Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2017-02

Customer
Mike Dooraghi

Organization: NREL
Phone: 303.384.6329

Calibration Facility
Solar Radiation Research Laboratory

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

Calibration date
05/24/2017

Report Date
May 25, 2017

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.

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

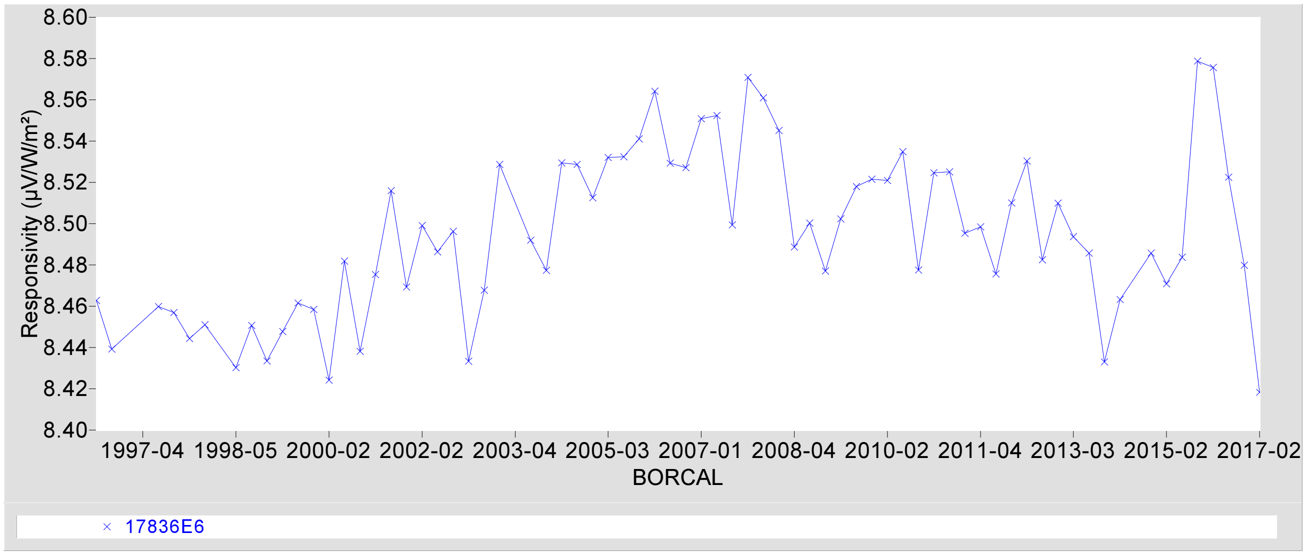
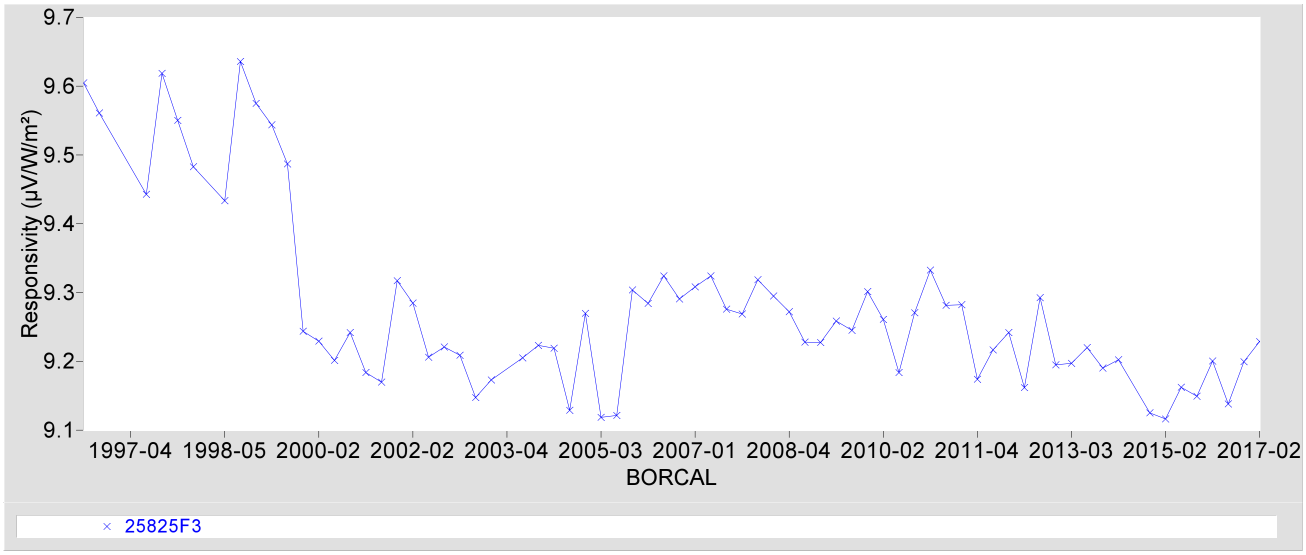


Figure 2. Eppley PSP Control Instrument History



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
010256 Kipp & Zonen CH1	10.816	92.457	+0.76 / -0.73	0	A1-2
080016 Kipp & Zonen CMP22	9.4585	105.72	+1.7 / -2.3	0.087000	A1-5
080034 Kipp & Zonen CH1	9.7528	102.53	+0.77 / -0.76	0	A1-8
080035 Kipp & Zonen CH1	9.8425	101.60	+0.86 / -0.79	0	A1-11
113796 Kipp & Zonen SP-LITE2	61.769	16.189	+1.8 / -4.7	0	A1-14
125275 Kipp & Zonen SP-LITE2	65.859	15.184	+1.9 / -2.2	0	A1-17
160430 Kipp & Zonen CMP22	9.6502	103.62	+1.4 / -1.8	0.087000	A1-20
35244 Eppley 8-48	7.4489	134.25	+2.5 / -1.8	0	A1-23
35246 Eppley 8-48	8.2205	121.65	+2.9 / -1.4	0	A1-26
PY60685 Licor LI200	9.1761	108.98	+1.2 / -1.5	0	A1-29
PY61760 Licor LI200	9.2164	108.50	+1.7 / -2.8	0	A1-32
PY63286 Licor LI200	8.1090	123.32	+1.2 / -1.2	0	A1-35
PY66480 Licor LI200	9.0029	111.08	+2.0 / -2.1	0	A1-38
S13135061 EKO ML-01	37.117	26.942	+2.4 / -1.6	0	A1-41

[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 A1-44.

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:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CH1	**Serial Number:**	010256
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

______________________________ ______________

Ibrahim Reda, 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

010256 Kipp & Zonen CH1

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

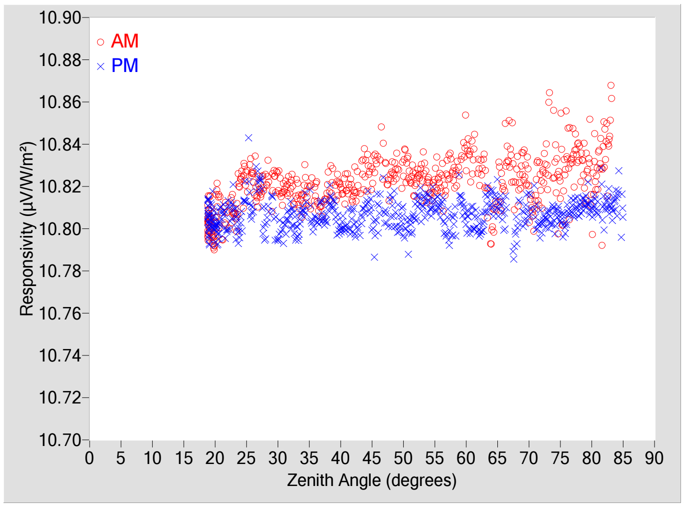


Figure 2. Responsivity vs Local Standard Time

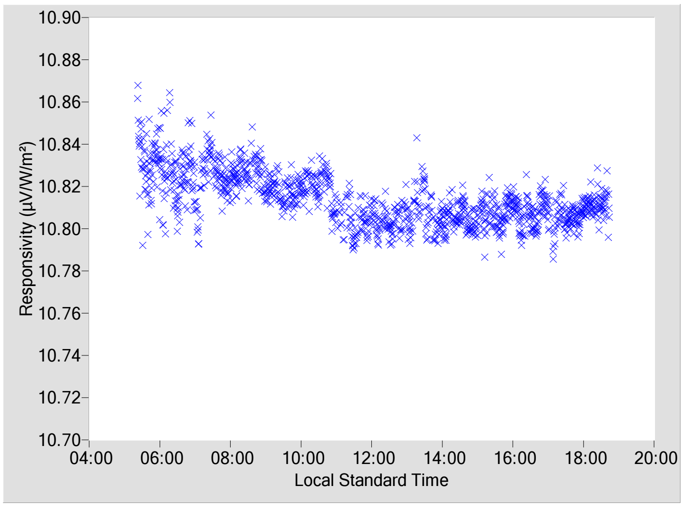


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.833	0.28	99.02	10.810	0.28	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.824	0.28	97.17	10.810	0.28	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.831	0.28	95.28	10.803	0.28	264.76
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.822	0.28	93.55	10.810	0.28	266.61
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.821	0.28	91.76	10.813	0.28	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.824	0.28	90.13	10.811	0.28	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.825	0.28	88.44	10.803	0.28	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.838	0.28	86.87	10.804	0.28	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.827	0.28	85.25	10.800	0.28	274.83
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.799	0.29	83.61	10.814	0.29	276.43
20	10.800	0.28	158.35	10.801	0.28	202.11	66	10.826	0.29	82.15	10.807	0.29	278.02
22	10.805	0.28	144.84	10.805	0.28	215.00	68	10.824	0.29	80.50	10.800	0.29	279.55
24	10.823	0.28	136.60	10.802	0.28	223.43	70	10.820	0.29	79.02	10.810	0.29	281.10
26	10.824	0.28	130.31	10.808	0.28	229.53	72	10.822	0.29	77.43	10.802	0.29	282.64
28	10.822	0.28	125.01	10.802	0.28	234.94	74	10.835	0.29	75.85	10.806	0.29	284.20
30	10.823	0.28	120.79	10.797	0.28	239.43	76	10.837	0.30	74.33	10.805	0.30	285.85
32	10.821	0.28	117.00	10.807	0.28	243.00	78	10.835	0.30	72.70	10.810	0.30	287.42
34	10.817	0.28	113.80	10.809	0.28	246.31	80	10.813	N/A	71.01	10.810	N/A	289.05
36	10.817	0.28	110.77	10.805	0.28	249.28	82	10.838	N/A	69.39	10.809	N/A	290.74
38	10.818	0.28	108.16	10.811	0.28	252.01	84	N/A	N/A	N/A	10.814	N/A	292.44
40	10.819	0.28	105.61	10.800	0.28	254.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.818	0.28	103.30	10.803	0.28	256.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.830	0.28	101.14	10.811	0.28	258.97	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

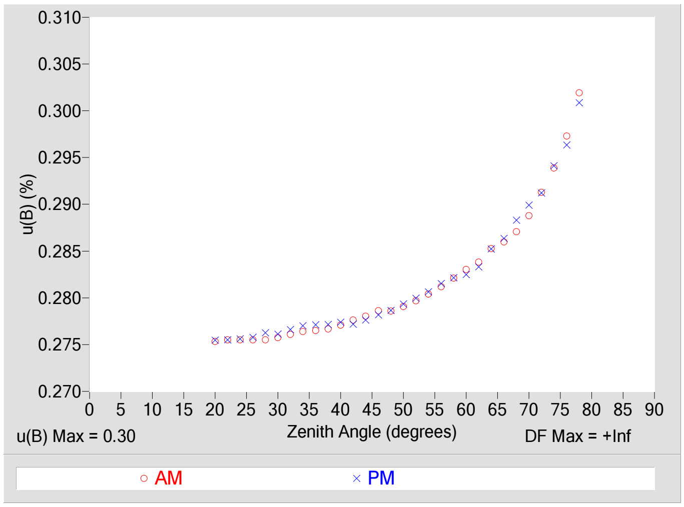


Figure 4. Residuals from Spline Interpolation

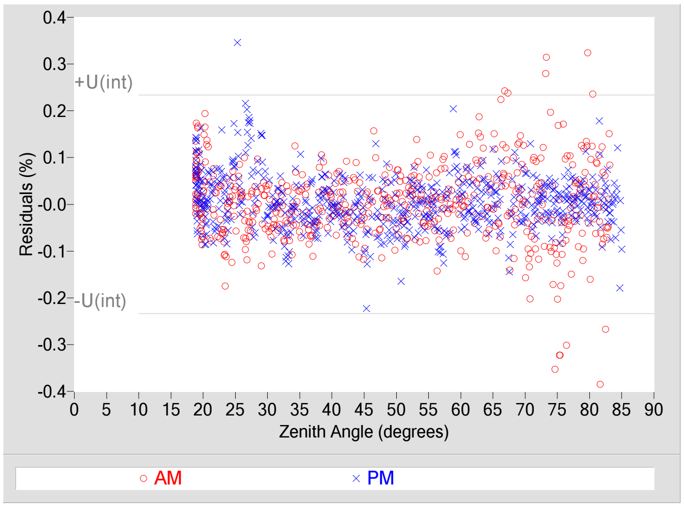


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.12
Combined Standard Uncertainty, u(c) (%)	±0.32
Effective degrees of freedom, DF(c)	66163
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.63
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 78°

Table 4. Calibration Label Values

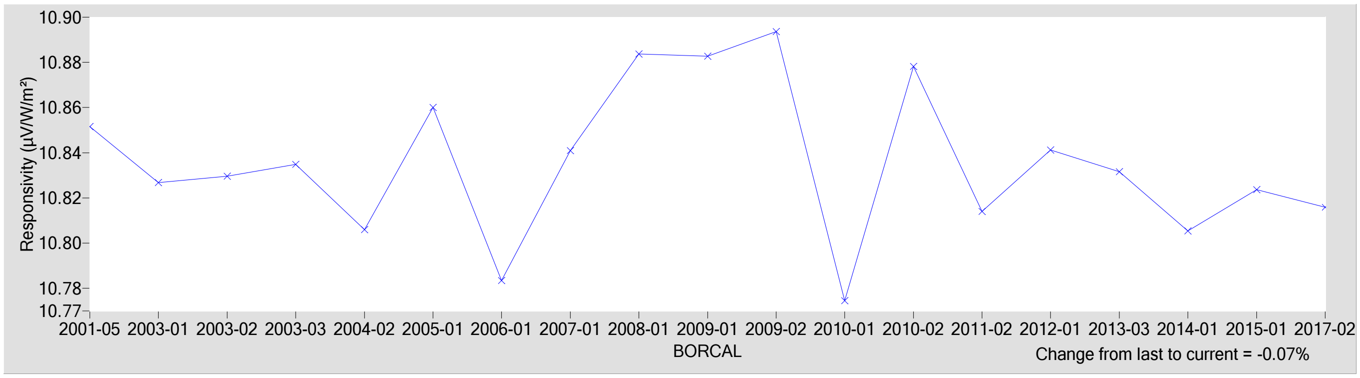
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.816	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.55
Offset Uncertainty, U(off) (%)	+0.21 / -0.17
Expanded Uncertainty, U (%)	+0.76 / -0.73
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:**	080016
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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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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.

