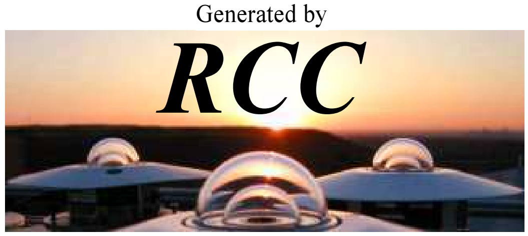
Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2018-03

Generated by



Radiometer Calibration and Characterization

<u>Customer</u>

Mike Dooraghi

Organization: NREL

Phone: 303.384.6329

<u>Calibration Facility</u>

Solar Radiation Research Laboratory

Latitude: 39.742°N

Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Calibration date

05/15/2018 to 05/16/2018

Report Date

May 23, 2018

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

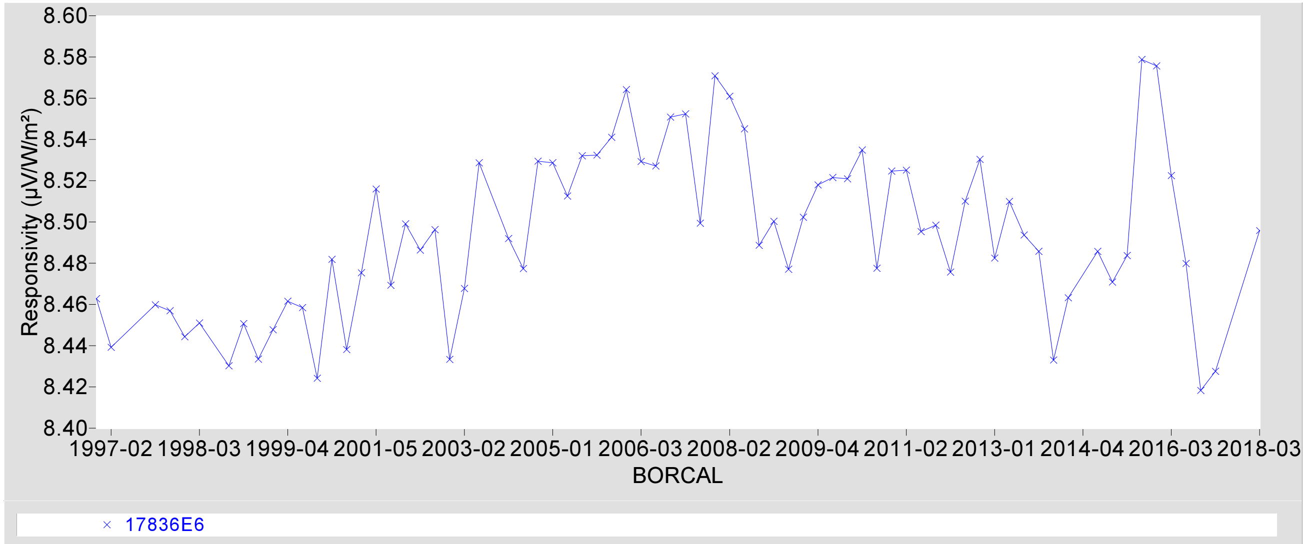
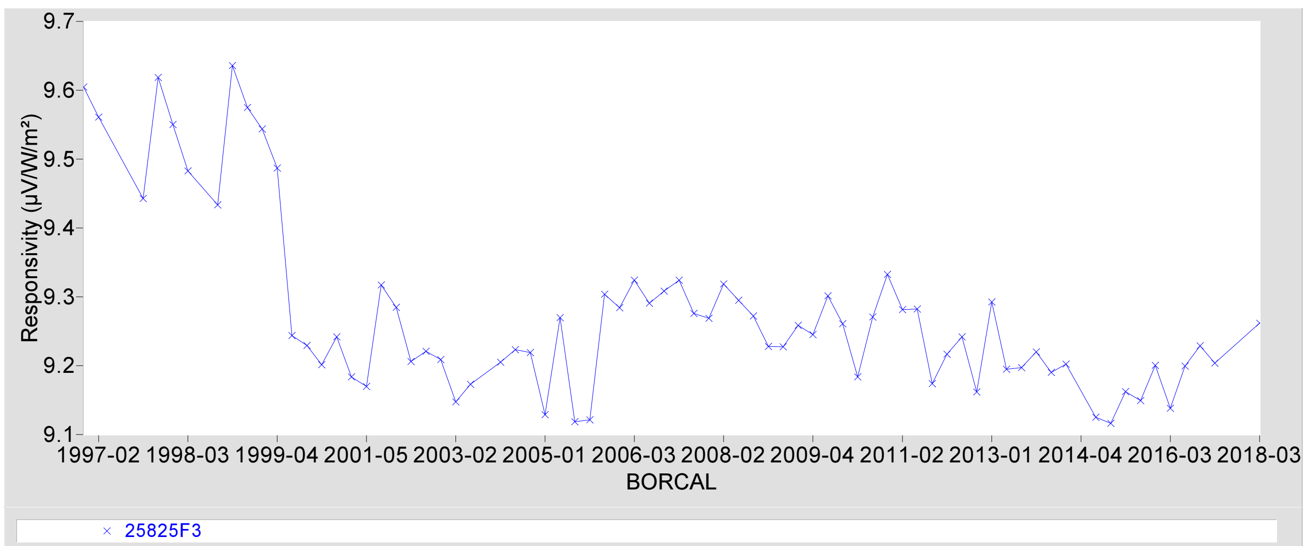


Figure 2. Eppley PSP Control Instrument History



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
080034 Kipp & Zonen CH1	9.7335	102.74	+0.89 / -1.9	0	A1-2
080035 Kipp & Zonen CH1	9.8674	101.34	+1.00 / -1.8	0	A1-5
113796 Kipp & Zonen SP-LITE2	62.596	15.976	+3.1 / -6.6	0	A1-8
114747 Kipp & Zonen CMP11	9.1239	109.60	+1.1 / -1.8	0.20500	A1-11
35244 Eppley 8-48	7.5044	133.25	+3.3 / -2.0	0	A1-14
920057 Kipp & Zonen CM21	14.150	70.671	+1.8 / -2.0	0.65000	A1-17
PY2276 Licor LI200	8.1361	122.91	+2.6 / -3.1	0	A1-20
PY28250 Licor LI200	11.615	86.093	+1.2 / -1.8	0	A1-23
PY60685 Licor LI200	9.1832	108.89	+1.3 / -0.85	0	A1-26
PY61760 Licor LI200	9.2095	108.58	+1.3 / -1.1	0	A1-29
PY63286 Licor LI200	8.0856	123.68	+1.1 / -0.78	0	A1-32
PY66480 Licor LI200	8.8915	112.47	+1.1 / -0.85	0	A1-35
PY66504 Licor LI200	7.1875	139.13	+2.6 / -3.9	0	A1-38
PY71863 Licor LI200	9.2666	107.92	+1.4 / -1.1	0	A1-41
PY89786 Licor LI200X	4.8471	206.31	+1.8 / -1.7	0	A1-44
PY89790 Licor LI200X	4.8573	205.88	+2.0 / -1.4	0	A1-47
S13135062 EKO ML-01	42.099	23.754	+2.5 / -2.2	0	A1-50
S17096006 EKO MS-80	10.314	96.959	+1.5 / -0.84	0.043000	A1-53

[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 A1-56.

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:**	080034
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

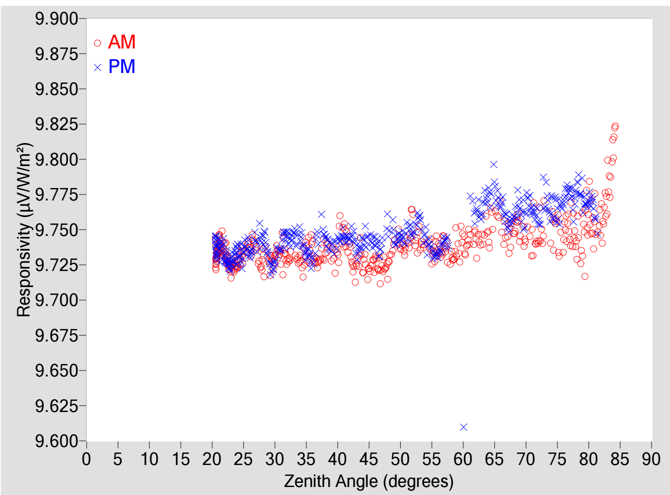


Figure 2. Responsivity vs Local Standard Time

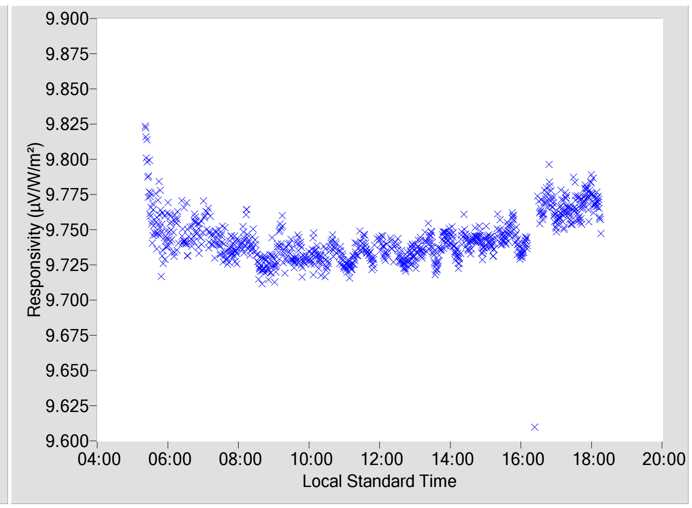


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.7279	0.29	102.08	9.7412	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7237	0.29	100.02	9.7517	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7421	0.29	98.13	9.7452	0.29	262.04
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7631	0.29	96.28	9.7473	0.29	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7394	0.29	94.53	9.7437	0.30	265.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7375	0.29	92.59	9.7336	0.30	267.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7300	0.29	90.81	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7416	0.30	89.21	9.6098	N/A	270.93
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7427	0.30	87.62	9.7614	0.30	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7437	0.30	85.97	9.7731	0.30	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7594	0.30	84.40	9.7691	0.31	275.46
22	9.7341	0.29	156.04	9.7325	0.29	203.74	68	9.7478	0.30	82.71	9.7584	0.31	276.93
24	9.7253	0.29	144.71	9.7343	0.29	215.49	70	9.7455	0.30	81.25	9.7648	N/A	278.58
26	9.7365	0.29	136.72	9.7357	0.29	223.29	72	9.7463	0.31	79.65	9.7567	N/A	280.18
28	9.7259	0.29	130.76	9.7446	0.29	229.27	74	9.7535	0.31	78.00	9.7640	N/A	281.74
30	9.7303	0.29	125.76	9.7282	0.29	234.28	76	9.7455	0.31	76.43	9.7708	N/A	283.33
32	9.7275	0.29	121.56	9.7460	0.29	238.56	78	9.7435	N/A	74.89	9.7779	N/A	284.97
34	9.7282	0.29	117.96	9.7467	0.29	242.25	80	9.7592	N/A	73.30	9.7709	N/A	286.57
36	9.7376	0.29	114.64	9.7271	0.29	245.37	82	9.7549	N/A	71.60	N/A	N/A	N/A
38	9.7363	0.29	111.73	9.7442	0.29	248.39	84	9.8125	N/A	69.94	N/A	N/A	N/A
40	9.7362	0.29	108.98	9.7417	0.29	251.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7338	0.29	106.46	9.7463	0.29	253.53	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7250	0.29	104.22	9.7414	0.29	255.89	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

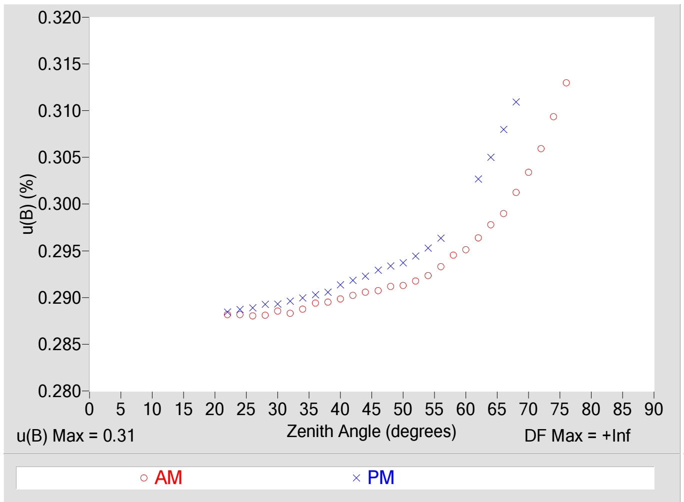


Figure 4. Residuals from Spline Interpolation

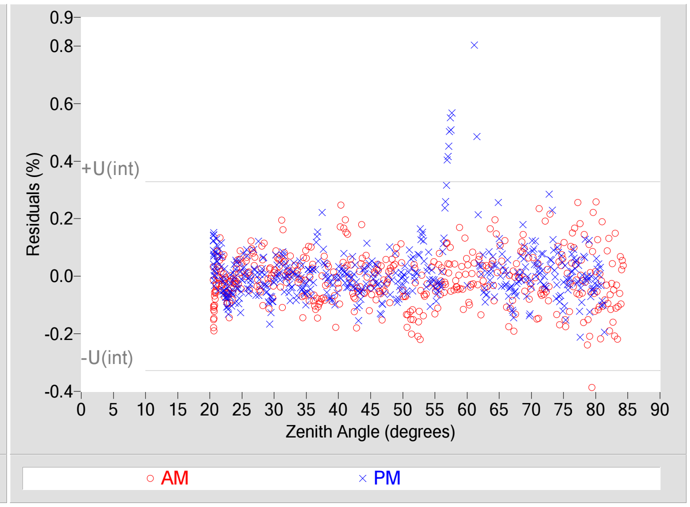


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	16716
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

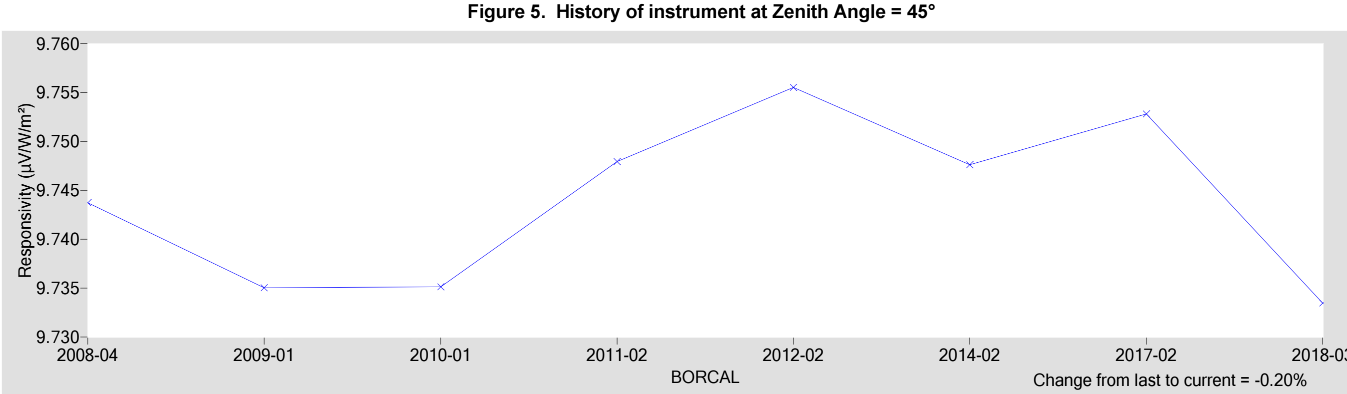
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.7335	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.30 / -1.3
Expanded Uncertainty, U (%)	+0.89 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CH1	**Serial Number:**	080035
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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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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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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:

