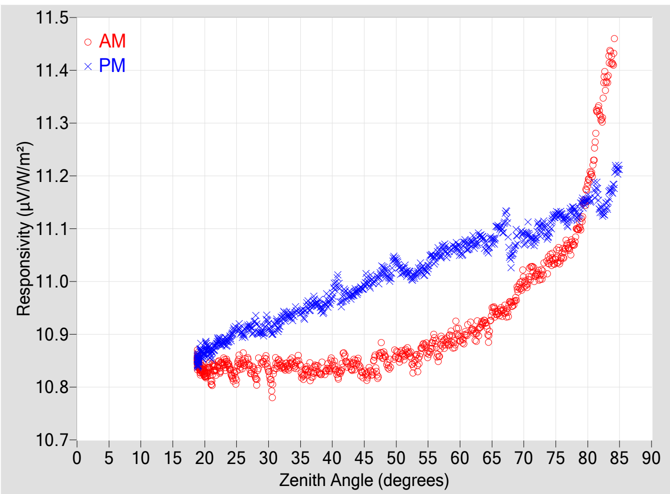


Figure 2. Responsivity vs Local Standard Time

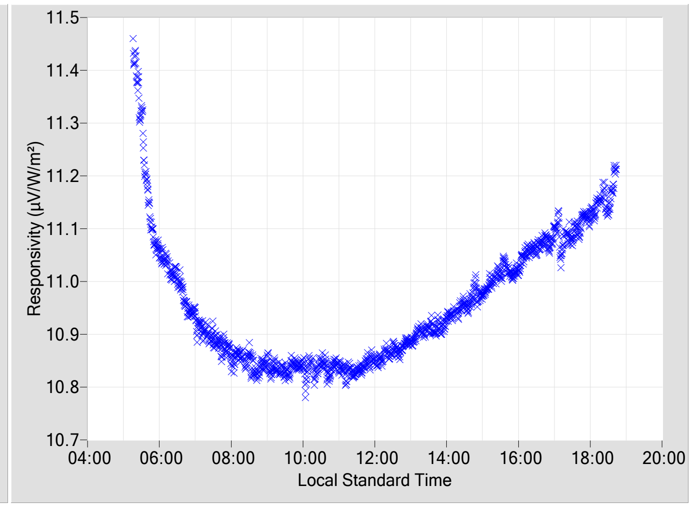


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.829	0.33	98.77	10.999	0.34	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.860	0.36	96.86	11.022	0.32	262.94
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.864	0.35	95.03	11.039	0.33	264.81
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.866	0.37	93.21	11.016	0.36	266.57
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.875	0.36	91.47	11.026	0.33	268.32
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.887	0.33	89.82	11.043	0.34	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.884	0.34	88.20	11.054	0.35	271.68
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.896	0.37	86.62	11.059	0.35	273.27
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.907	0.35	84.98	11.074	0.37	274.87
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.920	0.36	83.40	11.067	0.38	276.45
20	10.825	0.31	158.08	10.870	0.33	201.90	66	10.940	0.38	81.85	11.103	0.40	278.01
22	10.838	0.33	143.69	10.887	0.31	215.10	68	10.958	0.40	80.30	11.045	0.42	279.56
24	10.832	0.31	135.83	10.894	0.31	223.55	70	11.003	0.42	78.77	11.083	0.45	281.11
26	10.846	0.33	129.50	10.902	0.32	229.75	72	11.014	0.48	77.20	11.094	0.48	282.68
28	10.820	0.33	124.54	10.921	0.32	234.93	74	11.041	0.50	75.63	11.095	N/A	284.25
30	10.830	0.33	120.30	10.918	0.30	239.29	76	11.048	0.55	74.06	11.124	N/A	285.83
32	10.840	0.35	116.54	10.928	0.32	243.06	78	11.081	0.63	72.44	11.130	N/A	287.45
34	10.841	0.30	113.25	10.940	0.32	246.41	80	11.185	N/A	70.81	11.157	N/A	289.08
36	10.832	0.32	110.41	10.954	0.31	249.24	82	11.314	N/A	69.17	11.134	N/A	290.77
38	10.828	0.33	107.70	10.955	0.30	251.95	84	11.426	N/A	67.47	11.181	N/A	292.43
40	10.846	0.34	105.33	10.977	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.856	0.33	102.99	10.976	0.32	256.78	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.845	0.34	100.82	10.982	0.31	258.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

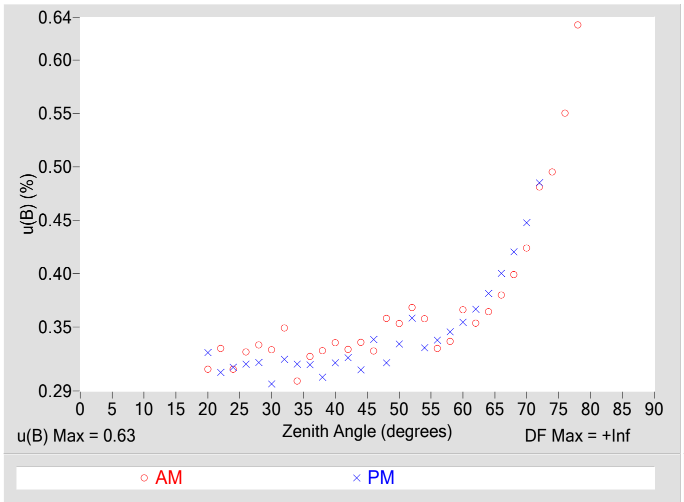


Figure 4. Residuals from Spline Interpolation

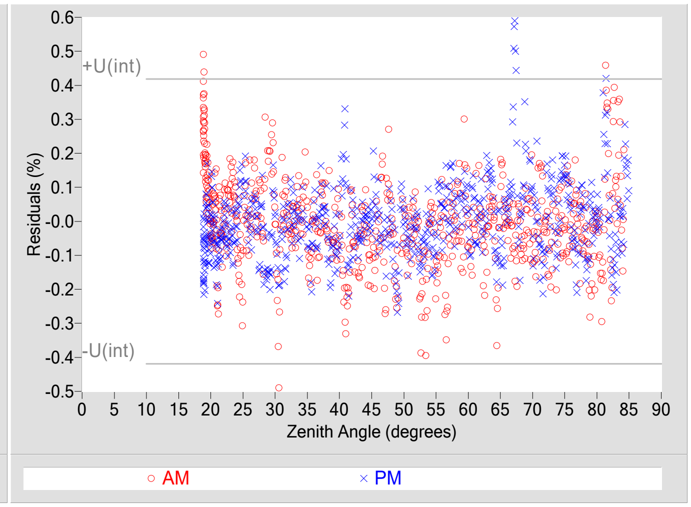


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	132757
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

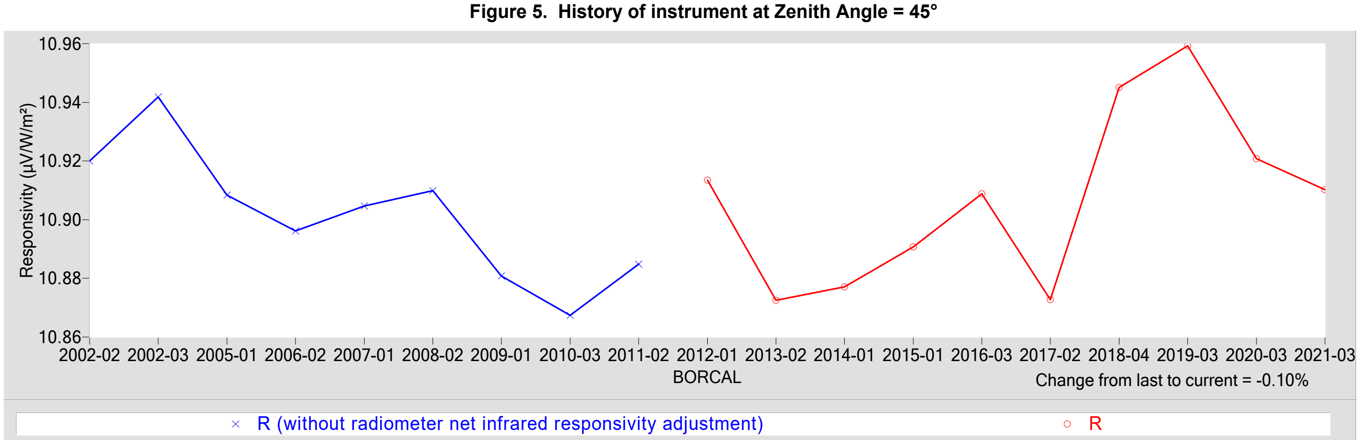
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.910	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+1.4 / -0.76
Expanded Uncertainty, U (%)	+2.1 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM3	**Serial Number:**	010284-UW-CM3
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† Through the World Radiometric Reference (WRR)   ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

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Afshín M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

010284-UW-CM3 Kipp & Zonen CM3

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

*R = (V - Rnet * Wnet) / I* [1]

where,

- *V* = radiometer output voltage (microvolts),
- *Rnet* = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- *Wnet* = effective net infrared measured by pyrgeometer (W/m²),
  = *Win - Wout* = *Win - σ * Tc^4*
  where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- *I* = reference irradiance (W/m²), beam (B) or global (G)
  where, *G = B * COS(Z) + D,*
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

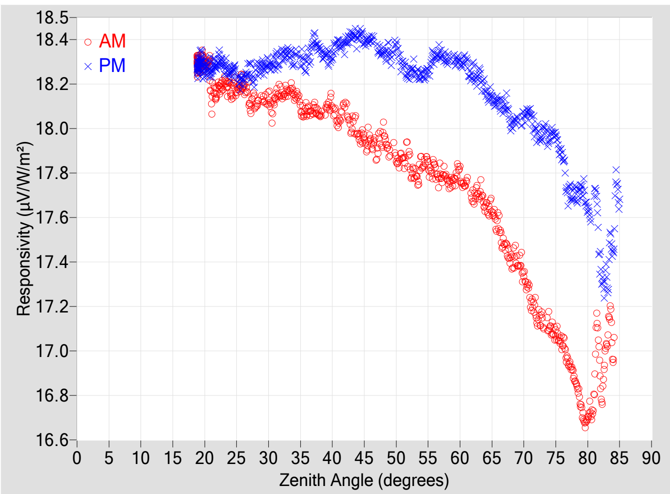


Figure 2. Responsivity vs Local Standard Time

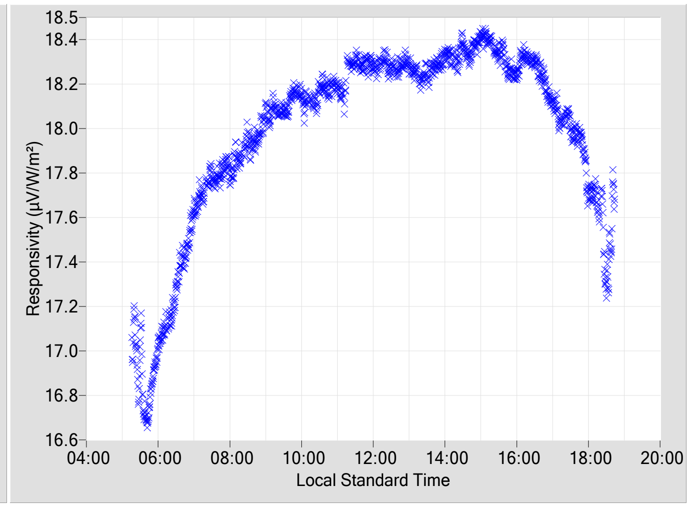


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	17.939	0.33	98.79	18.402	0.33	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	17.962	0.34	96.86	18.347	0.33	262.94
4	N/A	N/A	N/A	N/A	N/A	N/A	50	17.863	0.34	94.96	18.376	0.34	264.81
6	N/A	N/A	N/A	N/A	N/A	N/A	52	17.860	0.38	93.21	18.246	0.35	266.61
8	N/A	N/A	N/A	N/A	N/A	N/A	54	17.841	0.36	91.51	18.239	0.35	268.32
10	N/A	N/A	N/A	N/A	N/A	N/A	56	17.831	0.33	89.81	18.321	0.34	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	17.764	0.38	88.16	18.309	0.35	271.64
14	N/A	N/A	N/A	N/A	N/A	N/A	60	17.795	0.40	86.57	18.297	0.36	273.27
16	N/A	N/A	N/A	N/A	N/A	N/A	62	17.691	0.36	84.98	18.262	0.37	274.87
18	N/A	N/A	N/A	N/A	N/A	N/A	64	17.652	0.39	83.44	18.172	0.39	276.45
20	18.292	0.31	158.31	18.272	0.31	201.86	66	17.569	0.39	81.84	18.121	0.41	278.01
22	18.169	0.32	144.09	18.298	0.30	215.06	68	17.404	0.41	80.30	18.014	0.43	279.56
24	18.177	0.33	135.94	18.250	0.31	223.54	70	17.333	0.43	78.76	18.057	0.46	281.10
26	18.198	0.32	129.67	18.220	0.35	229.75	72	17.155	0.47	77.19	17.989	0.49	282.68
28	18.113	0.31	124.64	18.256	0.35	234.96	74	17.108	0.51	75.63	17.953	N/A	284.25
30	18.132	0.32	120.14	18.291	0.30	239.29	76	17.038	0.56	74.06	17.877	N/A	285.82
32	18.153	0.35	116.72	18.336	0.33	243.13	78	16.866	0.65	72.44	17.711	N/A	287.45
34	18.153	0.33	113.34	18.312	0.30	246.30	80	16.696	N/A	70.85	17.638	N/A	289.08
36	18.083	0.32	110.41	18.304	0.33	249.34	82	16.858	N/A	69.13	17.376	N/A	290.73
38	18.063	0.34	107.73	18.358	0.32	252.01	84	17.017	N/A	67.50	17.500	N/A	292.47
40	18.107	0.35	105.29	18.335	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	18.110	0.31	102.98	18.383	0.31	256.77	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.970	0.35	100.76	18.403	0.31	258.96	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

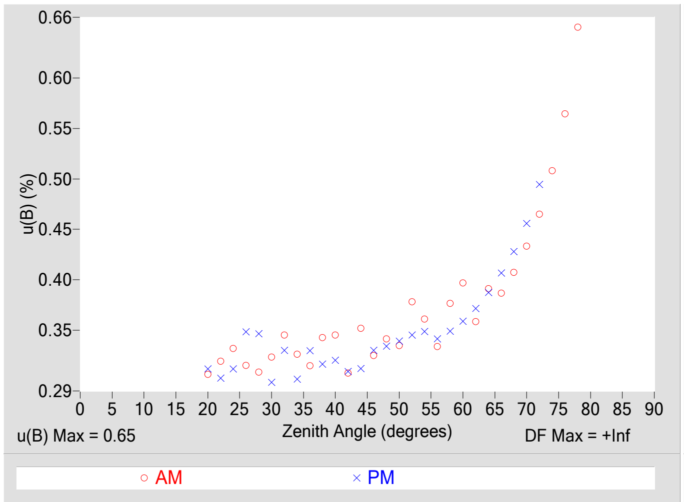


Figure 4. Residuals from Spline Interpolation

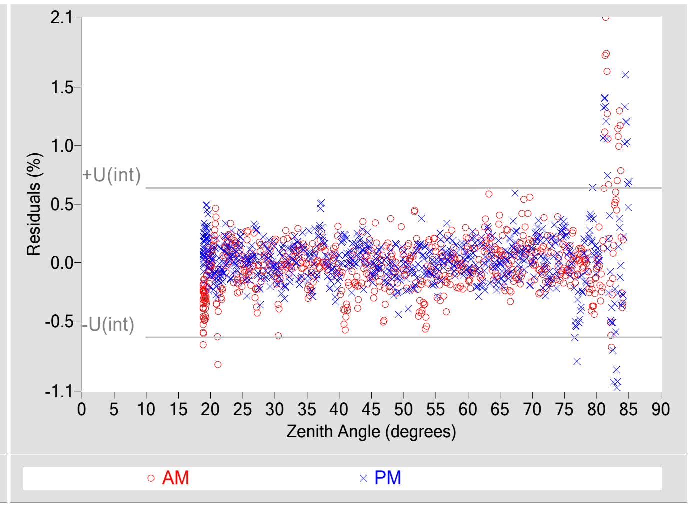


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.72
Effective degrees of freedom, DF(c)	33808
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.   Not accredited.