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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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† 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

______________________________________ __________________
Ibrahim Reda, 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

080016 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),
= $Win - Wout$ = $Win - \sigma * Tc^4$
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

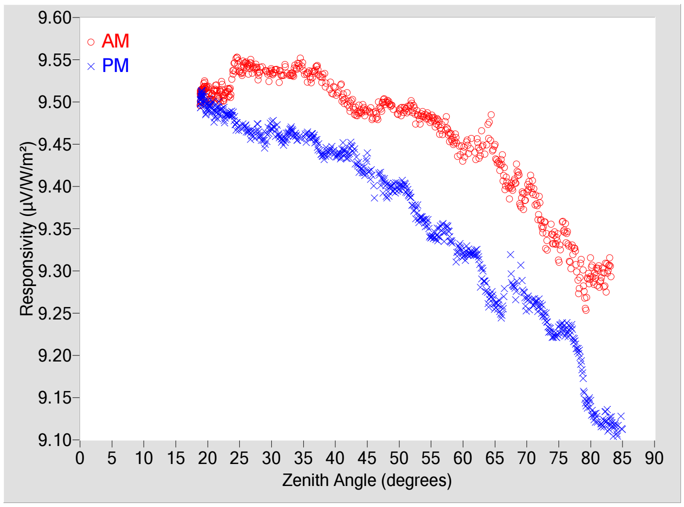


Figure 2. Responsivity vs Local Standard Time

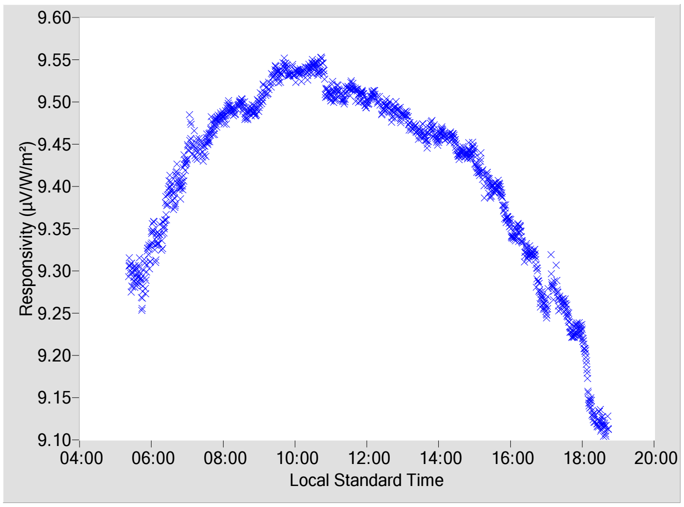


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.4841	0.34	99.18	9.4001	0.34	260.93
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4996	0.34	97.15	9.3962	0.34	262.92
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.4888	0.34	95.33	9.3992	0.35	264.81
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.4949	0.35	93.50	9.3800	0.36	266.54
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4838	0.36	91.84	9.3581	0.37	268.35
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4770	0.37	90.09	9.3428	0.38	269.99
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4584	0.38	88.41	9.3376	0.39	271.68
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.4401	0.39	86.81	9.3191	0.40	273.24
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.4452	0.41	85.17	9.3216	0.42	274.88
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.4638	0.42	83.71	9.2682	0.43	276.40
20	9.5123	0.30	157.97	9.4947	0.31	202.29	66	9.4244	0.44	82.11	9.2510	0.46	277.99
22	9.5116	0.31	144.98	9.4905	0.31	214.98	68	9.4037	0.46	80.51	9.2792	0.49	279.51
24	9.5378	0.31	136.56	9.4826	0.31	223.39	70	9.3918	0.49	79.03	9.2634	0.52	281.11
26	9.5441	0.31	130.32	9.4687	0.31	229.77	72	9.3695	0.53	77.47	9.2579	0.55	282.68
28	9.5349	0.31	125.23	9.4654	0.31	234.89	74	9.3414	0.58	75.86	9.2243	0.60	284.27
30	9.5351	0.31	120.73	9.4716	0.31	239.18	76	9.3458	0.65	74.30	9.2306	0.65	285.82
32	9.5372	0.31	117.14	9.4554	0.31	243.04	78	9.2900	0.74	72.68	9.2049	0.74	287.43
34	9.5416	0.32	113.74	9.4573	0.32	246.17	80	9.2993	N/A	71.07	9.1398	N/A	289.05
36	9.5302	0.32	110.81	9.4597	0.32	249.40	82	9.2924	N/A	69.35	9.1219	N/A	290.71
38	9.5286	0.32	108.24	9.4365	0.32	251.95	84	N/A	N/A	N/A	9.1133	N/A	292.44
40	9.5145	0.32	105.72	9.4376	0.33	254.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5005	0.33	103.31	9.4376	0.33	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.4897	0.33	101.25	9.4197	0.33	258.89	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

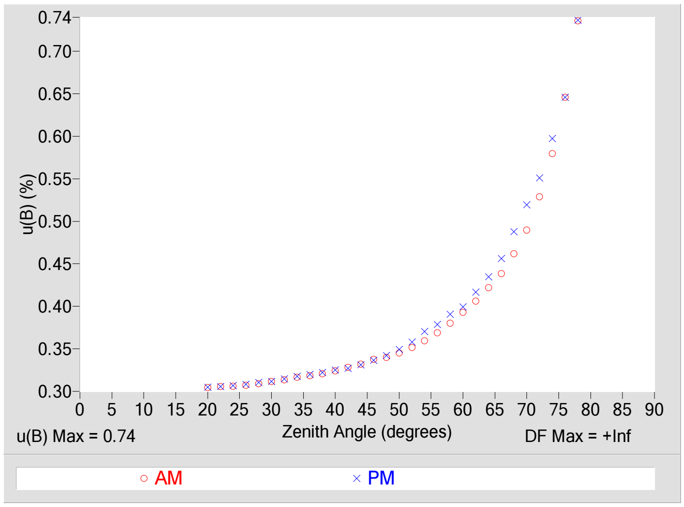


Figure 4. Residuals from Spline Interpolation

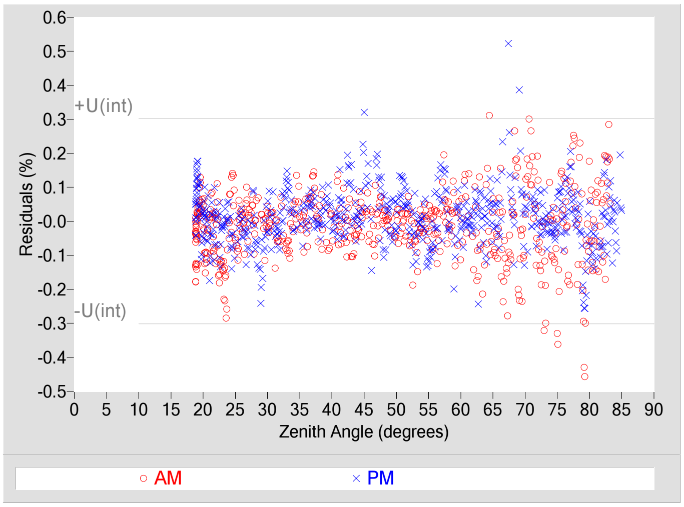


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	673117
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 78°

Table 4. Calibration Label Values

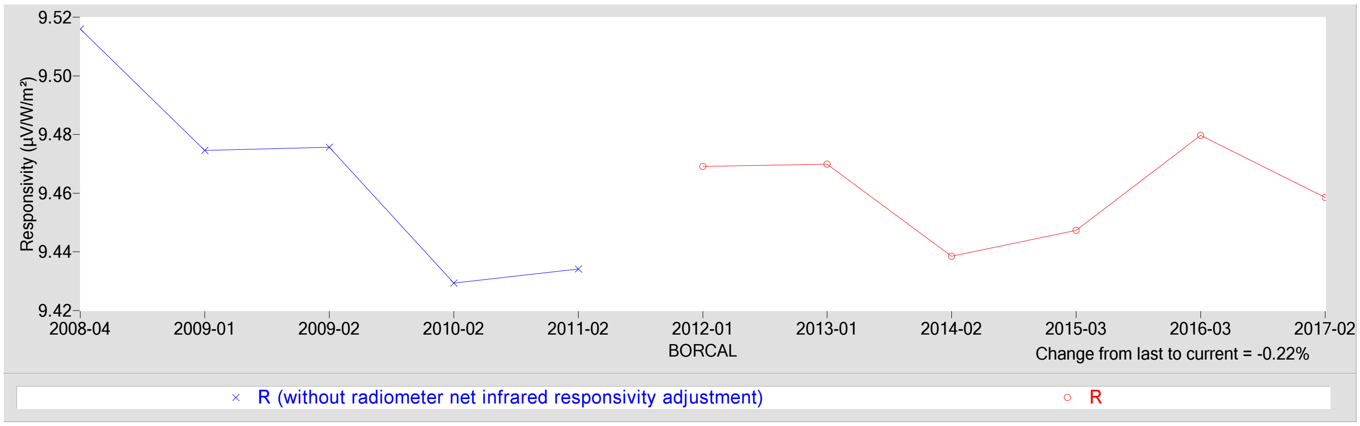
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.4585	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+0.88 / -1.5
Expanded Uncertainty, U (%)	+1.7 / -2.3
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

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CH1	**Serial Number:**	080034
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

______________________________ ____________

Ibrahim Reda, 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

080034 Kipp & Zonen CH1

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

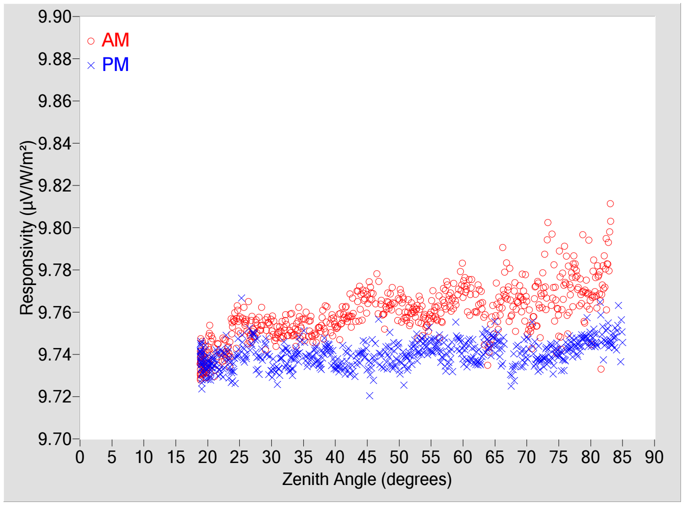


Figure 2. Responsivity vs Local Standard Time

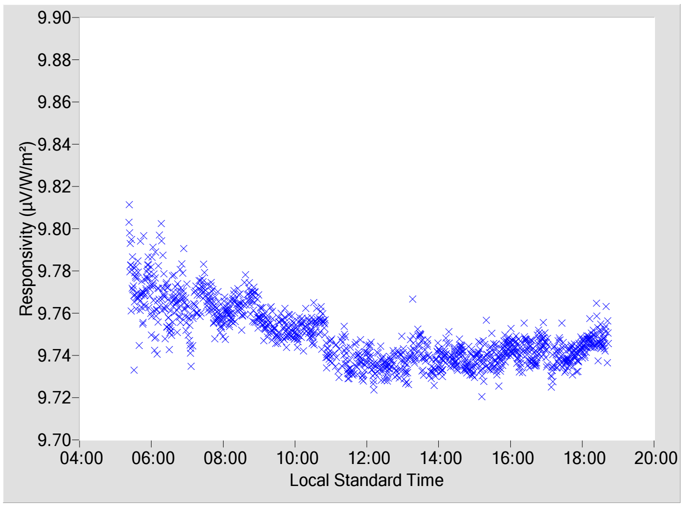


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.7663	0.28	99.02	9.7390	0.28	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7620	0.28	97.17	9.7397	0.28	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7647	0.28	95.28	9.7389	0.28	264.76
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7599	0.28	93.55	9.7410	0.28	266.61
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7564	0.28	91.76	9.7451	0.28	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7606	0.28	90.13	9.7453	0.28	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7652	0.28	88.44	9.7397	0.28	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7734	0.28	86.87	9.7404	0.28	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7622	0.28	85.25	9.7381	0.28	274.83
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7436	0.29	83.61	9.7454	0.29	276.43
20	9.7369	0.28	158.35	9.7349	0.28	202.11	66	9.7677	0.29	82.15	9.7410	0.29	278.02
22	9.7393	0.28	144.84	9.7366	0.28	215.00	68	9.7644	0.29	80.50	9.7341	0.29	279.55
24	9.7551	0.28	136.60	9.7319	0.28	223.43	70	9.7623	0.29	79.02	9.7417	0.29	281.10
26	9.7532	0.28	130.31	9.7384	0.28	229.53	72	9.7639	0.29	77.43	9.7366	0.29	282.64
28	9.7536	0.28	125.01	9.7379	0.28	234.94	74	9.7762	0.29	75.85	9.7394	0.29	284.20
30	9.7539	0.28	120.79	9.7332	0.28	239.43	76	9.7773	0.30	74.33	9.7395	0.30	285.85
32	9.7535	0.28	117.00	9.7401	0.28	243.00	78	9.7725	0.30	72.70	9.7436	0.30	287.42
34	9.7527	0.28	113.80	9.7413	0.28	246.31	80	9.7613	N/A	71.01	9.7466	N/A	289.05
36	9.7531	0.28	110.77	9.7394	0.28	249.28	82	9.7762	N/A	69.39	9.7462	N/A	290.74
38	9.7537	0.28	108.16	9.7403	0.28	252.01	84	N/A	N/A	N/A	9.7486	N/A	292.44
40	9.7536	0.28	105.61	9.7342	0.28	254.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7592	0.28	103.30	9.7364	0.28	256.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7657	0.28	101.14	9.7397	0.28	258.97	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

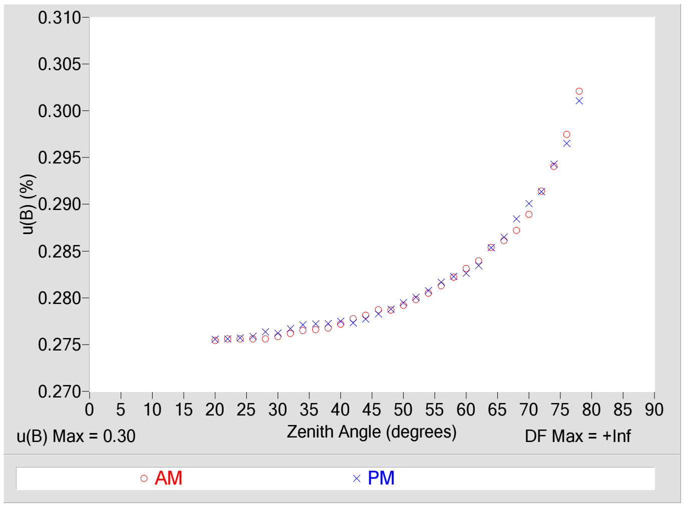


Figure 4. Residuals from Spline Interpolation

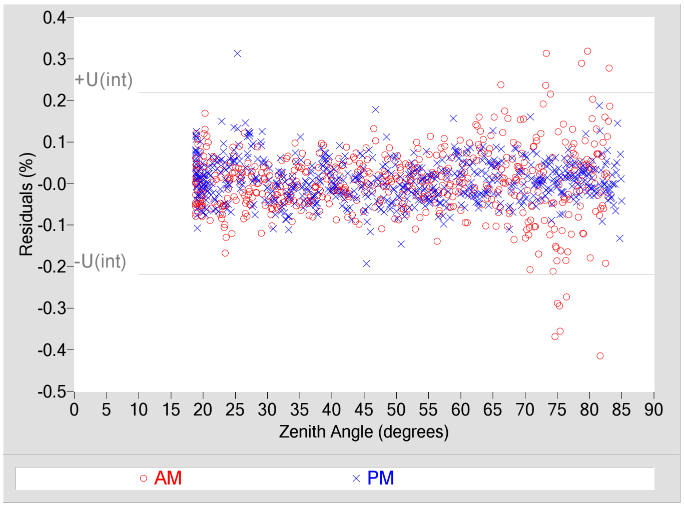


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.11
Combined Standard Uncertainty, u(c) (%)	±0.32
Effective degrees of freedom, DF(c)	83804
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.63
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 78°

Table 4. Calibration Label Values

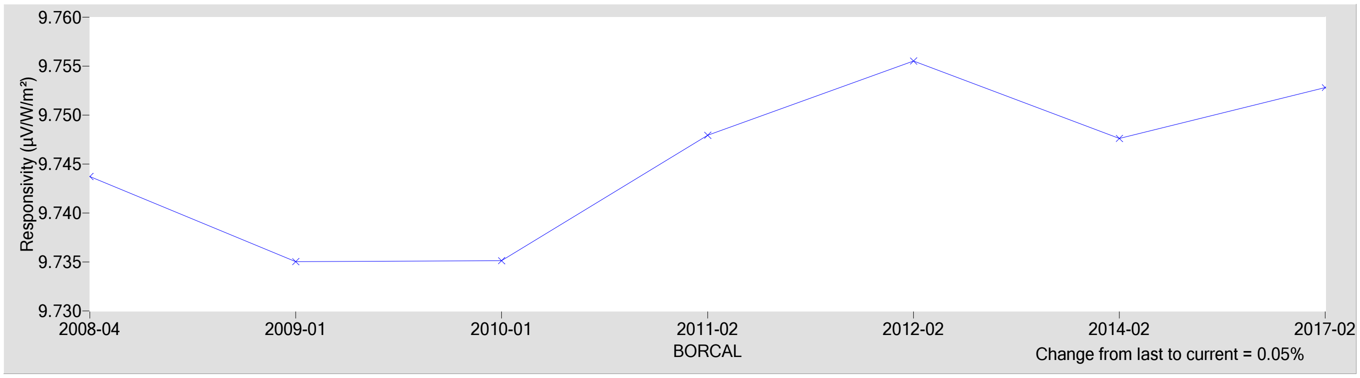
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.7528	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.55
Offset Uncertainty, U(off) (%)	+0.21 / -0.20
Expanded Uncertainty, U (%)	+0.77 / -0.76
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

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[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:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CH1	**Serial Number:**	080035
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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.