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

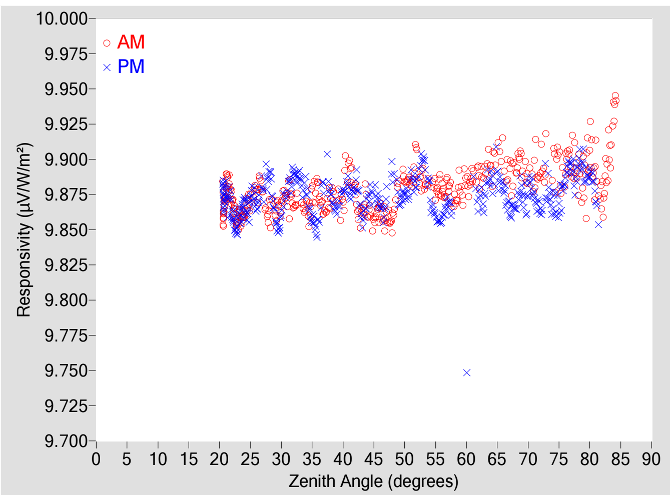


Figure 2. Responsivity vs Local Standard Time

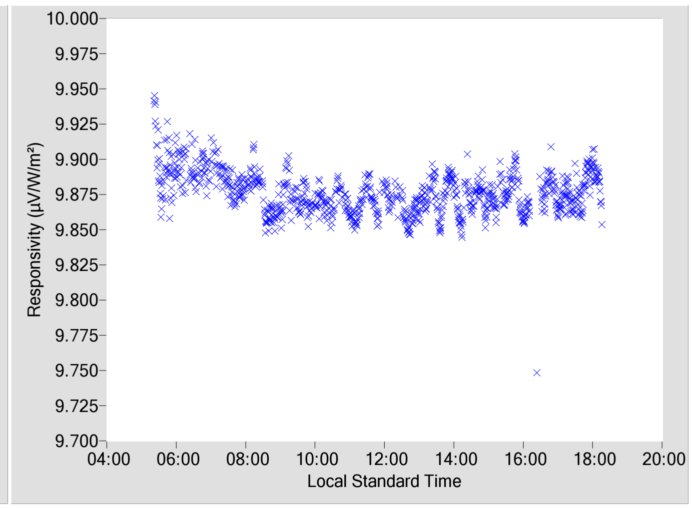


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	9.8642	0.29	102.08	9.8674	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8563	0.29	100.02	9.8902	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8872	0.29	98.13	9.8753	0.29	262.04
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.9085	0.29	96.28	9.8833	0.29	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8860	0.29	94.53	9.8779	0.30	265.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8795	0.29	92.59	9.8581	0.30	267.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8700	0.29	90.81	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8841	0.30	89.21	9.7483	N/A	270.93
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8892	0.30	87.62	9.8715	0.30	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.8906	0.30	85.97	9.8847	0.30	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.9033	0.30	84.40	9.8794	0.31	275.46
22	9.8706	0.29	156.04	9.8636	0.29	203.74	68	9.8915	0.30	82.71	9.8655	0.31	276.93
24	9.8611	0.29	144.71	9.8669	0.29	215.49	70	9.8889	0.30	81.25	9.8760	N/A	278.58
26	9.8771	0.29	136.72	9.8696	0.29	223.29	72	9.8936	0.31	79.65	9.8642	N/A	280.18
28	9.8612	0.29	130.76	9.8885	0.29	229.27	74	9.8989	0.31	78.00	9.8677	N/A	281.74
30	9.8679	0.29	125.76	9.8616	0.29	234.28	76	9.8935	0.31	76.43	9.8858	N/A	283.33
32	9.8668	0.29	121.56	9.8903	0.29	238.56	78	9.8908	N/A	74.89	9.8942	N/A	284.97
34	9.8658	0.29	117.96	9.8800	0.29	242.25	80	9.9021	N/A	73.30	9.8894	N/A	286.57
36	9.8798	0.29	114.64	9.8537	0.29	245.37	82	9.8723	N/A	71.60	N/A	N/A	N/A
38	9.8742	0.29	111.73	9.8753	0.29	248.39	84	9.9361	N/A	69.94	N/A	N/A	N/A
40	9.8744	0.29	108.98	9.8771	0.29	251.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8766	0.29	106.46	9.8837	0.29	253.53	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8642	0.29	104.22	9.8714	0.29	255.89	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

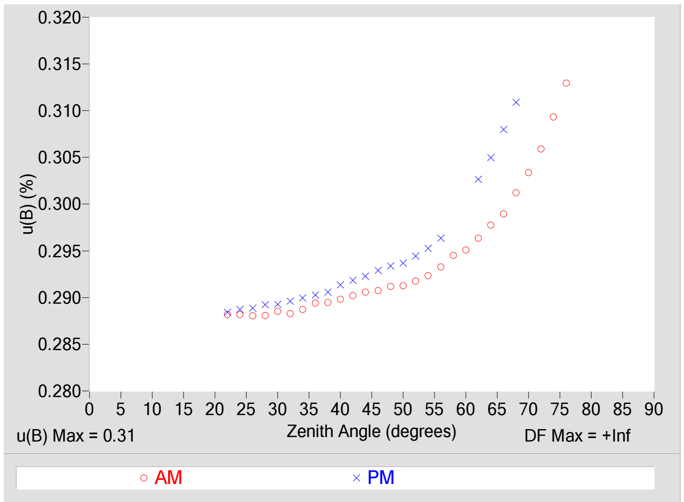


Figure 4. Residuals from Spline Interpolation

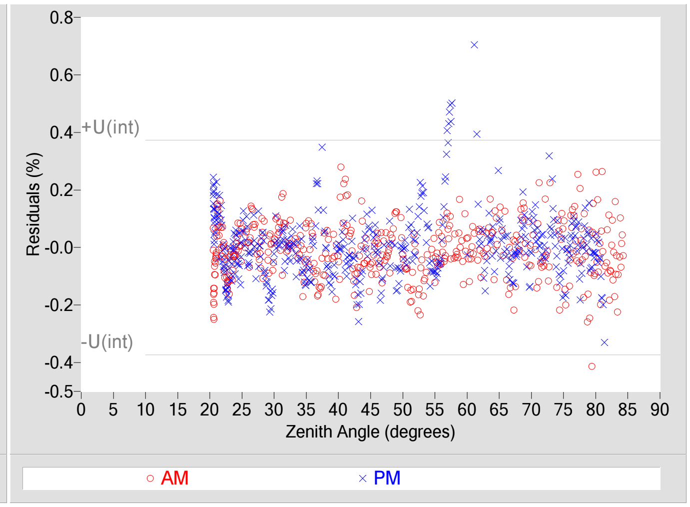


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	11267
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.71
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

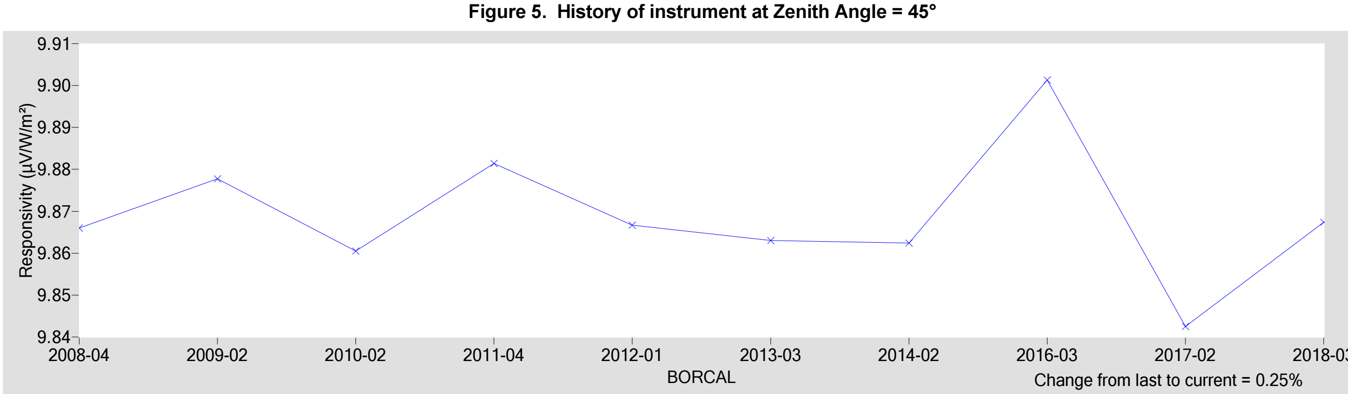
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.8674	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.42 / -1.2
Expanded Uncertainty, U (%)	+1.00 / -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:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	113796
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

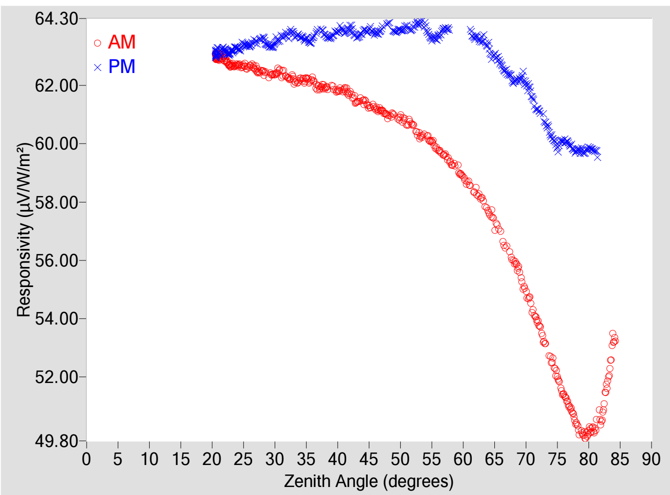


Figure 2. Responsivity vs Local Standard Time

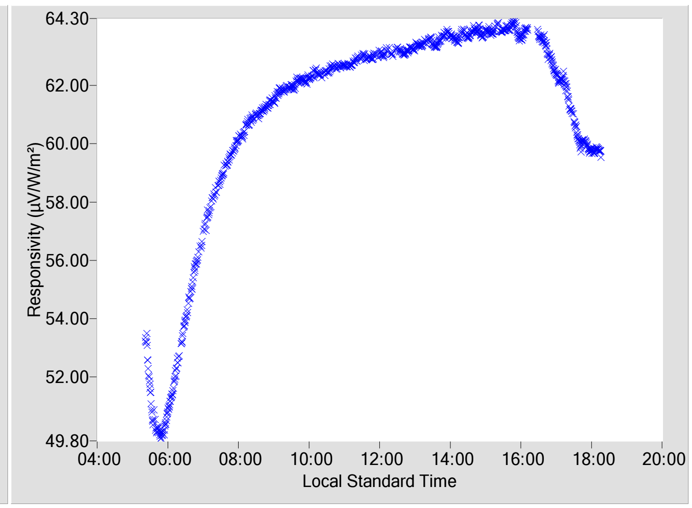


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	61.228	0.29	102.06	63.787	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	60.968	0.29	100.08	64.127	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	60.871	0.29	98.05	63.909	0.29	262.04
6	N/A	N/A	N/A	N/A	N/A	N/A	52	60.661	0.29	96.23	63.964	0.30	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	60.302	0.30	94.32	63.982	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	59.796	0.30	92.58	63.669	0.30	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	59.329	0.30	90.86	63.905	0.31	269.01
14	N/A	N/A	N/A	N/A	N/A	N/A	60	58.848	0.31	89.21	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	58.364	0.31	87.60	63.651	0.33	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	57.678	0.32	86.00	63.306	0.34	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	57.001	0.32	84.40	62.702	0.35	275.46
22	62.899	0.28	156.09	63.212	0.28	203.88	68	55.965	0.33	82.78	62.129	0.36	276.98
24	62.691	0.28	144.36	63.274	0.28	215.33	70	54.890	0.35	81.25	62.007	N/A	278.59
26	62.668	0.28	136.84	63.391	0.28	223.30	72	53.799	0.36	79.63	61.137	N/A	280.18
28	62.474	0.28	130.57	63.634	0.28	229.51	74	52.579	0.39	78.01	60.261	N/A	281.75
30	62.393	0.28	125.59	63.476	0.28	234.35	76	51.363	0.41	76.48	60.079	N/A	283.33
32	62.281	0.28	121.51	63.696	0.28	238.47	78	50.400	N/A	74.89	59.745	N/A	284.97
34	62.199	0.28	117.96	63.676	0.28	242.25	80	50.097	N/A	73.30	59.845	N/A	286.57
36	62.191	0.28	114.64	63.607	0.28	245.46	82	50.531	N/A	71.60	N/A	N/A	N/A
38	61.944	0.28	111.70	63.724	0.29	248.39	84	53.253	N/A	69.94	N/A	N/A	N/A
40	61.814	0.29	109.03	63.851	0.29	251.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	61.719	0.29	106.57	63.968	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	61.447	0.29	104.12	63.851	0.29	255.90	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

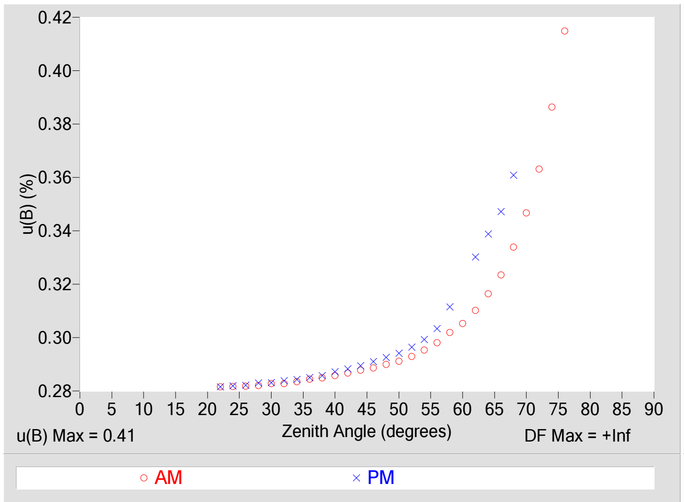


Figure 4. Residuals from Spline Interpolation

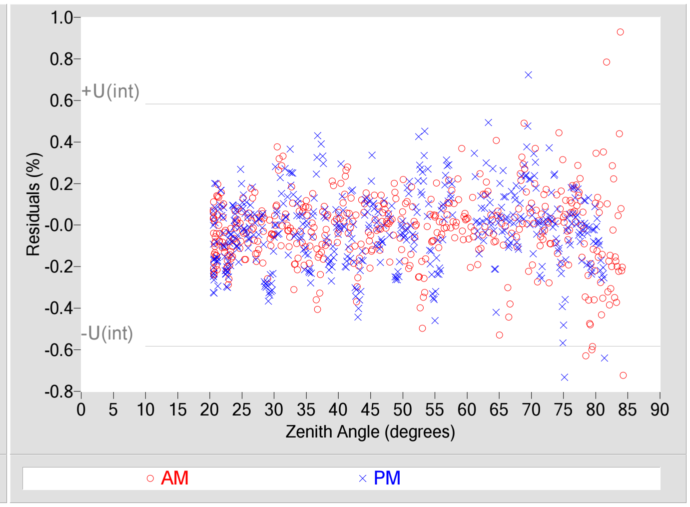


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	7240
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

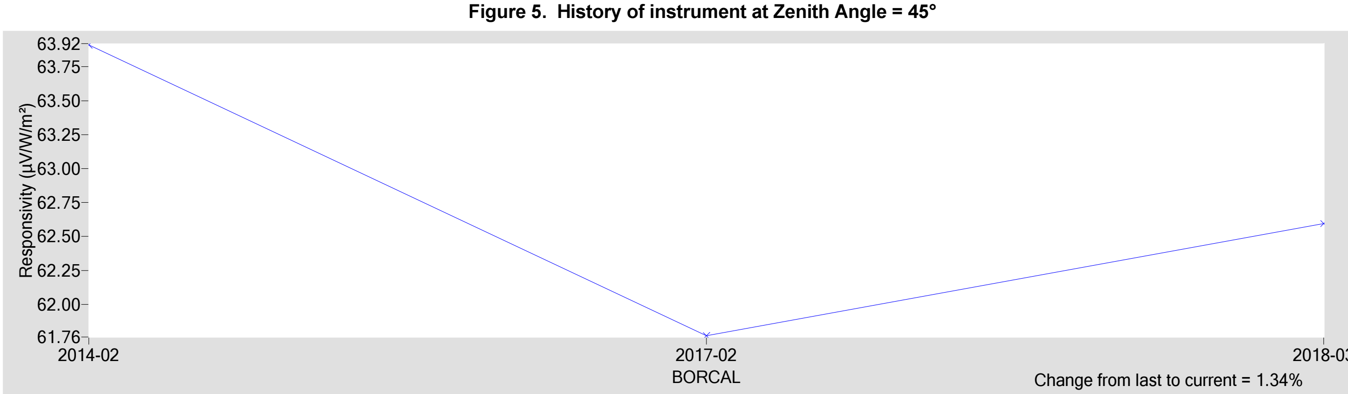
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
62.596	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.61
Offset Uncertainty, U(off) (%)	+2.4 / -6.0
Expanded Uncertainty, U (%)	+3.1 / -6.6
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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP11	**Serial Number:**	114747
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: 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

114747 Kipp & Zonen CMP11

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

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

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

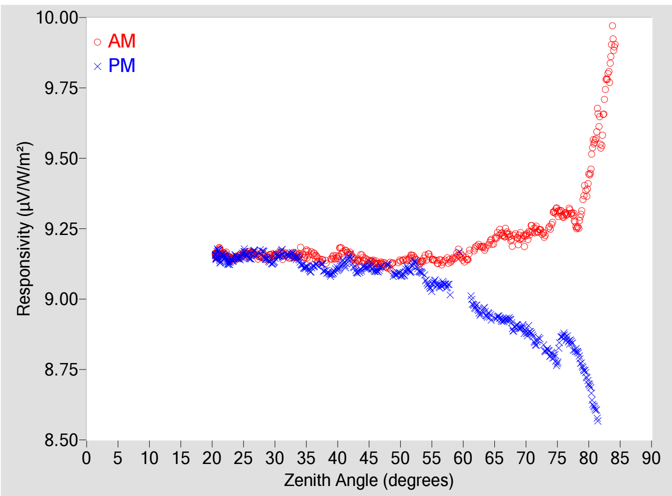


Figure 2. Responsivity vs Local Standard Time

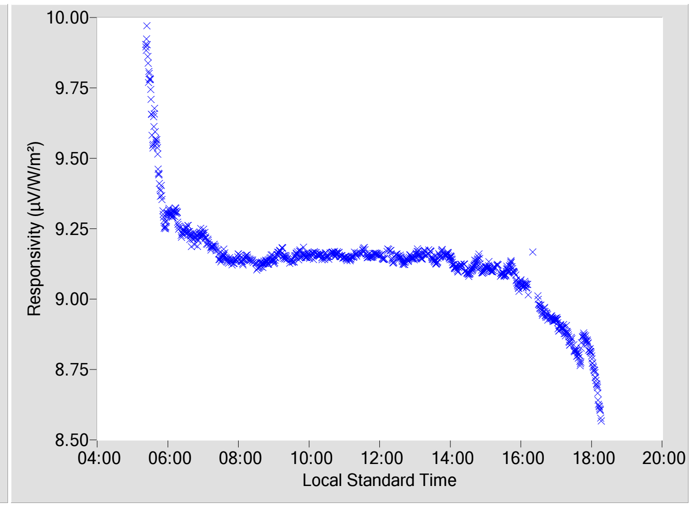


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.1289	0.29	102.03	9.1006	0.30	258.05
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1110	0.30	100.01	9.1212	0.30	260.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1365	0.30	98.08	9.0870	0.30	262.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1509	0.30	96.15	9.1261	0.30	264.01
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1466	0.30	94.38	9.0688	0.31	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1324	0.31	92.63	9.0466	0.31	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1379	0.31	90.85	9.0143	0.33	269.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1427	0.32	89.29	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1810	0.32	87.65	8.9705	0.34	272.24
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1965	0.33	85.89	8.9421	0.35	273.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2353	0.34	84.34	8.9282	0.36	275.42
22	9.1601	0.29	156.03	9.1479	0.29	203.80	68	9.2085	0.35	82.92	8.8936	0.38	277.03
24	9.1478	0.29	144.76	9.1457	0.29	215.52	70	9.2196	0.37	81.27	8.8800	N/A	278.59
26	9.1593	0.29	136.72	9.1445	0.29	223.18	72	9.2416	0.39	79.69	8.8565	N/A	280.12
28	9.1530	0.29	130.54	9.1667	0.29	229.53	74	9.2607	0.41	78.12	8.8003	N/A	281.75
30	9.1553	0.29	125.83	9.1402	0.29	234.19	76	9.2964	0.45	76.54	8.8708	N/A	283.34
32	9.1565	0.29	121.88	9.1562	0.29	238.58	78	9.2615	N/A	74.90	8.8164	N/A	284.93
34	9.1648	0.29	118.02	9.1309	0.29	242.21	80	9.4264	N/A	73.26	8.7003	N/A	286.58
36	9.1630	0.29	114.53	9.1115	0.29	245.48	82	9.5864	N/A	71.61	N/A	N/A	N/A
38	9.1322	0.29	111.55	9.0983	0.29	248.38	84	9.9155	N/A	69.95	N/A	N/A	N/A
40	9.1500	0.29	109.03	9.1067	0.29	251.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1602	0.29	106.54	9.1517	0.29	253.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1441	0.29	104.13	9.1113	0.30	255.92	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