Table 4. Calibration Label Values

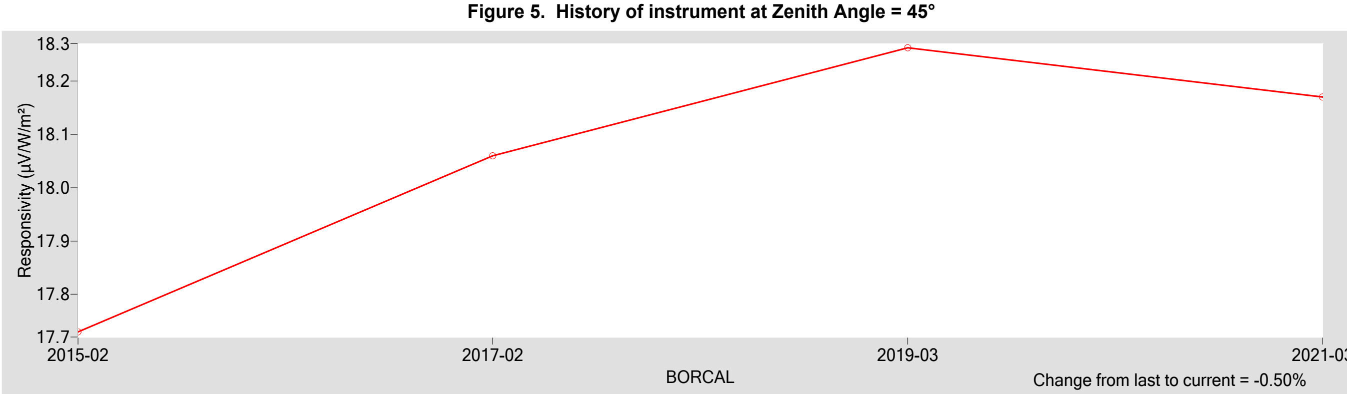
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
18.170	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.3 / -2.2
Expanded Uncertainty, U (%)	+2.1 / -3.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument: Pyranometer
Manufacturer: Kipp & Zonen
Model: CMP11
Serial Number: 140910
Calibration Date: 5/25/2021
Due Date: 5/25/2022
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/24-25

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

________________________________ ____________
Afshín M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

140910 Kipp & Zonen CMP11

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \quad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

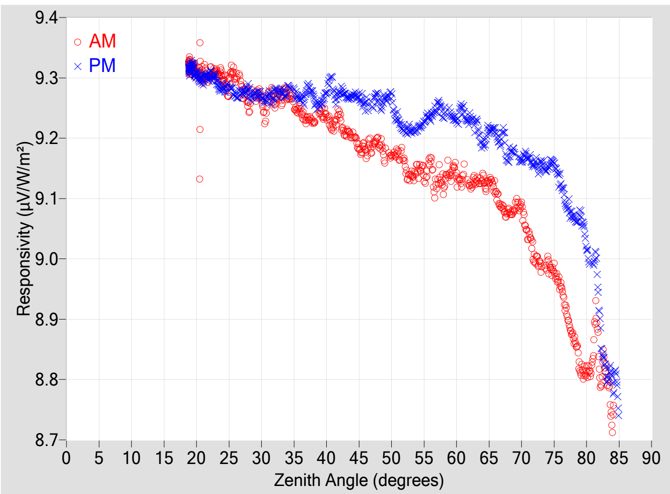


Figure 2. Responsivity vs Local Standard Time

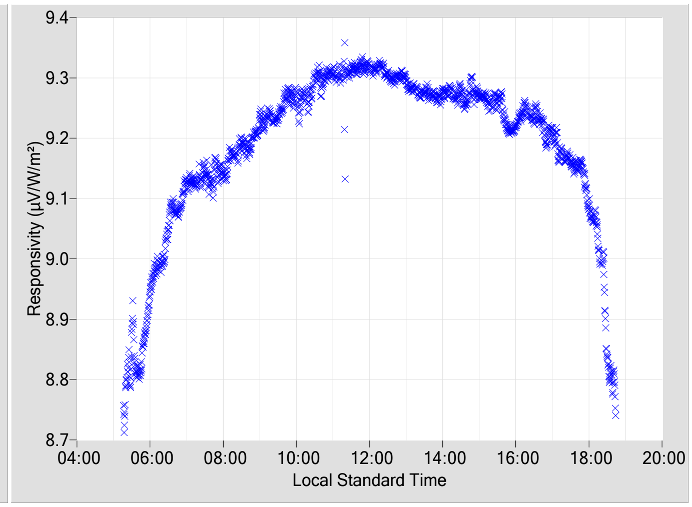


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1808	0.33	98.83	9.2581	0.33	260.97
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1922	0.37	96.85	9.2653	0.34	262.92
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1706	0.34	95.02	9.2663	0.34	264.79
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1588	0.37	93.24	9.2127	0.33	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1467	0.40	91.50	9.2166	0.34	268.38
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1608	0.35	89.80	9.2351	0.36	270.00
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1241	0.39	88.19	9.2400	0.35	271.66
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1394	0.40	86.56	9.2306	0.36	273.26
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1235	0.36	85.00	9.2316	0.38	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1314	0.37	83.42	9.1890	0.39	276.44
20	9.3085	0.31	158.24	9.3047	0.33	201.77	66	9.1116	0.39	81.87	9.2102	0.41	278.00
22	9.3043	0.31	143.88	9.3035	0.32	215.13	68	9.0777	0.41	80.32	9.1680	0.43	279.55
24	9.3025	0.33	135.90	9.2826	0.34	223.75	70	9.0832	0.44	78.75	9.1643	0.46	281.13
26	9.3019	0.31	129.65	9.2708	0.32	229.76	72	9.0031	0.47	77.22	9.1582	0.50	282.66
28	9.2559	0.33	124.60	9.2795	0.34	234.90	74	8.9909	0.52	75.62	9.1496	N/A	284.24
30	9.2616	0.31	120.27	9.2697	0.31	239.24	76	8.9566	0.57	74.05	9.1254	N/A	285.81
32	9.2572	0.36	116.46	9.2735	0.31	242.96	78	8.8698	0.66	72.47	9.0691	N/A	287.44
34	9.2706	0.31	113.34	9.2784	0.30	246.24	80	8.8127	N/A	70.83	9.0201	N/A	289.07
36	9.2455	0.33	110.46	9.2658	0.32	249.32	82	8.8191	N/A	69.15	8.9091	N/A	290.72
38	9.2259	0.32	107.68	9.2680	0.31	251.99	84	8.7368	N/A	67.49	8.7959	N/A	292.46
40	9.2382	0.37	105.33	9.2776	0.32	254.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2390	0.35	102.97	9.2757	0.31	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2031	0.33	100.85	9.2694	0.31	258.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

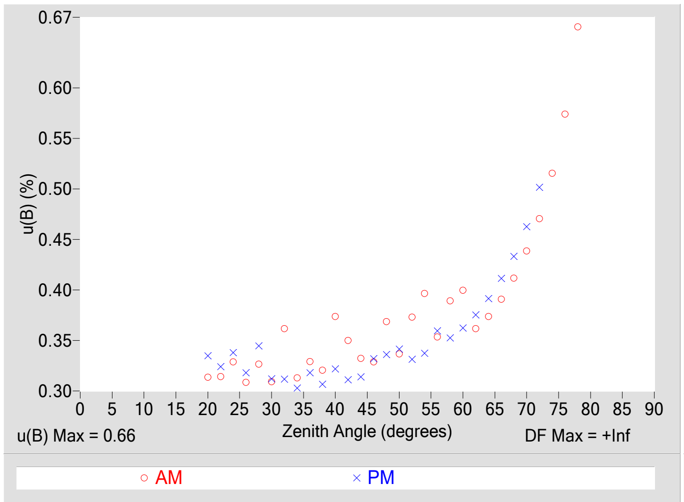


Figure 4. Residuals from Spline Interpolation

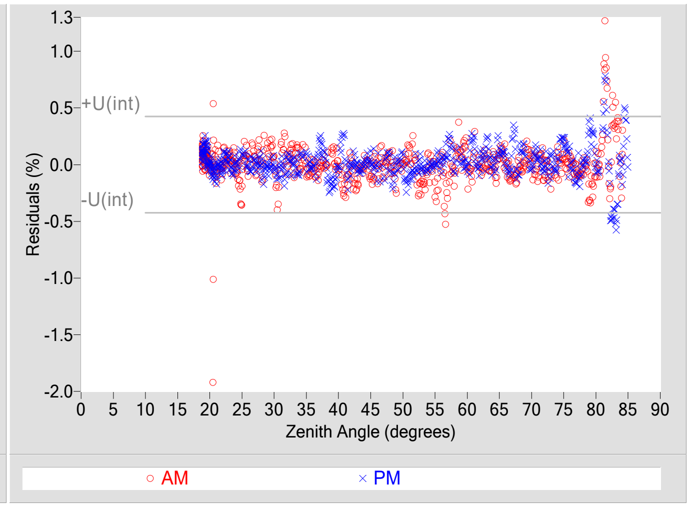


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.66
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.69
Effective degrees of freedom, DF(c)	146990
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

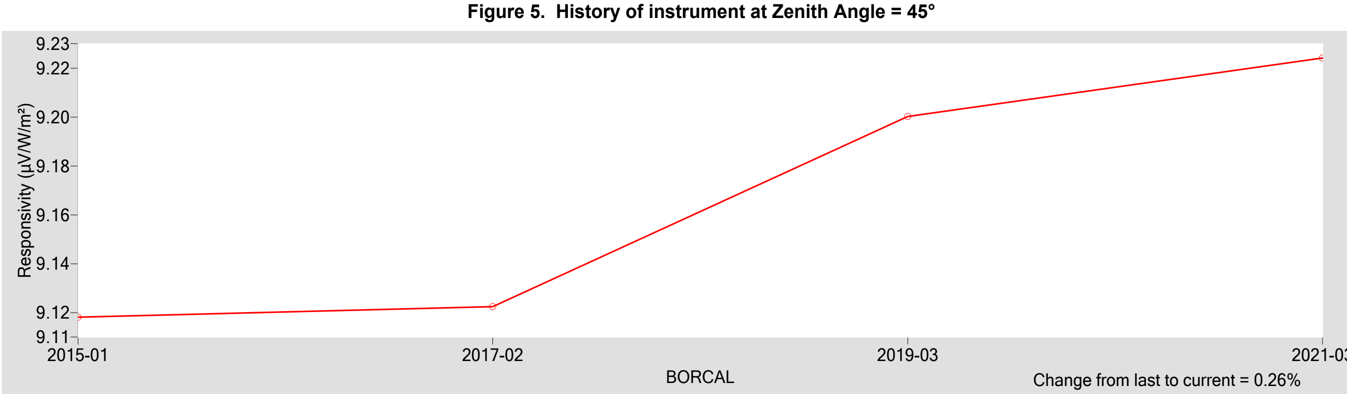
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.2241	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+0.59 / -1.1
Expanded Uncertainty, U (%)	+1.4 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory
Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	160430
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

______________________________ ____________

Afshín M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

160430 Kipp & Zonen CMP22

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

V = radiometer output voltage (microvolts),

Rnet = radiometer net infrared responsivity (μV/W/m²), see Table 4,

Wnet = effective net infrared measured by pyrgeometer (W/m²),

= *Win - Wout* = *Win - σ * Tc^4*

where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,

Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)

where, *G = B * COS(Z) + D,*

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

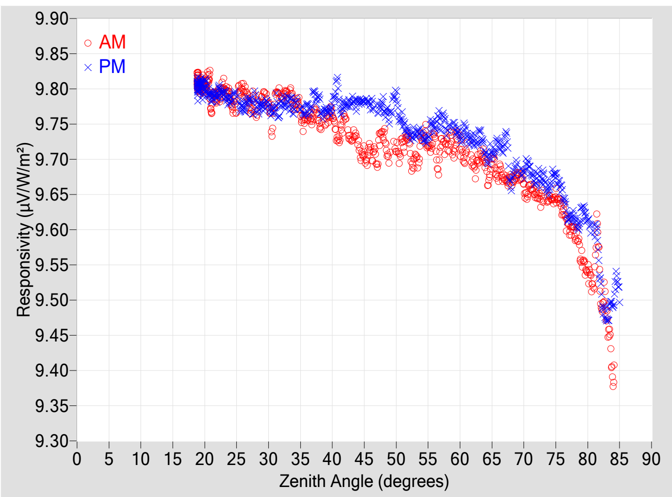


Figure 2. Responsivity vs Local Standard Time

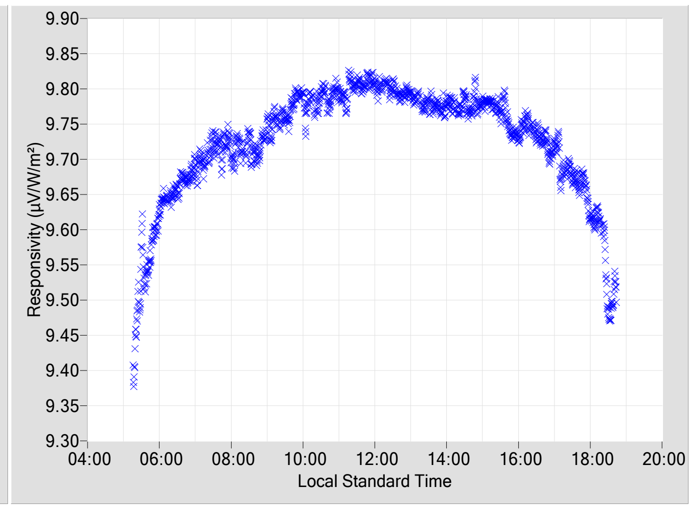


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.7098	0.33	98.80	9.7792	0.31	260.98
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7347	0.34	96.85	9.7749	0.33	262.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7144	0.34	94.98	9.7868	0.34	264.80
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7246	0.34	93.24	9.7356	0.34	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7292	0.37	91.51	9.7350	0.33	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7306	0.33	89.81	9.7468	0.34	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7210	0.37	88.19	9.7427	0.35	271.67
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7220	0.36	86.54	9.7310	0.36	273.26
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6954	0.37	85.01	9.7270	0.37	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.6938	0.37	83.43	9.7061	0.38	276.44
20	9.8038	0.31	158.37	9.8012	0.31	201.72	66	9.6800	0.38	81.88	9.7238	0.40	278.00
22	9.7890	0.30	144.01	9.7944	0.31	215.10	68	9.6727	0.40	80.29	9.6672	0.42	279.55
24	9.7875	0.31	135.95	9.7847	0.31	223.41	70	9.6620	0.43	78.76	9.6806	0.48	281.10
26	9.7993	0.32	129.64	9.7737	0.31	229.84	72	9.6499	0.46	77.19	9.6735	0.49	282.67
28	9.7683	0.33	124.56	9.7851	0.32	235.07	74	9.6447	0.50	75.62	9.6590	N/A	284.24
30	9.7757	0.31	120.29	9.7757	0.35	239.30	76	9.6282	0.55	74.06	9.6524	N/A	285.82
32	9.7876	0.31	116.53	9.7759	0.32	242.97	78	9.5950	0.64	72.47	9.6151	N/A	287.44
34	9.7779	0.33	113.35	9.7723	0.31	246.27	80	9.5402	N/A	70.84	9.6129	N/A	289.07
36	9.7584	0.36	110.39	9.7720	0.32	249.31	82	9.5121	N/A	69.12	9.5247	N/A	290.72
38	9.7503	0.30	107.73	9.7792	0.33	252.00	84	9.3947	N/A	67.50	9.5000	N/A	292.46
40	9.7642	0.35	105.28	9.7781	0.30	254.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7600	0.36	103.03	9.7784	0.31	256.77	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7233	0.31	100.81	9.7828	0.31	259.00	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

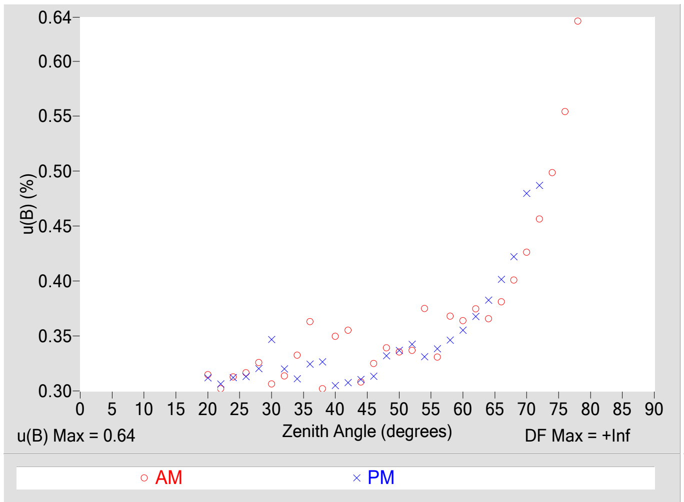


Figure 4. Residuals from Spline Interpolation

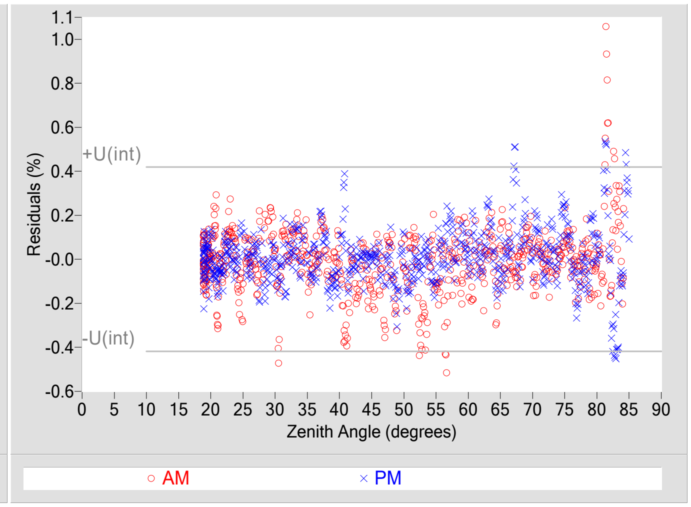


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	134384
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

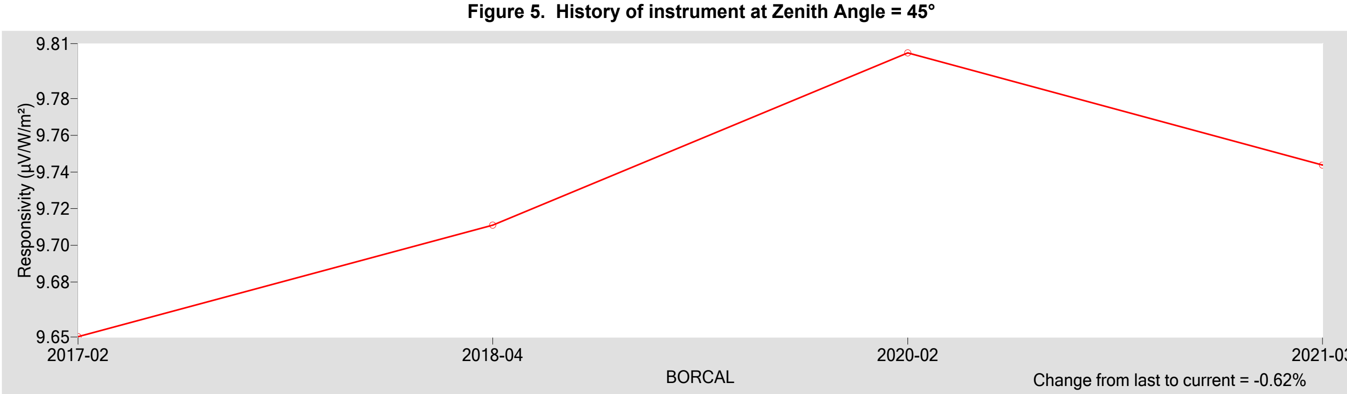
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.7438	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+0.45 / -0.35
Expanded Uncertainty, U (%)	+1.2 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	194362
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