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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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

____ ____________________

Ibrahim Reda, 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

080035 Kipp & Zonen CH1

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

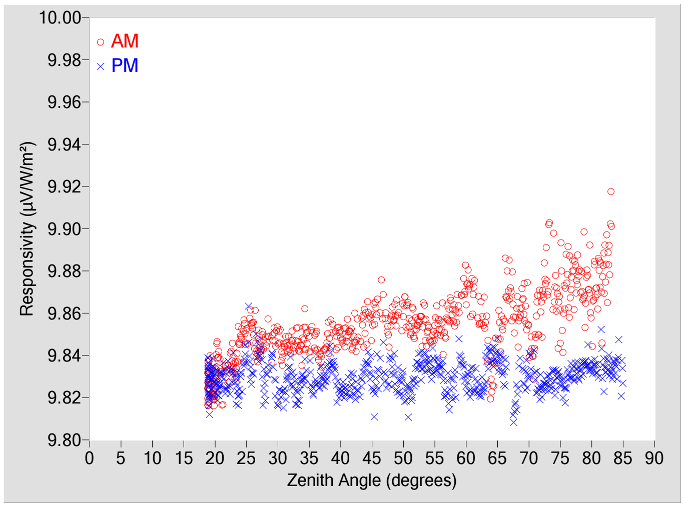


Figure 2. Responsivity vs Local Standard Time

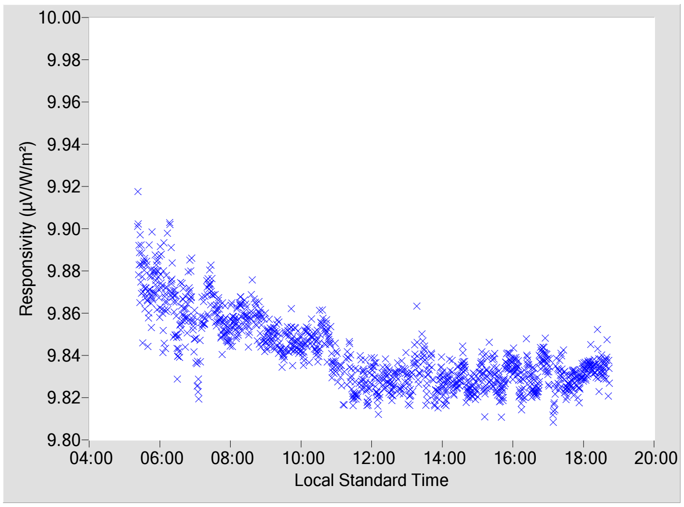


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.8634	0.28	99.02	9.8333	0.28	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8554	0.28	97.17	9.8346	0.28	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8623	0.28	95.28	9.8258	0.28	264.76
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8531	0.28	93.55	9.8328	0.28	266.61
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8506	0.28	91.76	9.8360	0.28	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8552	0.28	90.13	9.8338	0.28	270.02
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8594	0.28	88.44	9.8262	0.28	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8723	0.28	86.87	9.8273	0.28	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8589	0.28	85.25	9.8235	0.28	274.83
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.8268	0.29	83.61	9.8400	0.29	276.43
20	9.8271	0.28	158.35	9.8284	0.28	202.11	66	9.8610	0.29	82.15	9.8319	0.29	278.02
22	9.8319	0.28	144.84	9.8295	0.28	215.00	68	9.8580	0.29	80.50	9.8202	0.29	279.55
24	9.8478	0.28	136.60	9.8261	0.28	223.43	70	9.8529	0.29	79.02	9.8327	0.29	281.10
26	9.8523	0.28	130.31	9.8302	0.28	229.53	72	9.8638	0.29	77.43	9.8239	0.29	282.64
28	9.8467	0.28	125.01	9.8271	0.28	234.94	74	9.8750	0.29	75.85	9.8285	0.29	284.20
30	9.8496	0.28	120.79	9.8198	0.28	239.43	76	9.8776	0.30	74.33	9.8265	0.30	285.85
32	9.8455	0.28	117.00	9.8317	0.28	243.00	78	9.8790	0.30	72.70	9.8325	0.30	287.42
34	9.8477	0.28	113.80	9.8303	0.28	246.31	80	9.8588	N/A	71.01	9.8340	N/A	289.05
36	9.8467	0.28	110.77	9.8272	0.28	249.28	82	9.8811	N/A	69.39	9.8326	N/A	290.74
38	9.8475	0.28	108.16	9.8354	0.28	252.01	84	N/A	N/A	N/A	9.8350	N/A	292.44
40	9.8491	0.28	105.61	9.8227	0.28	254.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8480	0.28	103.30	9.8257	0.28	256.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8566	0.28	101.14	9.8354	0.28	258.97	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

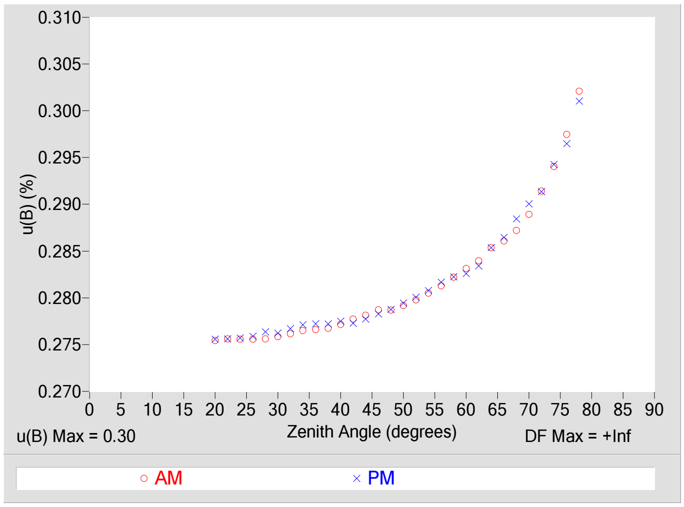


Figure 4. Residuals from Spline Interpolation

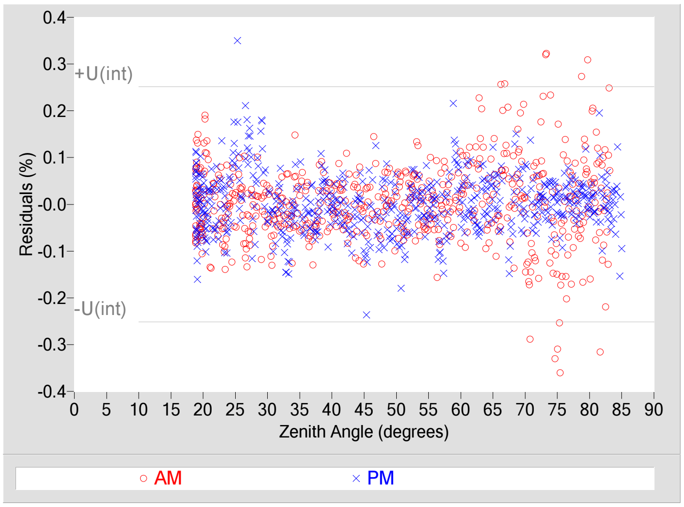


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.33
Effective degrees of freedom, DF(c)	51364
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.64
AM Valid zenith angle range	20° to 78°
PM Valid zenith angle range	20° to 78°

Table 4. Calibration Label Values

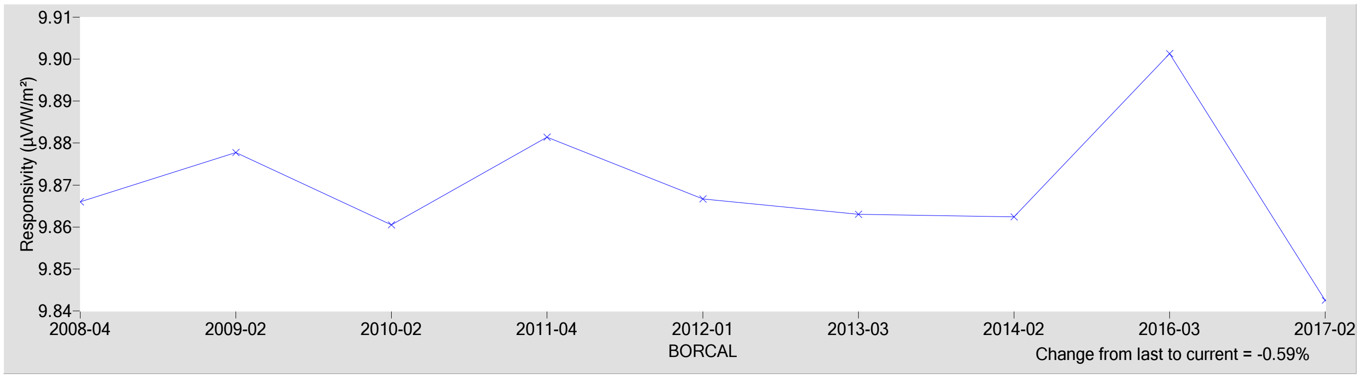
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.8425	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.55
Offset Uncertainty, U(off) (%)	+0.30 / -0.23
Expanded Uncertainty, U (%)	+0.86 / -0.79
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:**	113796
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

______________________________ ____________

Ibrahim Reda, 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

113796 Kipp & Zonen SP-LITE2

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

$$R = (V - R_{net} * W_{net}) / I \qquad [1]$$

where,

V = radiometer output voltage (microvolts),
R_{net} = radiometer net infrared responsivity (μV/W/m²), see Table 4,
W_{net} = effective net infrared measured by pyrgeometer (W/m²),
= $W_{in} - W_{out}$ = $W_{in} - \sigma * T_c^4$
where, W_{in} = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
T_c = 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

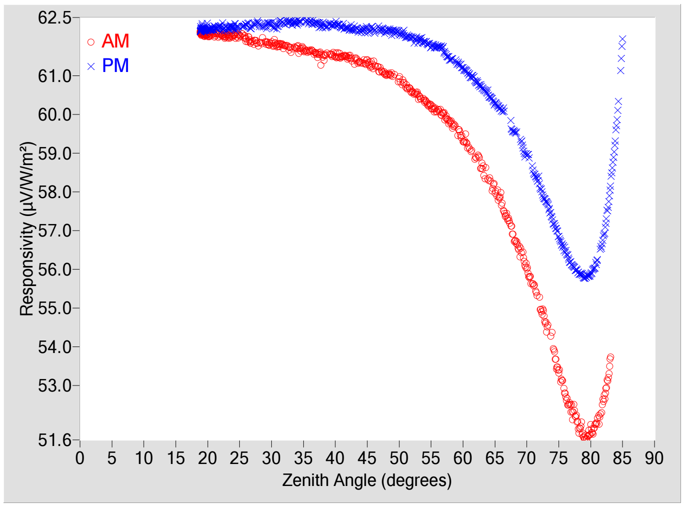


Figure 2. Responsivity vs Local Standard Time

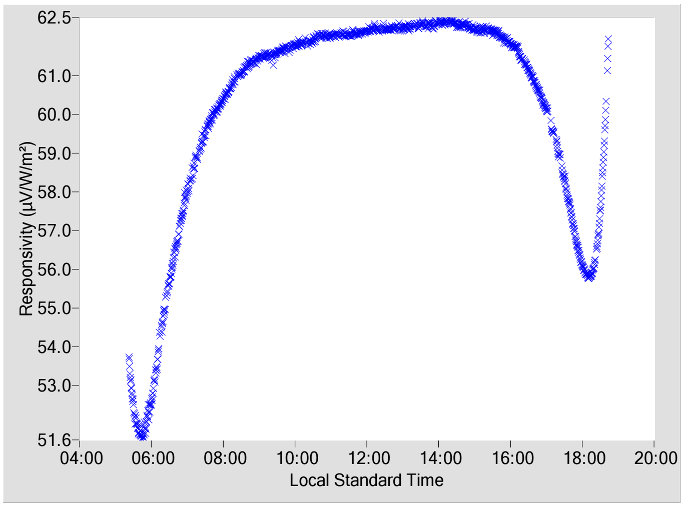


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	61.268	0.34	99.08	62.185	0.34	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	61.033	0.34	97.25	62.165	0.34	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	60.895	0.34	95.29	62.106	0.35	264.76
6	N/A	N/A	N/A	N/A	N/A	N/A	52	60.598	0.35	93.59	61.954	0.36	266.61
8	N/A	N/A	N/A	N/A	N/A	N/A	54	60.352	0.36	91.77	61.865	0.37	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	60.109	0.37	90.14	61.744	0.38	270.03
12	N/A	N/A	N/A	N/A	N/A	N/A	58	59.795	0.38	88.44	61.425	0.39	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	59.347	0.39	86.87	61.173	0.40	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	58.875	0.40	85.29	60.866	0.41	274.83
18	N/A	N/A	N/A	N/A	N/A	N/A	64	58.315	0.42	83.59	60.500	0.43	276.43
20	62.047	0.30	158.08	62.194	0.30	201.99	66	57.810	0.43	82.18	60.123	0.45	278.02
22	62.048	0.30	145.14	62.262	0.30	215.35	68	56.806	0.46	80.56	59.548	0.48	279.55
24	62.028	0.31	136.67	62.263	0.31	223.51	70	55.997	0.49	79.00	58.958	0.51	281.06
26	61.954	0.31	130.39	62.314	0.31	229.76	72	55.030	0.53	77.35	58.189	0.54	282.64
28	61.817	0.31	125.25	62.341	0.31	234.78	74	54.130	0.57	75.88	57.300	0.59	284.21
30	61.828	0.31	120.82	62.315	0.31	239.19	76	52.755	0.64	74.25	56.478	0.64	285.81
32	61.764	0.31	117.17	62.346	0.31	242.87	78	51.991	0.73	72.68	55.929	0.72	287.43
34	61.705	0.32	113.75	62.370	0.32	246.31	80	51.823	N/A	71.06	55.885	N/A	289.05
36	61.642	0.32	110.84	62.383	0.32	249.26	82	52.609	N/A	69.39	56.869	N/A	290.74
38	61.458	0.32	108.08	62.309	0.32	251.95	84	N/A	N/A	N/A	59.634	N/A	292.44
40	61.502	0.32	105.54	62.324	0.32	254.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	61.482	0.33	103.31	62.209	0.33	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	61.346	0.33	101.21	62.162	0.33	258.93	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

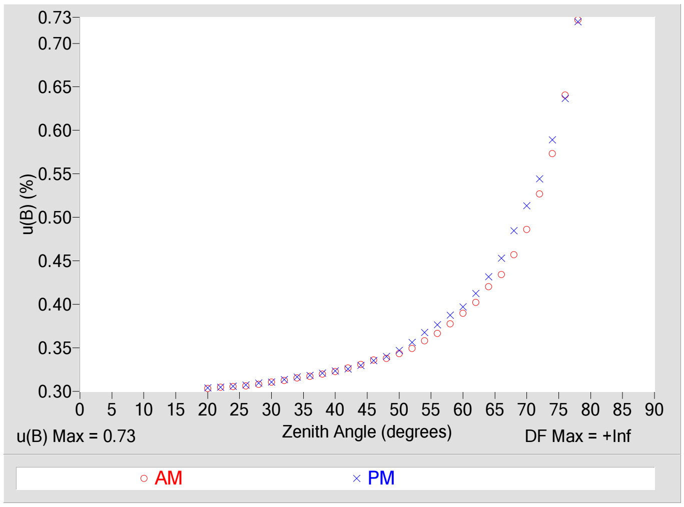


Figure 4. Residuals from Spline Interpolation

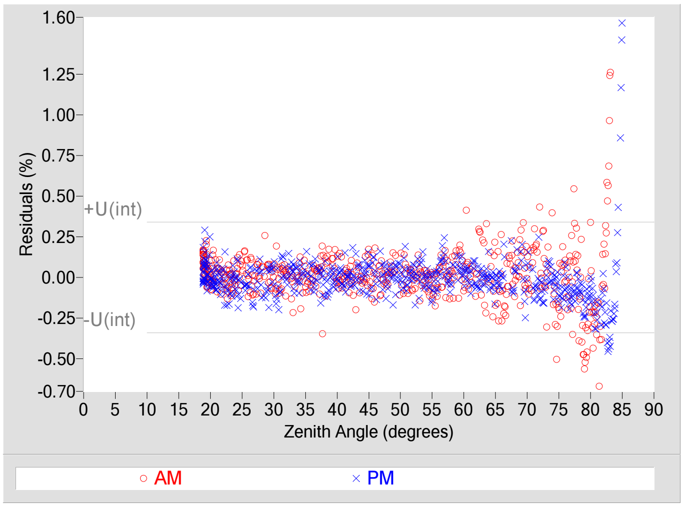


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.73
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	416599
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 78°

Table 4. Calibration Label Values

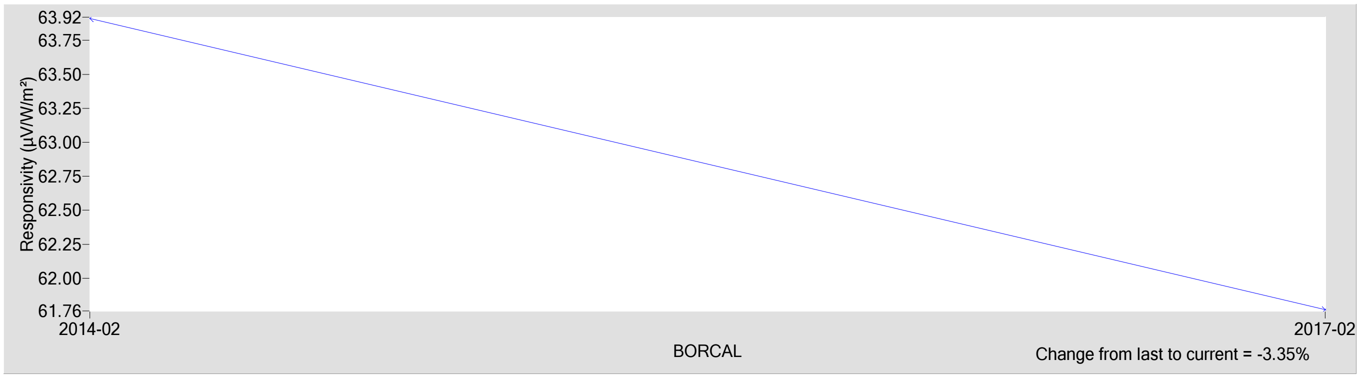
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
61.769	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+0.99 / -3.9
Expanded Uncertainty, U (%)	+1.8 / -4.7
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

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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:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	125275
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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.