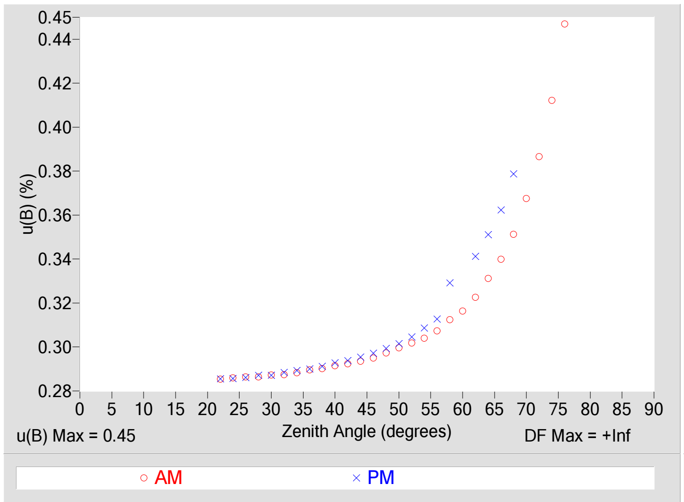


Figure 4. Residuals from Spline Interpolation

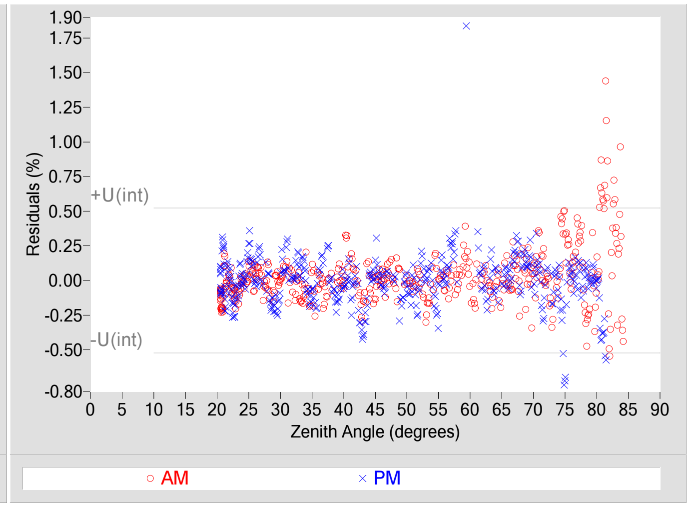


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	12270
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

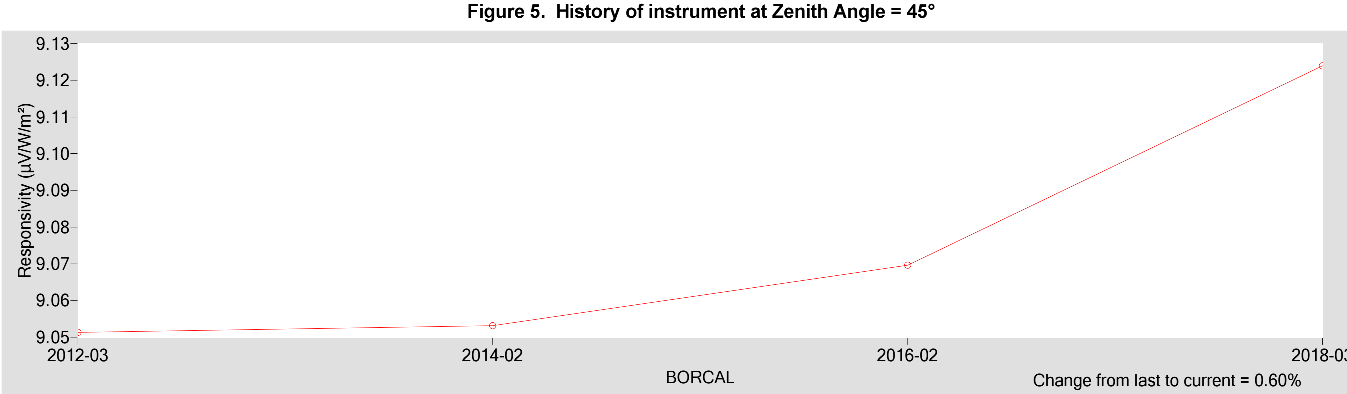
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.1239	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+0.45 / -1.2
Expanded Uncertainty, U (%)	+1.1 / -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:**	35244
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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:

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

where,

V = radiometer output voltage (microvolts),

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

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

= $Win - Wout$ = $Win - \sigma * Tc^4$

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

Tc = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

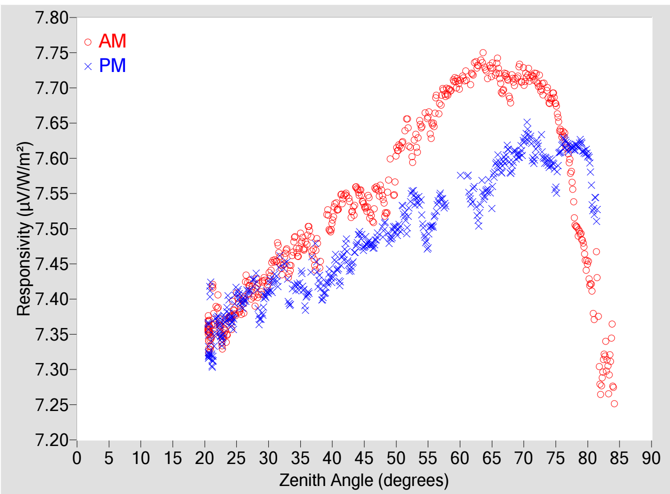


Figure 2. Responsivity vs Local Standard Time

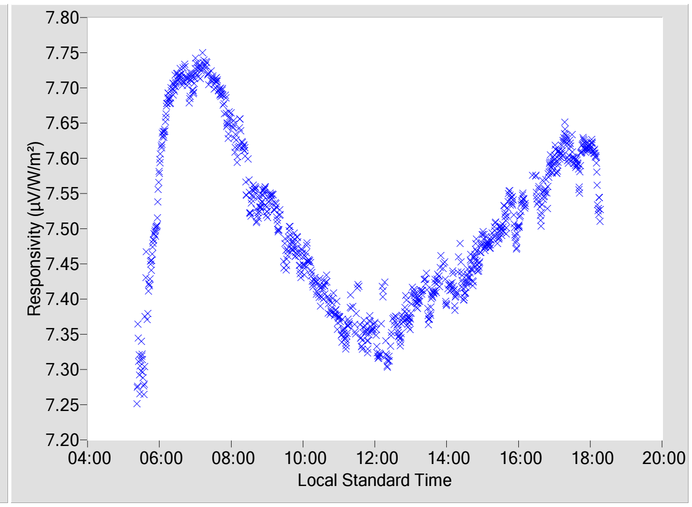


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5250	0.29	102.13	7.4774	0.29	258.09
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5396	0.29	100.01	7.5012	0.29	260.15
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5887	0.29	98.06	7.4980	0.30	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6329	0.30	96.18	7.5220	0.30	263.91
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6454	0.30	94.42	7.5172	0.30	265.83
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6586	0.30	92.63	7.5156	0.31	267.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6934	0.30	90.90	7.5324	0.31	269.00
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7050	0.31	89.30	7.5760	N/A	270.92
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7236	0.31	87.58	7.5476	0.33	272.20
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7268	0.32	86.01	7.5504	0.34	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7278	0.33	84.39	7.5927	0.35	275.45
22	7.3838	0.28	155.67	7.3703	0.28	203.52	68	7.6991	0.34	82.79	7.5850	0.37	276.97
24	7.3714	0.28	144.43	7.3736	0.28	215.46	70	7.7155	0.35	81.16	7.6212	N/A	278.57
26	7.3923	0.28	136.71	7.3946	0.28	223.40	72	7.7115	0.37	79.64	7.6164	N/A	280.17
28	7.4100	0.28	130.62	7.4252	0.28	229.35	74	7.6850	0.39	78.10	7.5923	N/A	281.78
30	7.4266	0.28	125.74	7.4150	0.28	234.33	76	7.6351	0.43	76.51	7.6210	N/A	283.37
32	7.4467	0.28	121.64	7.4619	0.29	238.04	78	7.5130	N/A	74.88	7.6159	N/A	284.96
34	7.4773	0.28	117.99	7.4167	0.29	242.27	80	7.4455	N/A	73.29	7.6054	N/A	286.56
36	7.4882	0.29	114.58	7.4016	0.29	245.44	82	7.2825	N/A	71.59	N/A	N/A	N/A
38	7.4489	0.29	111.60	7.4231	0.29	248.37	84	7.3024	N/A	69.98	N/A	N/A	N/A
40	7.5102	0.29	109.01	7.4305	0.29	251.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5483	0.29	106.48	7.4703	0.29	253.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5541	0.29	104.24	7.4873	0.29	255.93	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

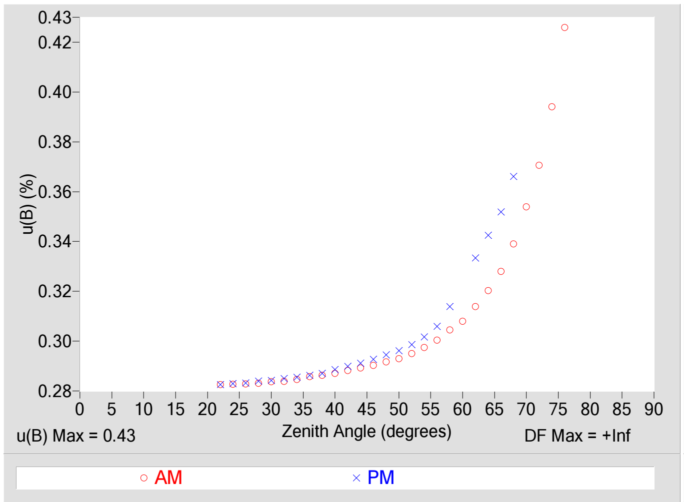


Figure 4. Residuals from Spline Interpolation

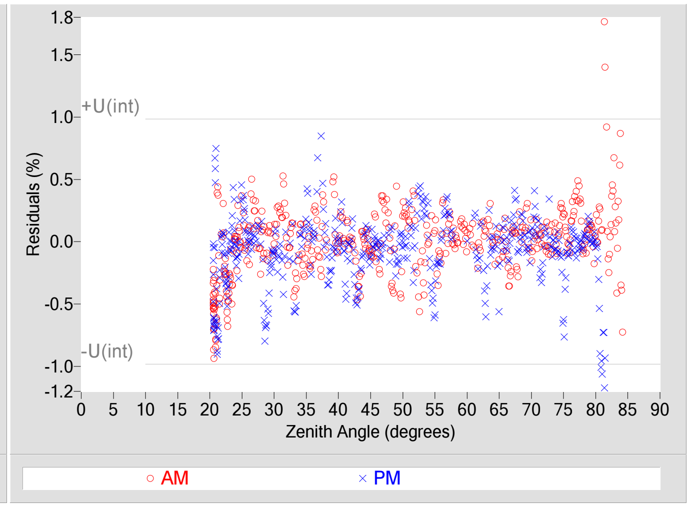


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.49
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	2490
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

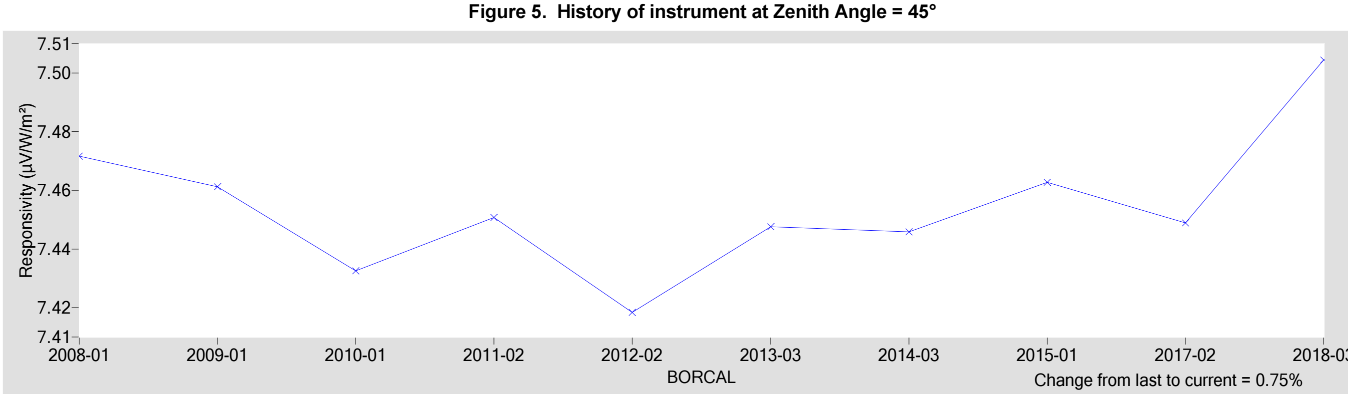
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5044	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+2.7 / -1.4
Expanded Uncertainty, U (%)	+3.3 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM21	**Serial Number:**	920057
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

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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

920057 Kipp & Zonen CM21

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),
  = $Win - Wout$ = $Win - \sigma * Tc\text{^}4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

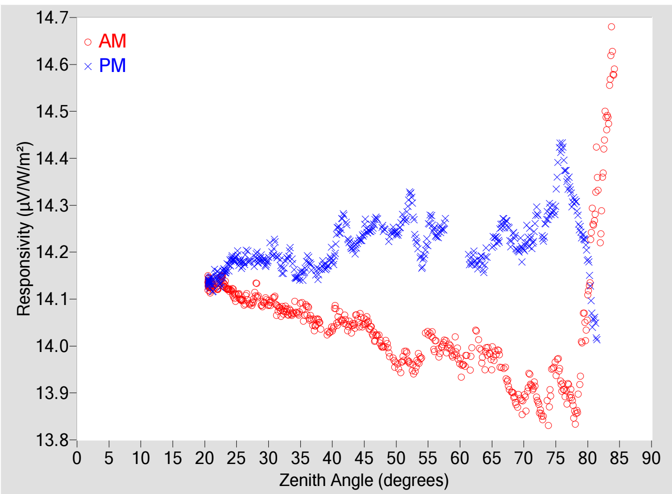


Figure 2. Responsivity vs Local Standard Time

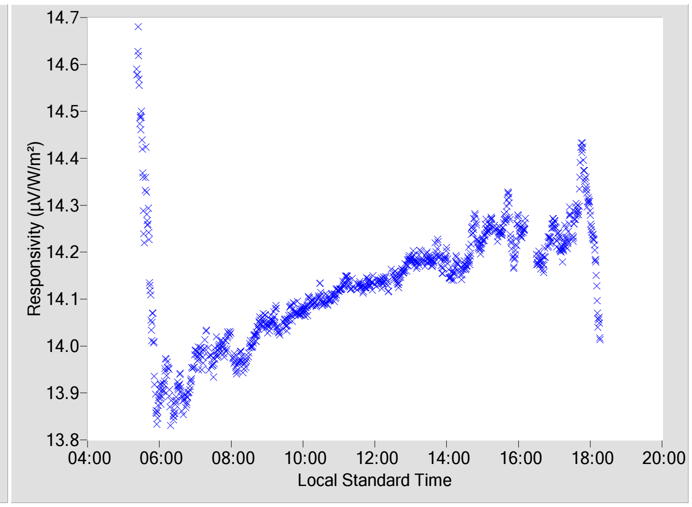


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	14.036	0.29	102.03	14.248	0.30	258.05
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.998	0.30	100.00	14.250	0.30	260.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.961	0.30	98.06	14.240	0.30	262.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.966	0.30	96.17	14.318	0.30	264.01
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.975	0.30	94.49	14.179	0.31	265.74
10	N/A	N/A	N/A	N/A	N/A	N/A	56	14.004	0.31	92.60	14.243	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.999	0.31	90.86	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.960	0.32	89.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.987	0.32	87.76	14.185	0.34	272.24
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.979	0.33	85.93	14.183	0.35	273.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	13.980	0.34	84.31	14.229	0.36	275.42
22	14.127	0.29	156.01	14.148	0.29	203.71	68	13.903	0.35	82.82	14.225	0.38	277.01
24	14.119	0.29	144.75	14.180	0.29	215.66	70	13.881	0.37	81.26	14.205	N/A	278.59
26	14.096	0.29	136.93	14.174	0.29	223.40	72	13.892	0.39	79.66	14.279	N/A	280.14
28	14.116	0.29	130.53	14.188	0.29	229.41	74	13.875	0.41	78.07	14.285	N/A	281.75
30	14.091	0.29	125.60	14.190	0.29	234.18	76	13.915	0.45	76.53	14.417	N/A	283.34
32	14.076	0.29	121.57	14.169	0.29	238.48	78	13.856	N/A	74.90	14.309	N/A	284.93
34	14.077	0.29	117.83	14.157	0.29	242.25	80	14.089	N/A	73.26	14.186	N/A	286.57
36	14.079	0.29	114.65	14.181	0.29	245.52	82	14.277	N/A	71.51	N/A	N/A	N/A
38	14.050	0.29	111.78	14.155	0.29	248.32	84	14.611	N/A	69.94	N/A	N/A	N/A
40	14.037	0.29	108.96	14.187	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	14.054	0.29	106.54	14.267	0.29	253.66	88	N/A	N/A	N/A	N/A	N/A	N/A
44	14.054	0.29	104.16	14.220	0.30	255.89	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