____ ________________

Afshín M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

194362 Kipp & Zonen SP-LITE2

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  - = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

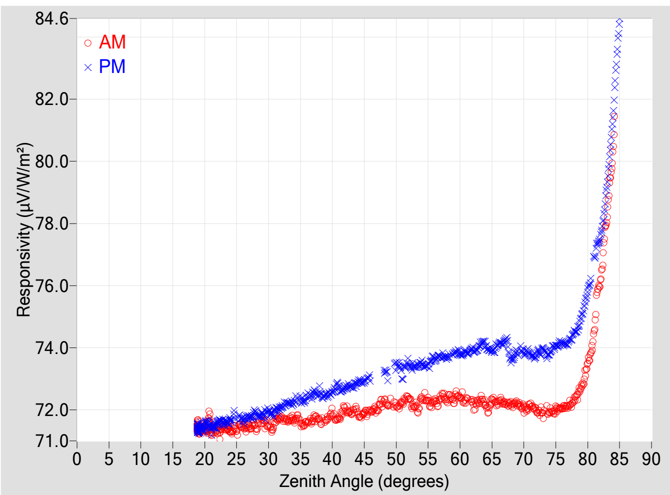


Figure 2. Responsivity vs Local Standard Time

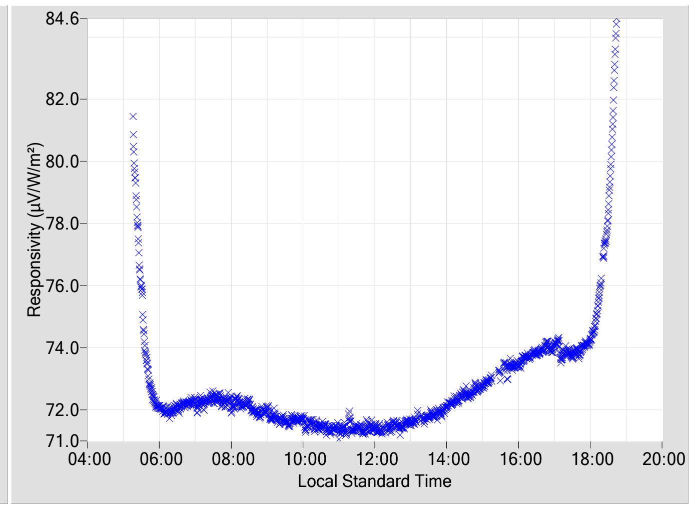


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	71.962	0.31	98.75	73.024	0.34	260.78
2	N/A	N/A	N/A	N/A	N/A	N/A	48	72.244	0.36	96.85	73.221	0.31	263.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	72.130	0.35	94.95	73.448	0.33	264.78
6	N/A	N/A	N/A	N/A	N/A	N/A	52	72.373	0.40	93.24	73.470	0.32	266.58
8	N/A	N/A	N/A	N/A	N/A	N/A	54	72.346	0.32	91.54	73.504	0.36	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	72.291	0.33	89.84	73.645	0.33	270.00
12	N/A	N/A	N/A	N/A	N/A	N/A	58	72.326	0.37	88.18	73.683	0.34	271.66
14	N/A	N/A	N/A	N/A	N/A	N/A	60	72.403	0.34	86.56	73.799	0.35	273.30
16	N/A	N/A	N/A	N/A	N/A	N/A	62	72.219	0.35	84.97	73.928	0.36	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	72.170	0.36	83.43	74.058	0.38	276.44
20	71.391	0.32	158.10	71.475	0.31	201.80	66	72.231	0.39	81.87	74.105	0.42	277.99
22	71.346	0.32	144.15	71.577	0.29	215.13	68	72.180	0.39	80.32	73.649	0.41	279.54
24	71.335	0.29	135.81	71.646	0.32	223.38	70	72.075	0.42	78.75	73.827	0.44	281.13
26	71.470	0.30	129.72	71.686	0.30	229.82	72	71.968	0.44	77.22	73.811	0.48	282.66
28	71.441	0.31	124.51	71.895	0.32	235.05	74	71.925	0.48	75.65	73.813	N/A	284.24
30	71.471	0.33	120.31	71.952	0.29	239.34	76	72.059	0.54	74.05	74.141	N/A	285.85
32	71.718	0.32	116.71	72.082	0.31	243.03	78	72.379	0.62	72.43	74.513	N/A	287.43
34	71.669	0.34	113.34	72.268	0.32	246.30	80	73.495	N/A	70.80	75.859	N/A	289.10
36	71.604	0.31	110.39	72.402	0.32	249.13	82	76.195	N/A	69.15	77.630	N/A	290.75
38	71.645	0.32	107.71	72.567	0.30	252.02	84	80.467	N/A	67.45	81.746	N/A	292.49
40	71.888	0.32	105.30	72.591	0.30	254.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	72.051	0.32	102.99	72.715	0.31	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	71.911	0.33	100.85	72.880	0.31	258.94	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

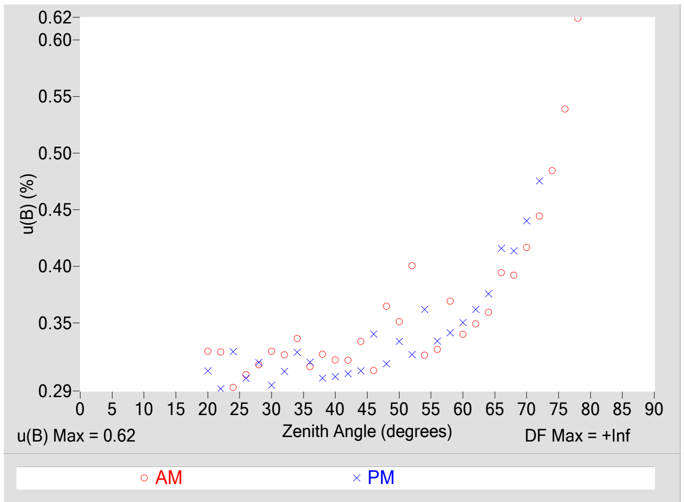


Figure 4. Residuals from Spline Interpolation

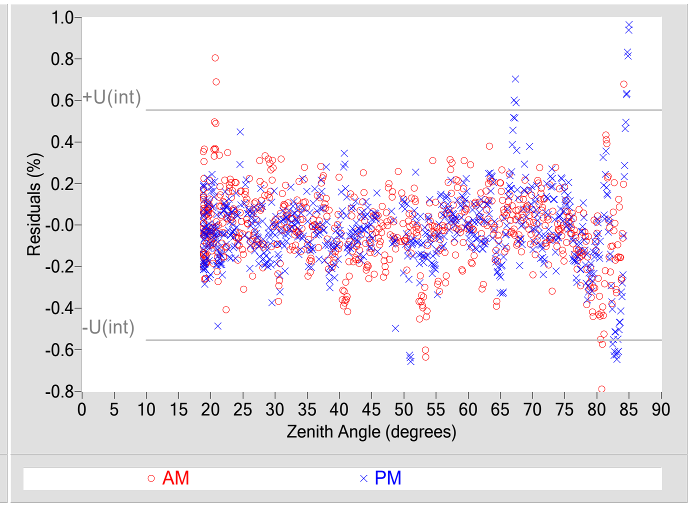


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	45716
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

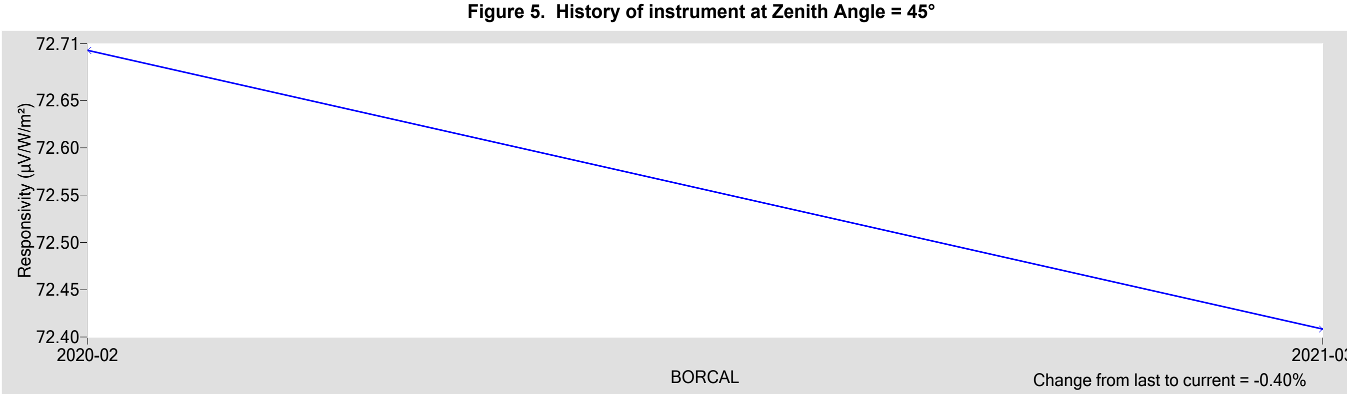
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
72.408	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+1.9 / -1.3
Expanded Uncertainty, U (%)	+2.7 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	19621F3
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† Through the World Radiometric Reference (WRR)   ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

____ ________________

Afshín M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

19621F3 Eppley PSP

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

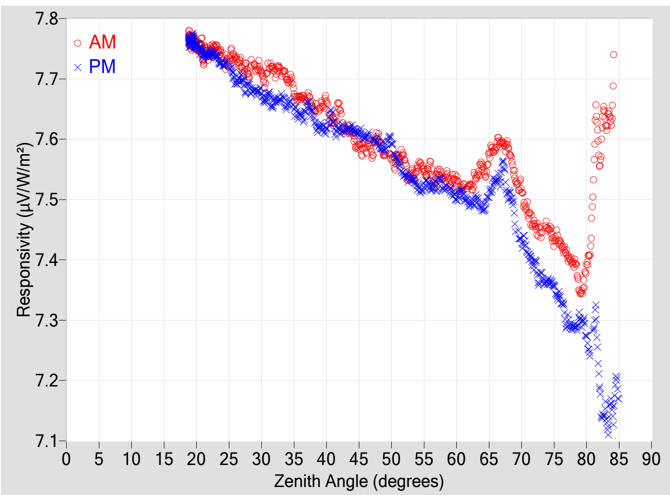


Figure 2. Responsivity vs Local Standard Time

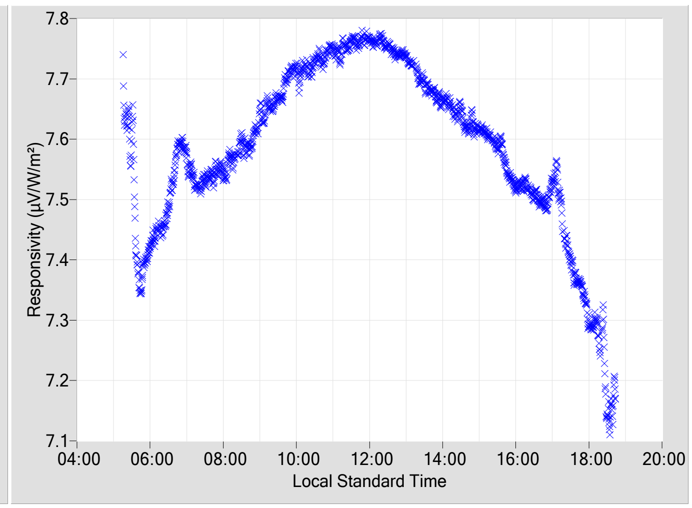


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5853	0.37	98.77	7.6041	0.39	261.00
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6005	0.39	96.87	7.5919	0.40	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5680	0.40	94.97	7.5955	0.40	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5663	0.40	93.22	7.5412	0.40	266.57
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5530	0.43	91.48	7.5221	0.41	268.32
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5510	0.42	89.82	7.5188	0.42	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5341	0.45	88.21	7.5191	0.44	271.64
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5343	0.44	86.58	7.5034	0.45	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5236	0.45	84.99	7.4928	0.48	274.88
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5543	0.47	83.41	7.4853	0.51	276.42
20	7.7547	0.34	158.23	7.7542	0.33	201.47	66	7.5853	0.50	81.85	7.5308	0.54	278.02
22	7.7427	0.36	144.06	7.7398	0.34	215.01	68	7.5847	0.53	80.31	7.5086	0.57	279.57
24	7.7350	0.35	135.81	7.7246	0.37	223.55	70	7.5194	0.57	78.77	7.4309	0.62	281.11
26	7.7341	0.36	129.52	7.6965	0.34	229.79	72	7.4578	0.64	77.20	7.3938	0.69	282.68
28	7.7098	0.34	124.59	7.6905	0.36	235.02	74	7.4532	0.68	75.64	7.3633	N/A	284.26
30	7.7100	0.36	120.32	7.6747	0.36	239.31	76	7.4271	0.76	74.07	7.3351	N/A	285.83
32	7.7115	0.35	116.57	7.6621	0.37	243.00	78	7.3944	0.89	72.45	7.2881	N/A	287.42
34	7.6980	0.36	113.31	7.6578	0.36	246.36	80	7.3892	N/A	70.82	7.2721	N/A	289.05
36	7.6695	0.37	110.42	7.6407	0.36	249.29	82	7.5763	N/A	69.17	7.1818	N/A	290.77
38	7.6518	0.37	107.74	7.6382	0.36	251.96	84	7.6619	N/A	67.47	7.1524	N/A	292.44
40	7.6644	0.36	105.33	7.6199	0.35	254.48	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6522	0.39	103.00	7.6168	0.36	256.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6072	0.36	100.77	7.6158	0.36	258.92	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

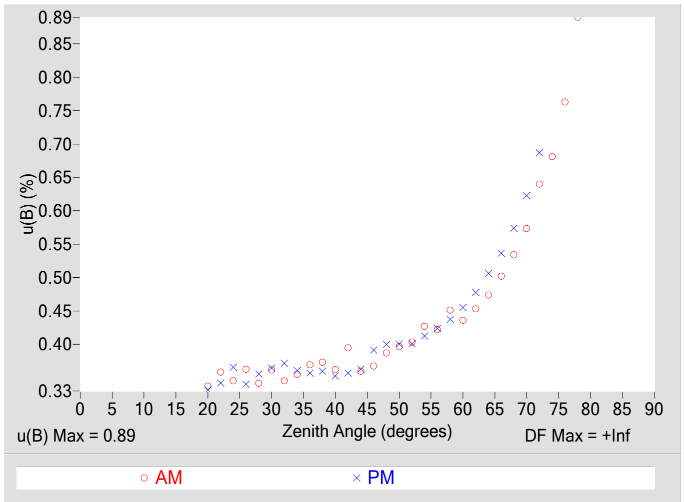


Figure 4. Residuals from Spline Interpolation

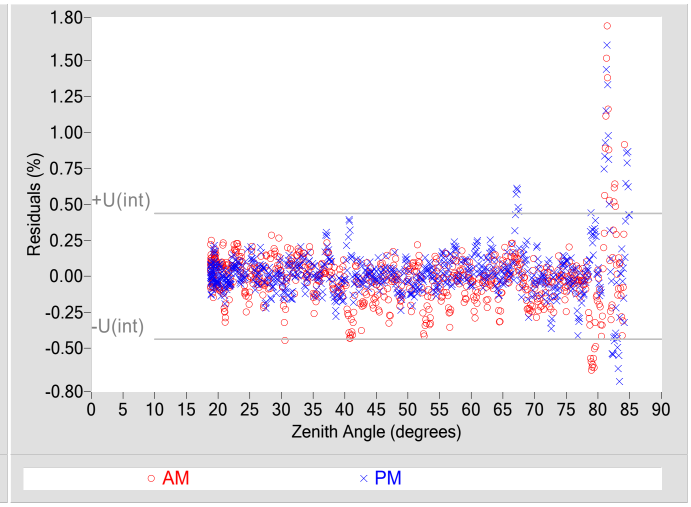


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.89
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.92
Effective degrees of freedom, DF(c)	396375
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.8
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

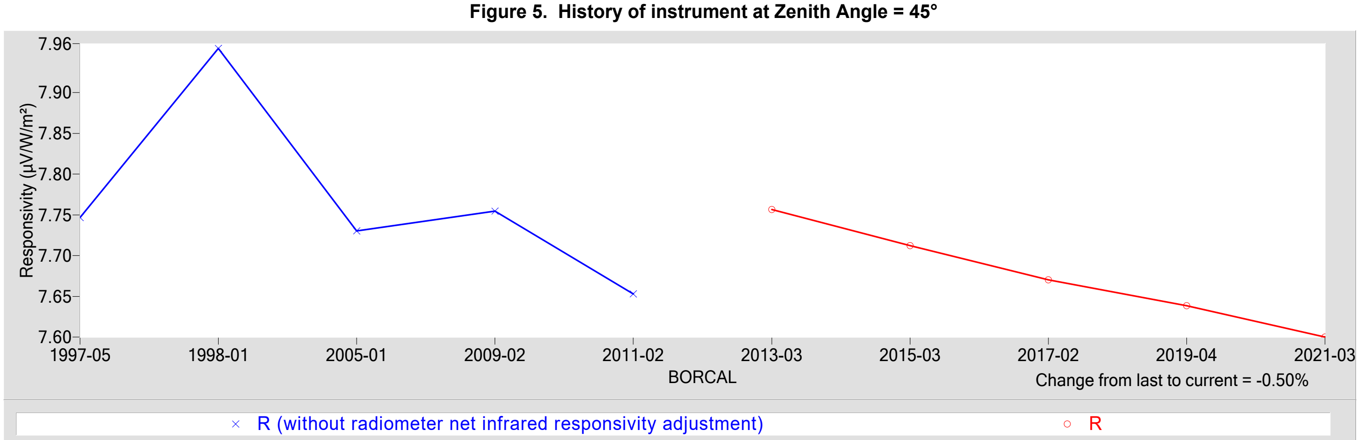
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6001	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+1.5 / -1.3
Expanded Uncertainty, U (%)	+2.4 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	25782F3
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