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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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

______________________________ _______________

Ibrahim Reda, 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

125275 Kipp & Zonen SP-LITE2

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

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

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

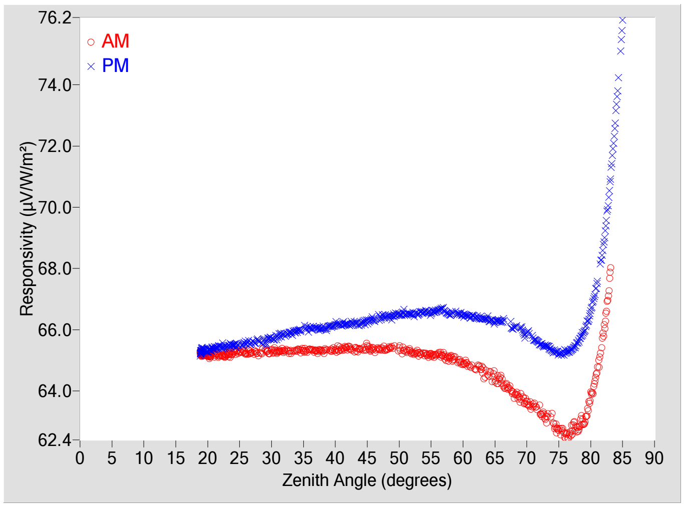


Figure 2. Responsivity vs Local Standard Time

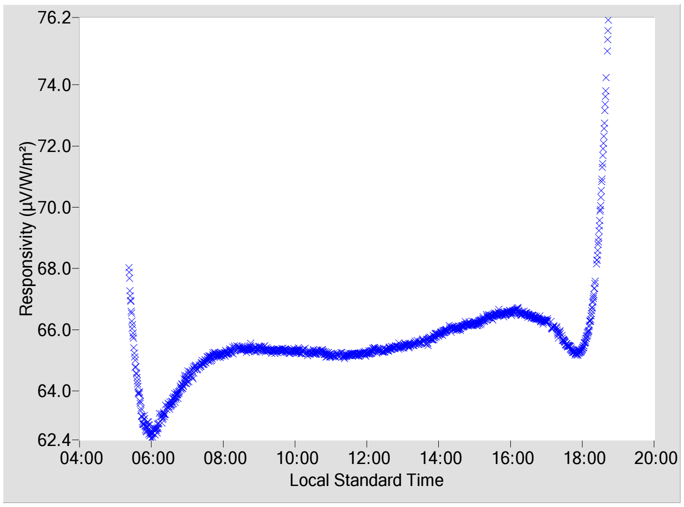


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	65.353	0.34	99.08	66.333	0.34	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	65.347	0.34	97.25	66.444	0.34	262.95
4	N/A	N/A	N/A	N/A	N/A	N/A	50	65.380	0.34	95.29	66.496	0.35	264.76
6	N/A	N/A	N/A	N/A	N/A	N/A	52	65.258	0.35	93.59	66.503	0.36	266.61
8	N/A	N/A	N/A	N/A	N/A	N/A	54	65.208	0.36	91.77	66.589	0.37	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	65.197	0.37	90.14	66.622	0.38	270.03
12	N/A	N/A	N/A	N/A	N/A	N/A	58	65.084	0.38	88.44	66.510	0.39	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	64.892	0.39	86.87	66.467	0.40	273.28
16	N/A	N/A	N/A	N/A	N/A	N/A	62	64.706	0.40	85.29	66.404	0.41	274.83
18	N/A	N/A	N/A	N/A	N/A	N/A	64	64.562	0.42	83.59	66.321	0.43	276.43
20	65.153	0.30	158.08	65.313	0.30	201.91	66	64.398	0.43	82.18	66.281	0.45	278.02
22	65.148	0.30	145.14	65.438	0.30	215.15	68	63.884	0.46	80.56	66.062	0.48	279.55
24	65.241	0.31	136.67	65.505	0.31	223.51	70	63.619	0.49	79.00	65.870	0.51	281.06
26	65.236	0.31	130.39	65.564	0.31	229.76	72	63.312	0.53	77.35	65.538	0.54	282.64
28	65.210	0.31	125.25	65.641	0.31	234.78	74	63.075	0.57	75.88	65.311	0.59	284.21
30	65.281	0.31	120.82	65.721	0.31	239.19	76	62.565	0.64	74.25	65.269	0.64	285.81
32	65.299	0.31	117.17	65.834	0.31	242.87	78	62.753	0.73	72.68	65.616	0.72	287.43
34	65.328	0.32	113.75	65.964	0.32	246.31	80	63.809	N/A	71.06	66.611	N/A	289.05
36	65.349	0.32	110.84	66.036	0.32	249.26	82	65.900	N/A	69.39	68.823	N/A	290.74
38	65.298	0.32	108.08	66.047	0.32	251.95	84	N/A	N/A	N/A	73.211	N/A	292.44
40	65.322	0.32	105.54	66.178	0.32	254.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	65.411	0.33	103.31	66.170	0.33	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	65.372	0.33	101.21	66.189	0.33	258.93	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

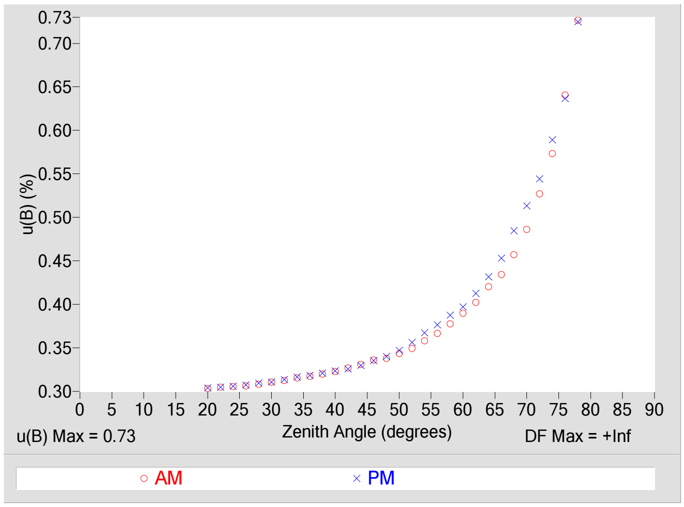


Figure 4. Residuals from Spline Interpolation

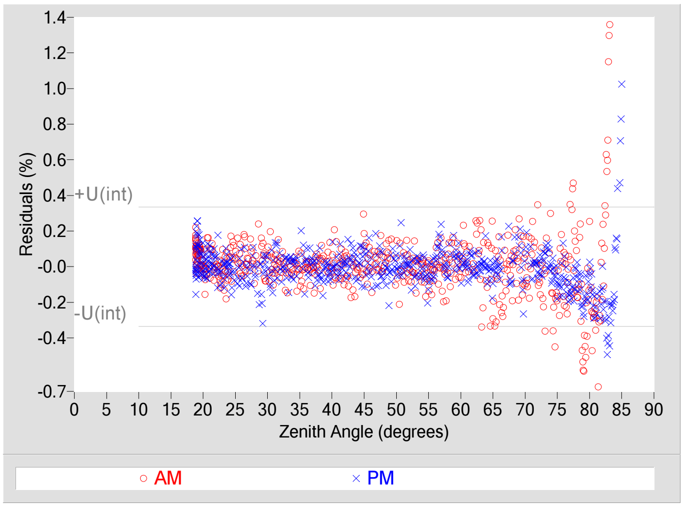


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.73
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	440889
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 78°

Table 4. Calibration Label Values

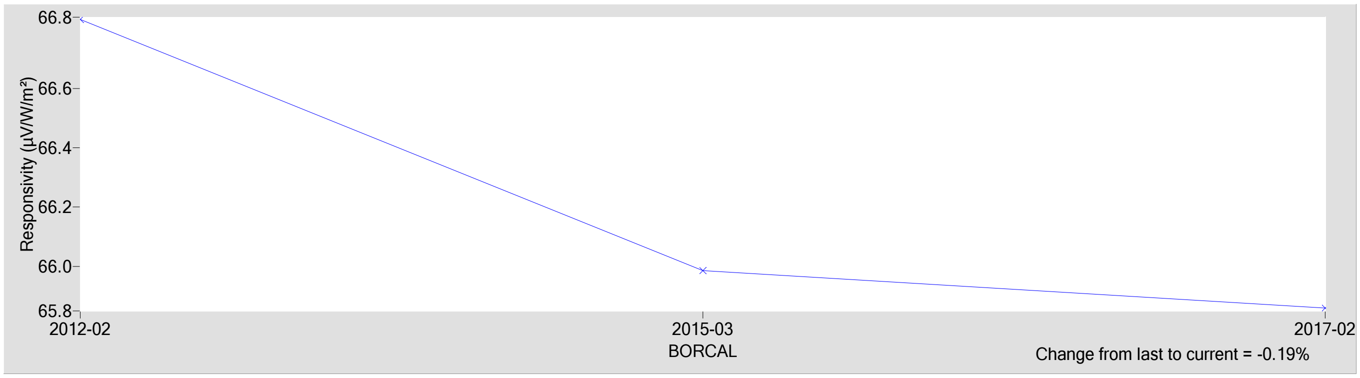
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
65.859	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.2 / -1.5
Expanded Uncertainty, U (%)	+1.9 / -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:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	160430
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† 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

Ibrahim Reda, 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),
= $Win - Wout$ = $Win - \sigma * Tc^4$
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

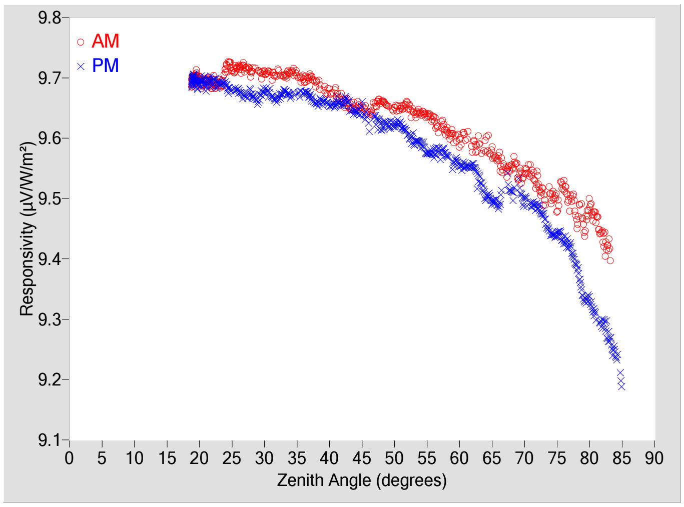


Figure 2. Responsivity vs Local Standard Time

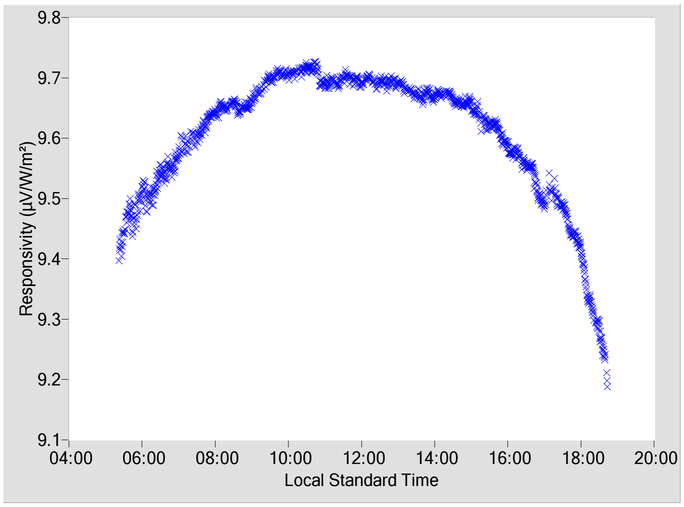


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.6427	0.34	99.18	9.6240	0.34	260.93
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.6601	0.34	97.15	9.6206	0.34	262.92
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6497	0.34	95.33	9.6225	0.35	264.81
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6549	0.35	93.50	9.6068	0.36	266.54
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.6417	0.36	91.84	9.5904	0.37	268.35
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6336	0.37	90.09	9.5756	0.38	269.99
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6113	0.38	88.41	9.5713	0.39	271.68
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5958	0.39	86.81	9.5554	0.40	273.24
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.5884	0.41	85.17	9.5541	0.42	274.88
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.5889	0.42	83.71	9.5049	0.43	276.40
20	9.6970	0.30	157.97	9.6933	0.30	202.29	66	9.5641	0.44	82.11	9.4885	0.46	277.99
22	9.6919	0.31	144.98	9.6950	0.31	214.98	68	9.5514	0.46	80.51	9.5097	0.49	279.51
24	9.7147	0.31	136.56	9.6895	0.31	223.39	70	9.5398	0.49	79.03	9.4972	0.52	281.11
26	9.7175	0.31	130.32	9.6785	0.31	229.77	72	9.5277	0.53	77.47	9.4857	0.55	282.68
28	9.7107	0.31	125.23	9.6731	0.31	234.89	74	9.5054	0.58	75.86	9.4420	0.60	284.27
30	9.7080	0.31	120.73	9.6785	0.31	239.18	76	9.5194	0.65	74.30	9.4309	0.65	285.82
32	9.7085	0.31	117.14	9.6666	0.31	243.04	78	9.4658	0.74	72.68	9.3867	0.74	287.43
34	9.7092	0.32	113.74	9.6701	0.32	246.17	80	9.4864	N/A	71.07	9.3320	N/A	289.05
36	9.6974	0.32	110.81	9.6752	0.32	249.40	82	9.4361	N/A	69.35	9.2937	N/A	290.71
38	9.6917	0.32	108.24	9.6575	0.32	251.95	84	N/A	N/A	N/A	9.2427	N/A	292.44
40	9.6790	0.32	105.72	9.6552	0.33	254.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.6638	0.33	103.31	9.6575	0.33	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.6518	0.33	101.25	9.6433	0.33	258.89	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

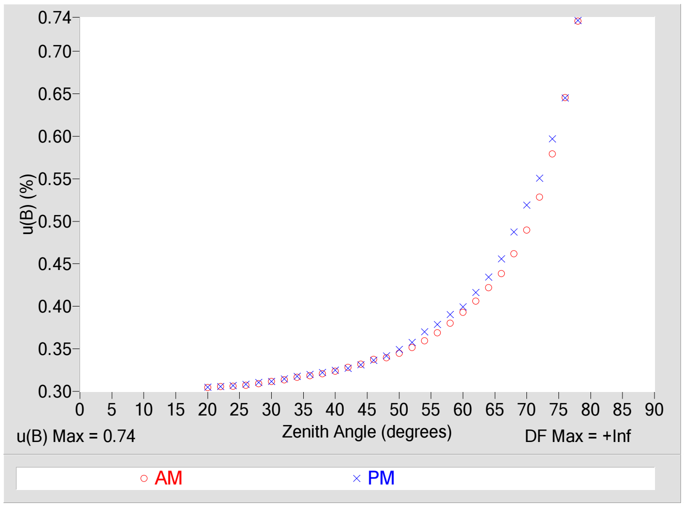


Figure 4. Residuals from Spline Interpolation

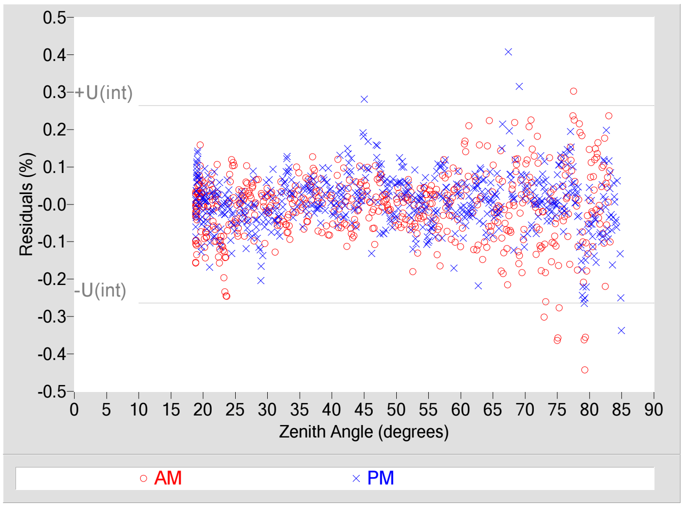


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	1129094
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 78°

Table 4. Calibration Label Values

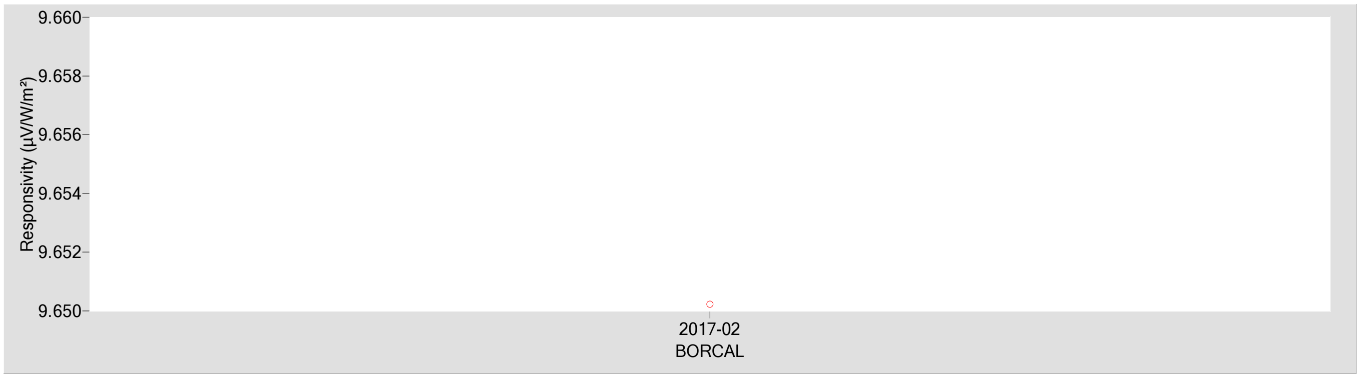
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.6502	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+0.61 / -0.98
Expanded Uncertainty, U (%)	+1.4 / -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

[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.