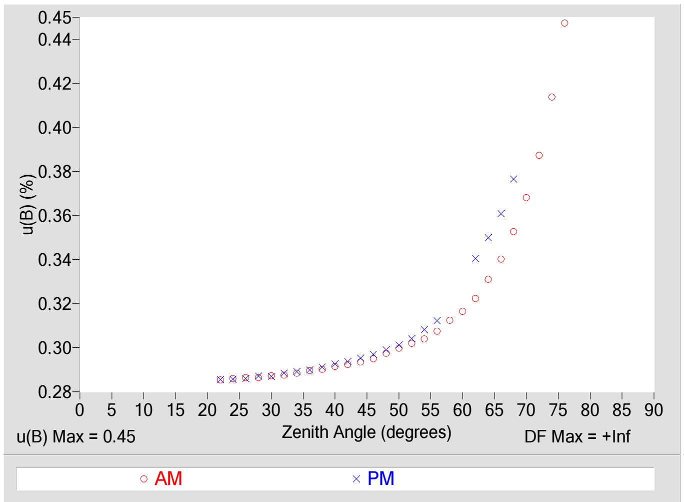


Figure 4. Residuals from Spline Interpolation

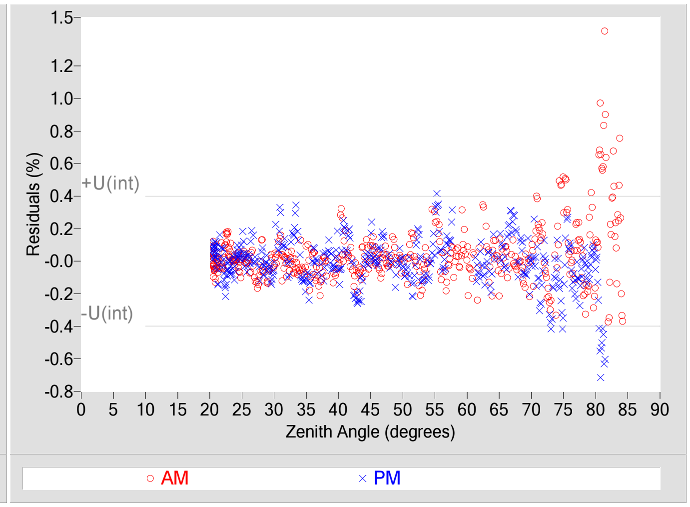


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	29160
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.96
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

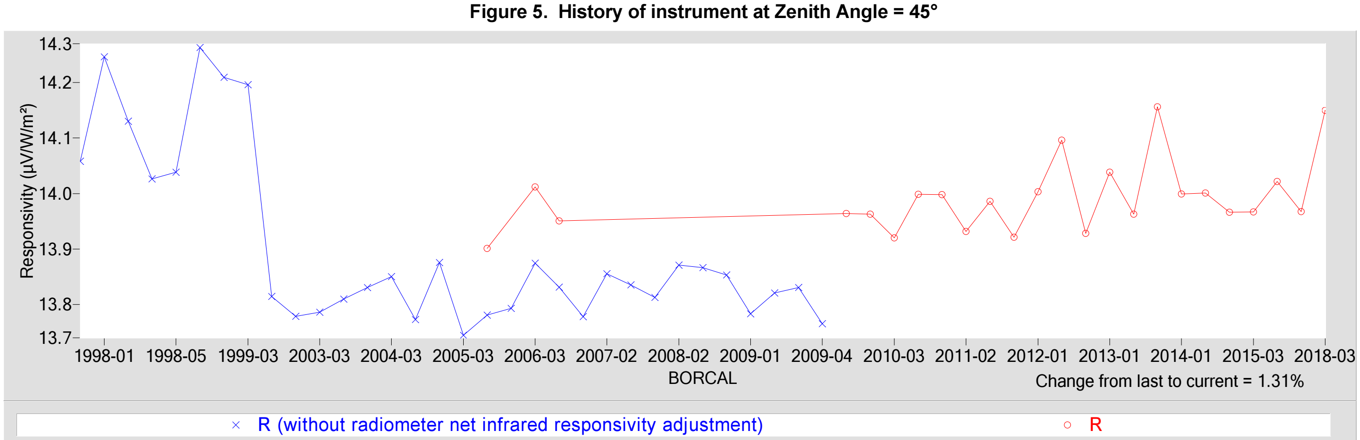
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
14.150	0.65000

† Rnet determination date: 03/03/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+1.2 / -1.3
Expanded Uncertainty, U (%)	+1.8 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY2276
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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

PY2276 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

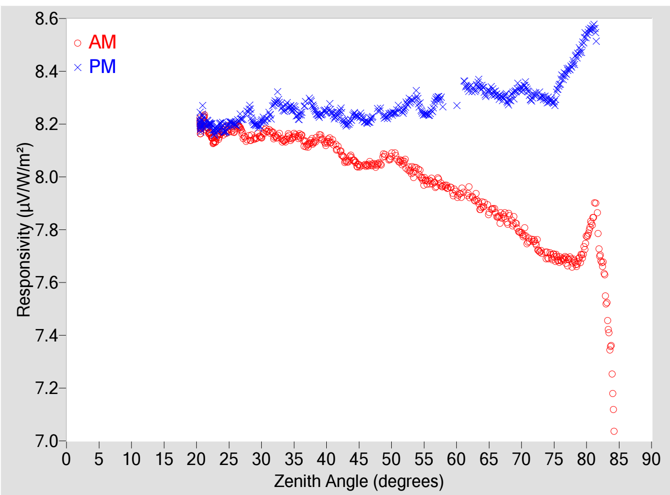


Figure 2. Responsivity vs Local Standard Time

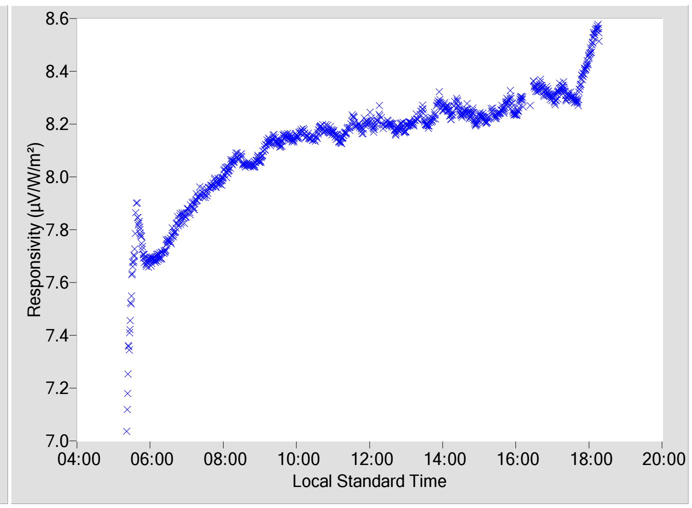


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0442	0.29	101.99	8.2072	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0485	0.29	100.09	8.2545	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0759	0.29	98.14	8.2402	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0541	0.29	96.17	8.2593	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0246	0.30	94.29	8.2940	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9828	0.30	92.55	8.2430	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9652	0.30	90.94	8.2658	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9327	0.31	89.15	8.2704	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9406	0.31	87.67	8.3364	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8880	0.32	86.03	8.3353	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8644	0.33	84.38	8.3148	0.35	275.42
22	8.1689	0.28	156.29	8.2002	0.28	203.76	68	7.8409	0.34	82.85	8.2838	0.37	276.98
24	8.1710	0.28	144.48	8.1893	0.28	215.35	70	7.7835	0.35	81.20	8.3309	N/A	278.59
26	8.1799	0.28	137.27	8.2019	0.28	223.31	72	7.7528	0.37	79.64	8.3123	N/A	280.19
28	8.1448	0.28	130.61	8.2562	0.28	229.48	74	7.6971	0.39	78.11	8.2901	N/A	281.75
30	8.1533	0.28	125.78	8.2111	0.28	234.30	76	7.6866	0.43	76.49	8.3646	N/A	283.34
32	8.1536	0.28	121.47	8.2790	0.28	238.58	78	7.6759	N/A	74.90	8.4368	N/A	284.98
34	8.1495	0.28	117.91	8.2677	0.29	242.26	80	7.7604	N/A	73.31	8.5401	N/A	286.58
36	8.1571	0.29	114.65	8.2354	0.29	245.46	82	7.7197	N/A	71.61	N/A	N/A	N/A
38	8.1331	0.29	111.70	8.2633	0.29	248.40	84	7.2177	N/A	69.94	N/A	N/A	N/A
40	8.1306	0.29	109.03	8.2484	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1038	0.29	106.49	8.2424	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0706	0.29	104.26	8.2298	0.29	255.90	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

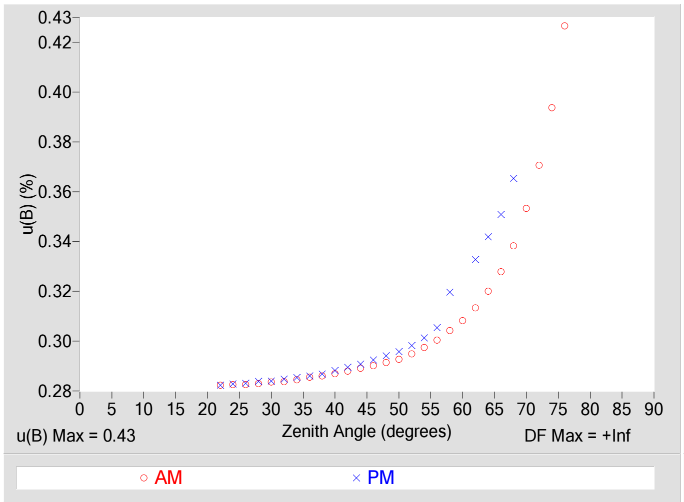


Figure 4. Residuals from Spline Interpolation

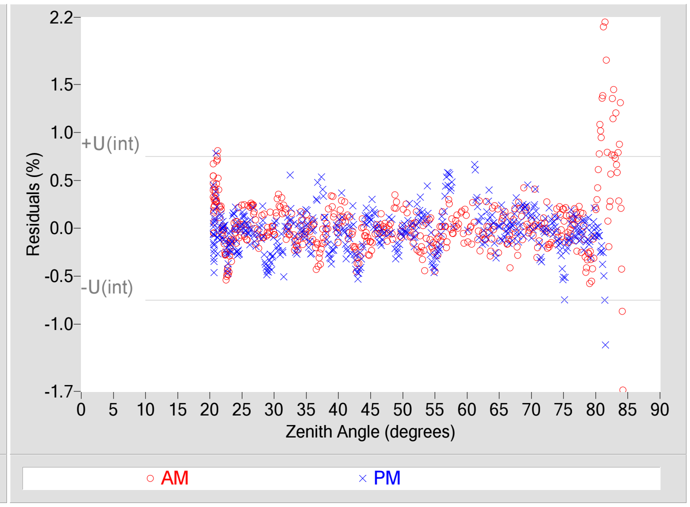


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.37
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	4290
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

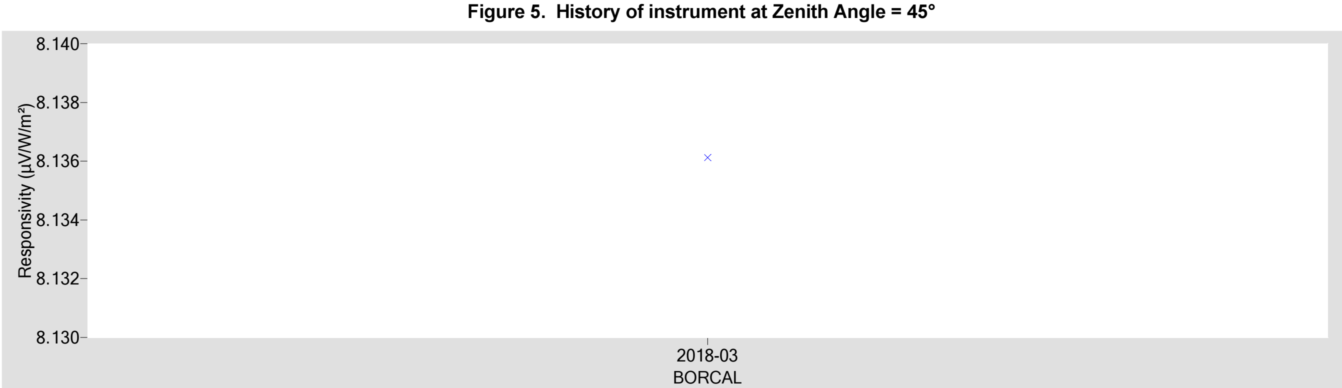
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.1361	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+1.9 / -2.5
Expanded Uncertainty, U (%)	+2.6 / -3.1
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

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[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:**	PY28250
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: RCC

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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
PY28250 Licor LI200

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

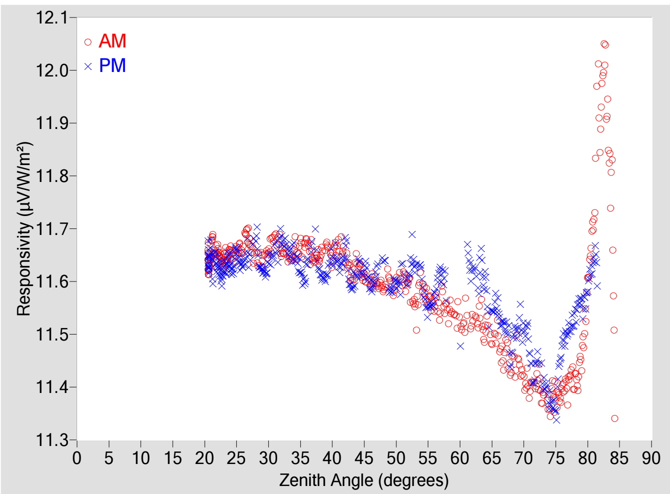


Figure 2. Responsivity vs Local Standard Time

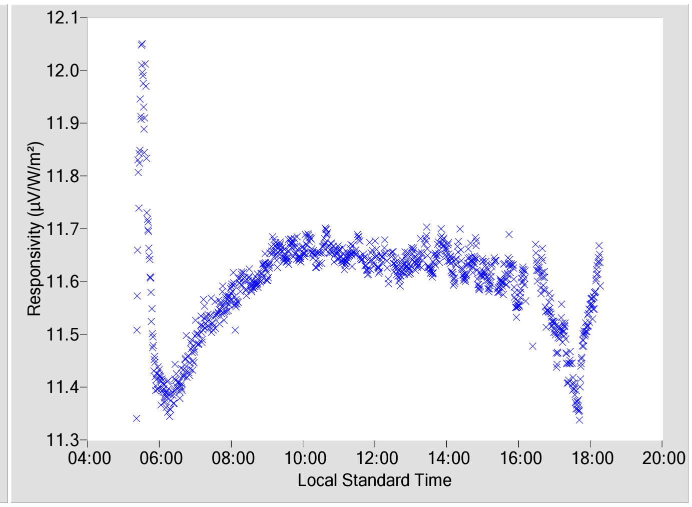


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	11.600	0.29	101.99	11.588	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.587	0.29	100.09	11.641	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.594	0.29	98.14	11.598	0.29	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.593	0.29	96.17	11.615	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.598	0.30	94.29	11.604	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.560	0.30	92.55	11.570	0.30	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.546	0.30	90.94	11.563	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.519	0.31	89.15	11.478	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.526	0.31	87.67	11.617	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.506	0.32	86.03	11.589	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.497	0.33	84.38	11.541	0.35	275.42
22	11.654	0.28	156.29	11.632	0.28	203.76	68	11.439	0.34	82.85	11.455	0.36	276.98
24	11.655	0.28	144.48	11.632	0.28	215.35	70	11.411	0.35	81.20	11.503	N/A	278.59
26	11.658	0.28	137.27	11.636	0.28	223.31	72	11.406	0.37	79.64	11.451	N/A	280.19
28	11.648	0.28	130.61	11.682	0.28	229.48	74	11.362	0.39	78.11	11.374	N/A	281.75
30	11.659	0.28	125.78	11.638	0.28	234.30	76	11.394	0.42	76.49	11.478	N/A	283.34
32	11.660	0.28	121.47	11.682	0.28	238.58	78	11.411	N/A	74.90	11.535	N/A	284.98
34	11.660	0.28	117.91	11.654	0.28	242.26	80	11.585	N/A	73.31	11.589	N/A	286.58
36	11.675	0.28	114.65	11.630	0.29	245.46	82	11.909	N/A	71.61	N/A	N/A	N/A
38	11.647	0.29	111.70	11.620	0.29	248.40	84	11.620	N/A	69.94	N/A	N/A	N/A
40	11.648	0.29	109.03	11.642	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.652	0.29	106.49	11.663	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.635	0.29	104.26	11.628	0.29	255.90	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