_____________________________________ __________________

Afshín M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

25782F3 Eppley PSP

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

*R = (V - Rnet * Wnet) / I* [1]

where,

V = radiometer output voltage (microvolts),
Rnet = radiometer net infrared responsivity (μV/W/m²), see Table 4,
Wnet = effective net infrared measured by pyrgeometer (W/m²),
= *Win - Wout* = *Win - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, *G = B * COS(Z) + D,*
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

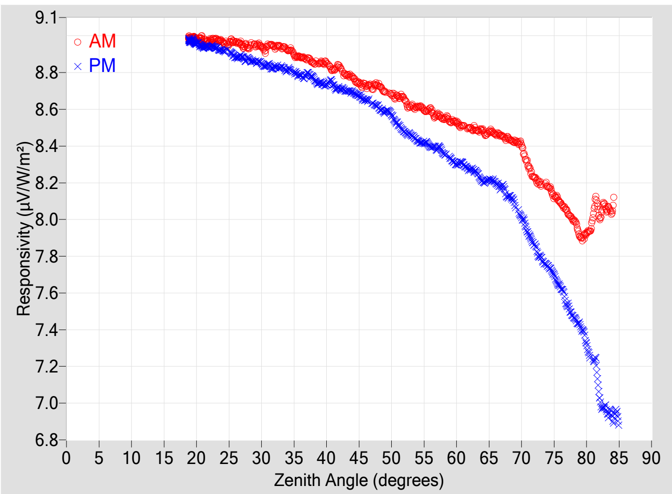


Figure 2. Responsivity vs Local Standard Time

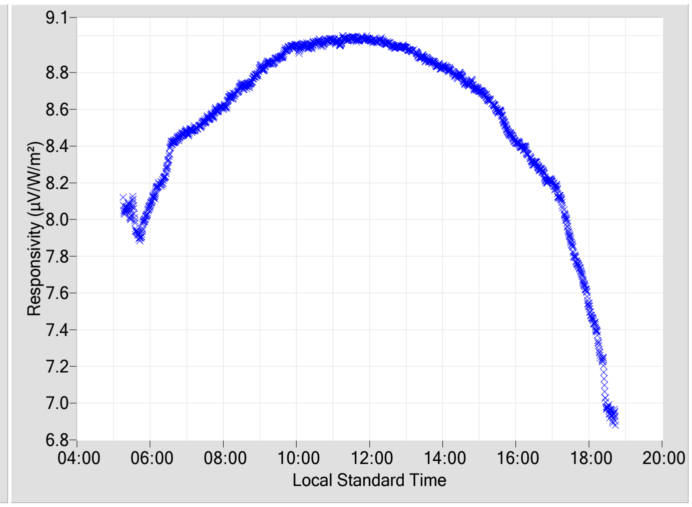


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7291	0.33	98.77	8.6500	0.36	261.00
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7306	0.35	96.87	8.6091	0.36	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6805	0.36	94.97	8.5718	0.36	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6539	0.36	93.22	8.4781	0.35	266.57
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6131	0.38	91.48	8.4298	0.36	268.32
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5961	0.37	89.82	8.3955	0.37	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5482	0.40	88.21	8.3596	0.38	271.64
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5299	0.38	86.58	8.3027	0.39	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4994	0.39	84.99	8.2724	0.41	274.88
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4863	0.40	83.41	8.2086	0.43	276.42
20	8.9826	0.32	158.23	8.9587	0.31	201.47	66	8.4647	0.43	81.85	8.1982	0.45	278.02
22	8.9694	0.34	144.06	8.9387	0.32	215.01	68	8.4427	0.45	80.31	8.1249	0.48	279.57
24	8.9675	0.32	135.81	8.9202	0.34	223.55	70	8.4075	0.48	78.77	8.0113	0.52	281.11
26	8.9659	0.34	129.52	8.8852	0.32	229.79	72	8.2279	0.54	77.20	7.8611	0.57	282.68
28	8.9375	0.32	124.59	8.8758	0.33	235.02	74	8.1823	0.57	75.64	7.7461	N/A	284.26
30	8.9415	0.34	120.32	8.8485	0.34	239.31	76	8.0908	0.64	74.07	7.6301	N/A	285.83
32	8.9395	0.32	116.57	8.8286	0.35	243.00	78	7.9957	0.74	72.45	7.4694	N/A	287.42
34	8.9230	0.33	113.31	8.8150	0.33	246.36	80	7.9262	N/A	70.82	7.3210	N/A	289.05
36	8.8841	0.34	110.42	8.7844	0.33	249.29	82	8.0251	N/A	69.17	7.0240	N/A	290.77
38	8.8525	0.35	107.74	8.7695	0.33	251.96	84	8.0467	N/A	67.51	6.9245	N/A	292.44
40	8.8551	0.33	105.33	8.7368	0.32	254.48	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8324	0.37	103.00	8.7128	0.32	256.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7746	0.32	100.77	8.6922	0.33	258.92	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

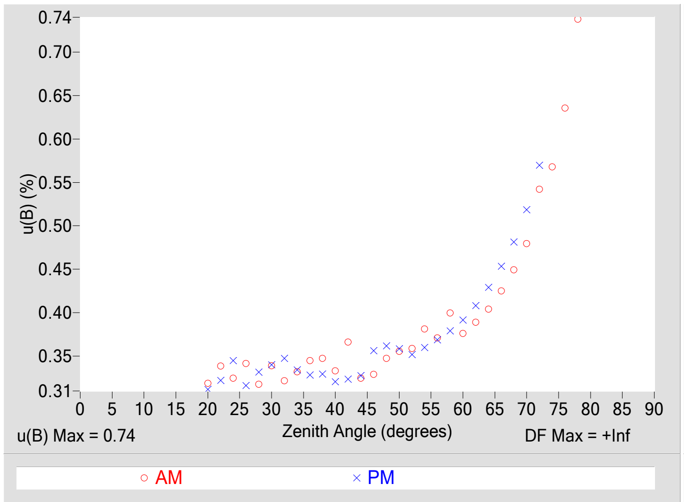


Figure 4. Residuals from Spline Interpolation

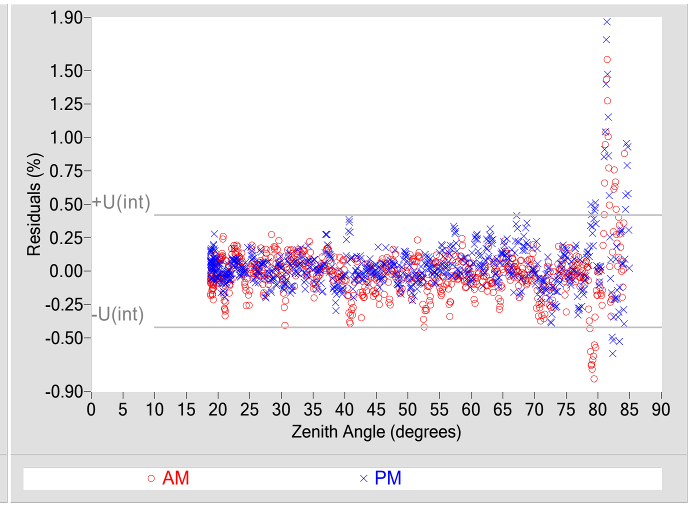


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	228911
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

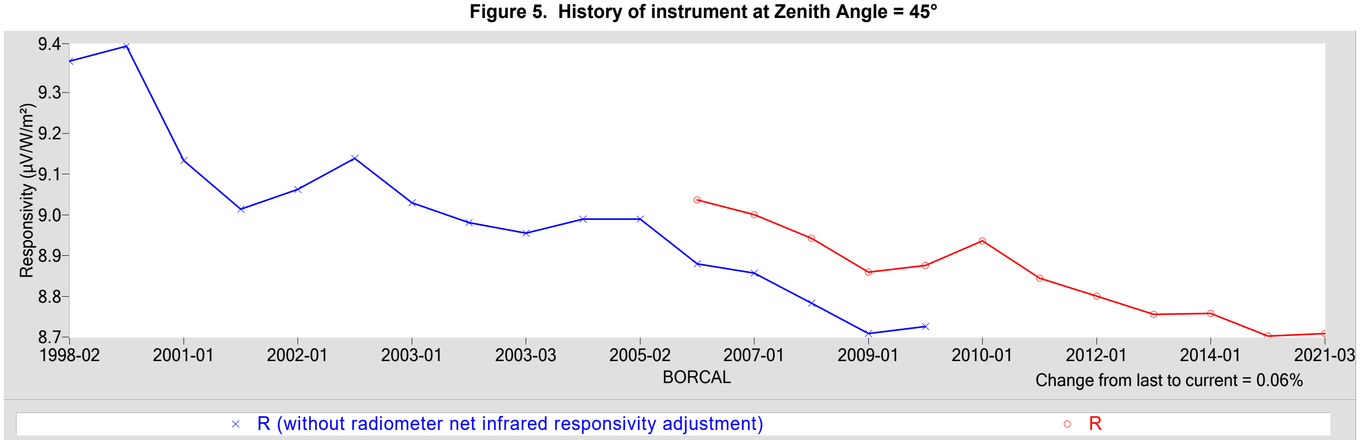
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.7083	0.76000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+2.7 / -4.7
Expanded Uncertainty, U (%)	+3.5 / -5.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

ACCREDITED

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	28400F3
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

_______________________________________ __________________

Afshín M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

28400F3 Eppley PSP

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

V = radiometer output voltage (microvolts),
Rnet = radiometer net infrared responsivity (µV/W/m²), see Table 4,
Wnet = effective net infrared measured by pyrgeometer (W/m²),
= *Win - Wout* = *Win - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, *G = B * COS(Z) + D,*
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

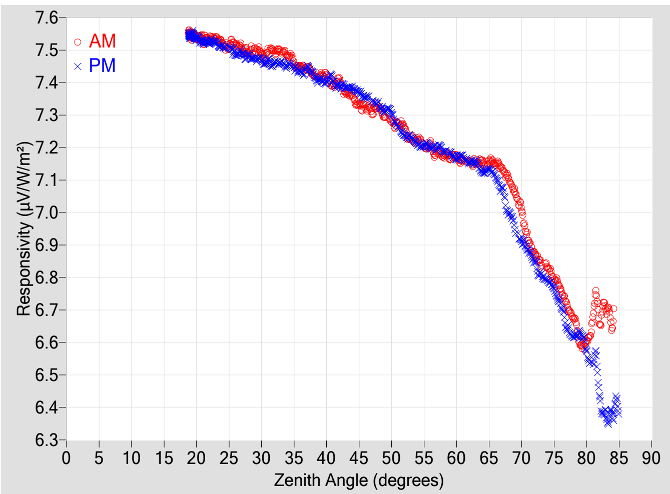


Figure 2. Responsivity vs Local Standard Time

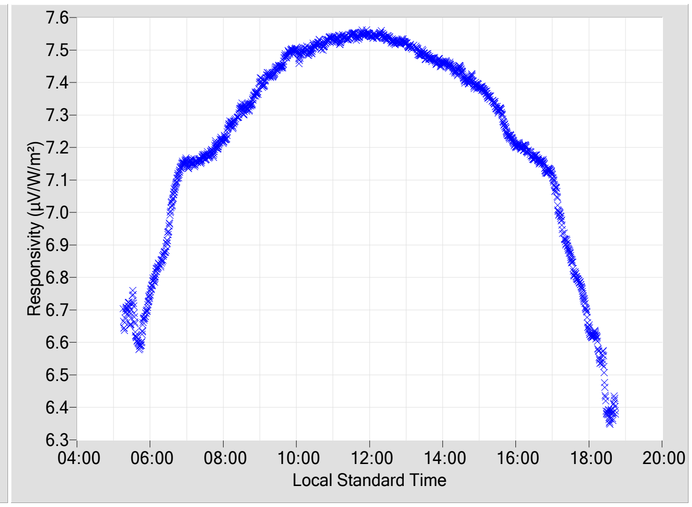


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.3228	0.37	98.77	7.3549	0.39	261.00
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3225	0.39	96.87	7.3284	0.40	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2798	0.40	94.97	7.3068	0.41	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2609	0.41	93.22	7.2373	0.41	266.57
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2249	0.43	91.48	7.2116	0.42	268.32
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2066	0.43	89.82	7.1990	0.43	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1726	0.46	88.21	7.1882	0.45	271.64
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1727	0.44	86.58	7.1672	0.46	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1578	0.46	84.99	7.1539	0.49	274.88
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.1566	0.48	83.41	7.1248	0.52	276.42
20	7.5393	0.34	158.23	7.5369	0.33	201.47	66	7.1486	0.52	81.85	7.1081	0.55	278.02
22	7.5314	0.36	144.06	7.5239	0.34	215.01	68	7.1056	0.55	80.31	6.9990	0.59	279.57
24	7.5209	0.35	135.81	7.5103	0.37	223.55	70	7.0126	0.59	78.77	6.9118	0.65	281.11
26	7.5178	0.36	129.52	7.4883	0.34	229.79	72	6.8745	0.66	77.20	6.8494	0.72	282.68
28	7.4908	0.34	124.59	7.4844	0.36	235.02	74	6.8320	0.71	75.64	6.7891	N/A	284.26
30	7.4904	0.36	120.32	7.4671	0.37	239.31	76	6.7641	0.80	74.07	6.7157	N/A	285.83
32	7.4941	0.35	116.57	7.4594	0.37	243.00	78	6.6755	0.94	72.45	6.6194	N/A	287.42
34	7.4815	0.36	113.31	7.4528	0.36	246.36	80	6.6036	N/A	70.82	6.5732	N/A	289.05
36	7.4494	0.37	110.42	7.4332	0.36	249.29	82	6.6732	N/A	69.17	6.4280	N/A	290.77
38	7.4230	0.38	107.74	7.4245	0.36	251.96	84	6.6593	N/A	67.47	6.3800	N/A	292.44
40	7.4245	0.36	105.33	7.4044	0.36	254.48	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4063	0.40	103.00	7.3902	0.36	256.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3560	0.36	100.77	7.3809	0.37	258.92	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

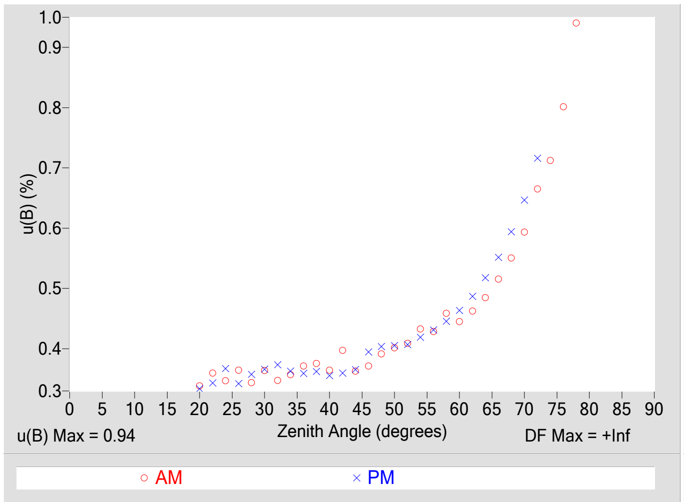


Figure 4. Residuals from Spline Interpolation

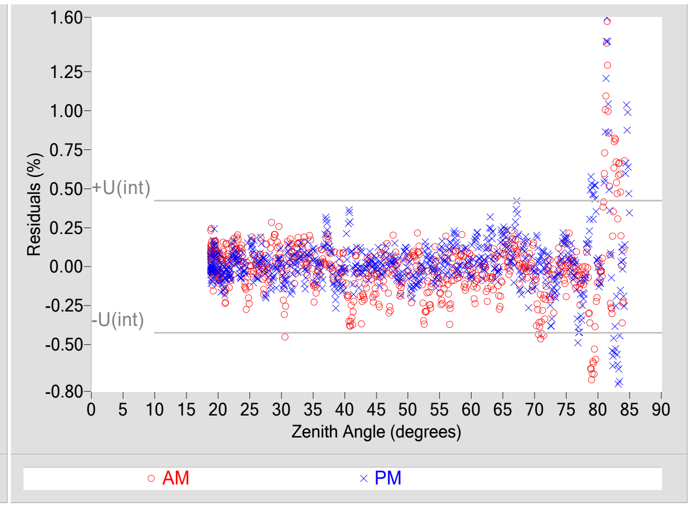


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.94
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.96
Effective degrees of freedom, DF(c)	550225
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.9
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

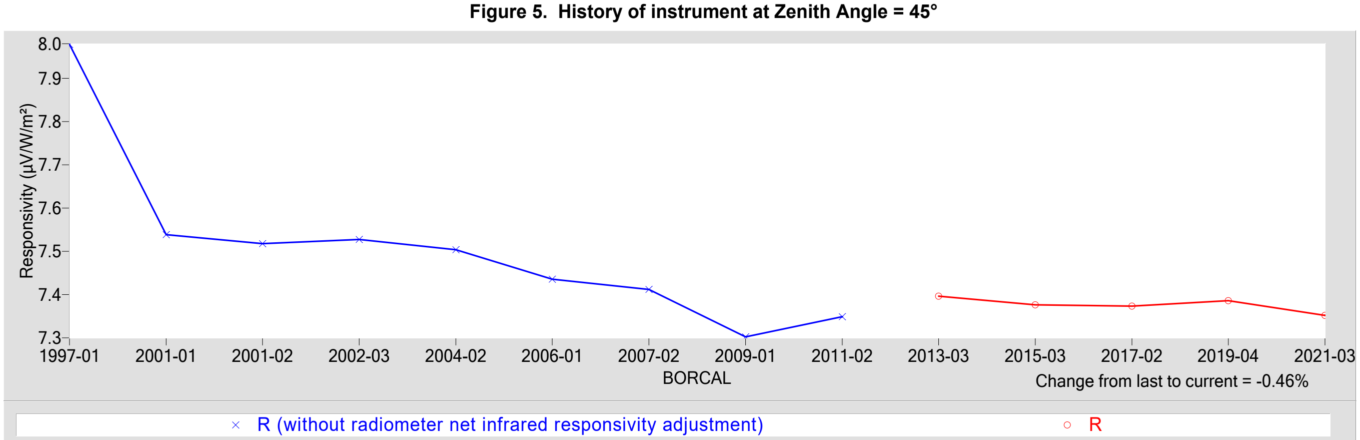
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.3515	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+1.9 / -2.5
Expanded Uncertainty, U (%)	+2.8 / -3.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31394F3
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† Through the World Radiometric Reference (WRR)　　‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