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[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: Black and White Pyranometer

Manufacturer: Eppley

Model: 8-48

Serial Number: 35244

Calibration Date: 5/24/2017

Due Date: 5/24/2018

Customer: Mike Dooraghi

Environmental Conditions: see page 4

Test Dates: 5/24

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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.

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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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

____ ____________________

Ibrahim Reda, 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

35244 Eppley 8-48

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

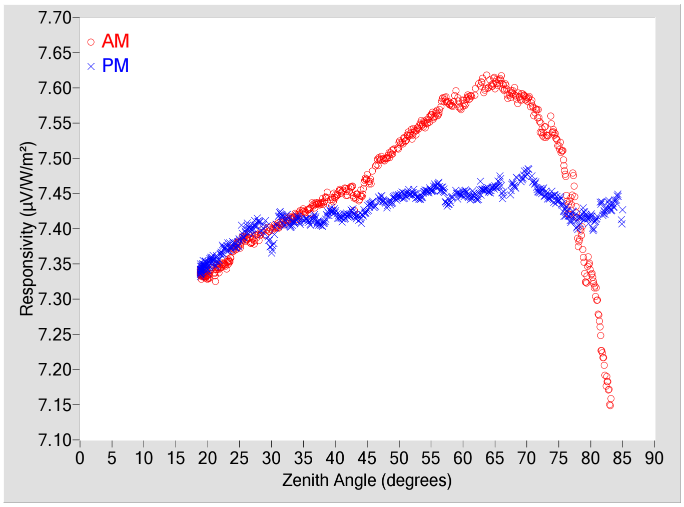


Figure 2. Responsivity vs Local Standard Time

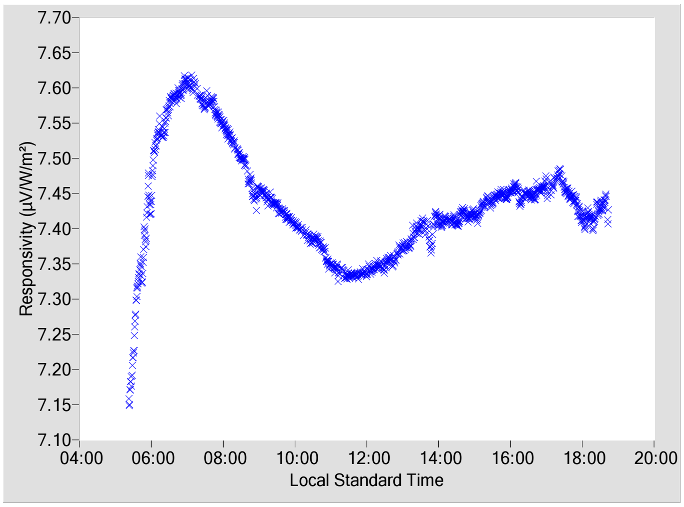


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM			PM			Zenith Angle (deg.)	AM			PM		
	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle		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	7.4819	0.34	99.31	7.4342	0.34	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4995	0.34	97.18	7.4339	0.34	262.89
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5193	0.34	95.27	7.4465	0.35	264.75
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5352	0.35	93.53	7.4505	0.36	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5493	0.36	91.76	7.4530	0.37	268.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5642	0.37	90.12	7.4622	0.38	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5766	0.38	88.43	7.4394	0.39	271.62
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5773	0.39	86.84	7.4493	0.40	273.27
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5941	0.40	85.32	7.4455	0.42	274.82
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.6039	0.42	83.65	7.4537	0.43	276.42
20	7.3330	0.30	158.52	7.3458	0.30	202.40	66	7.6089	0.44	82.13	7.4580	0.46	278.01
22	7.3453	0.31	145.09	7.3653	0.31	215.31	68	7.5929	0.46	80.55	7.4613	0.49	279.54
24	7.3707	0.31	136.61	7.3770	0.31	223.58	70	7.5842	0.49	78.99	7.4803	0.52	281.13
26	7.3858	0.31	130.13	7.4004	0.31	229.99	72	7.5504	0.53	77.42	7.4534	0.55	282.63
28	7.3899	0.31	125.02	7.4111	0.31	234.83	74	7.5435	0.58	75.89	7.4464	0.60	284.23
30	7.3993	0.31	120.96	7.3721	0.31	239.16	76	7.4780	0.65	74.32	7.4250	0.65	285.84
32	7.4084	0.31	117.23	7.4085	0.31	243.01	78	7.3942	0.74	72.67	7.4063	0.73	287.42
34	7.4173	0.32	113.86	7.4155	0.32	246.36	80	7.3405	N/A	71.05	7.4148	N/A	289.08
36	7.4258	0.32	110.89	7.4085	0.32	249.26	82	7.2137	N/A	69.42	7.4247	N/A	290.73
38	7.4373	0.32	108.15	7.4068	0.32	252.06	84	N/A	N/A	N/A	7.4430	N/A	292.47
40	7.4459	0.32	105.64	7.4238	0.32	254.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4526	0.33	103.34	7.4194	0.33	256.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4474	0.33	101.12	7.4157	0.33	258.97	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

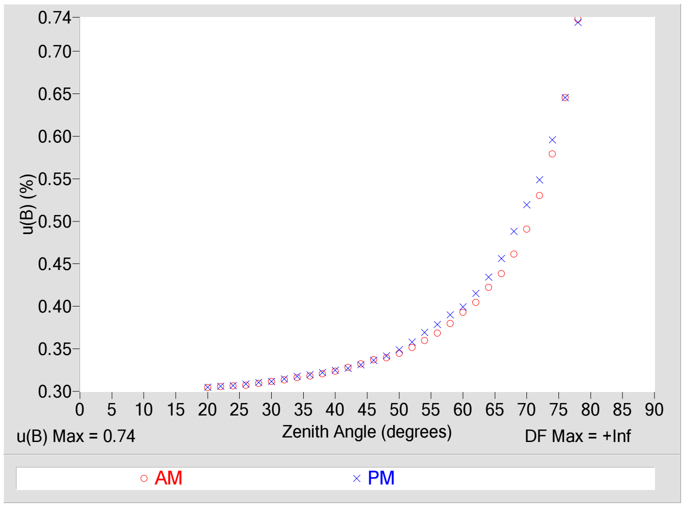


Figure 4. Residuals from Spline Interpolation

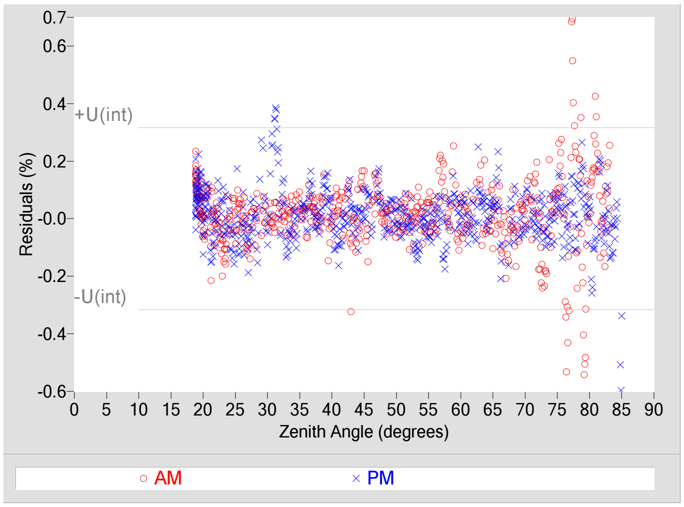


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	588716
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 78°

Table 4. Calibration Label Values

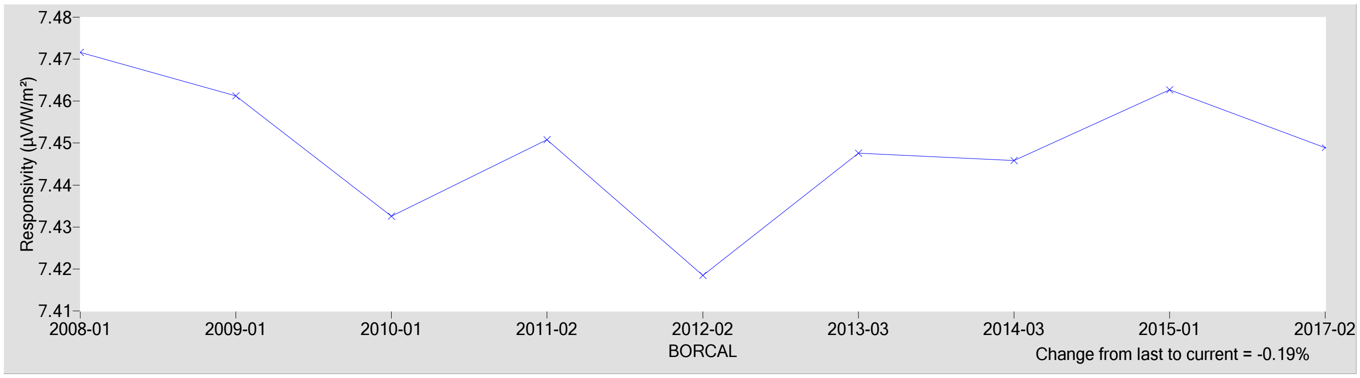
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.4489	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.7 / -1.0
Expanded Uncertainty, U (%)	+2.5 / -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

[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:	Black and White Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	35246
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

______________________________ ______________

Ibrahim Reda, 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

35246 Eppley 8-48

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

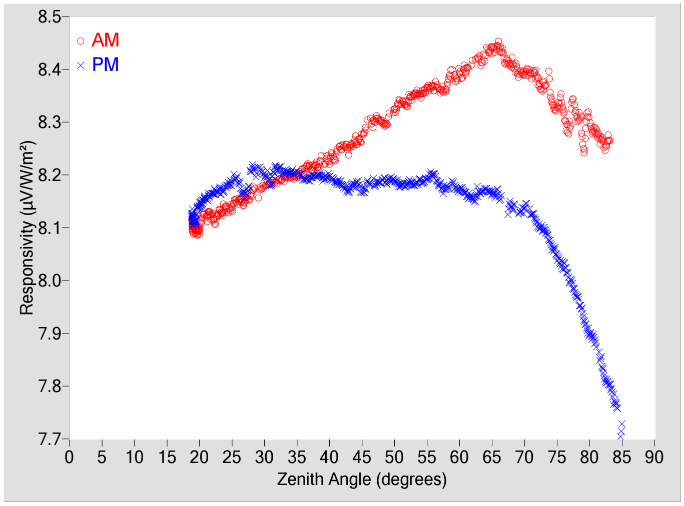


Figure 2. Responsivity vs Local Standard Time

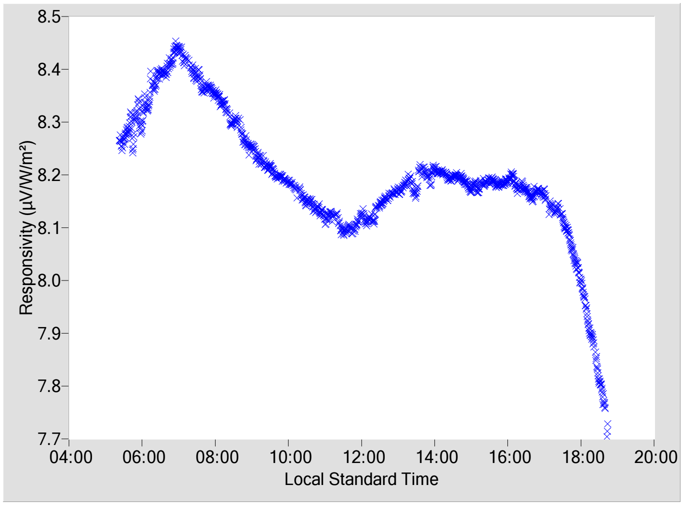


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM			PM			Zenith Angle (deg.)	AM			PM		
	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle		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	8.3045	0.34	99.31	8.1853	0.34	260.99
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3010	0.34	97.18	8.1881	0.34	262.89
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3221	0.34	95.27	8.1895	0.35	264.75
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3371	0.35	93.53	8.1843	0.36	266.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3537	0.36	91.76	8.1894	0.37	268.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3655	0.37	90.12	8.2000	0.38	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3677	0.38	88.43	8.1757	0.39	271.62
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3918	0.39	86.84	8.1714	0.40	273.27
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4125	0.40	85.32	8.1554	0.41	274.82
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4278	0.42	83.65	8.1721	0.43	276.42
20	8.0985	0.30	158.52	8.1434	0.30	202.40	66	8.4420	0.44	82.13	8.1622	0.46	278.01
22	8.1203	0.31	145.09	8.1660	0.31	215.31	68	8.4105	0.46	80.55	8.1400	0.49	279.54
24	8.1386	0.31	136.61	8.1767	0.31	223.58	70	8.3933	0.49	78.99	8.1385	0.52	281.13
26	8.1510	0.31	130.13	8.1850	0.31	229.99	72	8.3819	0.53	77.42	8.1066	0.55	282.63
28	8.1657	0.31	125.02	8.2110	0.31	234.83	74	8.3606	0.58	75.89	8.0697	0.59	284.23
30	8.1782	0.31	120.96	8.1987	0.31	239.16	76	8.3215	0.64	74.32	8.0284	0.64	285.84
32	8.1877	0.31	117.23	8.2108	0.31	243.01	78	8.3105	0.74	72.67	7.9711	0.73	287.42
34	8.1975	0.32	113.86	8.2051	0.32	246.36	80	8.3028	N/A	71.05	7.8992	N/A	289.08
36	8.2080	0.32	110.89	8.1921	0.32	249.26	82	8.2654	N/A	69.42	7.8339	N/A	290.73
38	8.2178	0.32	108.15	8.1984	0.32	252.06	84	N/A	N/A	N/A	7.7682	N/A	292.47
40	8.2310	0.32	105.64	8.1967	0.32	254.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2535	0.33	103.34	8.1802	0.33	256.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2628	0.33	101.12	8.1826	0.33	258.97	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

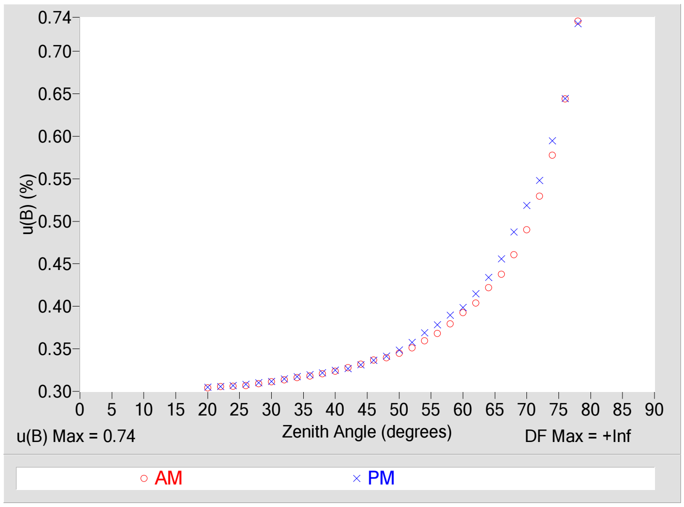


Figure 4. Residuals from Spline Interpolation

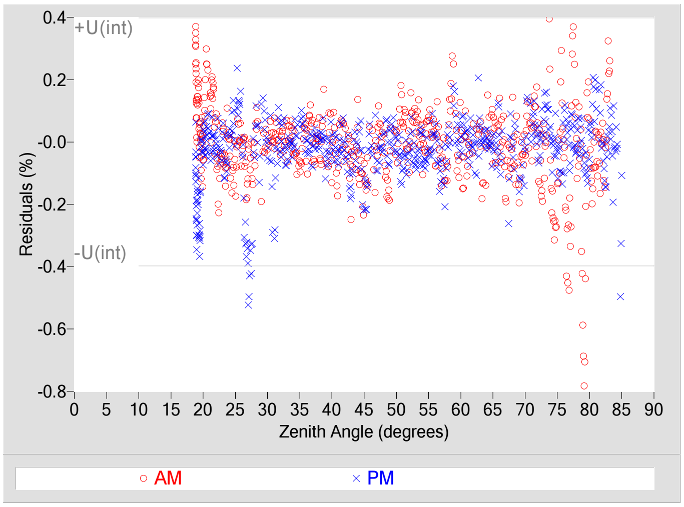


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	245461
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 78°

Table 4. Calibration Label Values

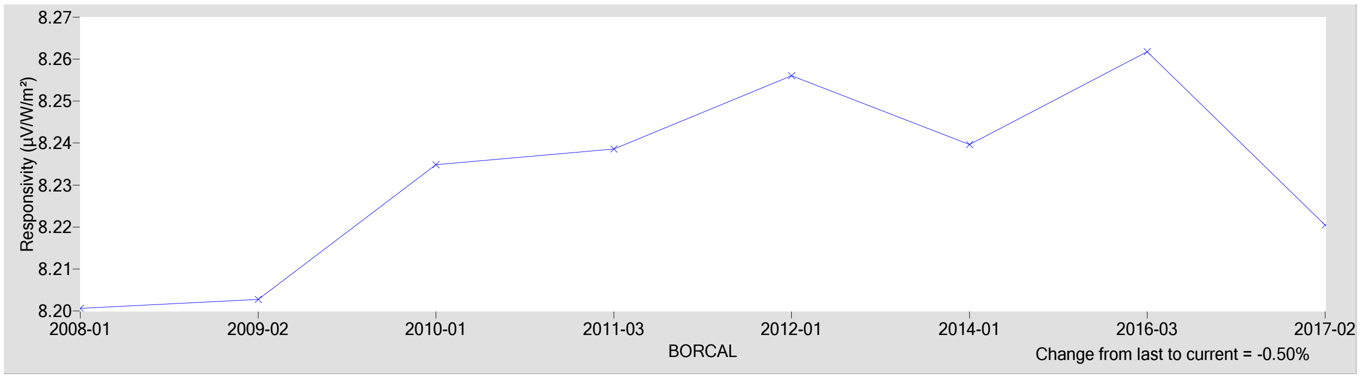
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.2205	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+2.1 / -0.60
Expanded Uncertainty, U (%)	+2.9 / -1.4
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

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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.