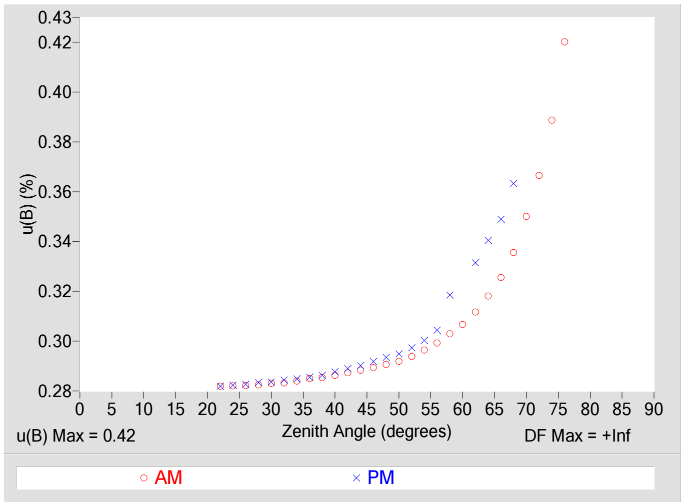


Figure 4. Residuals from Spline Interpolation

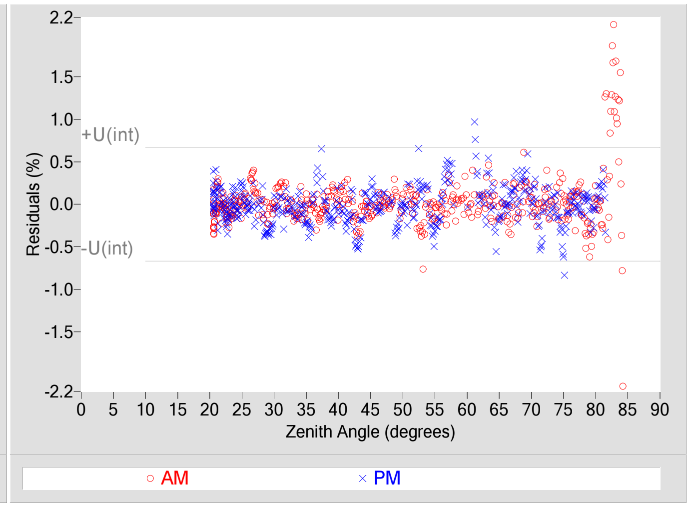


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	5445
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

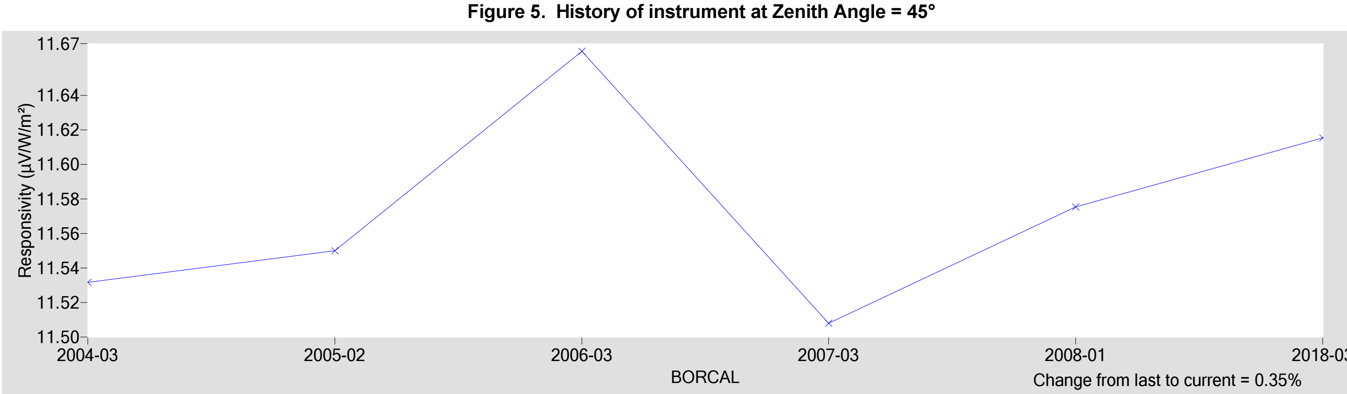
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
11.615	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.57 / -1.2
Expanded Uncertainty, U (%)	+1.2 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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:**	PY60685
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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

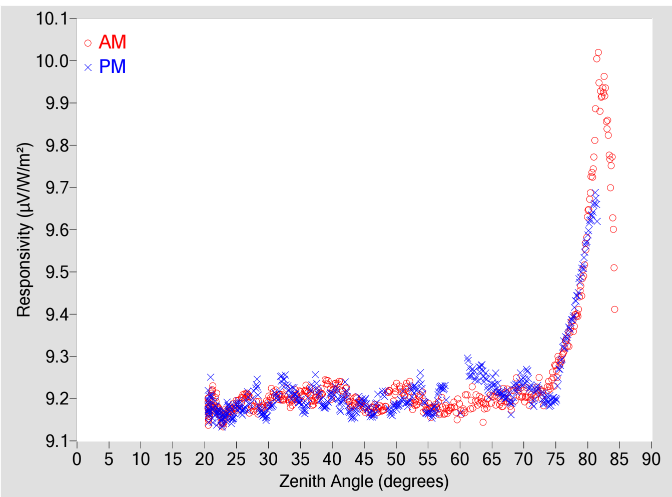


Figure 2. Responsivity vs Local Standard Time

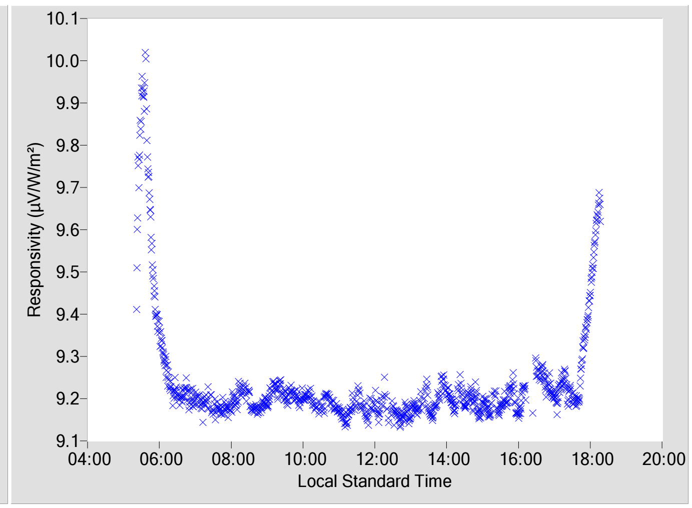


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1706	0.29	101.99	9.1624	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1744	0.29	100.09	9.2126	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2225	0.29	98.14	9.1828	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2210	0.29	96.17	9.1968	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1976	0.30	94.29	9.2250	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1793	0.30	92.55	9.1717	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1743	0.30	90.94	9.1969	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1744	0.31	89.15	9.1656	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2005	0.31	87.67	9.2640	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1834	0.32	86.03	9.2444	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2013	0.33	84.38	9.2194	0.35	275.42
22	9.1831	0.28	156.29	9.1681	0.28	203.76	68	9.1920	0.34	82.85	9.1849	0.36	276.98
24	9.1731	0.28	144.48	9.1667	0.28	215.35	70	9.2053	0.35	81.20	9.2394	N/A	278.59
26	9.2006	0.28	137.27	9.1720	0.28	223.31	72	9.2144	0.37	79.64	9.2234	N/A	280.19
28	9.1817	0.28	130.61	9.2301	0.28	229.48	74	9.2280	0.39	78.11	9.1922	N/A	281.75
30	9.1920	0.28	125.78	9.1770	0.28	234.30	76	9.3004	0.42	76.49	9.3072	N/A	283.34
32	9.2027	0.28	121.47	9.2445	0.28	238.58	78	9.3847	N/A	74.90	9.4241	N/A	284.98
34	9.2023	0.28	117.91	9.2168	0.29	242.26	80	9.6117	N/A	73.31	9.5882	N/A	286.58
36	9.2196	0.29	114.65	9.1858	0.29	245.46	82	9.9171	N/A	71.61	N/A	N/A	N/A
38	9.2122	0.29	111.70	9.2062	0.29	248.40	84	9.6122	N/A	69.94	N/A	N/A	N/A
40	9.2148	0.29	109.03	9.2071	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2200	0.29	106.49	9.2143	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1943	0.29	104.26	9.1863	0.29	255.90	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

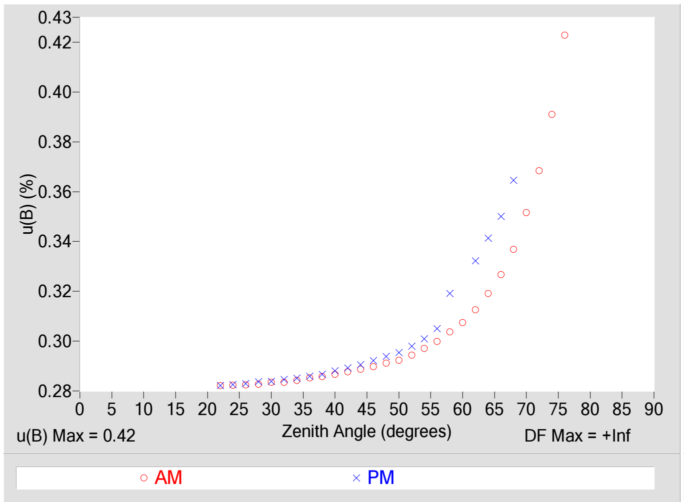


Figure 4. Residuals from Spline Interpolation

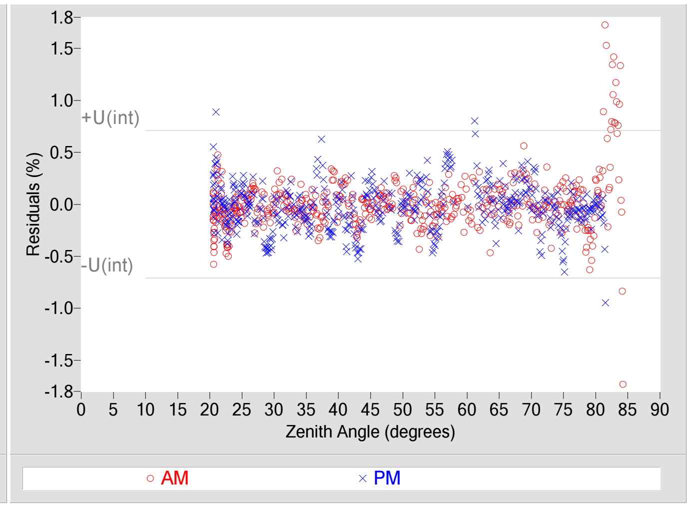


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.36
Combined Standard Uncertainty, u(c) (%)	±0.55
Effective degrees of freedom, DF(c)	4759
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

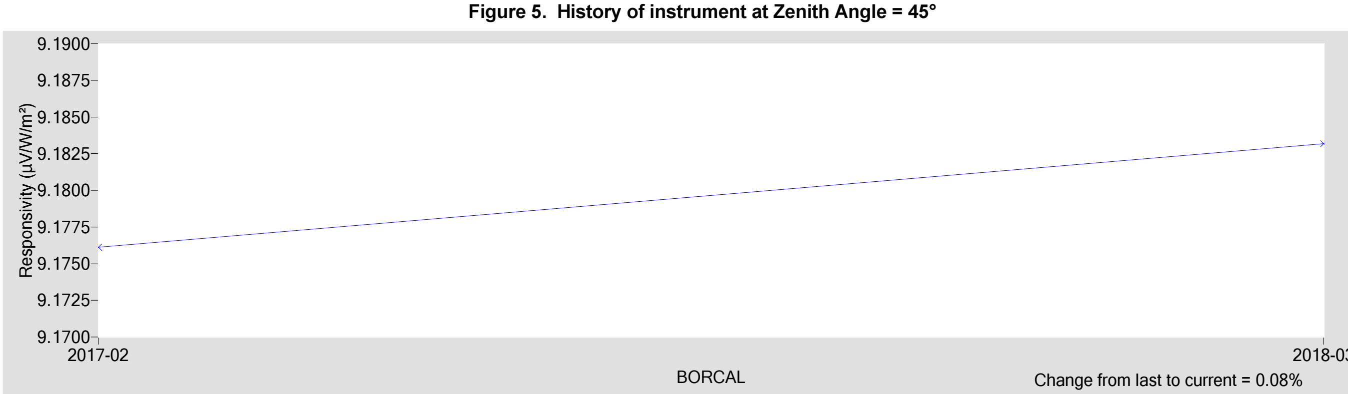
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.1832	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.67 / -0.23
Expanded Uncertainty, U (%)	+1.3 / -0.85
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:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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 - σ * Tc^4*
  - where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
  - *Tc* = case temperature of pyrgeometer (K).
- *I* = reference irradiance (W/m²), beam (B) or global (G)
  - where, *G = B * COS(Z) + D,*
  - *Z* = zenith angle (degrees),
  - *D* = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

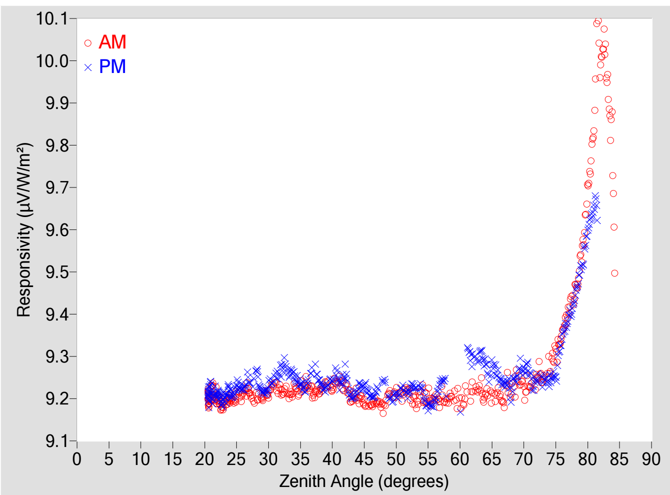


Figure 2. Responsivity vs Local Standard Time

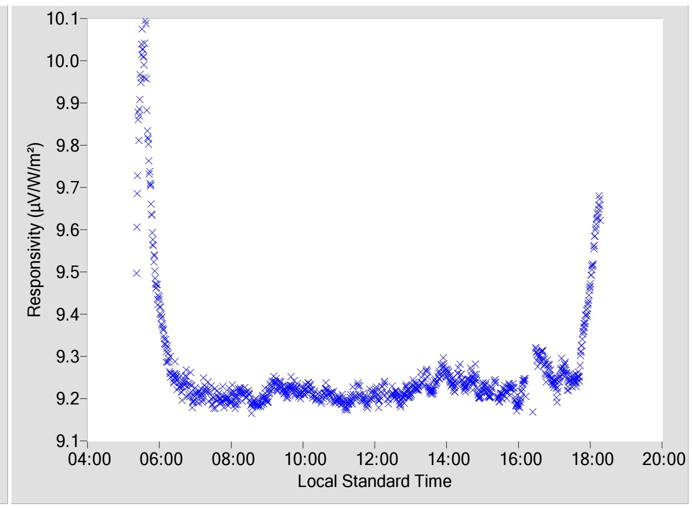


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1837	0.29	101.99	9.2049	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1820	0.29	100.09	9.2413	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2143	0.29	98.14	9.2104	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2150	0.29	96.17	9.2154	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2130	0.30	94.29	9.2199	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2012	0.30	92.55	9.1925	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1946	0.30	90.94	9.2053	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1933	0.31	89.15	9.1681	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2240	0.31	87.67	9.2962	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2076	0.32	86.03	9.2786	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2151	0.33	84.38	9.2523	0.35	275.42
22	9.2003	0.28	156.29	9.2100	0.28	203.76	68	9.2213	0.34	82.85	9.2121	0.36	276.98
24	9.1990	0.28	144.48	9.2163	0.28	215.35	70	9.2203	0.35	81.20	9.2655	N/A	278.59
26	9.2052	0.28	137.27	9.2252	0.28	223.31	72	9.2456	0.37	79.64	9.2464	N/A	280.19
28	9.2003	0.28	130.61	9.2628	0.28	229.48	74	9.2687	0.39	78.11	9.2418	N/A	281.75
30	9.2117	0.28	125.78	9.2299	0.28	234.30	76	9.3565	0.42	76.49	9.3456	N/A	283.34
32	9.2177	0.28	121.47	9.2712	0.28	238.58	78	9.4520	N/A	74.90	9.4447	N/A	284.98
34	9.2205	0.28	117.91	9.2535	0.29	242.26	80	9.6834	N/A	73.31	9.5972	N/A	286.58
36	9.2335	0.29	114.65	9.2342	0.29	245.46	82	10.002	N/A	71.61	N/A	N/A	N/A
38	9.2196	0.29	111.70	9.2406	0.29	248.40	84	9.7093	N/A	69.94	N/A	N/A	N/A
40	9.2268	0.29	109.03	9.2418	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2283	0.29	106.49	9.2564	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2031	0.29	104.26	9.2260	0.29	255.90	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