____ ________________

Afshín M. Andreas, Deputy Technical Manager　　Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31394F3 Eppley PSP

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

*R = (V - Rnet * Wnet) / I* [1]

where,

V = radiometer output voltage (microvolts),
Rnet = radiometer net infrared responsivity (µV/W/m²), see Table 4,
Wnet = effective net infrared measured by pyrgeometer (W/m²),
= *Win - Wout* = *Win - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, *G = B * COS(Z) + D,*
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

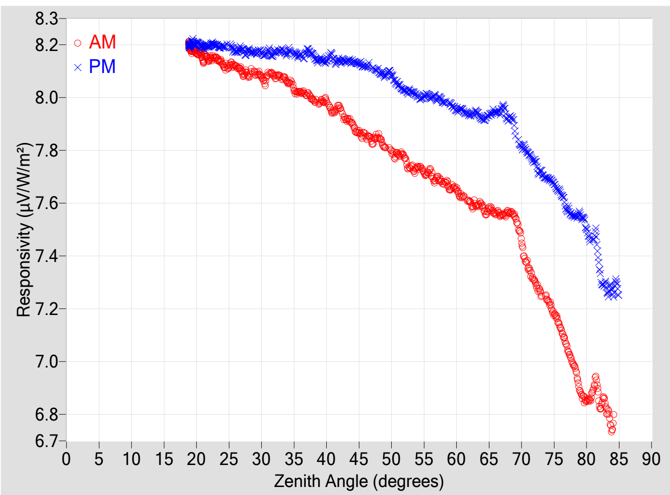


Figure 2. Responsivity vs Local Standard Time

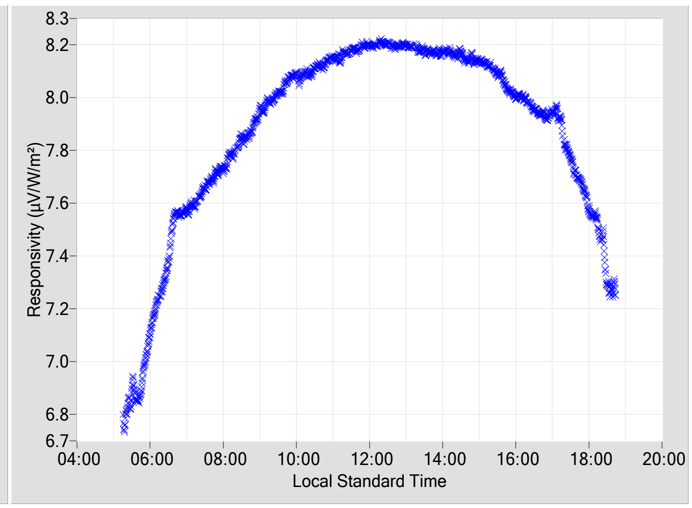


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8554	0.36	98.77	8.1189	0.39	261.00
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8502	0.38	96.87	8.0977	0.39	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7951	0.39	94.97	8.0886	0.39	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7739	0.40	93.22	8.0282	0.39	266.57
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7351	0.42	91.48	8.0078	0.40	268.32
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7172	0.42	89.82	7.9995	0.41	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6776	0.45	88.21	7.9830	0.43	271.64
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6532	0.43	86.58	7.9545	0.44	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6073	0.45	84.99	7.9356	0.47	274.88
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5880	0.47	83.41	7.9201	0.49	276.42
20	8.1717	0.33	158.23	8.2034	0.33	201.47	66	7.5623	0.50	81.85	7.9450	0.52	278.02
22	8.1468	0.36	144.06	8.1976	0.34	215.01	68	7.5661	0.53	80.31	7.9216	0.56	279.57
24	8.1278	0.34	135.81	8.1944	0.36	223.55	70	7.4615	0.58	78.77	7.8151	0.61	281.11
26	8.1197	0.36	129.52	8.1759	0.34	229.79	72	7.3055	0.65	77.20	7.7594	0.67	282.68
28	8.0846	0.34	124.59	8.1800	0.35	235.02	74	7.2350	0.69	75.64	7.6931	N/A	284.26
30	8.0801	0.36	120.32	8.1707	0.36	239.31	76	7.1287	0.78	74.07	7.6385	N/A	285.83
32	8.0802	0.34	116.57	8.1699	0.37	243.00	78	6.9887	0.92	72.45	7.5530	N/A	287.42
34	8.0590	0.35	113.31	8.1718	0.36	246.36	80	6.8554	N/A	70.82	7.5026	N/A	289.05
36	8.0206	0.37	110.42	8.1612	0.35	249.29	82	6.8476	N/A	69.17	7.3420	N/A	290.77
38	7.9900	0.37	107.74	8.1586	0.35	251.96	84	6.7570	N/A	67.47	7.2685	N/A	292.44
40	7.9904	0.36	105.33	8.1420	0.35	254.48	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9632	0.39	103.00	8.1400	0.35	256.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8980	0.36	100.77	8.1352	0.36	258.92	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

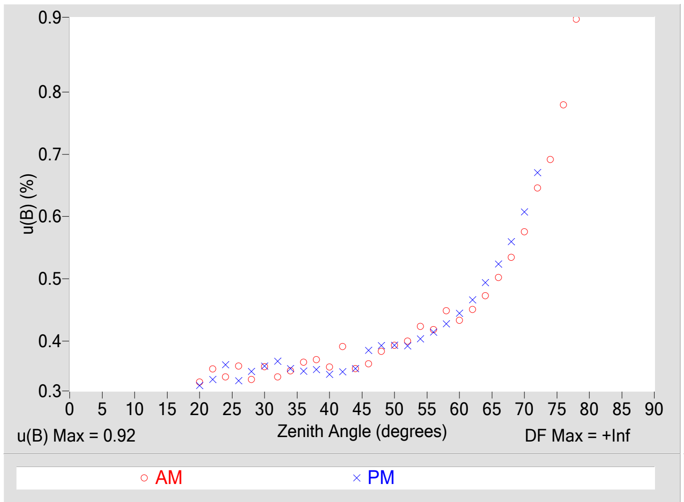


Figure 4. Residuals from Spline Interpolation

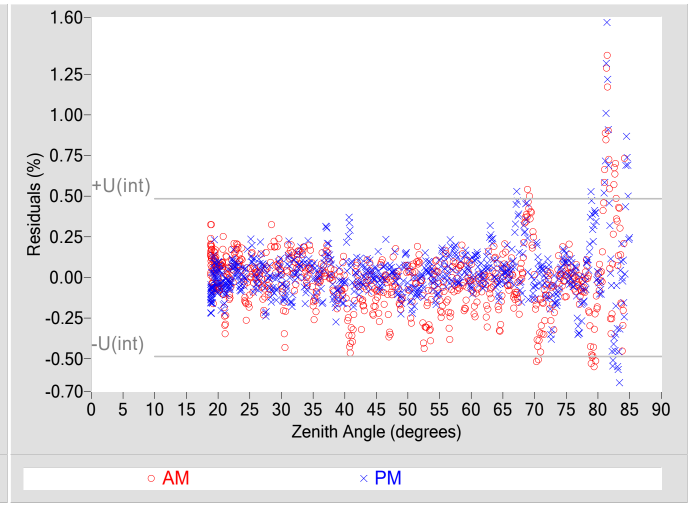


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.92
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.95
Effective degrees of freedom, DF(c)	300883
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.9
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

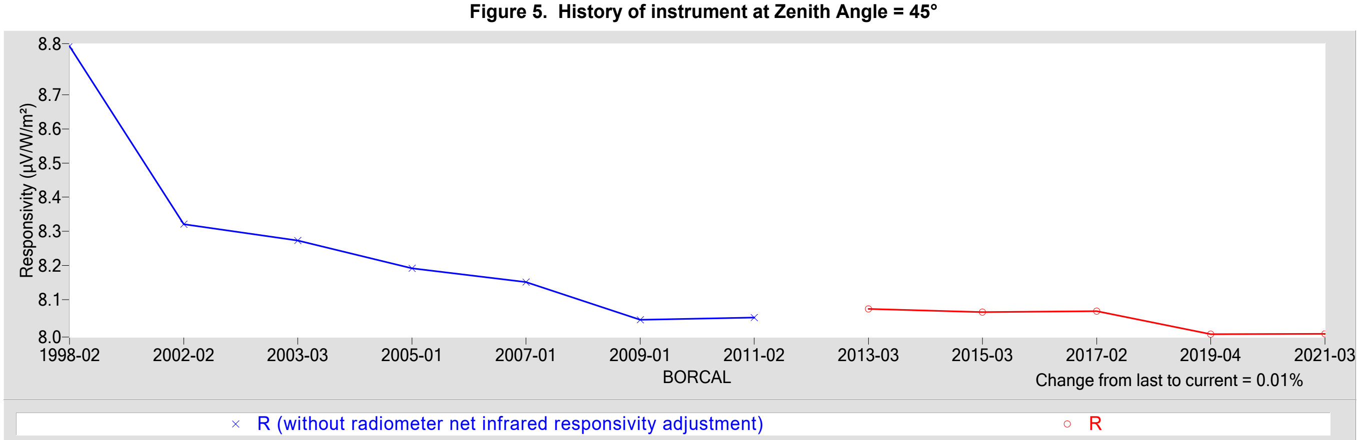
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9993	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+2.2 / -4.3
Expanded Uncertainty, U (%)	+3.0 / -5.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Revised Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200R	**Serial Number:**	PY108623
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

______________________________ ____________

Afshín M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results
PY108623 Licor LI200R

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \quad [1]$$

where,

V = radiometer output voltage (microvolts),
Rnet = radiometer net infrared responsivity (µV/W/m²), see Table 4,
Wnet = effective net infrared measured by pyrgeometer (W/m²),
= *Win - Wout* = *Win - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, *G = B * COS(Z) + D,*
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

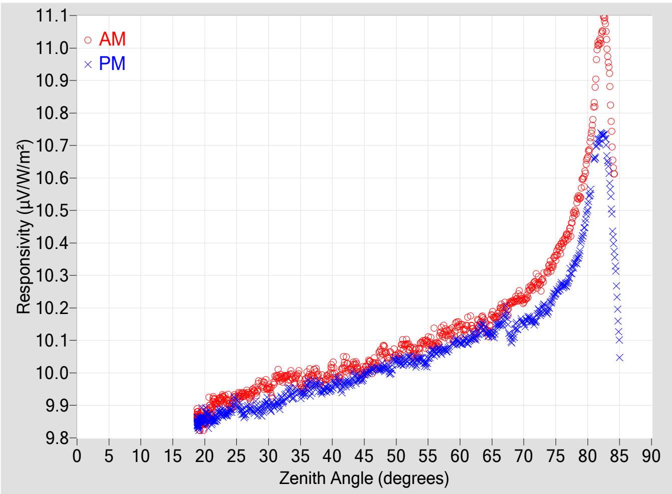


Figure 2. Responsivity vs Local Standard Time

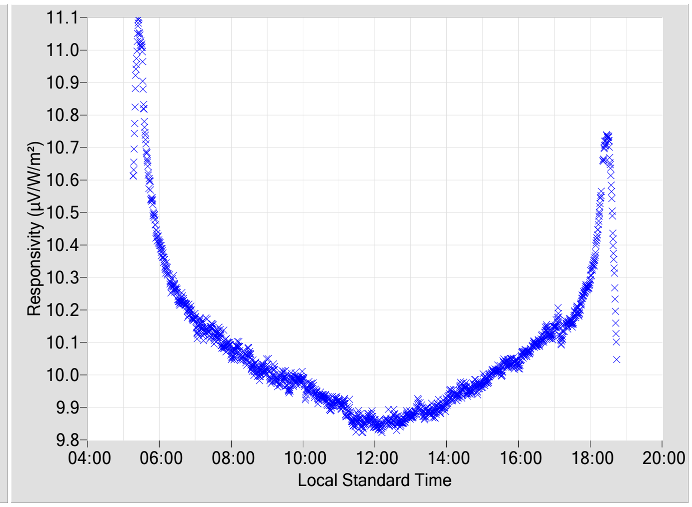


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.022	0.34	98.78	10.009	0.34	260.98
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.073	0.31	96.86	10.016	0.32	262.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.052	0.32	95.04	10.037	0.32	264.78
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.080	0.37	93.20	10.043	0.34	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.091	0.36	91.51	10.042	0.35	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.096	0.35	89.85	10.065	0.34	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.121	0.35	88.19	10.071	0.34	271.67
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.143	0.37	86.60	10.092	0.35	273.30
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.136	0.35	84.97	10.111	0.37	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.144	0.38	83.43	10.129	0.40	276.44
20	9.8522	0.31	158.12	9.8647	0.32	201.83	66	10.180	0.38	81.87	10.148	0.40	278.00
22	9.9067	0.30	144.16	9.8687	0.31	215.07	68	10.217	0.40	80.29	10.107	0.42	279.55
24	9.9007	0.32	135.83	9.8840	0.31	223.50	70	10.223	0.42	78.76	10.154	0.45	281.10
26	9.9323	0.32	129.54	9.8751	0.33	229.83	72	10.280	0.45	77.19	10.172	0.48	282.67
28	9.9431	0.31	124.50	9.8880	0.32	235.06	74	10.323	0.49	75.66	10.204	N/A	284.24
30	9.9523	0.31	120.28	9.9033	0.34	239.27	76	10.394	0.55	74.05	10.271	N/A	285.82
32	9.9825	0.34	116.62	9.9120	0.31	243.04	78	10.497	0.63	72.43	10.339	N/A	287.44
34	9.9779	0.30	113.31	9.9338	0.31	246.31	80	10.668	N/A	70.80	10.513	N/A	289.07
36	9.9823	0.31	110.40	9.9566	0.31	249.25	82	11.026	N/A	69.16	10.725	N/A	290.76
38	9.9779	0.31	107.70	9.9556	0.31	251.94	84	10.658	N/A	67.46	10.425	N/A	292.42
40	10.017	0.33	105.28	9.9573	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.029	0.32	102.98	9.9668	0.32	256.71	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.010	0.35	100.80	9.9815	0.32	258.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

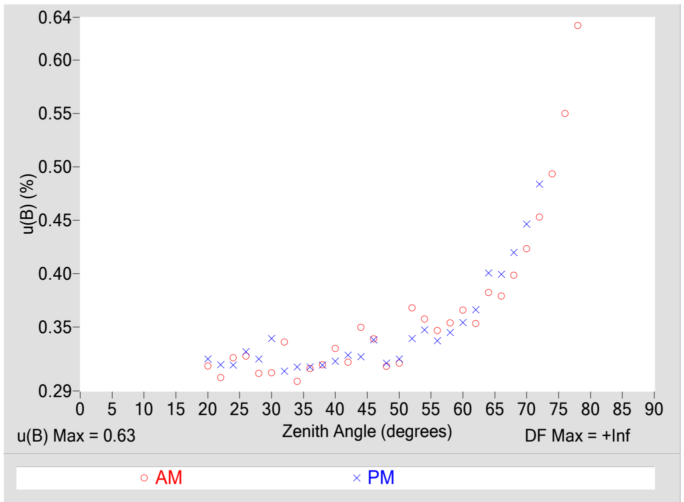


Figure 4. Residuals from Spline Interpolation

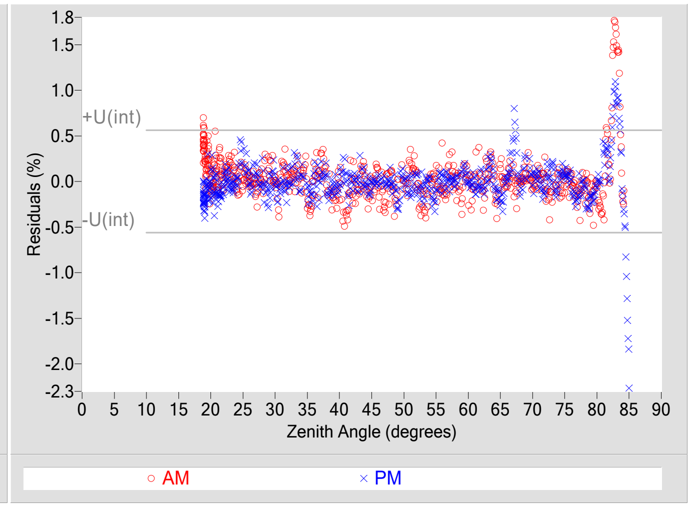


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.69
Effective degrees of freedom, DF(c)	47591
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