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[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:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY60685
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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.

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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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

____ ________________
Ibrahim Reda, 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

PY60685 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

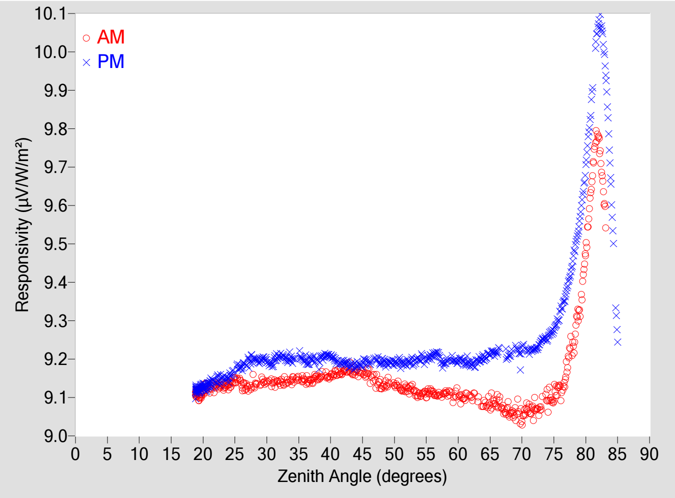


Figure 2. Responsivity vs Local Standard Time

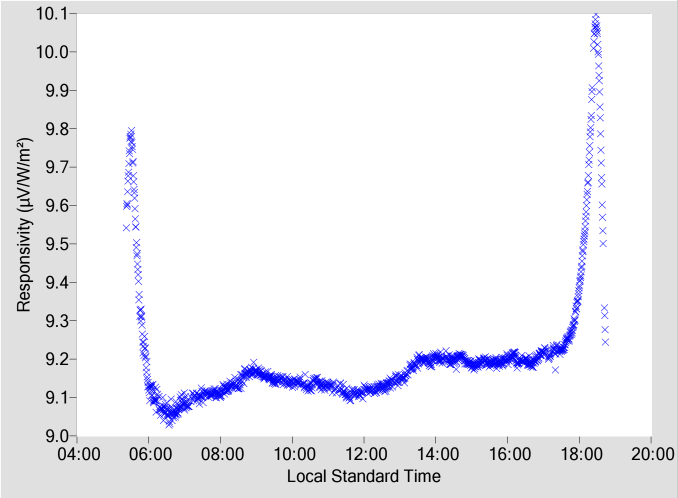


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	9.1608	0.34	99.09	9.1913	0.34	261.05
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1292	0.34	97.26	9.1928	0.34	262.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1323	0.34	95.25	9.1903	0.35	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1227	0.35	93.55	9.1907	0.36	266.58
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1071	0.36	91.78	9.2009	0.37	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1153	0.37	90.14	9.2101	0.38	270.03
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1125	0.38	88.45	9.1919	0.39	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1101	0.39	86.75	9.1954	0.40	273.29
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1010	0.40	85.21	9.1879	0.41	274.84
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0832	0.42	83.63	9.2026	0.43	276.44
20	9.1126	0.30	158.51	9.1288	0.30	202.04	66	9.0868	0.44	82.15	9.2174	0.45	277.99
22	9.1266	0.31	145.32	9.1473	0.31	215.19	68	9.0640	0.46	80.57	9.2091	0.49	279.55
24	9.1333	0.31	136.64	9.1513	0.31	223.53	70	9.0455	0.49	79.00	9.2287	0.52	281.11
26	9.1359	0.31	130.24	9.1784	0.31	229.77	72	9.0692	0.53	77.43	9.2259	0.55	282.65
28	9.1370	0.31	124.98	9.2007	0.31	234.89	74	9.0943	0.58	75.90	9.2544	0.59	284.21
30	9.1389	0.31	120.96	9.1952	0.31	239.21	76	9.1206	0.64	74.34	9.3216	0.64	285.82
32	9.1394	0.31	117.05	9.2071	0.31	242.86	78	9.2295	0.74	72.65	9.4615	0.73	287.43
34	9.1448	0.32	113.81	9.1993	0.32	246.27	80	9.4805	N/A	71.07	9.7024	N/A	289.06
36	9.1469	0.32	110.80	9.1969	0.32	249.34	82	9.7658	N/A	69.39	10.072	N/A	290.75
38	9.1513	0.32	108.11	9.1923	0.32	251.98	84	N/A	N/A	N/A	9.6240	N/A	292.45
40	9.1556	0.32	105.66	9.2062	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1665	0.33	103.31	9.1911	0.33	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1700	0.33	101.14	9.1843	0.33	258.93	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

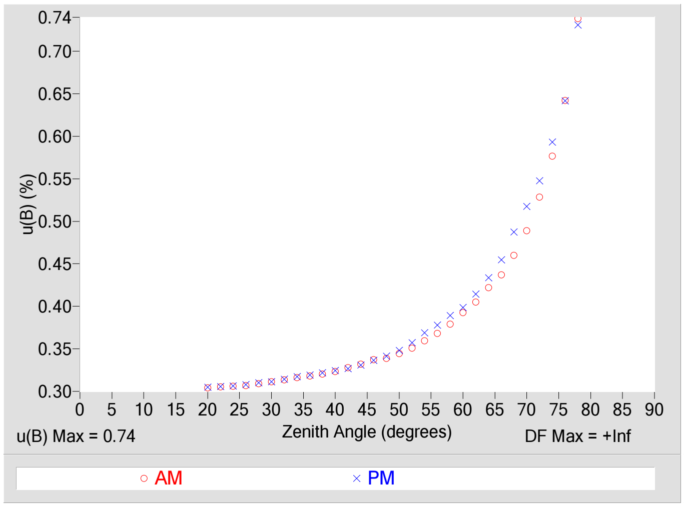


Figure 4. Residuals from Spline Interpolation

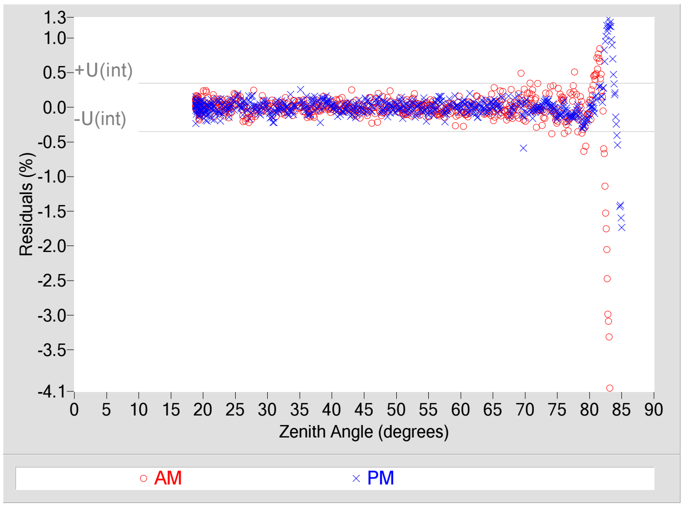


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	398334
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 78°

Table 4. Calibration Label Values

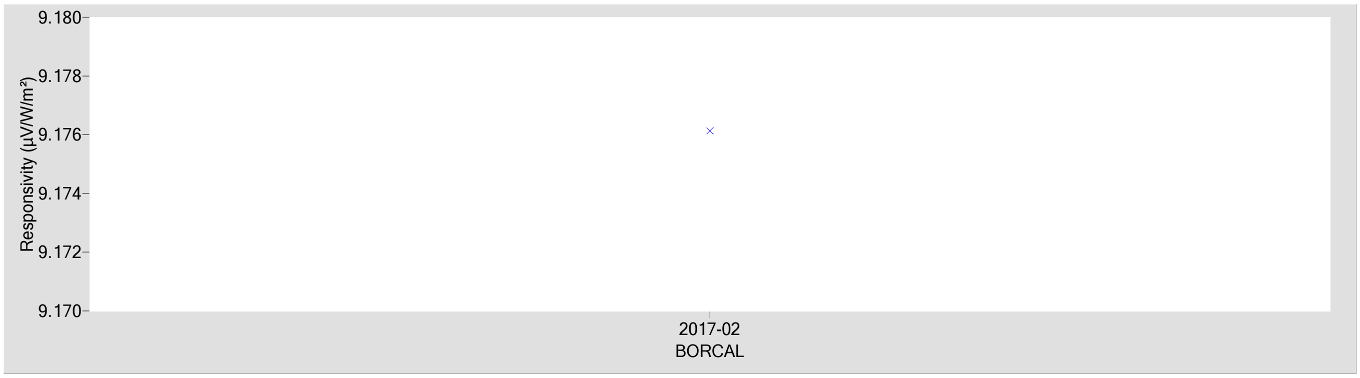
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.1761	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+0.37 / -0.75
Expanded Uncertainty, U (%)	+1.2 / -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:**	PY61760
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

______________________________ ____________

Ibrahim Reda, 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

PY61760 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

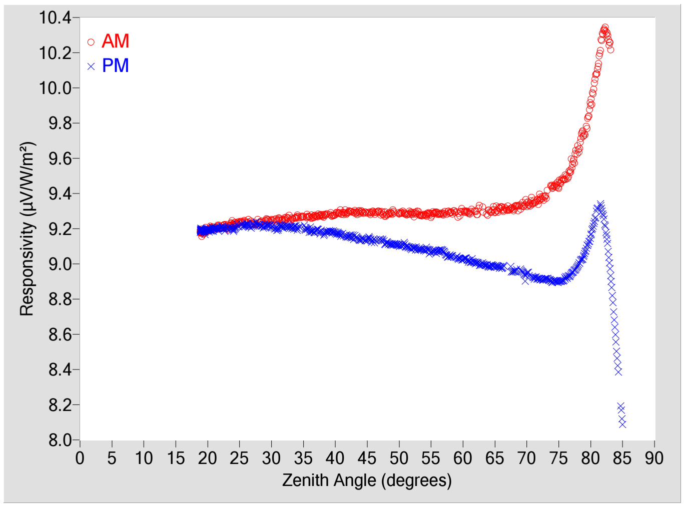


Figure 2. Responsivity vs Local Standard Time

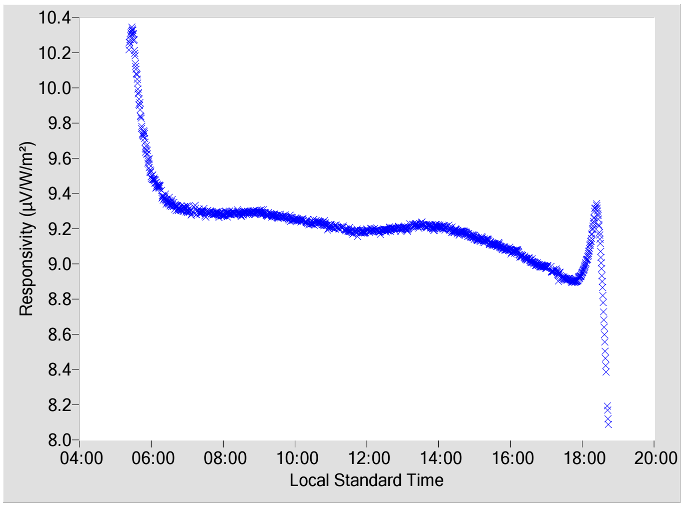


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.2934	0.34	99.09	9.1328	0.34	261.05
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2795	0.34	97.26	9.1178	0.34	262.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2886	0.34	95.25	9.1066	0.35	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2875	0.35	93.55	9.0892	0.36	266.58
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2772	0.36	91.78	9.0807	0.37	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2884	0.37	90.14	9.0724	0.38	270.03
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2933	0.38	88.45	9.0447	0.39	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3022	0.39	86.75	9.0268	0.40	273.29
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2918	0.40	85.21	9.0066	0.41	274.84
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2962	0.42	83.63	8.9864	0.43	276.44
20	9.1913	0.30	158.51	9.1927	0.30	202.04	66	9.3182	0.44	82.15	8.9801	0.45	277.99
22	9.2068	0.31	145.32	9.2074	0.31	215.19	68	9.3171	0.46	80.57	8.9568	0.49	279.55
24	9.2274	0.31	136.64	9.1981	0.31	223.53	70	9.3431	0.49	79.00	8.9385	0.52	281.07
26	9.2353	0.31	130.24	9.2233	0.31	229.77	72	9.3681	0.53	77.43	8.9145	0.55	282.65
28	9.2378	0.31	124.98	9.2213	0.31	234.89	74	9.4393	0.58	75.90	8.8999	0.59	284.21
30	9.2456	0.31	120.96	9.2149	0.31	239.21	76	9.4868	0.64	74.34	8.9176	0.64	285.82
32	9.2524	0.31	117.05	9.2118	0.31	242.86	78	9.6467	0.74	72.65	8.9929	0.73	287.43
34	9.2658	0.32	113.81	9.2044	0.32	246.27	80	9.9069	N/A	71.07	9.1622	N/A	289.06
36	9.2689	0.32	110.80	9.1894	0.32	249.34	82	10.316	N/A	69.39	9.2584	N/A	290.75
38	9.2745	0.32	108.11	9.1765	0.32	251.98	84	N/A	N/A	N/A	8.5305	N/A	292.45
40	9.2827	0.32	105.66	9.1754	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2927	0.33	103.31	9.1570	0.33	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2960	0.33	101.14	9.1377	0.33	258.93	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

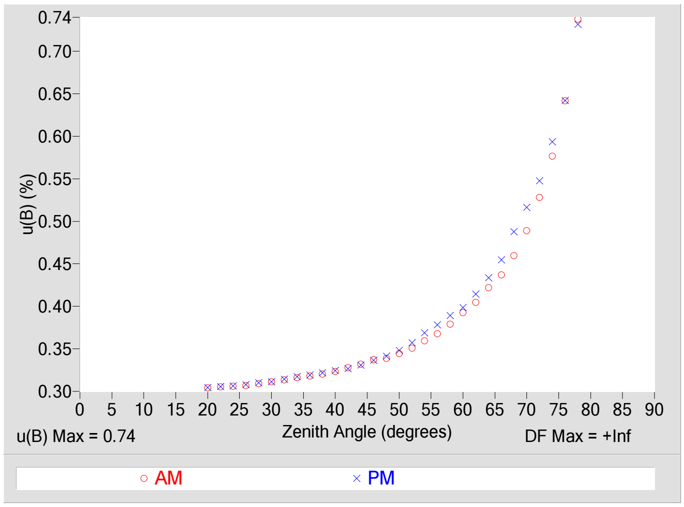


Figure 4. Residuals from Spline Interpolation

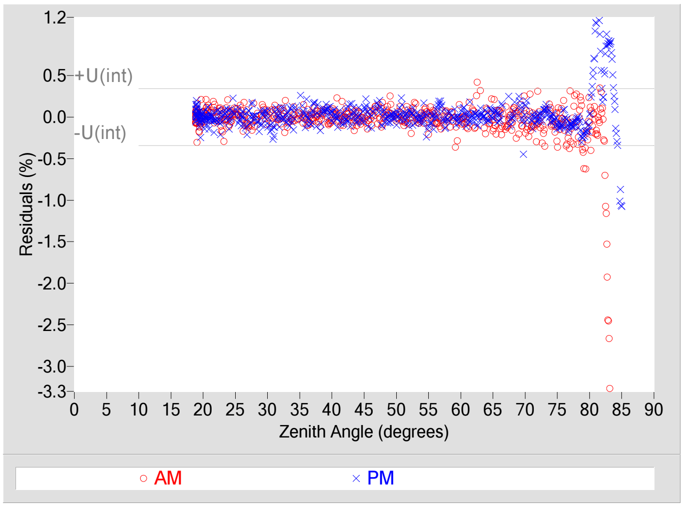


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	426954
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 78°

Table 4. Calibration Label Values

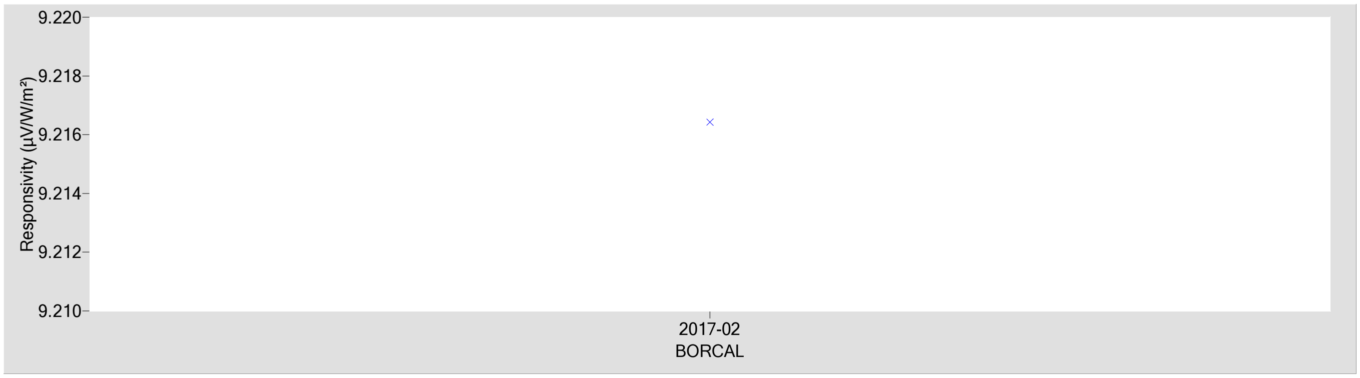
R @ 45° (µV/W/m^2)	Rnet (µV/W/m^2) †
9.2164	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+0.93 / -2.1
Expanded Uncertainty, U (%)	+1.7 / -2.8
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.