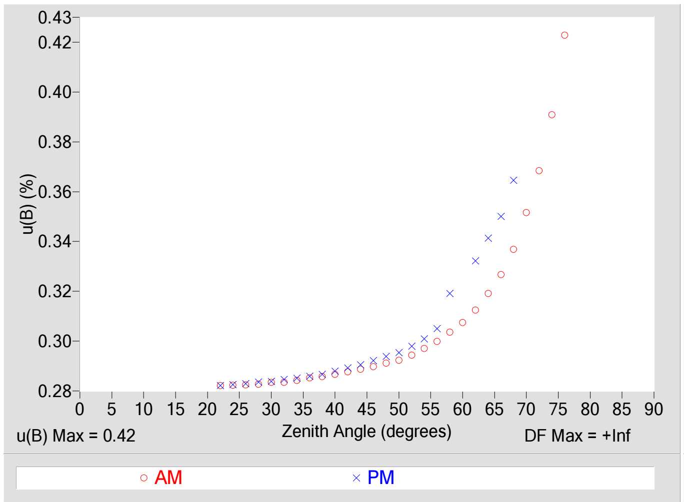


Figure 4. Residuals from Spline Interpolation

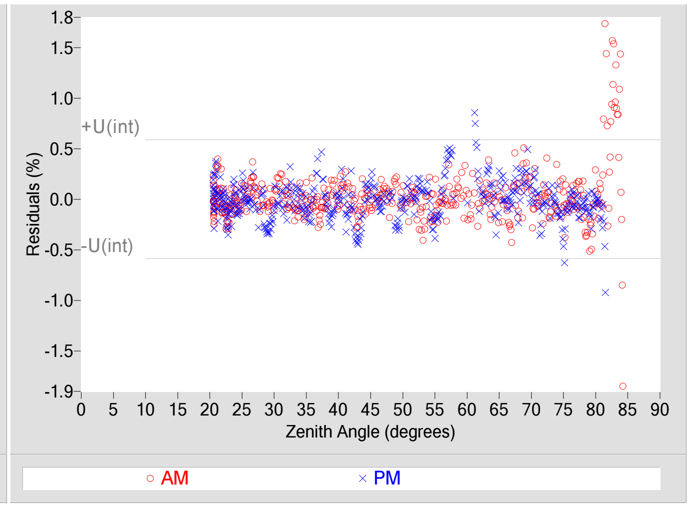


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	7685
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

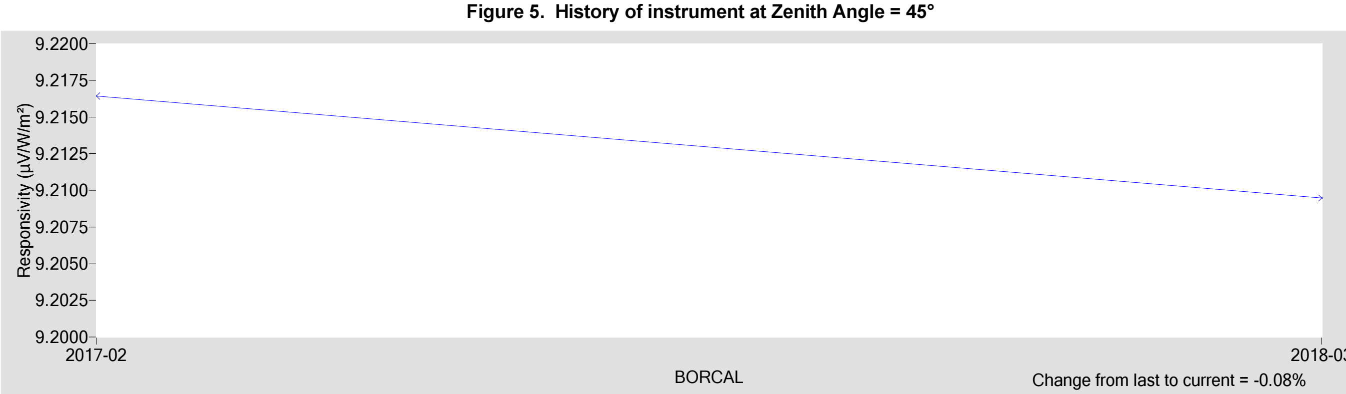
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.2095	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.67 / -0.45
Expanded Uncertainty, U (%)	+1.3 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY63286
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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

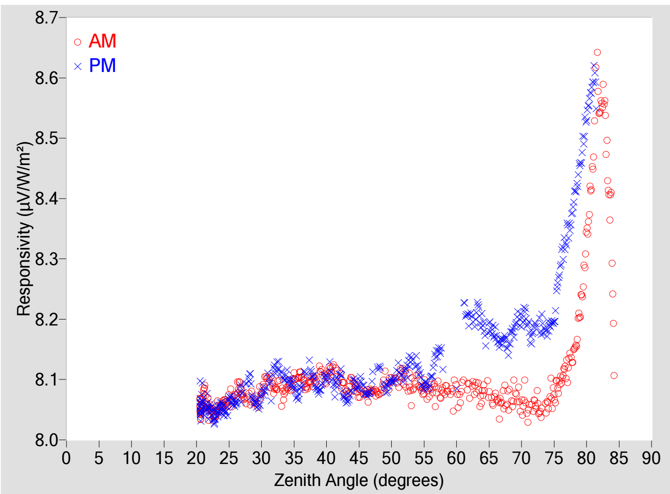


Figure 2. Responsivity vs Local Standard Time

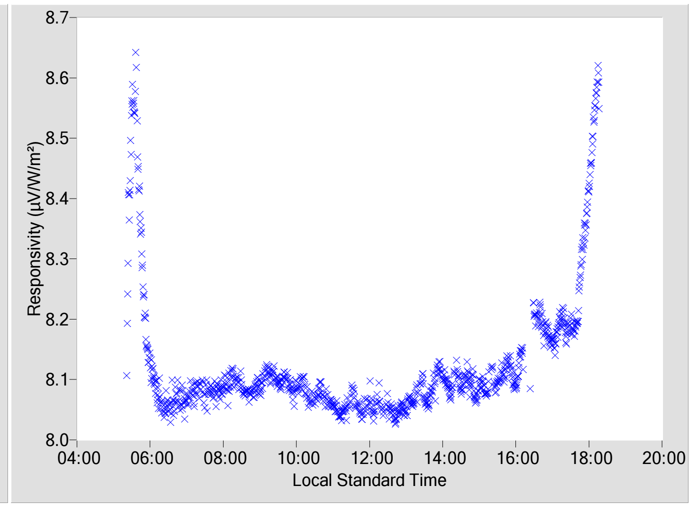


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0782	0.29	101.99	8.0757	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0776	0.29	100.09	8.1197	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0993	0.29	98.14	8.0972	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1035	0.29	96.17	8.1095	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1012	0.30	94.29	8.1223	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0822	0.30	92.55	8.0996	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0808	0.30	90.94	8.1169	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0735	0.31	89.15	8.0850	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0852	0.31	87.67	8.2039	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0759	0.32	86.03	8.1921	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0713	0.33	84.38	8.1719	0.35	275.42
22	8.0525	0.28	156.29	8.0510	0.28	203.76	68	8.0683	0.34	82.85	8.1526	0.37	276.98
24	8.0593	0.28	144.48	8.0525	0.28	215.35	70	8.0525	0.35	81.20	8.1966	N/A	278.59
26	8.0714	0.28	137.27	8.0617	0.28	223.31	72	8.0575	0.37	79.64	8.1879	N/A	280.19
28	8.0687	0.28	130.61	8.1027	0.28	229.48	74	8.0553	0.39	78.11	8.1836	N/A	281.75
30	8.0779	0.28	125.78	8.0743	0.28	234.30	76	8.0983	0.43	76.49	8.2928	N/A	283.34
32	8.0844	0.28	121.47	8.1175	0.28	238.58	78	8.1422	N/A	74.90	8.3963	N/A	284.98
34	8.0887	0.28	117.91	8.1028	0.29	242.26	80	8.3261	N/A	73.31	8.5383	N/A	286.58
36	8.1073	0.29	114.65	8.0857	0.29	245.46	82	8.5532	N/A	71.61	N/A	N/A	N/A
38	8.1007	0.29	111.70	8.1018	0.29	248.40	84	8.2751	N/A	69.94	N/A	N/A	N/A
40	8.1030	0.29	109.03	8.1024	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1035	0.29	106.49	8.1051	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0959	0.29	104.26	8.0915	0.29	255.90	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

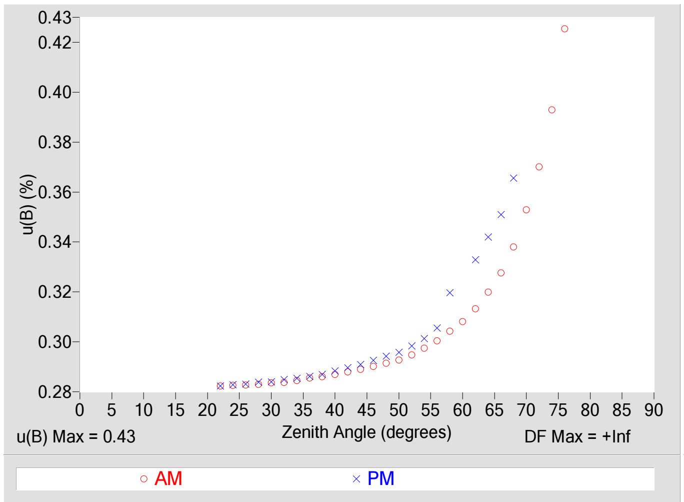


Figure 4. Residuals from Spline Interpolation

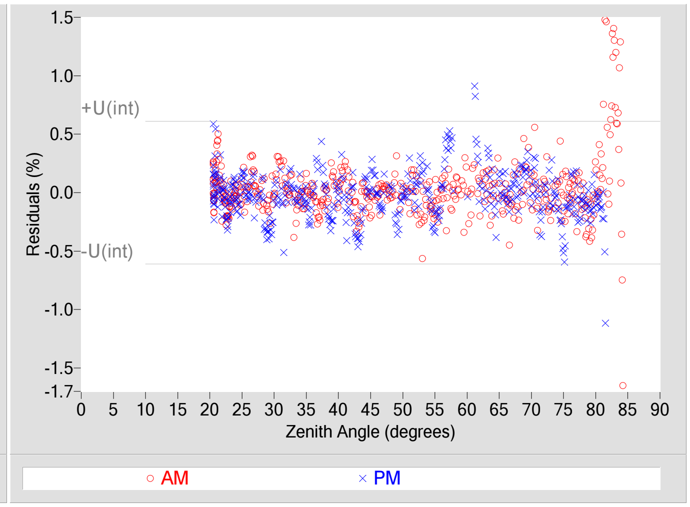


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	7044
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

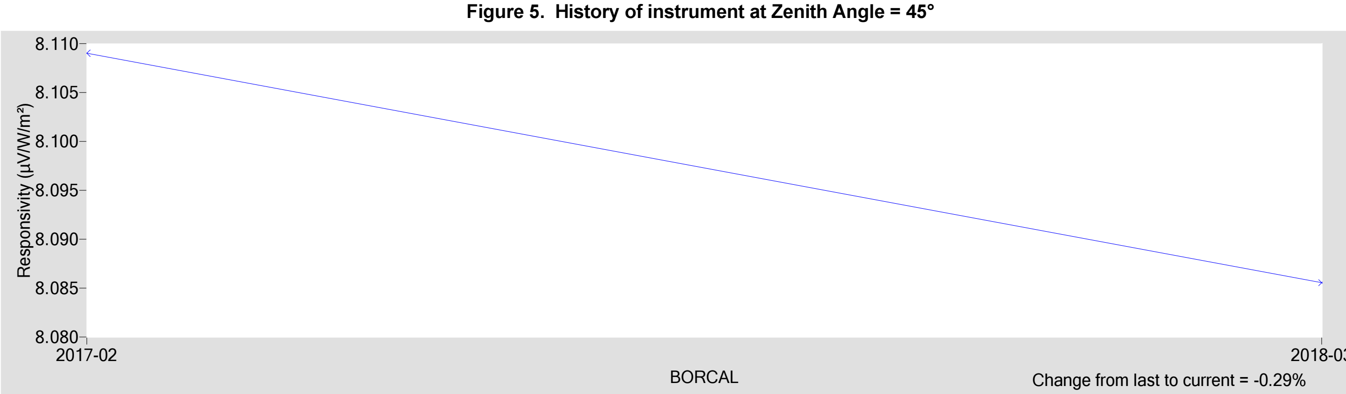
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0856	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.45 / -0.15
Expanded Uncertainty, U (%)	+1.1 / -0.78
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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[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:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

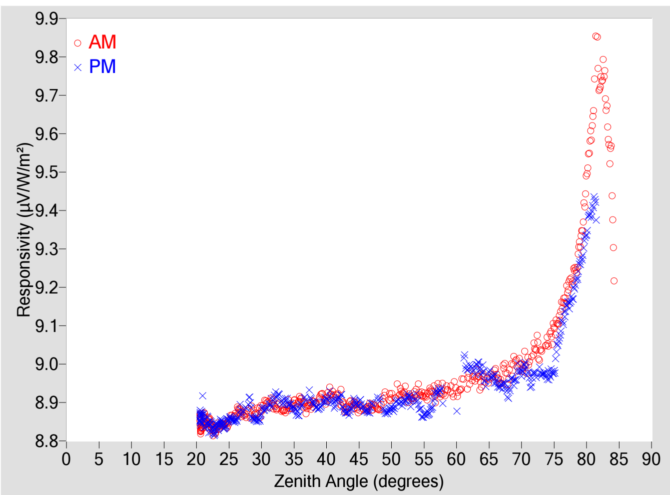


Figure 2. Responsivity vs Local Standard Time

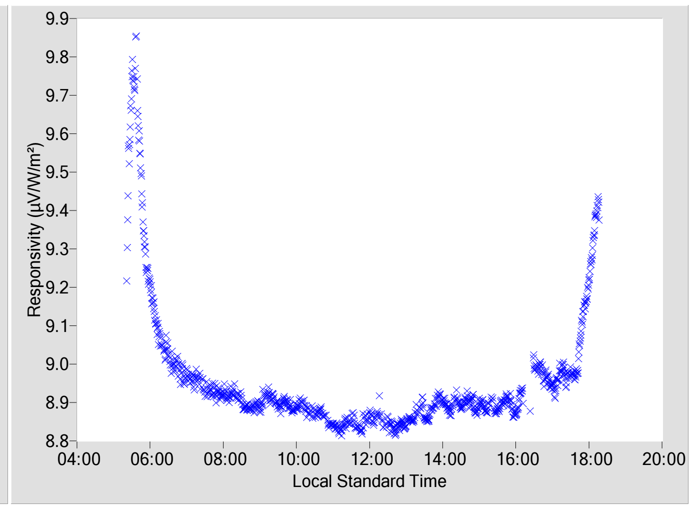


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8834	0.29	101.99	8.8776	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8830	0.29	100.09	8.9088	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9157	0.29	98.14	8.8847	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9258	0.29	96.17	8.9036	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9365	0.30	94.29	8.9018	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9309	0.30	92.55	8.8801	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9274	0.30	90.94	8.8979	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9273	0.31	89.15	8.8775	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9628	0.31	87.67	8.9919	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9615	0.32	86.03	8.9772	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9820	0.33	84.38	8.9568	0.35	275.42
22	8.8482	0.28	156.29	8.8430	0.28	203.76	68	8.9672	0.34	82.85	8.9247	0.36	276.98
24	8.8429	0.28	144.48	8.8442	0.28	215.35	70	8.9927	0.35	81.20	8.9791	N/A	278.59
26	8.8656	0.28	137.27	8.8543	0.28	223.31	72	9.0385	0.37	79.64	8.9746	N/A	280.19
28	8.8740	0.28	130.61	8.9010	0.28	229.48	74	9.0547	0.39	78.11	8.9690	N/A	281.75
30	8.8805	0.28	125.78	8.8720	0.28	234.30	76	9.1366	0.42	76.49	9.0857	N/A	283.34
32	8.8896	0.28	121.47	8.9144	0.28	238.58	78	9.2335	N/A	74.90	9.1883	N/A	284.98
34	8.8888	0.28	117.91	8.9008	0.29	242.26	80	9.4698	N/A	73.31	9.3465	N/A	286.58
36	8.9082	0.29	114.65	8.8859	0.29	245.46	82	9.7337	N/A	71.61	N/A	N/A	N/A
38	8.8995	0.29	111.70	8.8991	0.29	248.40	84	9.4107	N/A	69.94	N/A	N/A	N/A
40	8.9083	0.29	109.03	8.9082	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9173	0.29	106.49	8.9126	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8945	0.29	104.26	8.8955	0.29	255.90	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