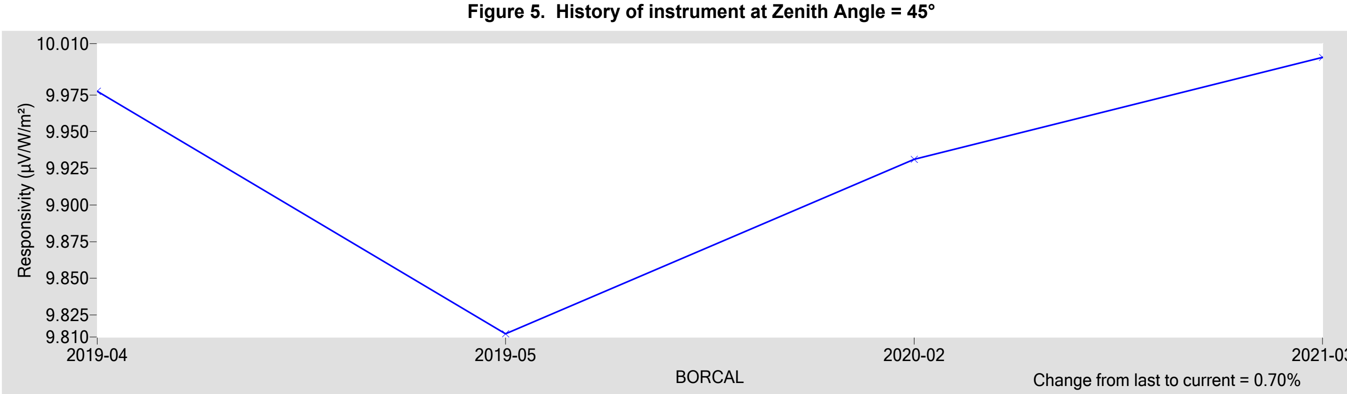
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.001	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+1.4 / -0.97
Expanded Uncertainty, U (%)	+2.1 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY1711
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

____________________________________ ________________

Afshín M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

PY1711 Licor LI200

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

V = radiometer output voltage (microvolts),
$Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
$Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
= $Win - Wout$ = $Win - \sigma * Tc^4$
where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, $G = B * COS(Z) + D$,
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

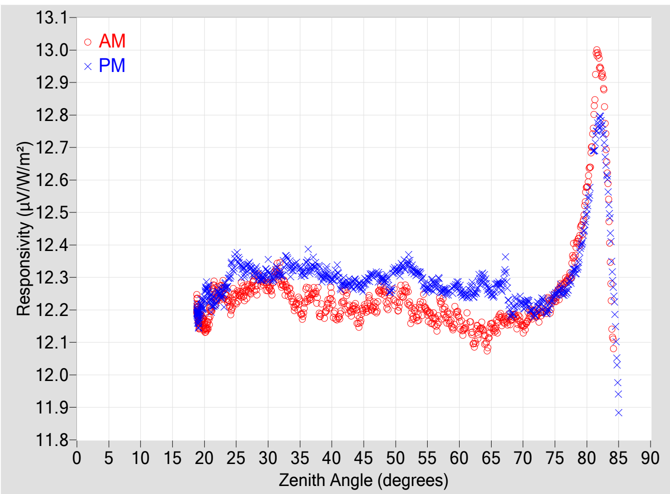


Figure 2. Responsivity vs Local Standard Time

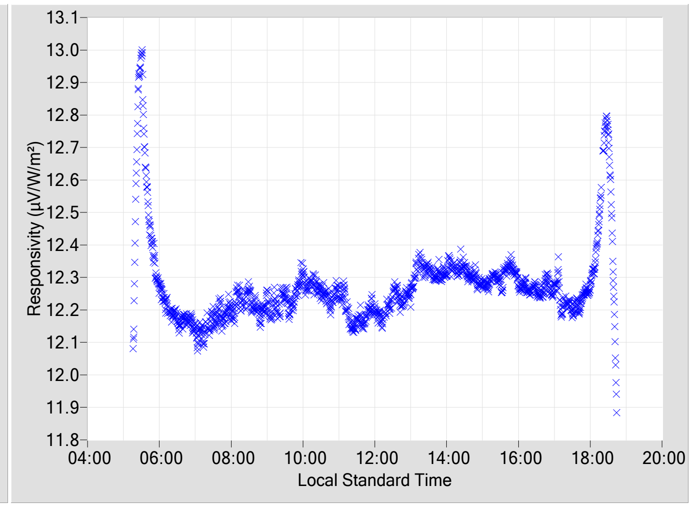


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	12.221	0.34	98.78	12.303	0.34	260.98
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.260	0.31	96.86	12.294	0.32	262.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.232	0.32	95.04	12.322	0.32	264.78
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.233	0.37	93.20	12.345	0.34	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.210	0.36	91.51	12.305	0.35	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.171	0.35	89.85	12.279	0.34	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.184	0.35	88.19	12.255	0.34	271.67
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.172	0.36	86.60	12.267	0.35	273.30
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.124	0.35	84.97	12.261	0.36	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.116	0.38	83.43	12.289	0.40	276.44
20	12.151	0.31	158.12	12.239	0.32	201.83	66	12.158	0.38	81.87	12.279	0.40	278.00
22	12.236	0.30	144.16	12.246	0.31	215.07	68	12.171	0.40	80.29	12.197	0.42	279.55
24	12.212	0.32	135.83	12.314	0.31	223.50	70	12.149	0.42	78.76	12.216	0.44	281.10
26	12.252	0.32	129.54	12.322	0.33	229.83	72	12.188	0.45	77.19	12.198	0.48	282.67
28	12.273	0.31	124.50	12.317	0.32	235.06	74	12.215	0.49	75.66	12.205	N/A	284.24
30	12.273	0.31	120.28	12.308	0.35	239.27	76	12.274	0.55	74.05	12.263	N/A	285.82
32	12.296	0.34	116.62	12.311	0.31	243.04	78	12.372	0.63	72.43	12.321	N/A	287.44
34	12.213	0.30	113.31	12.331	0.31	246.31	80	12.577	N/A	70.80	12.505	N/A	289.07
36	12.241	0.31	110.40	12.342	0.31	249.25	82	12.958	N/A	69.16	12.780	N/A	290.76
38	12.207	0.31	107.70	12.319	0.31	251.94	84	12.160	N/A	67.46	12.331	N/A	292.42
40	12.230	0.33	105.28	12.294	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.239	0.32	102.98	12.285	0.32	256.71	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.175	0.35	100.80	12.276	0.32	258.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

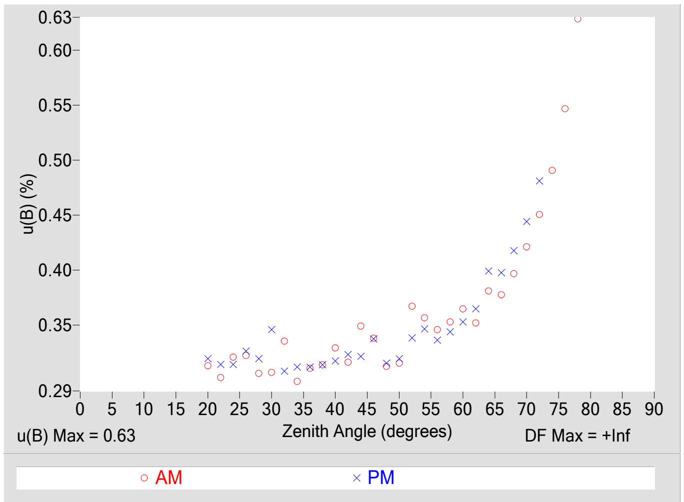


Figure 4. Residuals from Spline Interpolation

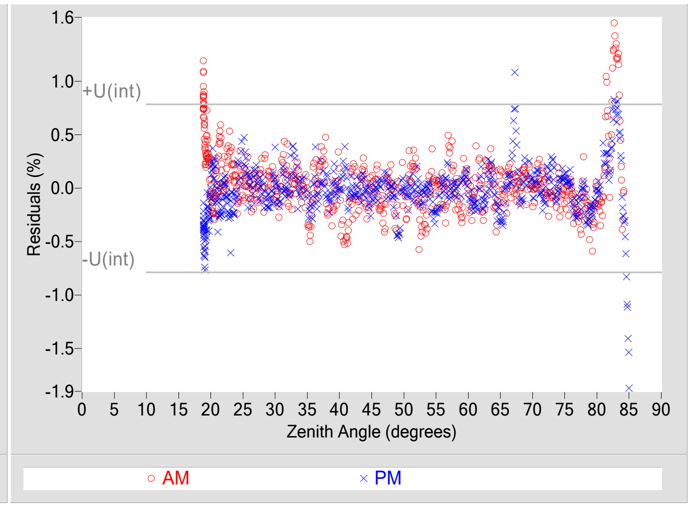


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.39
Combined Standard Uncertainty, u(c) (%)	±0.74
Effective degrees of freedom, DF(c)	16351
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

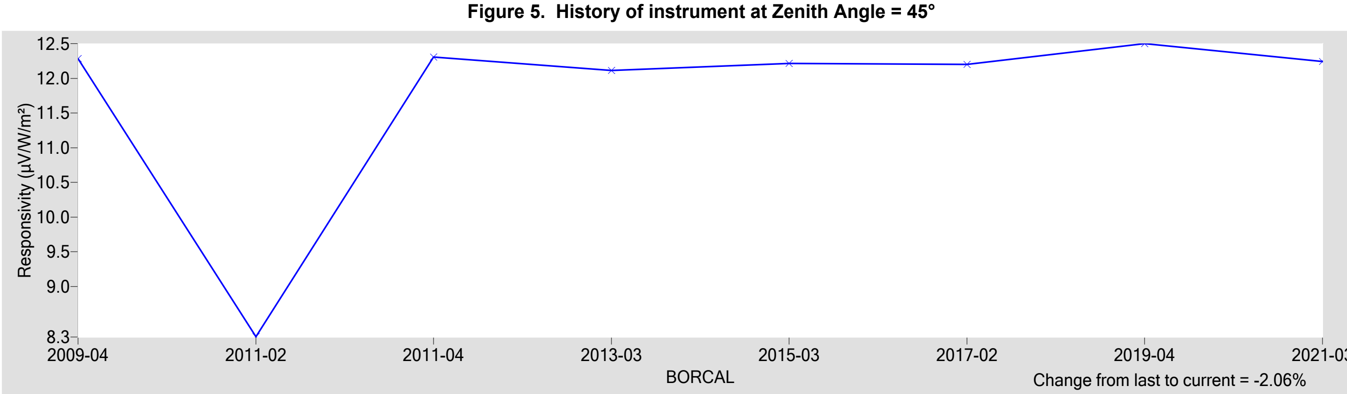
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
12.241	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.85 / -0.57
Expanded Uncertainty, U (%)	+1.6 / -1.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory
Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY1744
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

______________________________ _______________

Afshín M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

PY1744 Licor LI200

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

*R = (V - Rnet * Wnet) / I* [1]

where,

- *V* = radiometer output voltage (microvolts),
- *Rnet* = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- *Wnet* = effective net infrared measured by pyrgeometer (W/m²),
  = *Win - Wout* = *Win - σ * Tc^4*
  where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- *I* = reference irradiance (W/m²), beam (B) or global (G)
  where, *G = B * COS(Z) + D,*
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

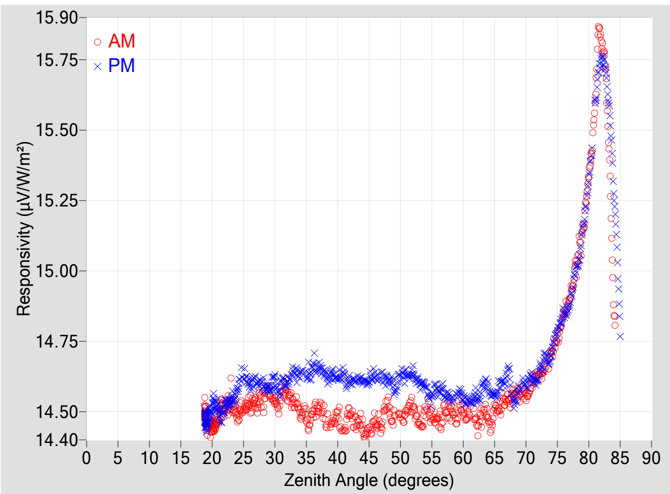


Figure 2. Responsivity vs Local Standard Time

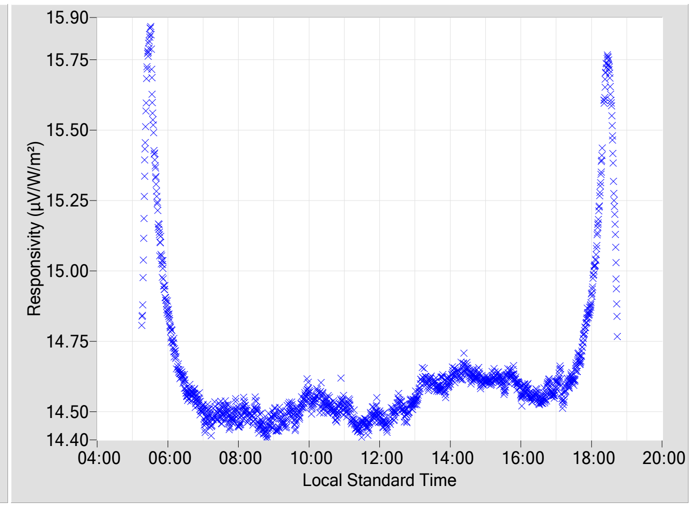


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	14.463	0.34	98.78	14.630	0.34	260.98
2	N/A	N/A	N/A	N/A	N/A	N/A	48	14.520	0.31	96.86	14.615	0.31	262.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	14.488	0.31	95.04	14.632	0.32	264.78
6	N/A	N/A	N/A	N/A	N/A	N/A	52	14.518	0.37	93.20	14.637	0.34	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	14.501	0.36	91.51	14.592	0.35	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	14.473	0.35	89.85	14.572	0.34	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	14.502	0.35	88.19	14.546	0.34	271.67
14	N/A	N/A	N/A	N/A	N/A	N/A	60	14.507	0.36	86.60	14.545	0.35	273.30
16	N/A	N/A	N/A	N/A	N/A	N/A	62	14.466	0.35	84.97	14.554	0.36	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	14.477	0.38	83.43	14.580	0.40	276.44
20	14.443	0.31	158.12	14.520	0.32	201.83	66	14.520	0.38	81.87	14.601	0.40	278.00
22	14.504	0.30	144.16	14.522	0.31	215.07	68	14.569	0.40	80.29	14.538	0.42	279.55
24	14.483	0.32	135.83	14.579	0.31	223.50	70	14.559	0.42	78.76	14.596	0.44	281.10
26	14.523	0.32	129.54	14.597	0.33	229.83	72	14.634	0.45	77.19	14.634	0.48	282.67
28	14.543	0.31	124.50	14.596	0.32	235.06	74	14.706	0.49	75.66	14.704	N/A	284.24
30	14.536	0.31	120.28	14.608	0.34	239.27	76	14.844	0.54	74.05	14.847	N/A	285.82
32	14.567	0.34	116.62	14.607	0.31	243.04	78	15.023	0.63	72.43	15.010	N/A	287.44
34	14.489	0.30	113.31	14.636	0.31	246.31	80	15.341	N/A	70.80	15.330	N/A	289.07
36	14.495	0.31	110.40	14.661	0.31	249.25	82	15.816	N/A	69.16	15.747	N/A	290.76
38	14.473	0.31	107.70	14.635	0.31	251.94	84	14.897	N/A	67.46	15.296	N/A	292.42
40	14.496	0.33	105.28	14.623	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	14.494	0.32	102.98	14.609	0.32	256.71	88	N/A	N/A	N/A	N/A	N/A	N/A
44	14.434	0.35	100.80	14.610	0.32	258.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

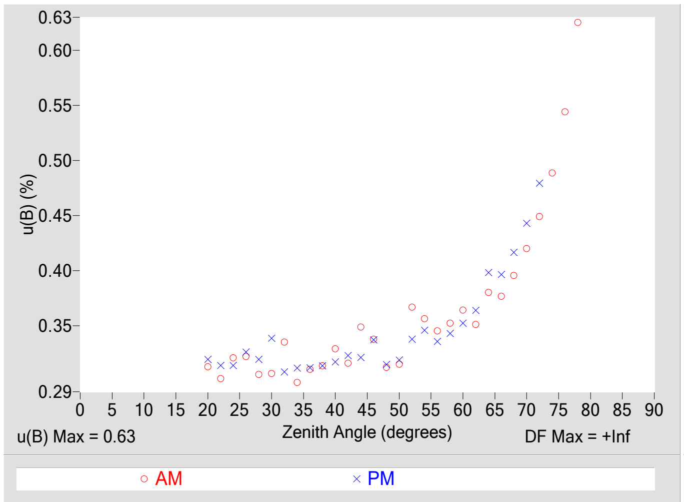


Figure 4. Residuals from Spline Interpolation

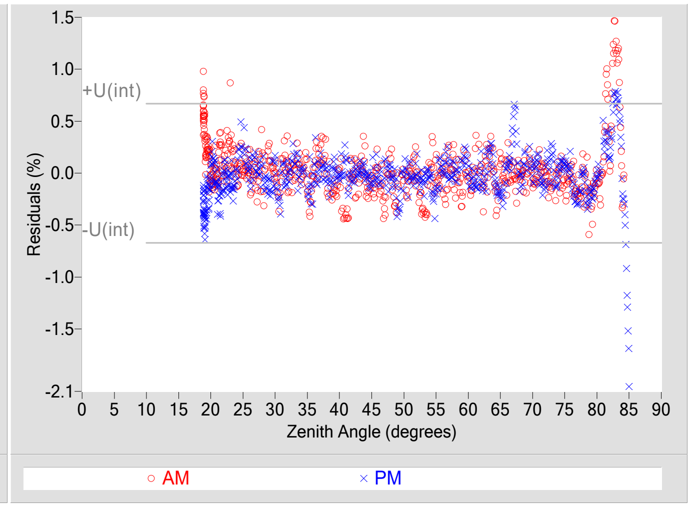


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.71
Effective degrees of freedom, DF(c)	25904
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