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[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:**	PY63286
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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.

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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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

Ibrahim Reda, 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

PY63286 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

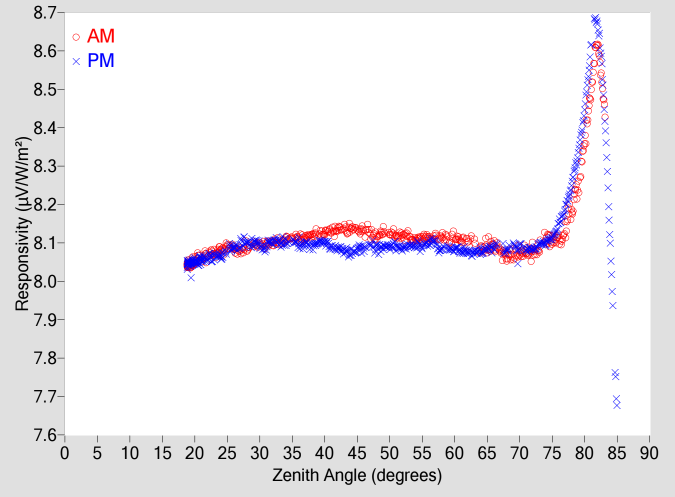


Figure 2. Responsivity vs Local Standard Time

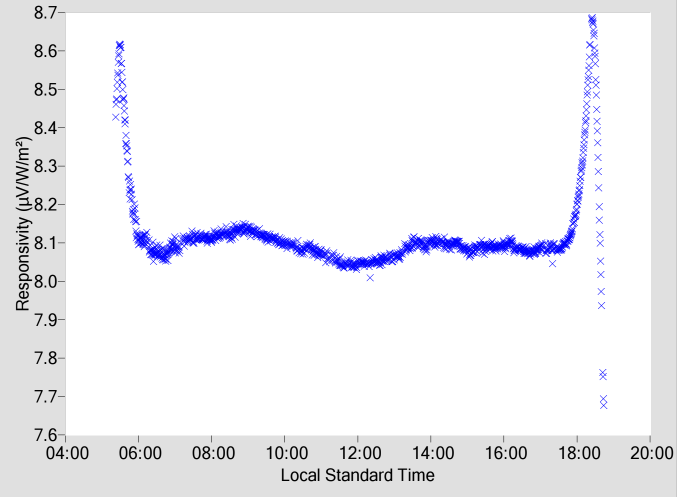


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1316	0.34	99.09	8.0871	0.34	261.05
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1157	0.34	97.26	8.0869	0.34	262.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1238	0.34	95.25	8.0904	0.35	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1193	0.35	93.55	8.0855	0.36	266.58
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1087	0.36	91.78	8.0927	0.37	268.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1156	0.37	90.14	8.0993	0.38	270.03
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1161	0.38	88.45	8.0843	0.39	271.63
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1151	0.39	86.75	8.0833	0.40	273.29
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1040	0.41	85.21	8.0762	0.41	274.84
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0863	0.42	83.63	8.0774	0.43	276.44
20	8.0510	0.30	158.51	8.0526	0.30	202.04	66	8.0954	0.44	82.15	8.0885	0.46	277.99
22	8.0639	0.31	145.32	8.0632	0.31	215.19	68	8.0634	0.46	80.57	8.0807	0.49	279.55
24	8.0819	0.31	136.64	8.0643	0.31	223.53	70	8.0723	0.49	79.00	8.0914	0.52	281.11
26	8.0855	0.31	130.24	8.0894	0.31	229.77	72	8.0765	0.53	77.43	8.0835	0.55	282.65
28	8.0873	0.31	124.98	8.1014	0.31	234.89	74	8.1072	0.58	75.90	8.0989	0.59	284.21
30	8.0953	0.31	120.96	8.0944	0.31	239.21	76	8.1110	0.64	74.34	8.1483	0.64	285.82
32	8.0989	0.31	117.05	8.1011	0.31	242.86	78	8.1768	0.74	72.65	8.2542	0.73	287.43
34	8.1099	0.32	113.81	8.1007	0.32	246.27	80	8.3639	N/A	71.07	8.4500	N/A	289.06
36	8.1139	0.32	110.80	8.0971	0.32	249.34	82	8.6073	N/A	69.39	8.6599	N/A	290.75
38	8.1200	0.32	108.11	8.0907	0.32	251.98	84	N/A	N/A	N/A	8.0706	N/A	292.45
40	8.1259	0.32	105.66	8.1000	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1361	0.33	103.31	8.0856	0.33	256.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1395	0.33	101.14	8.0743	0.33	258.93	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

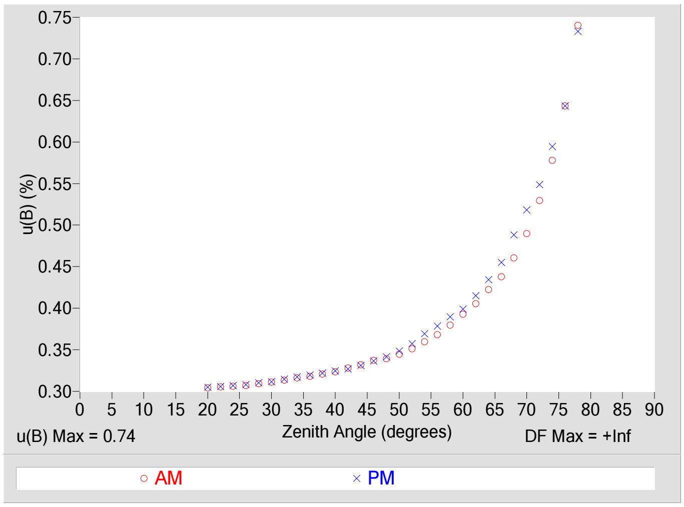


Figure 3. Type-B Standard Uncertainty vs Zenith Angle

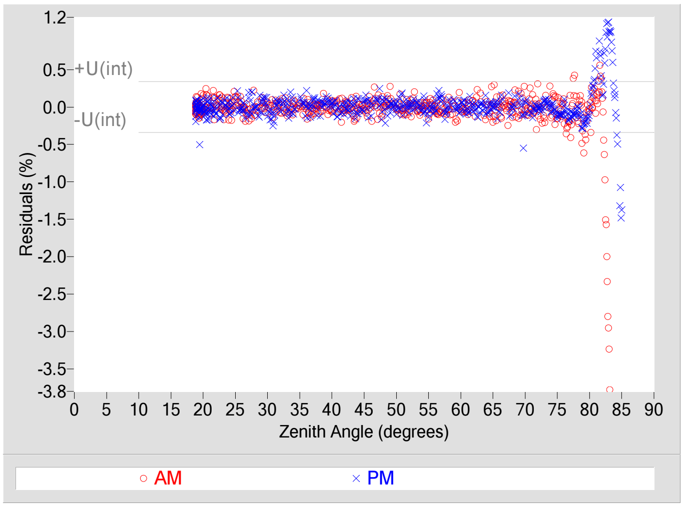


Figure 4. Residuals from Spline Interpolation

Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	447791
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 78°

Table 4. Calibration Label Values

R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1090	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+0.38 / -0.43
Expanded Uncertainty, U (%)	+1.2 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

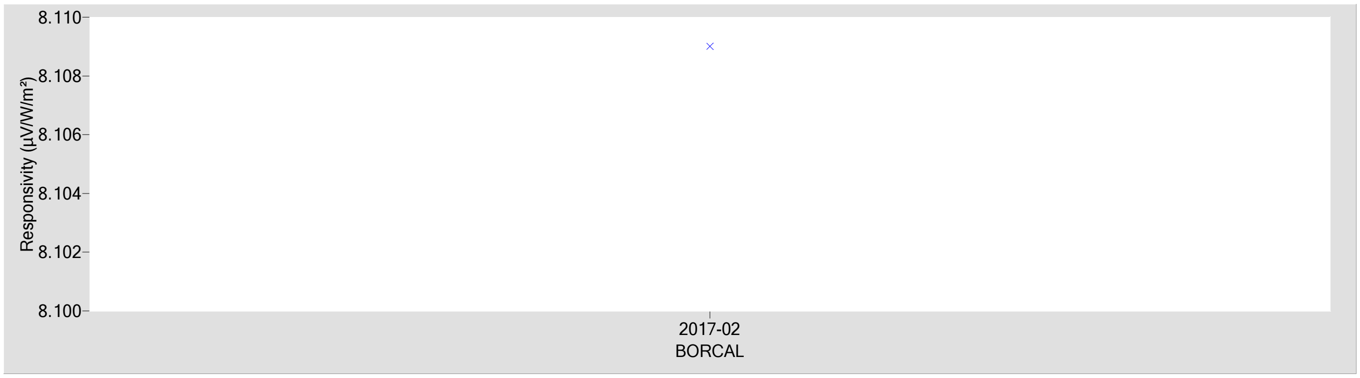


Figure 5. History of instrument at Zenith Angle = 45°

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:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY66480
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

________________________________ ____________

Ibrahim Reda, 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

PY66480 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

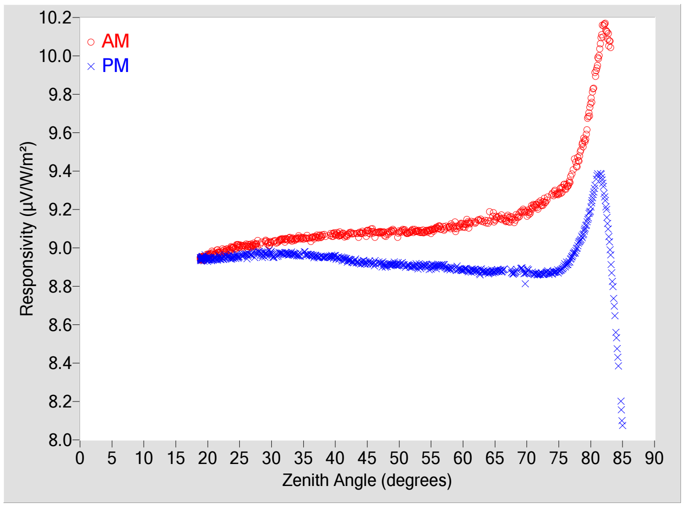


Figure 2. Responsivity vs Local Standard Time

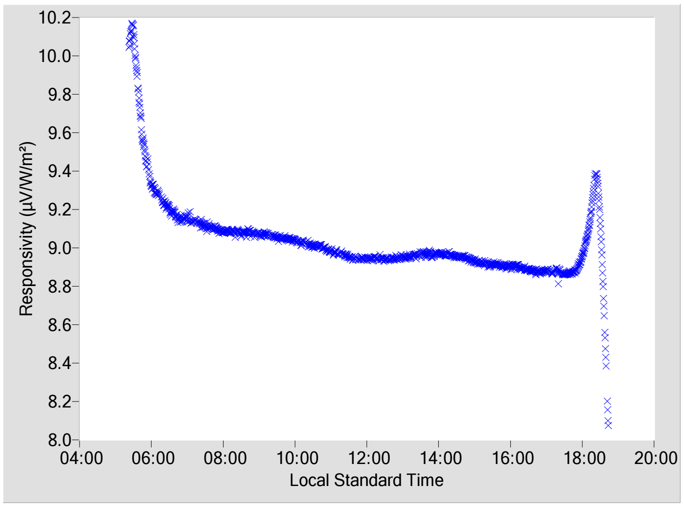


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.0794	0.34	99.10	8.9192	0.34	261.00
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0693	0.34	97.24	8.9083	0.34	262.87
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0775	0.34	95.32	8.9137	0.35	264.77
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0868	0.35	93.56	8.9026	0.36	266.58
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0860	0.36	91.78	8.9097	0.37	268.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1069	0.37	90.06	8.9054	0.38	270.04
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1111	0.38	88.45	8.8929	0.39	271.64
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1148	0.39	86.76	8.8870	0.40	273.29
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1329	0.40	85.30	8.8824	0.41	274.84
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1495	0.42	83.62	8.8722	0.43	276.44
20	8.9579	0.30	158.21	8.9422	0.30	201.74	66	9.1555	0.44	82.15	8.8812	0.45	277.95
22	8.9717	0.31	145.56	8.9482	0.31	214.59	68	9.1452	0.46	80.53	8.8703	0.49	279.56
24	9.0002	0.31	136.78	8.9523	0.31	223.41	70	9.1839	0.49	78.98	8.8787	0.52	281.11
26	9.0092	0.31	130.15	8.9655	0.31	229.78	72	9.2272	0.53	77.43	8.8643	0.55	282.65
28	9.0210	0.31	125.28	8.9744	0.31	235.11	74	9.2776	0.58	75.84	8.8702	0.59	284.21
30	9.0254	0.31	121.15	8.9658	0.31	239.36	76	9.3210	0.65	74.26	8.9107	0.64	285.82
32	9.0425	0.31	117.06	8.9690	0.31	242.93	78	9.4507	0.74	72.69	9.0166	0.73	287.44
34	9.0494	0.32	113.82	8.9627	0.32	246.30	80	9.7461	N/A	71.07	9.2167	N/A	289.06
36	9.0474	0.32	110.72	8.9627	0.32	249.29	82	10.147	N/A	69.40	9.3007	N/A	290.75
38	9.0620	0.32	108.19	8.9515	0.32	252.04	84	N/A	N/A	N/A	8.5284	N/A	292.47
40	9.0725	0.32	105.61	8.9522	0.32	254.47	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0698	0.33	103.35	8.9361	0.33	256.77	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0789	0.33	101.14	8.9210	0.33	259.03	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

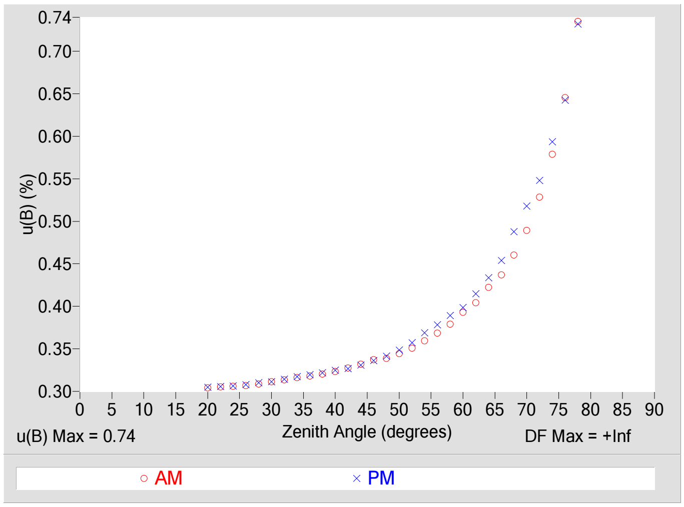


Figure 4. Residuals from Spline Interpolation

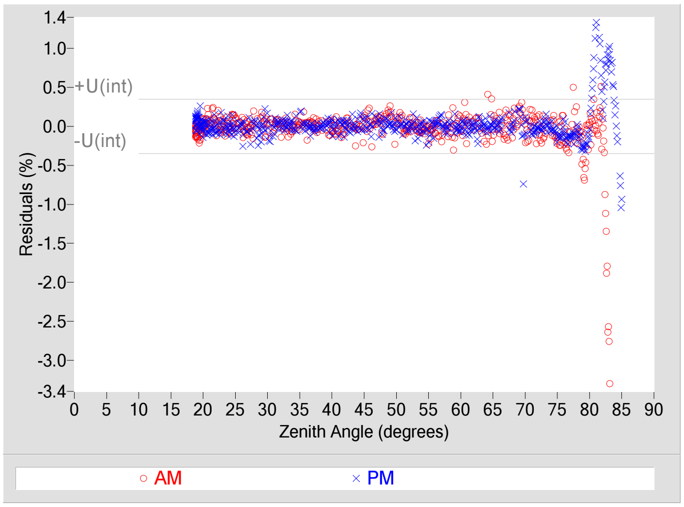


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	386899
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 78°