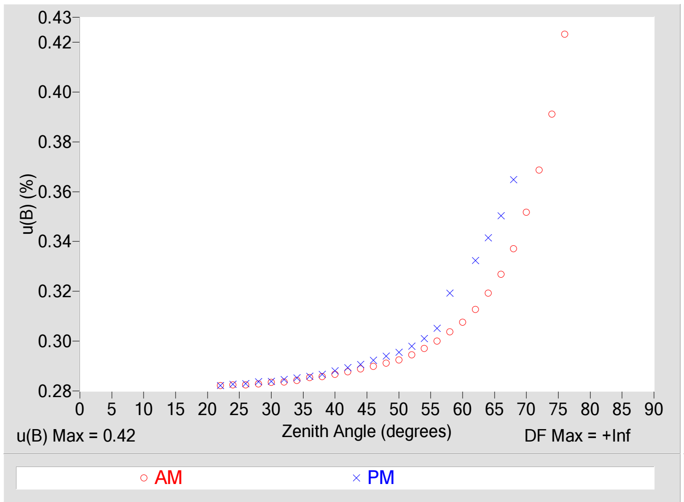


Figure 4. Residuals from Spline Interpolation

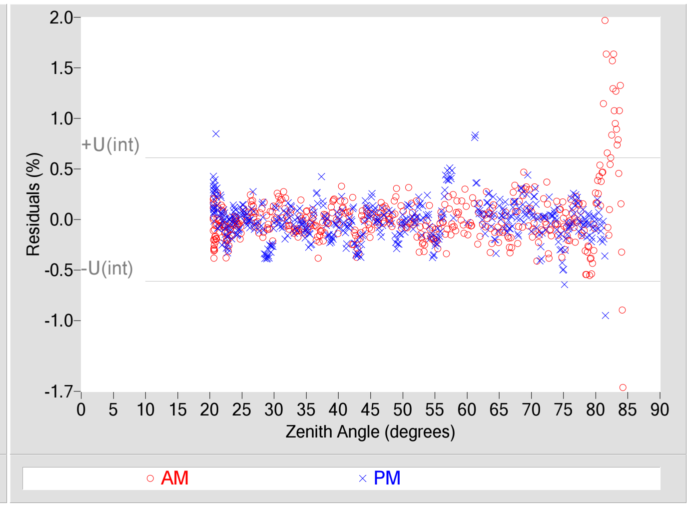


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	6915
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

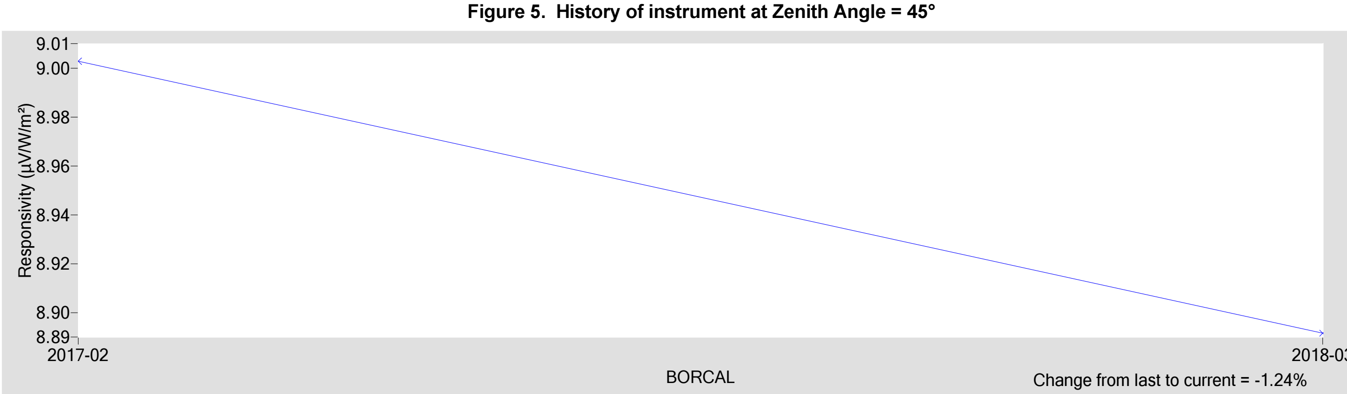
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.8915	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.51 / -0.22
Expanded Uncertainty, U (%)	+1.1 / -0.85
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:**	PY66504
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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

PY66504 Licor LI200

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

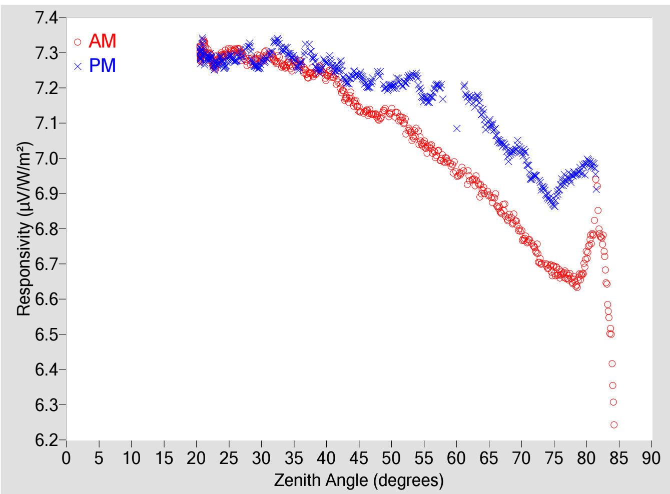


Figure 2. Responsivity vs Local Standard Time

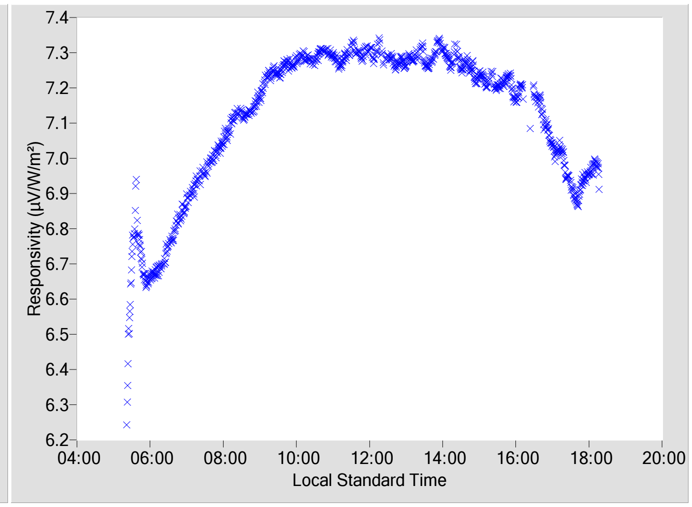


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.1335	0.29	101.99	7.2089	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.1139	0.29	100.09	7.2416	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.1311	0.29	98.14	7.2063	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.0995	0.30	96.17	7.2136	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.0676	0.30	94.29	7.2214	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.0302	0.30	92.55	7.1698	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.9972	0.31	90.94	7.1681	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9538	0.31	89.15	7.0847	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9504	0.31	87.67	7.1719	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9122	0.32	86.03	7.1252	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.8839	0.33	84.38	7.0706	0.35	275.42
22	7.2923	0.28	156.29	7.2865	0.28	203.76	68	6.8307	0.34	82.85	7.0082	0.37	276.98
24	7.2920	0.28	144.48	7.2733	0.28	215.35	70	6.7810	0.36	81.20	7.0169	N/A	278.59
26	7.3072	0.28	137.27	7.2797	0.28	223.31	72	6.7431	0.37	79.64	6.9510	N/A	280.19
28	7.2712	0.28	130.61	7.3193	0.28	229.48	74	6.6917	0.40	78.11	6.8916	N/A	281.75
30	7.2801	0.28	125.78	7.2725	0.28	234.30	76	6.6718	0.43	76.49	6.9240	N/A	283.34
32	7.2772	0.28	121.47	7.3311	0.29	238.58	78	6.6525	N/A	74.90	6.9544	N/A	284.98
34	7.2688	0.28	117.91	7.3024	0.29	242.26	80	6.7175	N/A	73.31	6.9834	N/A	286.58
36	7.2699	0.29	114.65	7.2697	0.29	245.46	82	6.7980	N/A	71.61	N/A	N/A	N/A
38	7.2426	0.29	111.70	7.2830	0.29	248.40	84	6.3894	N/A	69.94	N/A	N/A	N/A
40	7.2337	0.29	109.03	7.2714	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2091	0.29	106.49	7.2621	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.1663	0.29	104.26	7.2381	0.29	255.90	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

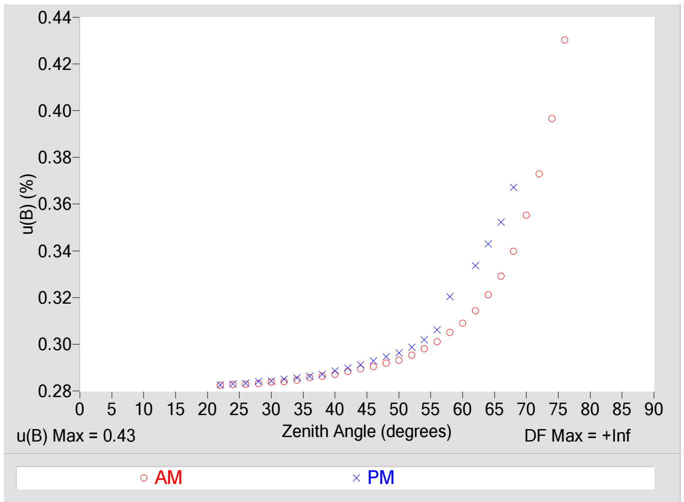


Figure 4. Residuals from Spline Interpolation

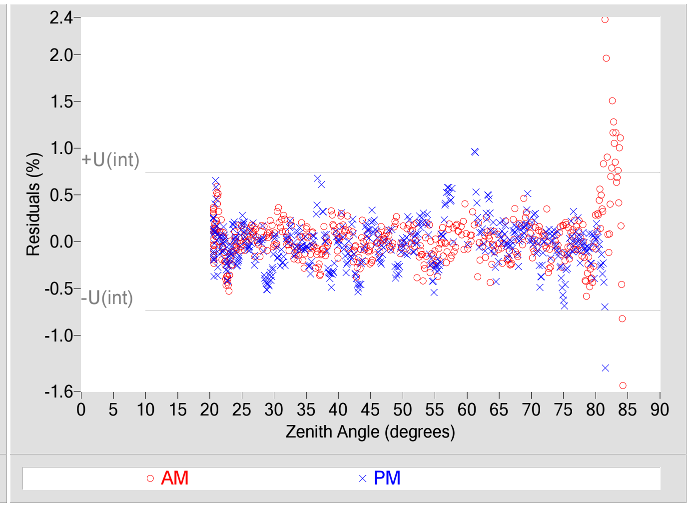


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.37
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	4528
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

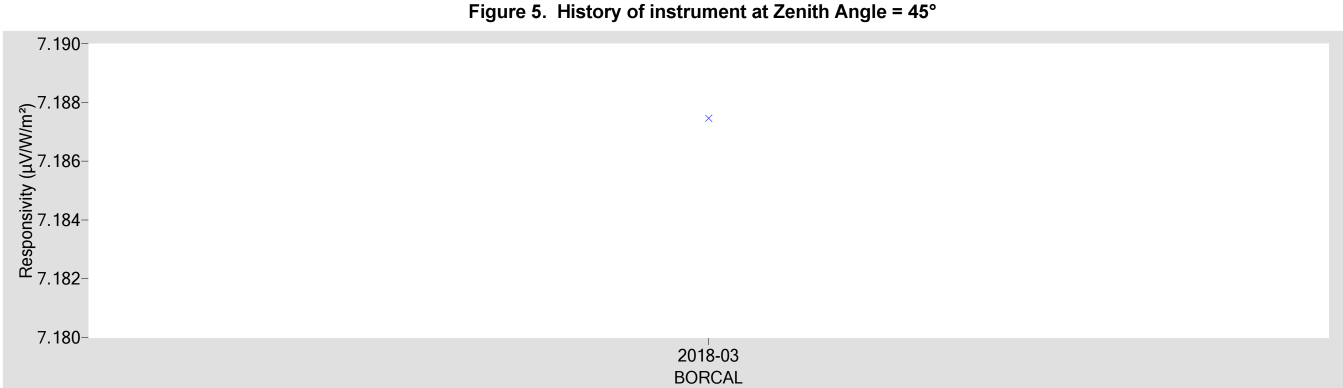
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.1875	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+2.0 / -3.3
Expanded Uncertainty, U (%)	+2.6 / -3.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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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

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY71863
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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

PY71863 Licor LI200

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

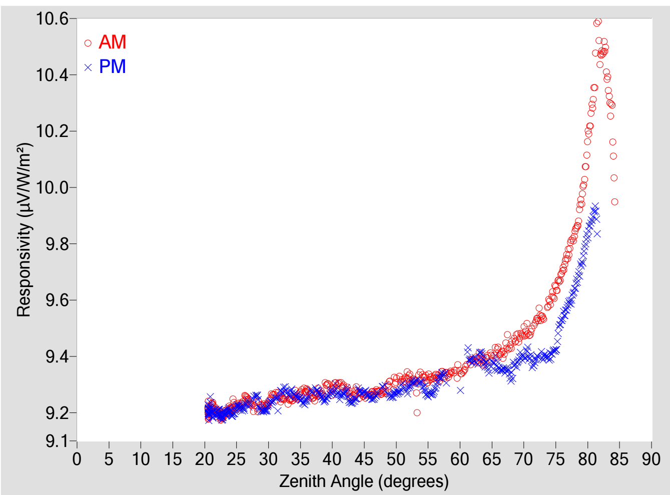


Figure 2. Responsivity vs Local Standard Time

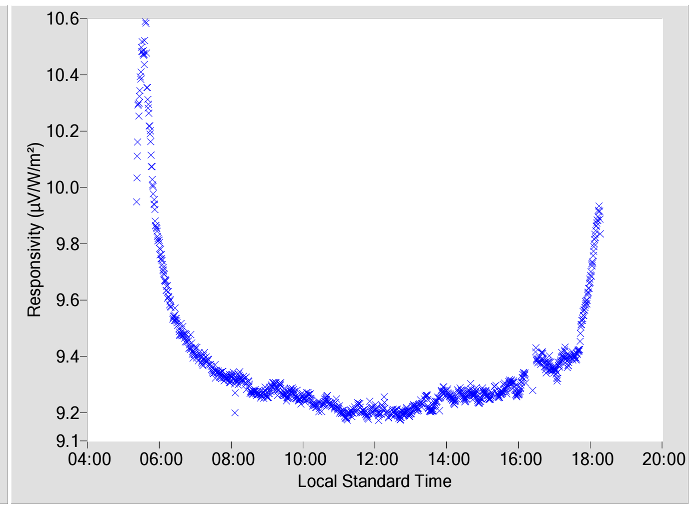


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2689	0.29	101.99	9.2521	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2716	0.29	100.09	9.2902	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3146	0.29	98.14	9.2712	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3270	0.29	96.17	9.2884	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3358	0.30	94.29	9.2997	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3272	0.30	92.55	9.2811	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3361	0.30	90.94	9.3055	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3424	0.31	89.15	9.2797	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3877	0.31	87.67	9.3853	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.3855	0.32	86.03	9.3710	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.4220	0.33	84.38	9.3600	0.35	275.42
22	9.2012	0.28	156.29	9.2033	0.28	203.76	68	9.4382	0.34	82.85	9.3276	0.36	276.98
24	9.2141	0.28	144.48	9.2034	0.28	215.35	70	9.4851	0.35	81.20	9.3954	N/A	278.59
26	9.2347	0.28	137.27	9.2173	0.28	223.31	72	9.5281	0.37	79.64	9.3962	N/A	280.19
28	9.2258	0.28	130.61	9.2605	0.28	229.48	74	9.5897	0.39	78.11	9.3995	N/A	281.75
30	9.2342	0.28	125.78	9.2271	0.28	234.30	76	9.7019	0.42	76.49	9.5347	N/A	283.34
32	9.2492	0.28	121.47	9.2758	0.28	238.58	78	9.8383	N/A	74.90	9.6498	N/A	284.98
34	9.2550	0.28	117.91	9.2636	0.29	242.26	80	10.149	N/A	73.31	9.8358	N/A	286.58
36	9.2790	0.29	114.65	9.2489	0.29	245.46	82	10.477	N/A	71.61	N/A	N/A	N/A
38	9.2730	0.29	111.70	9.2675	0.29	248.40	84	10.141	N/A	69.94	N/A	N/A	N/A
40	9.2798	0.29	109.03	9.2735	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2865	0.29	106.49	9.2741	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2734	0.29	104.26	9.2688	0.29	255.90	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