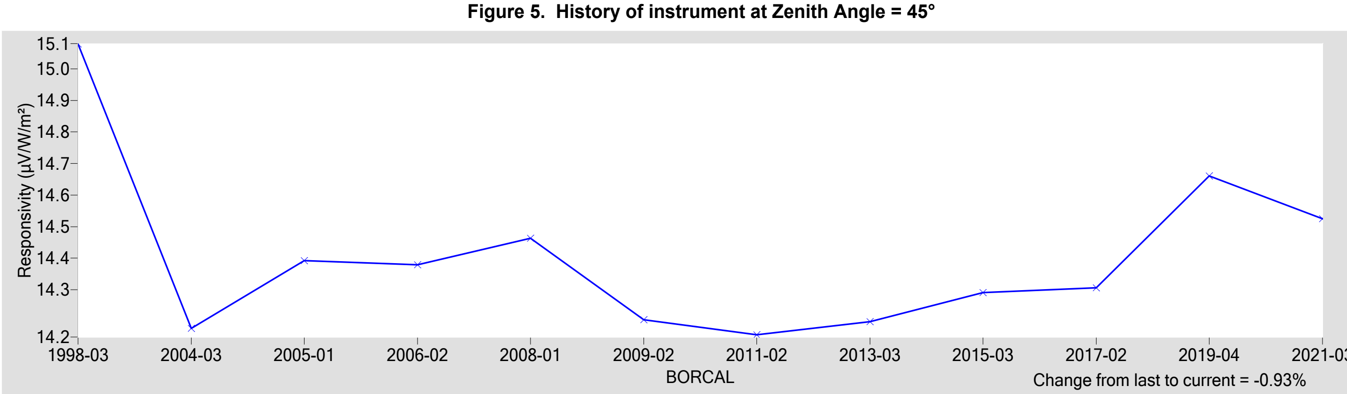
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
14.525	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.94 / -0.63
Expanded Uncertainty, U (%)	+1.7 / -1.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY25070
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

________________________________ ____________

Afshín M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

PY25070 Licor LI200

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \quad [1]$$

where,

V = radiometer output voltage (microvolts),
$Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
$Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
= $Win - Wout$ = $Win - \sigma * Tc\^4$
where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, $G = B * COS(Z) + D$,
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

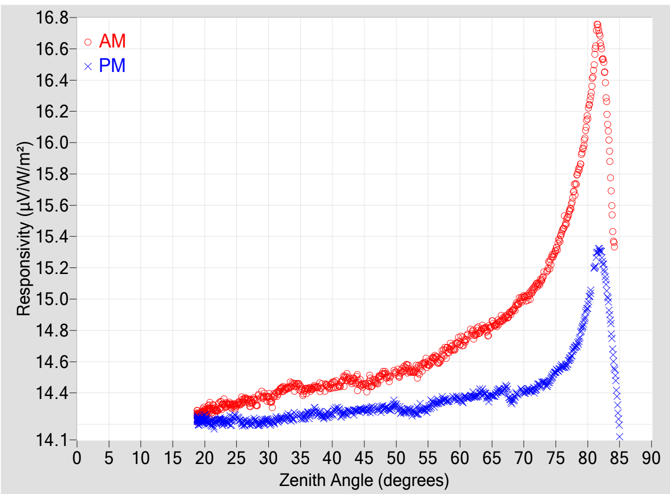


Figure 2. Responsivity vs Local Standard Time

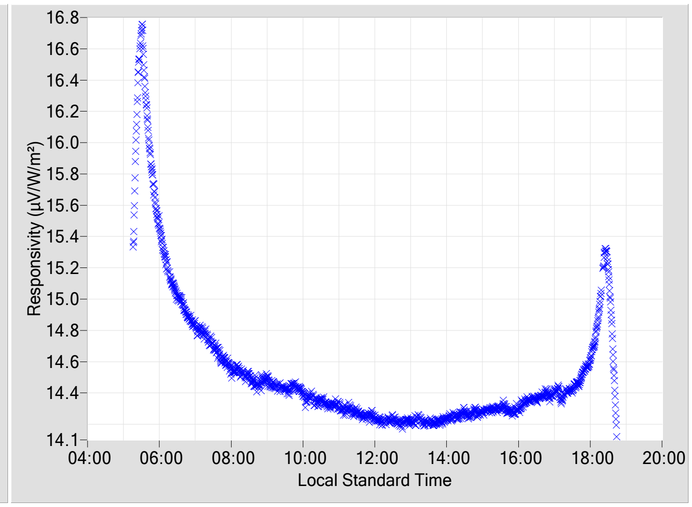


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	14.468	0.34	98.78	14.298	0.34	260.98
2	N/A	N/A	N/A	N/A	N/A	N/A	48	14.528	0.31	96.86	14.306	0.31	262.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	14.535	0.31	95.04	14.315	0.32	264.78
6	N/A	N/A	N/A	N/A	N/A	N/A	52	14.545	0.37	93.20	14.291	0.34	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	14.570	0.36	91.51	14.301	0.35	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	14.627	0.35	89.85	14.331	0.34	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	14.665	0.35	88.19	14.349	0.34	271.67
14	N/A	N/A	N/A	N/A	N/A	N/A	60	14.733	0.36	86.60	14.358	0.35	273.30
16	N/A	N/A	N/A	N/A	N/A	N/A	62	14.776	0.35	84.97	14.382	0.36	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	14.808	0.38	83.43	14.387	0.40	276.44
20	14.278	0.31	158.12	14.230	0.32	201.83	66	14.846	0.38	81.87	14.415	0.40	278.00
22	14.300	0.30	144.16	14.222	0.31	215.07	68	14.918	0.40	80.29	14.354	0.42	279.55
24	14.323	0.32	135.83	14.216	0.31	223.50	70	15.012	0.42	78.76	14.406	0.44	281.10
26	14.353	0.32	129.54	14.204	0.33	229.83	72	15.092	0.45	77.19	14.436	0.48	282.67
28	14.341	0.31	124.50	14.217	0.32	235.06	74	15.216	0.49	75.66	14.476	N/A	284.24
30	14.368	0.31	120.28	14.219	0.34	239.27	76	15.431	0.54	74.05	14.570	N/A	285.82
32	14.425	0.34	116.62	14.238	0.31	243.04	78	15.720	0.62	72.43	14.693	N/A	287.44
34	14.444	0.30	113.31	14.248	0.31	246.31	80	16.181	N/A	70.80	14.963	N/A	289.07
36	14.422	0.31	110.40	14.265	0.31	249.25	82	16.640	N/A	69.16	15.293	N/A	290.76
38	14.435	0.31	107.70	14.265	0.31	251.94	84	15.439	N/A	67.46	14.651	N/A	292.42
40	14.453	0.33	105.28	14.272	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	14.494	0.32	102.98	14.274	0.32	256.71	88	N/A	N/A	N/A	N/A	N/A	N/A
44	14.472	0.35	100.80	14.288	0.32	258.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

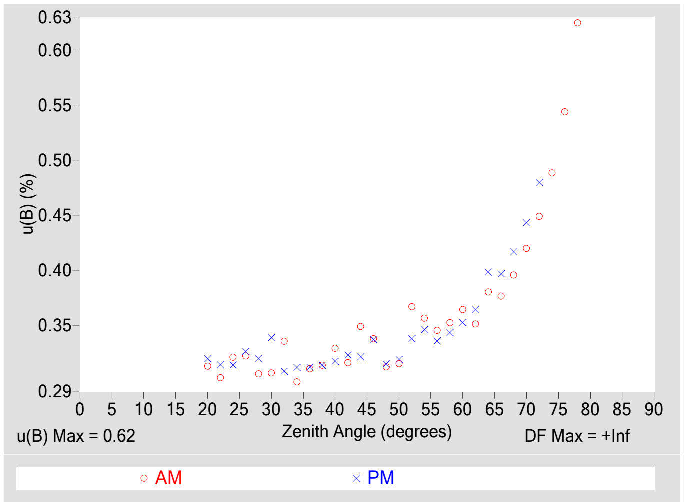


Figure 4. Residuals from Spline Interpolation

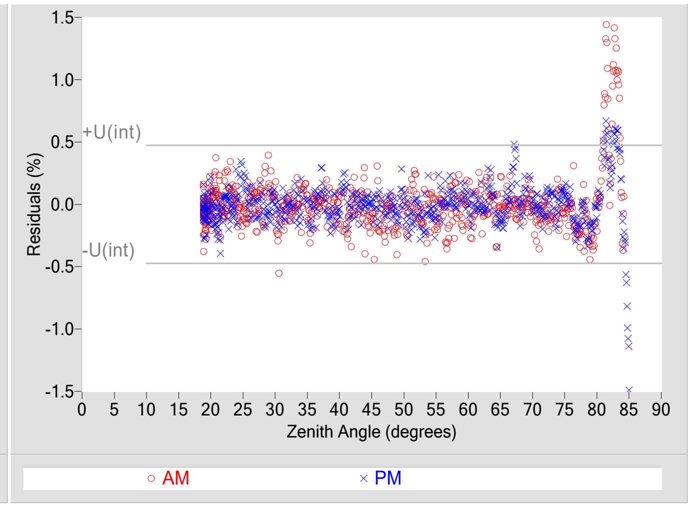


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	82164
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

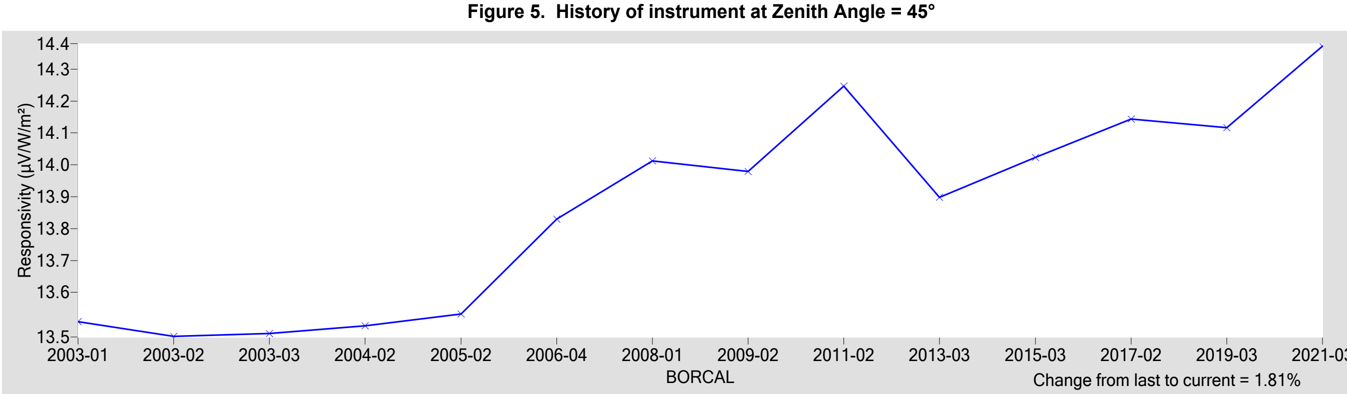
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
14.372	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+2.5 / -1.1
Expanded Uncertainty, U (%)	+3.2 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

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[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY28246
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

____ ____________________

Afshín M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

PY28246 Licor LI200

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- *V* = radiometer output voltage (microvolts),
- *Rnet* = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- *Wnet* = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, *Win* = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- *I* = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

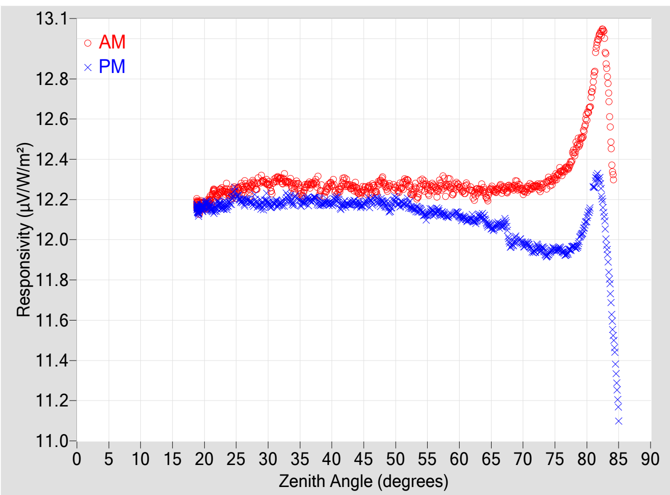


Figure 2. Responsivity vs Local Standard Time

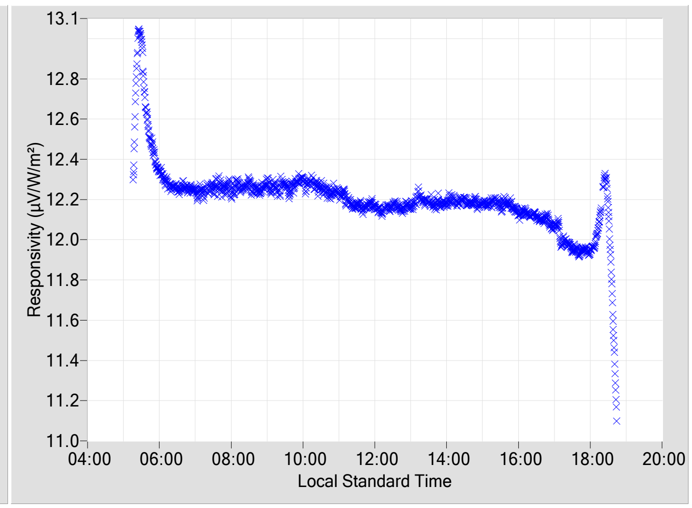


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	12.250	0.34	98.78	12.190	0.34	260.98
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.292	0.31	96.86	12.188	0.32	262.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.258	0.32	95.04	12.197	0.32	264.78
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.281	0.37	93.20	12.178	0.34	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.273	0.36	91.51	12.147	0.35	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.264	0.35	89.85	12.135	0.34	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.266	0.35	88.19	12.117	0.34	271.67
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.267	0.36	86.60	12.117	0.35	273.30
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.239	0.35	84.97	12.102	0.36	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.233	0.38	83.43	12.099	0.40	276.44
20	12.168	0.31	158.12	12.168	0.32	201.83	66	12.249	0.38	81.87	12.076	0.40	278.00
22	12.216	0.30	144.16	12.169	0.31	215.07	68	12.262	0.40	80.29	11.979	0.42	279.55
24	12.226	0.32	135.83	12.186	0.31	223.50	70	12.243	0.42	78.76	11.978	0.44	281.10
26	12.252	0.32	129.54	12.189	0.33	229.83	72	12.268	0.45	77.19	11.955	0.48	282.67
28	12.266	0.31	124.50	12.190	0.32	235.06	74	12.286	0.49	75.66	11.929	N/A	284.24
30	12.281	0.31	120.28	12.189	0.34	239.27	76	12.340	0.55	74.05	11.950	N/A	285.82
32	12.296	0.34	116.62	12.182	0.31	243.04	78	12.440	0.63	72.43	11.965	N/A	287.44
34	12.258	0.30	113.31	12.190	0.31	246.31	80	12.612	N/A	70.80	12.107	N/A	289.07
36	12.269	0.31	110.40	12.198	0.31	249.25	82	13.014	N/A	69.16	12.280	N/A	290.76
38	12.251	0.31	107.70	12.185	0.31	251.94	84	12.379	N/A	67.46	11.603	N/A	292.42
40	12.278	0.33	105.28	12.182	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.290	0.32	102.98	12.178	0.32	256.71	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.243	0.35	100.80	12.178	0.32	258.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

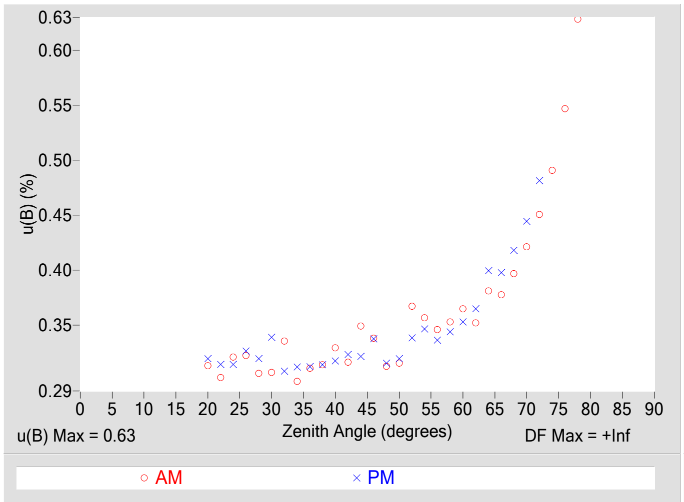


Figure 4. Residuals from Spline Interpolation

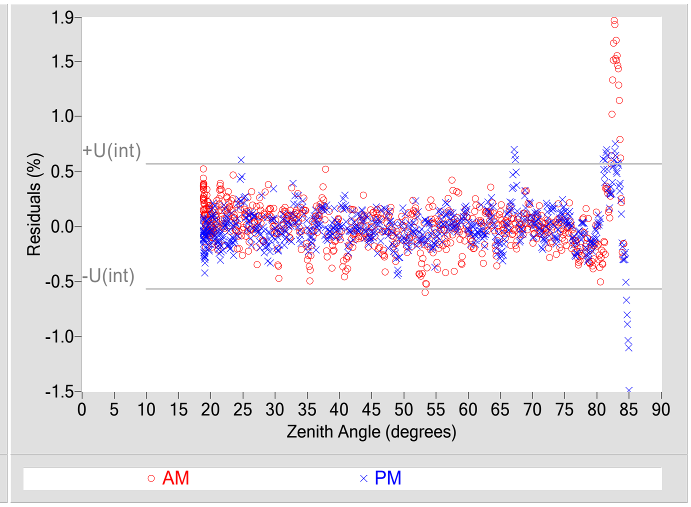


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.69
Effective degrees of freedom, DF(c)	44604
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

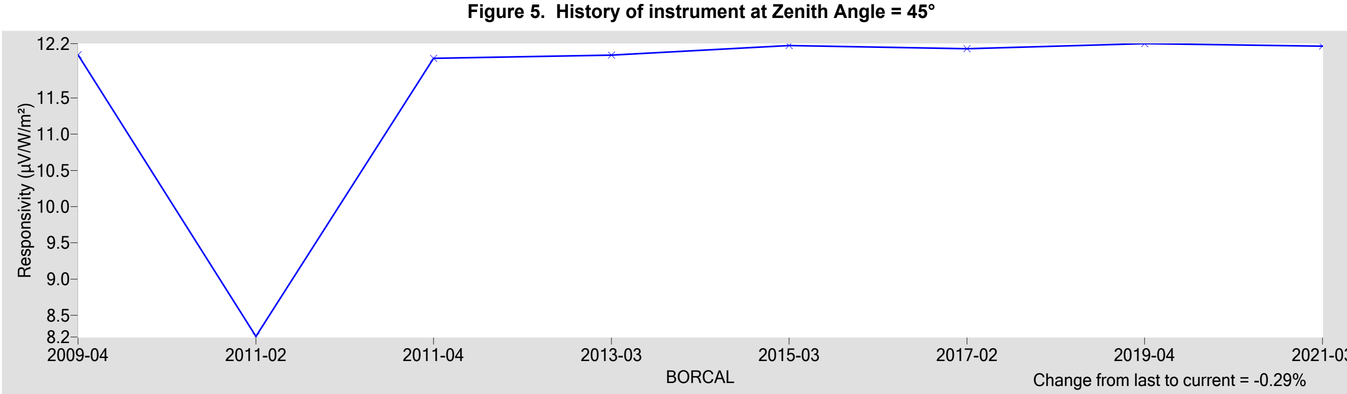
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
12.214	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.68 / -0.79
Expanded Uncertainty, U (%)	+1.4 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY28262
Calibration Date:	5/25/2021	**Due Date:**	5/25/2022
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/24-25		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. 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 International System (SI) Units of Measurement.