Table 4. Calibration Label Values

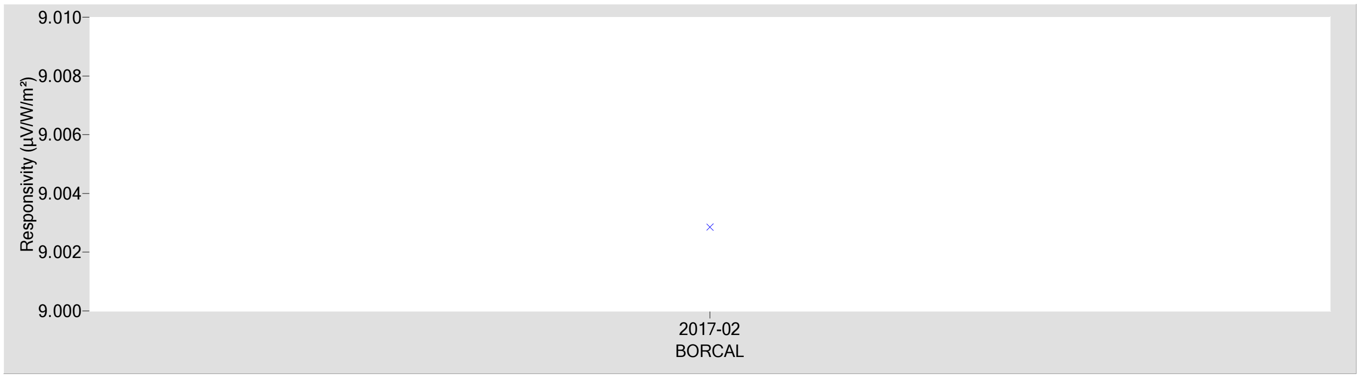
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.0029	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.2 / -1.3
Expanded Uncertainty, U (%)	+2.0 / -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:	Silicon Pyranometer	**Manufacturer:**	EKO
Model:	ML-01	**Serial Number:**	S13135061
Calibration Date:	5/24/2017	**Due Date:**	5/24/2018
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/24		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† 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

____ ________________

Ibrahim Reda, 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

S13135061 EKO ML-01

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

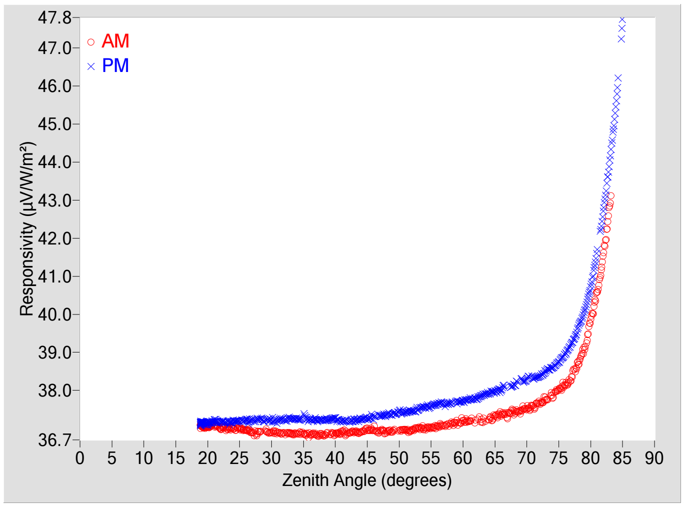


Figure 2. Responsivity vs Local Standard Time

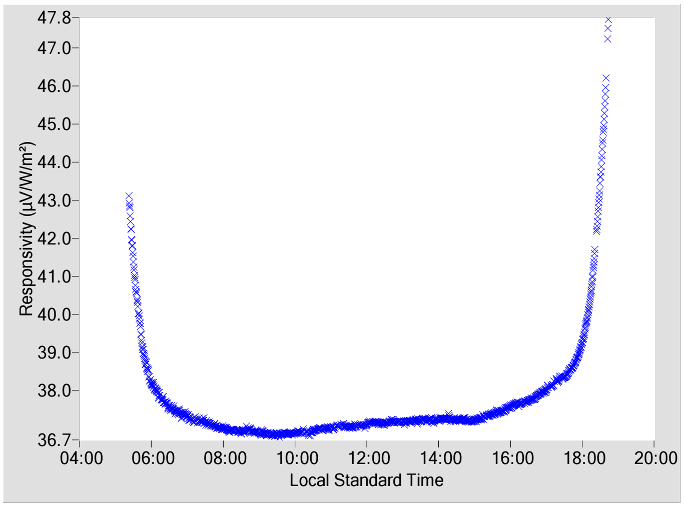


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	36.976	0.34	99.20	37.298	0.34	261.00
2	N/A	N/A	N/A	N/A	N/A	N/A	48	36.902	0.34	97.18	37.358	0.34	262.94
4	N/A	N/A	N/A	N/A	N/A	N/A	50	36.945	0.34	95.19	37.448	0.35	264.74
6	N/A	N/A	N/A	N/A	N/A	N/A	52	36.951	0.35	93.53	37.459	0.36	266.59
8	N/A	N/A	N/A	N/A	N/A	N/A	54	36.988	0.36	91.75	37.565	0.37	268.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	37.045	0.37	90.11	37.647	0.38	270.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	37.120	0.38	88.40	37.660	0.39	271.61
14	N/A	N/A	N/A	N/A	N/A	N/A	60	37.201	0.39	86.86	37.721	0.40	273.26
16	N/A	N/A	N/A	N/A	N/A	N/A	62	37.184	0.40	85.31	37.787	0.41	274.85
18	N/A	N/A	N/A	N/A	N/A	N/A	64	37.250	0.42	83.59	37.922	0.43	276.42
20	37.045	0.30	158.21	37.135	0.30	201.56	66	37.375	0.43	82.12	38.030	0.45	278.01
22	37.005	0.30	144.99	37.169	0.30	215.45	68	37.425	0.46	80.55	38.131	0.48	279.53
24	37.004	0.31	136.83	37.184	0.31	223.42	70	37.530	0.49	78.98	38.312	0.51	281.13
26	36.956	0.31	130.22	37.216	0.31	229.93	72	37.677	0.53	77.41	38.377	0.54	282.66
28	36.909	0.31	125.08	37.249	0.31	234.77	74	37.872	0.57	75.88	38.604	0.59	284.23
30	36.897	0.31	120.79	37.217	0.31	239.22	76	38.140	0.64	74.32	38.963	0.64	285.83
32	36.874	0.31	117.21	37.230	0.31	243.04	78	38.702	0.73	72.67	39.627	0.72	287.41
34	36.864	0.32	113.77	37.246	0.32	246.28	80	39.844	N/A	71.09	40.761	N/A	289.07
36	36.827	0.32	110.76	37.226	0.32	249.23	82	41.561	N/A	69.41	42.751	N/A	290.73
38	36.829	0.32	108.14	37.229	0.32	251.94	84	N/A	N/A	N/A	45.634	N/A	292.46
40	36.858	0.32	105.63	37.247	0.32	254.43	86	N/A	N/A	N/A	N/A	N/A	N/A
42	36.872	0.33	103.27	37.194	0.33	256.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	36.902	0.33	101.21	37.242	0.33	258.90	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

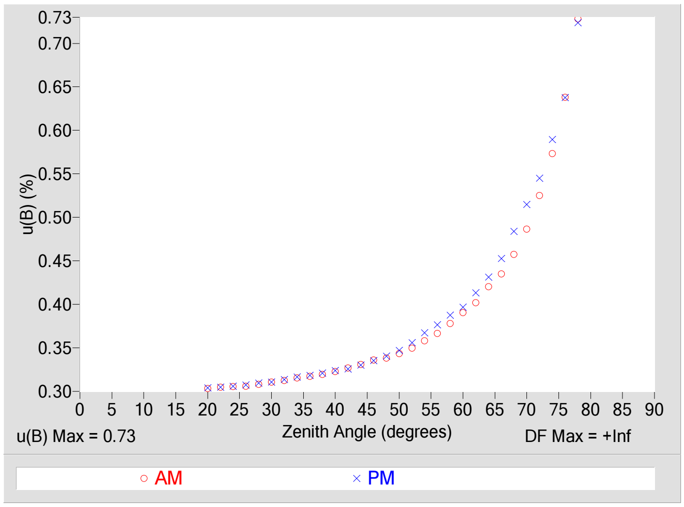


Figure 4. Residuals from Spline Interpolation

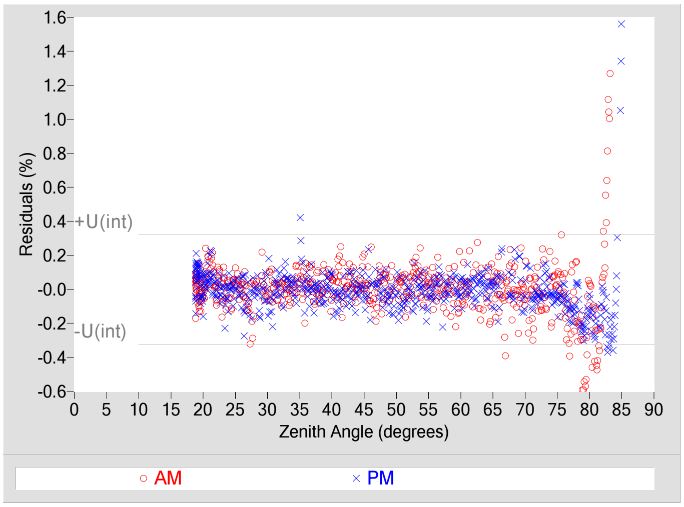


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.73
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	530682
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 78°

Table 4. Calibration Label Values

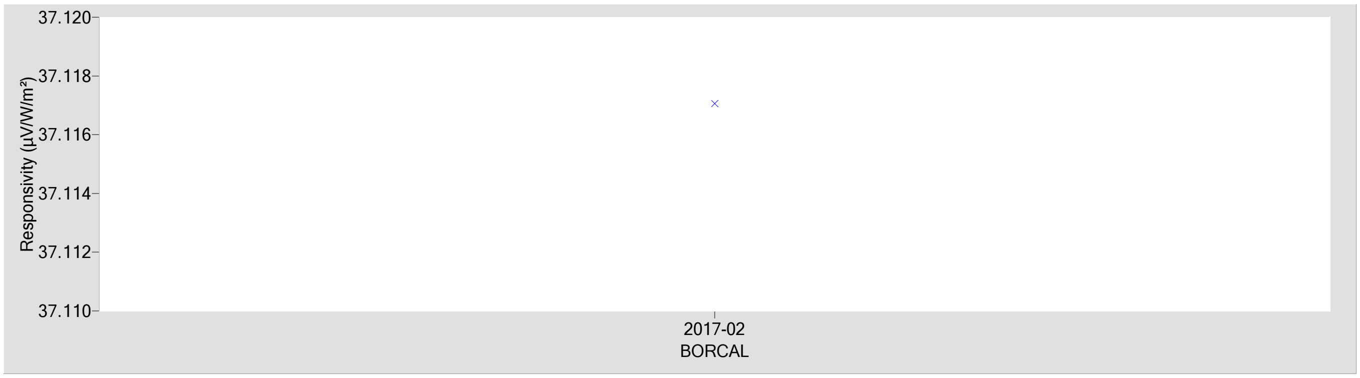
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
37.117	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.6 / -0.78
Expanded Uncertainty, U (%)	+2.4 / -1.6
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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[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.

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Environmental and Sky Conditions for BORCAL-SW 2017-02

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

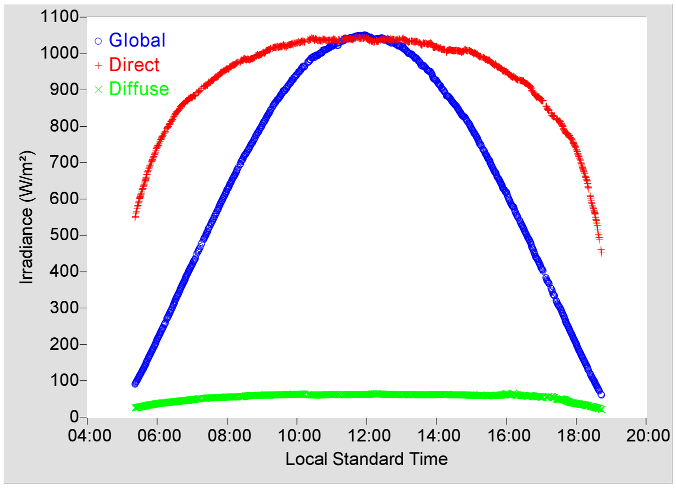
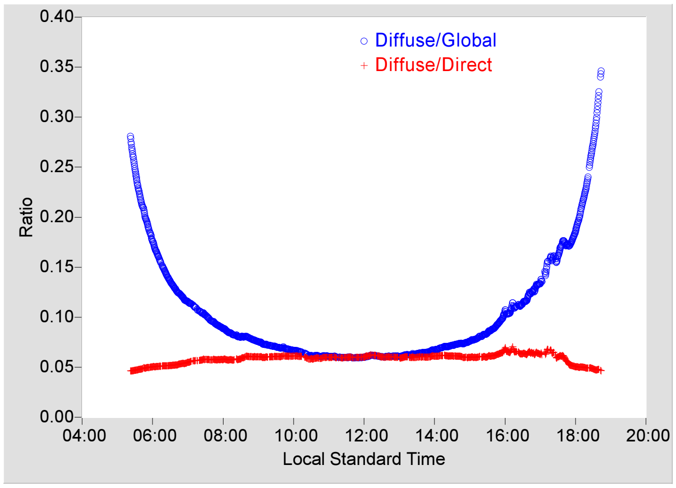


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

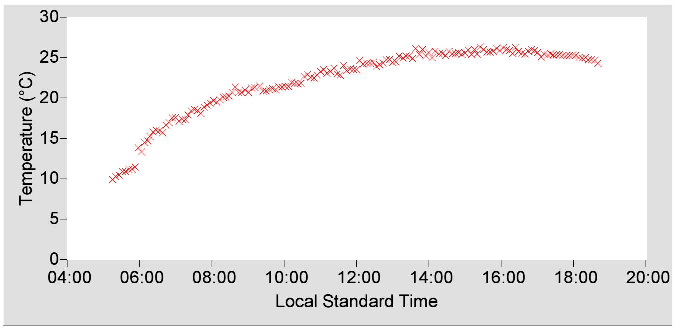


Figure 9. Humidity

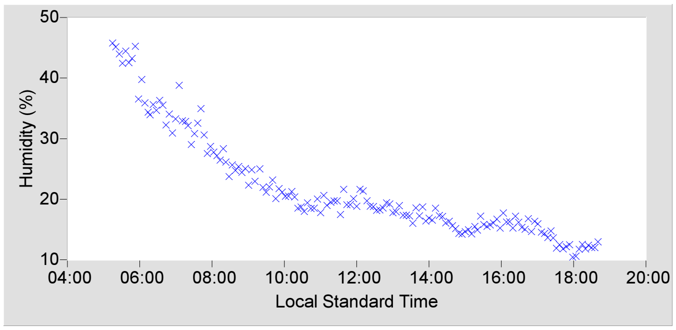


Figure 10. Pressure

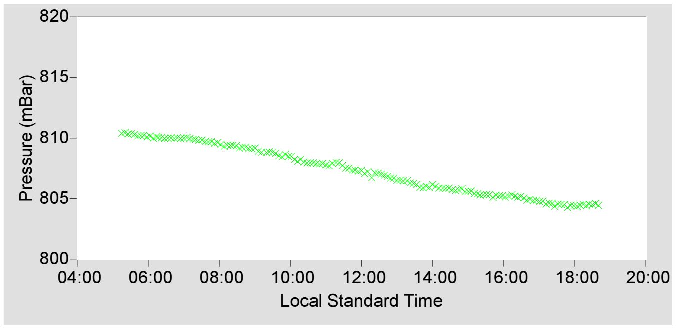


Figure 11. Effective Net Infrared

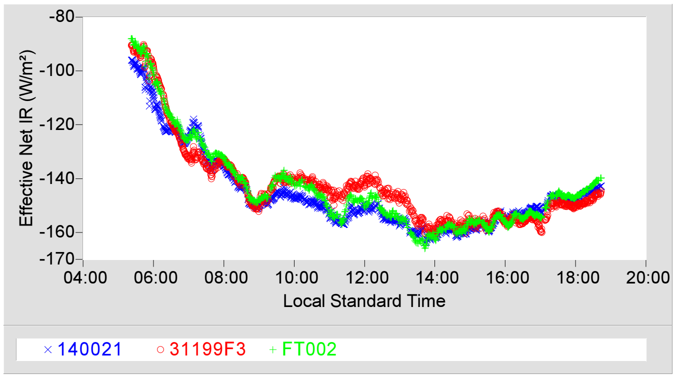


Figure 12. Estimated Broadband Aerosol Optical Depth

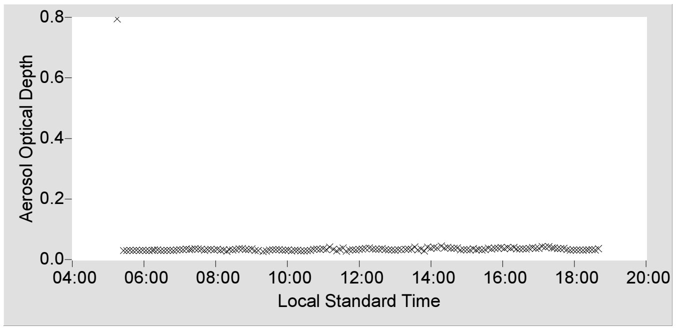


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	22.17	9.92	26.30
Humidity (%)	21.82	10.43	45.78
Pressure (mBar)	807.3	804.2	810.4
Est. Aerosol Optical Depth (BB)	0.039	0.026	0.794

For other information about the calibration facility visit: http://www.nrel.gov/solar_radiation/

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

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