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.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/30/2021	04/30/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/30/2021	04/30/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and RCC

____ __________________

Afshín M. Andreas, Deputy Technical Manager — Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

PY28262 Licor LI200

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

*R = (V - Rnet * Wnet) / I* [1]

where,

V = radiometer output voltage (microvolts),
Rnet = radiometer net infrared responsivity (μV/W/m²), see Table 4,
Wnet = effective net infrared measured by pyrgeometer (W/m²),
= *Win - Wout* = *Win - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, *G = B * COS(Z) + D,*
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

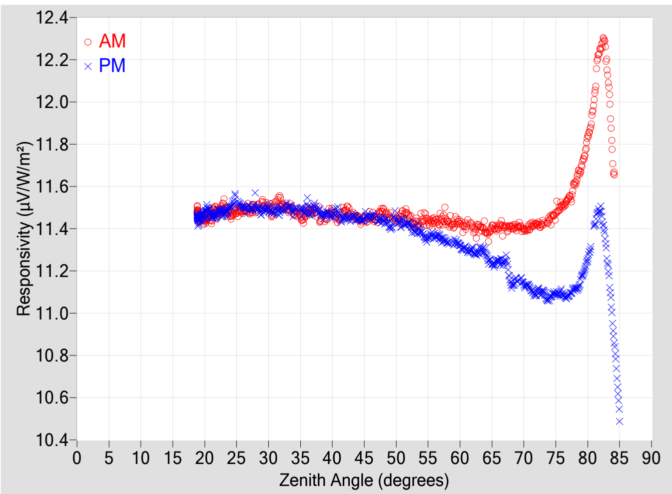


Figure 2. Responsivity vs Local Standard Time

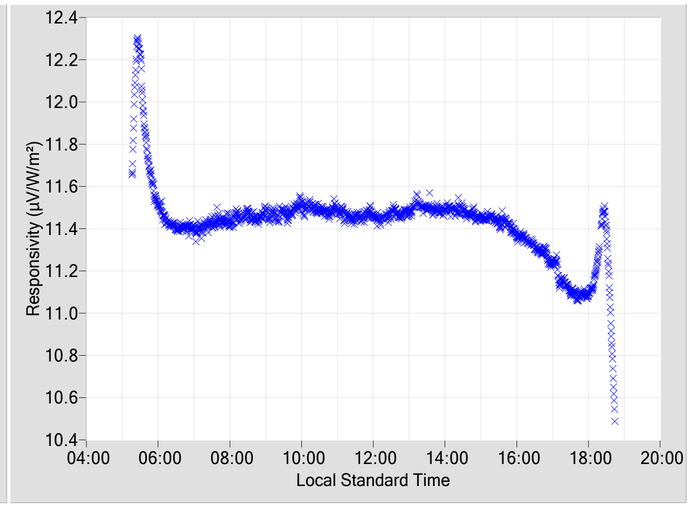


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	11.457	0.34	98.78	11.455	0.34	260.98
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.479	0.31	96.86	11.439	0.32	262.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.449	0.32	95.04	11.449	0.32	264.78
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.454	0.37	93.20	11.422	0.34	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.439	0.36	91.51	11.381	0.35	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.437	0.35	89.85	11.364	0.34	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.435	0.35	88.19	11.334	0.34	271.67
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.431	0.37	86.60	11.317	0.35	273.30
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.406	0.35	84.97	11.296	0.37	274.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.392	0.38	83.43	11.281	0.40	276.44
20	11.446	0.31	158.12	11.473	0.32	201.83	66	11.404	0.38	81.87	11.245	0.40	278.00
22	11.475	0.30	144.16	11.478	0.31	215.07	68	11.408	0.40	80.29	11.143	0.42	279.55
24	11.468	0.32	135.83	11.504	0.31	223.50	70	11.397	0.42	78.76	11.136	0.45	281.10
26	11.492	0.32	129.54	11.499	0.33	229.83	72	11.423	0.45	77.19	11.099	0.48	282.67
28	11.492	0.31	124.50	11.500	0.32	235.13	74	11.439	0.49	75.66	11.070	N/A	284.24
30	11.502	0.31	120.28	11.499	0.34	239.27	76	11.511	0.55	74.05	11.095	N/A	285.82
32	11.519	0.34	116.62	11.489	0.31	243.04	78	11.616	0.63	72.43	11.116	N/A	287.44
34	11.475	0.30	113.31	11.485	0.31	246.31	80	11.830	N/A	70.80	11.261	N/A	289.07
36	11.480	0.31	110.40	11.504	0.31	249.25	82	12.248	N/A	69.16	11.475	N/A	290.76
38	11.457	0.31	107.70	11.479	0.31	251.94	84	11.714	N/A	67.46	10.927	N/A	292.42
40	11.479	0.33	105.28	11.465	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.489	0.32	102.98	11.454	0.32	256.71	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.453	0.35	100.80	11.445	0.32	258.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

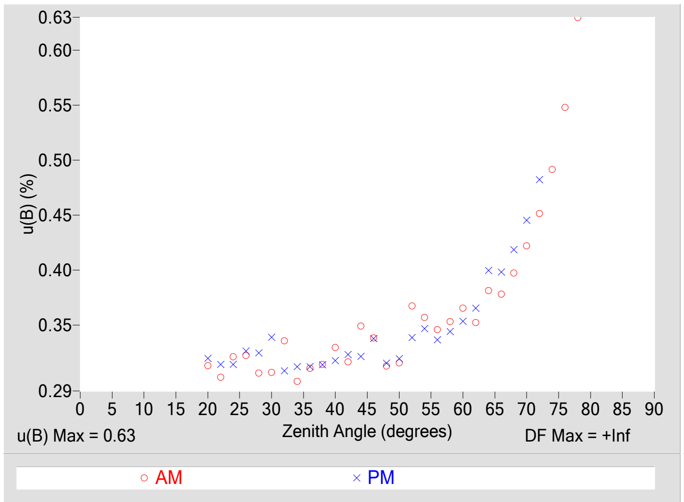


Figure 4. Residuals from Spline Interpolation

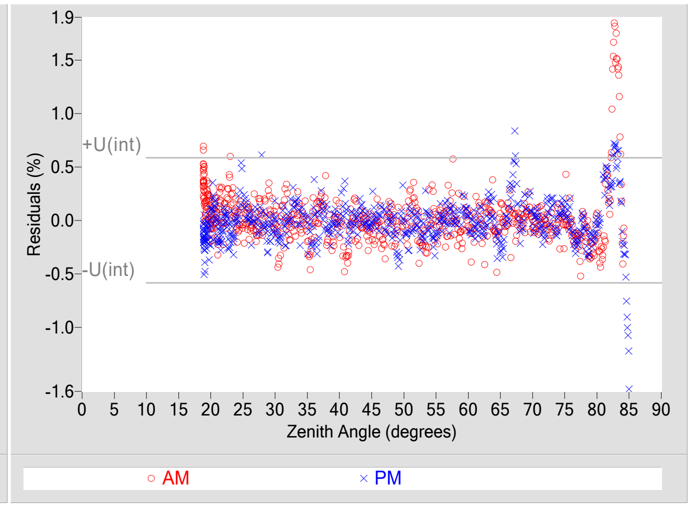


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.69
Effective degrees of freedom, DF(c)	40860
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

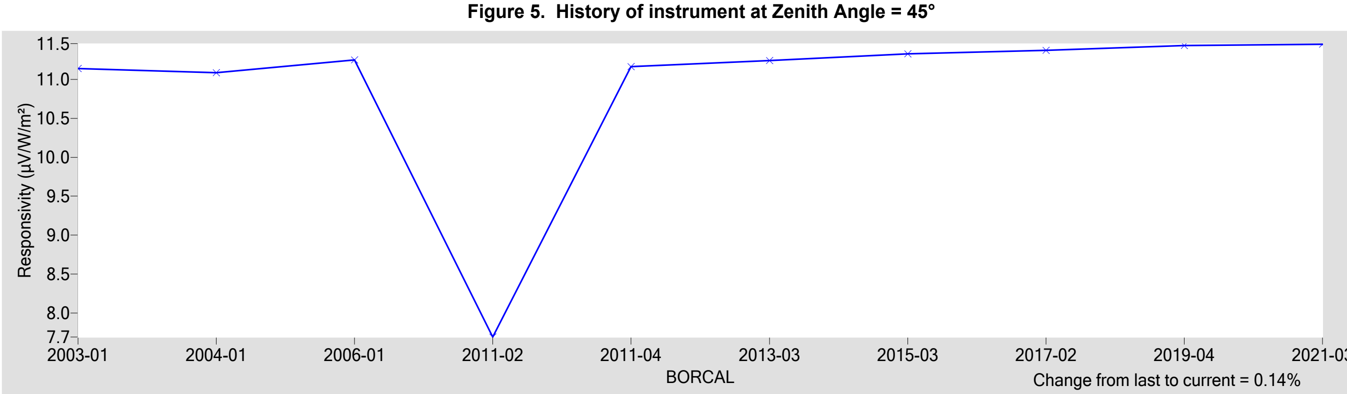
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.451	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.59 / -1.2
Expanded Uncertainty, U (%)	+1.3 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Environmental and Sky Conditions for BORCAL-SW 2021-03

Calibration Facility: Solar Radiation Research Laboratory

Latitude: 39.742°N   Longitude: 105.180°W   Elevation: 1828.8 meters AMSL   Time Zone: -7.0

Reference Irradiance:

Figure 6. Reference Irradiance

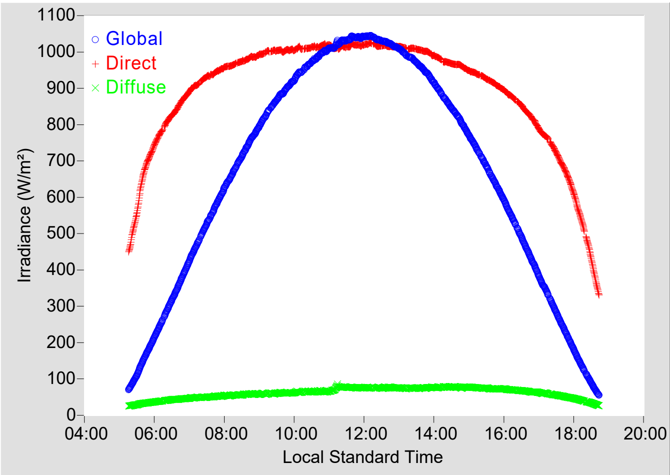
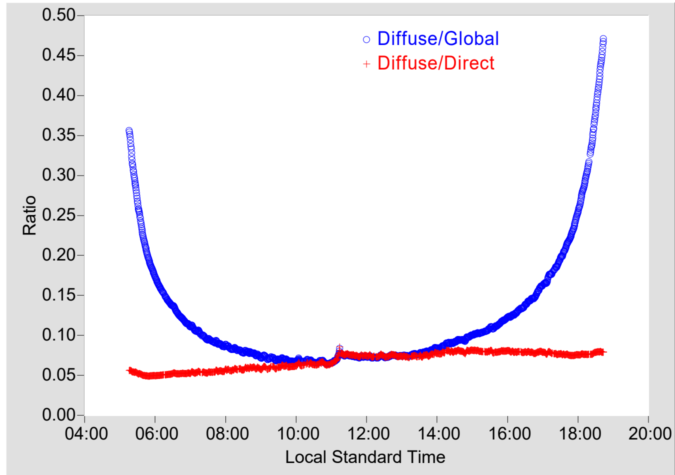


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

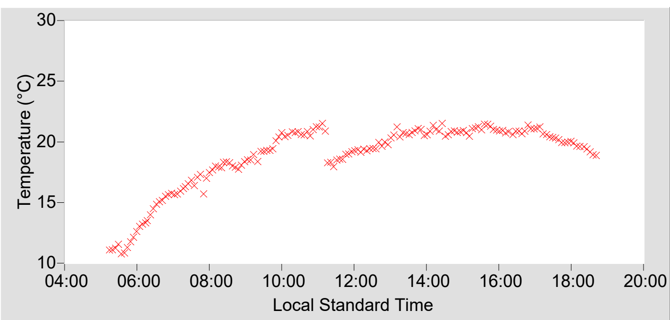


Figure 9. Humidity

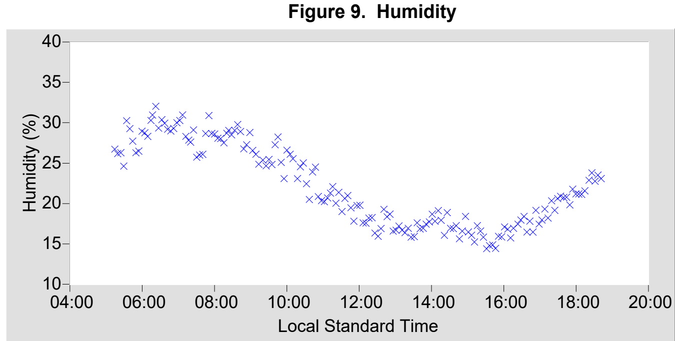


Figure 10. Pressure

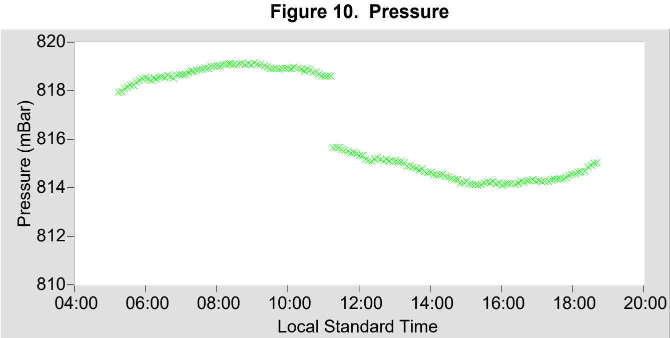


Figure 11. Effective Net Infrared

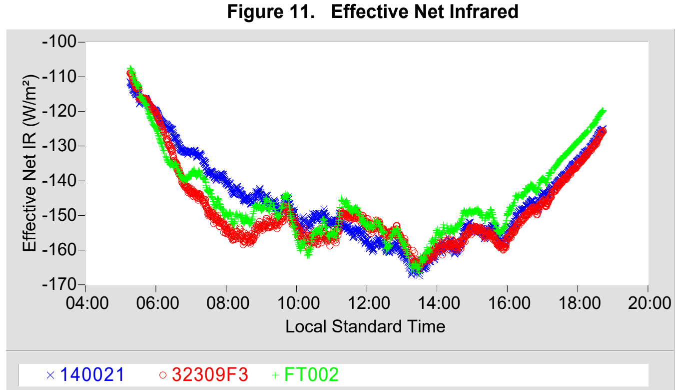


Figure 12. Estimated Broadband Aerosol Optical Depth

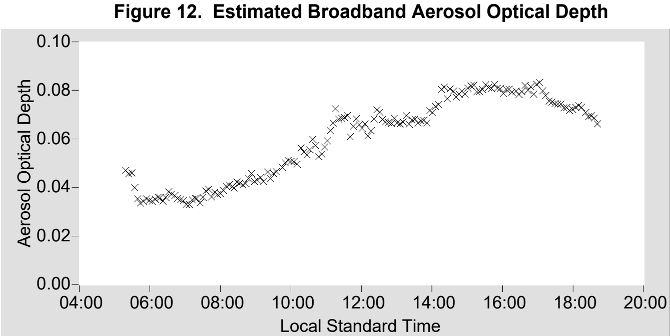


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	18.81	10.76	21.52
Humidity (%)	22.16	14.42	32.03
Pressure (mBar)	816.5	814.1	819.2
Est. Aerosol Optical Depth (BB)	0.060	0.033	0.083

For other information about the calibration facility visit: http://www.nrel.gov/esif/solar-radiation-research-laboratory.html

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Solar Radiation Research Laboratory
Comments:
Avg. Station Pressure & Temperature is for Denver, CO, which is used for the Solar Position Algorithm (SPA).

010284-UW-CM3 Kipp & Zonen CM3
Comments:
Retro-fitted from CNR1

PY1711 Licor LI200
Comments:
Cal'd with mated 147 Ohm Licor shunt

PY25070 Licor LI200
Comments:
The resistor was changed just prior to BORCAL 2006-04. Prior it was using a LICOR factory resistor, it is now using a small resistor (of very similar restistance) installed inside the Bendix Connector for use at the SRRL BMS Radiometer Tower.