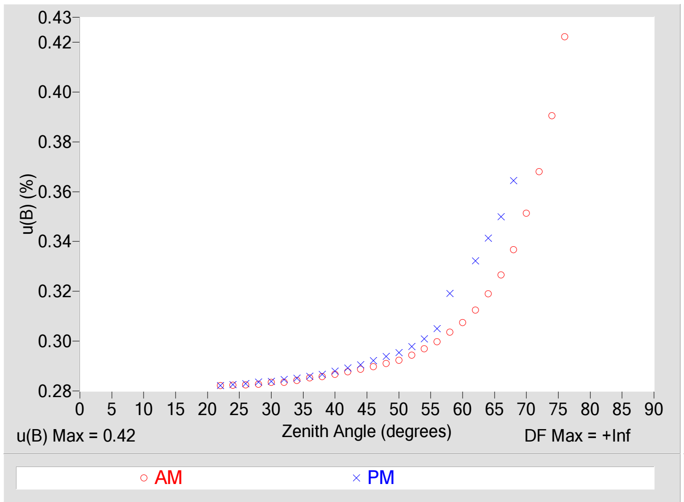


Figure 4. Residuals from Spline Interpolation

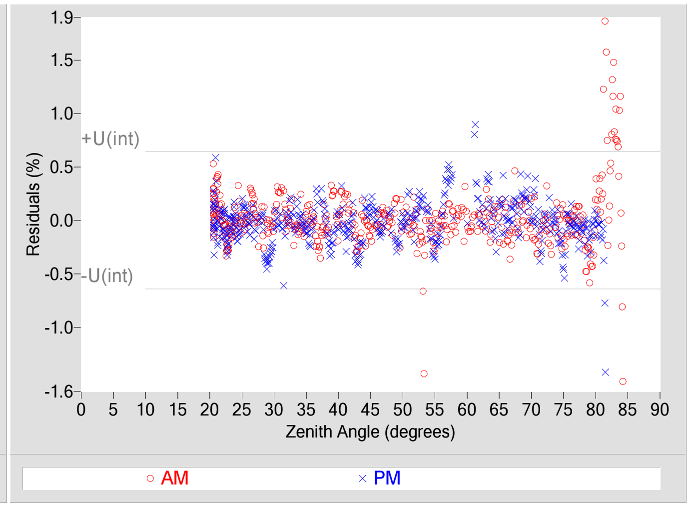


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	6060
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

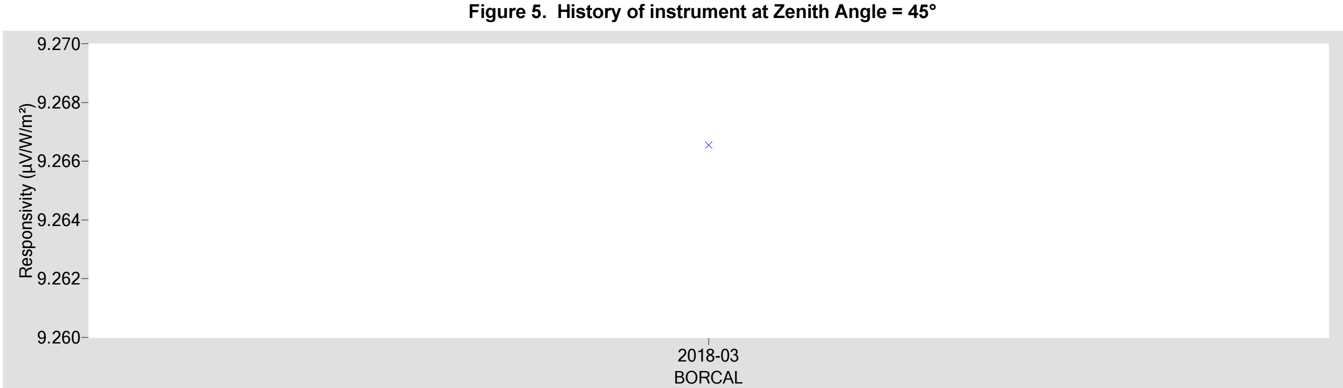
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.2666	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.82 / -0.43
Expanded Uncertainty, U (%)	+1.4 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Campbell Scientific's Licor LI200	**Manufacturer:**	Licor
Model:	LI200X	**Serial Number:**	PY89786
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: RCC

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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

PY89786 Licor LI200X

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

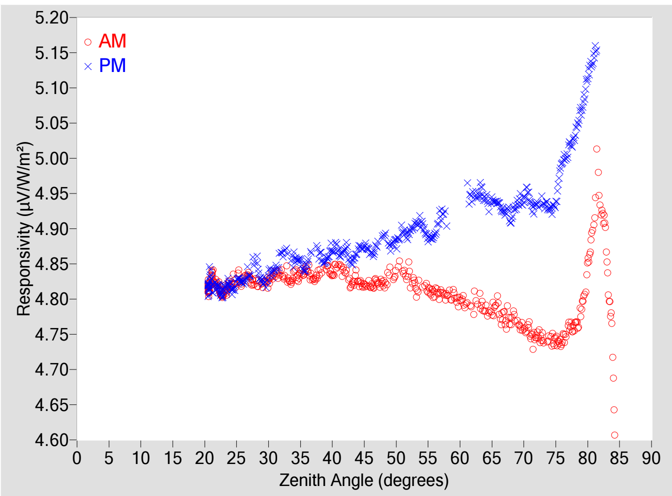


Figure 2. Responsivity vs Local Standard Time

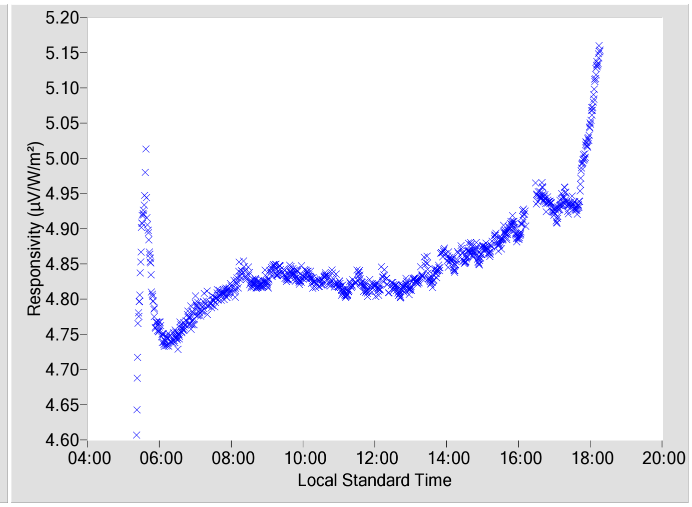


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	4.8196	0.29	102.04	4.8650	0.30	258.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	4.8219	0.29	99.97	4.8903	0.30	260.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	4.8373	0.30	98.08	4.8825	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	4.8351	0.30	96.12	4.8933	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	4.8174	0.30	94.22	4.9053	0.30	265.80
10	N/A	N/A	N/A	N/A	N/A	N/A	56	4.8081	0.30	92.60	4.8908	0.31	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	4.8044	0.31	90.97	4.9037	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	4.7970	0.31	89.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	4.7928	0.32	87.54	4.9459	0.34	272.09
18	N/A	N/A	N/A	N/A	N/A	N/A	64	4.7833	0.33	85.96	4.9432	0.35	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	4.7925	0.33	84.41	4.9359	0.36	275.42
22	4.8202	0.28	156.21	4.8170	0.28	203.77	68	4.7687	0.35	82.86	4.9119	0.37	276.99
24	4.8208	0.28	144.65	4.8178	0.28	215.36	70	4.7561	0.36	81.20	4.9410	N/A	278.59
26	4.8254	0.28	137.02	4.8249	0.28	223.32	72	4.7471	0.38	79.64	4.9345	N/A	280.19
28	4.8237	0.28	130.66	4.8531	0.29	229.34	74	4.7449	0.41	78.10	4.9281	N/A	281.75
30	4.8254	0.29	125.72	4.8345	0.29	234.30	76	4.7415	0.44	76.49	4.9947	N/A	283.34
32	4.8349	0.29	121.43	4.8645	0.29	238.78	78	4.7638	N/A	74.90	5.0351	N/A	284.98
34	4.8353	0.29	117.95	4.8569	0.29	242.21	80	4.8450	N/A	73.26	5.1162	N/A	286.58
36	4.8412	0.29	114.66	4.8498	0.29	245.47	82	4.9316	N/A	71.61	N/A	N/A	N/A
38	4.8391	0.29	111.76	4.8636	0.29	248.48	84	4.6839	N/A	69.90	N/A	N/A	N/A
40	4.8342	0.29	108.96	4.8703	0.29	251.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	4.8403	0.29	106.54	4.8722	0.29	253.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	4.8267	0.29	104.16	4.8700	0.29	255.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

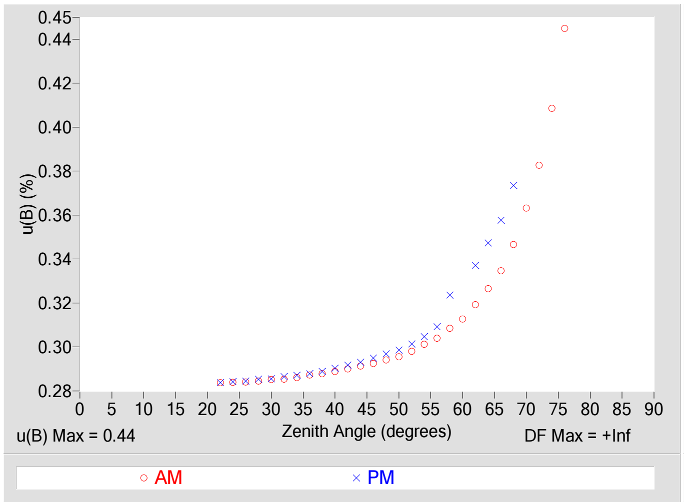


Figure 4. Residuals from Spline Interpolation

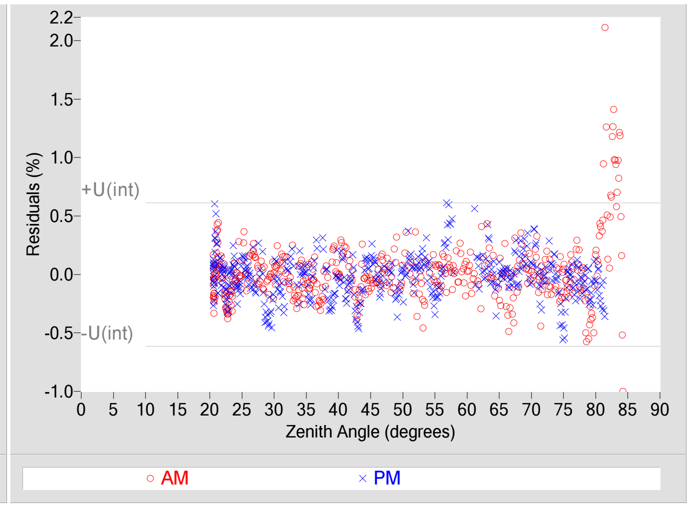


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	7909
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

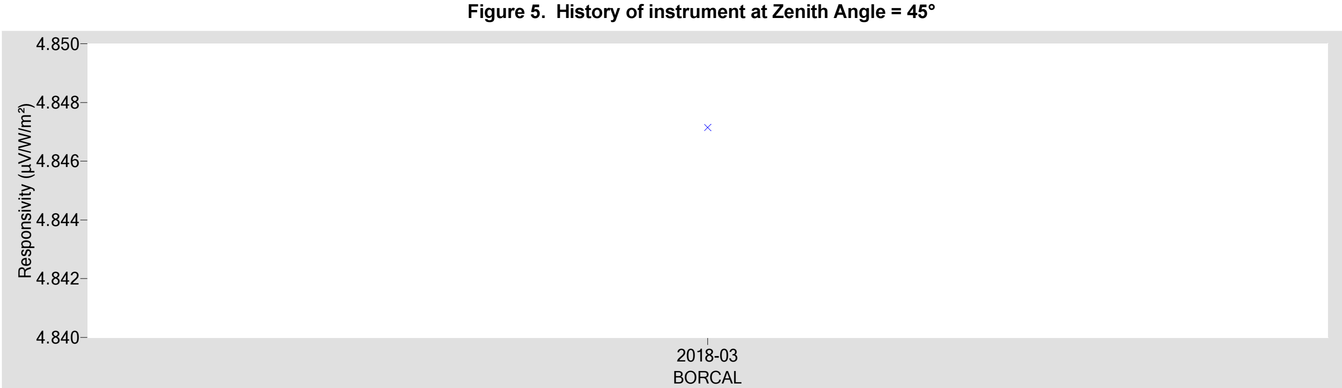
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
4.8471	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+1.2 / -1.0
Expanded Uncertainty, U (%)	+1.8 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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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:	Campbell Scientific's Licor LI200	**Manufacturer:**	Licor
Model:	LI200X	**Serial Number:**	PY89790
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: RCC

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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

PY89790 Licor LI200X

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

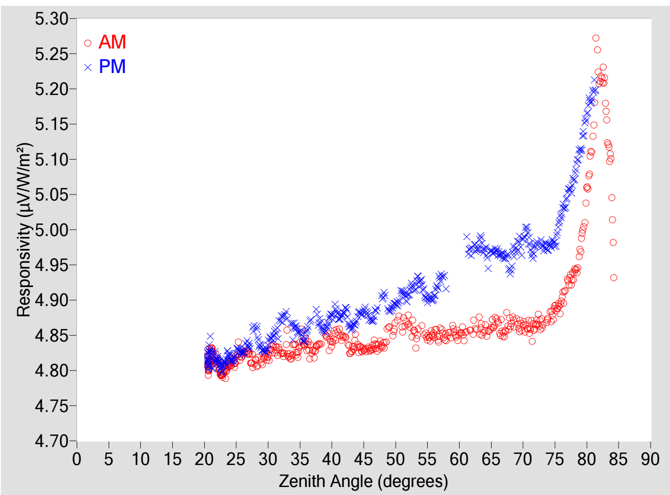


Figure 2. Responsivity vs Local Standard Time

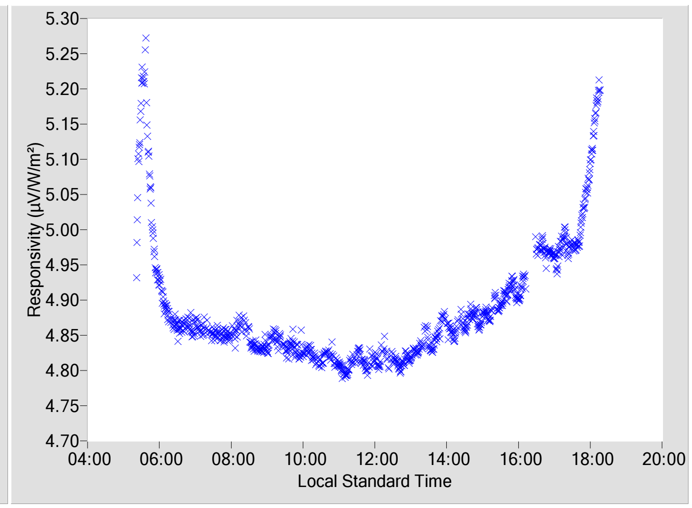


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	4.8304	0.29	102.04	4.8714	0.30	258.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	4.8356	0.29	99.97	4.9059	0.30	260.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	4.8632	0.30	98.08	4.8953	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	4.8678	0.30	96.12	4.9072	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	4.8636	0.30	94.22	4.9238	0.30	265.80
10	N/A	N/A	N/A	N/A	N/A	N/A	56	4.8517	0.30	92.60	4.9049	0.31	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	4.8468	0.31	90.97	4.9161	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	4.8498	0.31	89.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	4.8599	0.32	87.54	4.9703	0.34	272.09
18	N/A	N/A	N/A	N/A	N/A	N/A	64	4.8562	0.33	85.96	4.9701	0.35	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	4.8705	0.33	84.41	4.9682	0.36	275.42
22	4.8127	0.28	156.21	4.8145	0.28	203.77	68	4.8655	0.35	82.86	4.9432	0.37	276.99
24	4.8092	0.28	144.65	4.8182	0.28	215.36	70	4.8613	0.36	81.20	4.9834	N/A	278.59
26	4.8235	0.28	137.02	4.8264	0.28	223.32	72	4.8655	0.38	79.64	4.9786	N/A	280.19
28	4.8113	0.28	130.66	4.8603	0.29	229.34	74	4.8765	0.41	78.10	4.9753	N/A	281.75
30	4.8201	0.29	125.72	4.8377	0.29	234.30	76	4.8978	0.44	76.49	5.0236	N/A	283.34
32	4.8257	0.29	121.43	4.8735	0.29	238.78	78	4.9387	N/A	74.90	5.0763	N/A	284.98
34	4.8307	0.29	117.95	4.8601	0.29	242.21	80	5.0504	N/A	73.26	5.1641	N/A	286.58
36	4.8371	0.29	114.66	4.8552	0.29	245.47	82	5.2151	N/A	71.61	N/A	N/A	N/A
38	4.8373	0.29	111.76	4.8684	0.29	248.48	84	5.0148	N/A	69.90	N/A	N/A	N/A
40	4.8402	0.29	108.96	4.8781	0.29	251.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	4.8476	0.29	106.54	4.8849	0.29	253.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	4.8360	0.29	104.16	4.8764	0.29	255.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

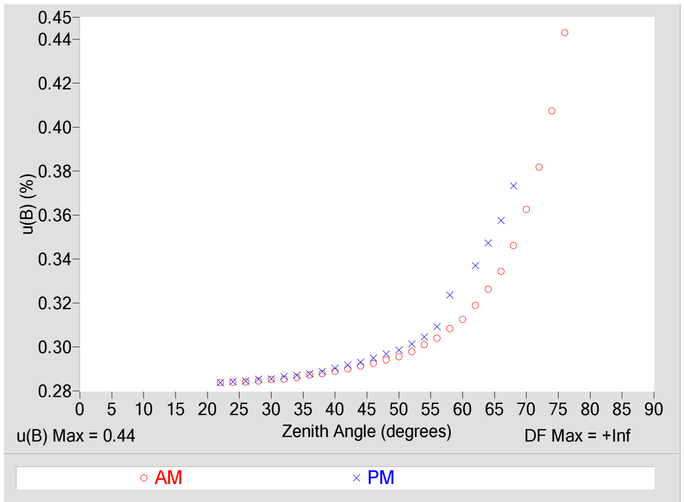


Figure 4. Residuals from Spline Interpolation

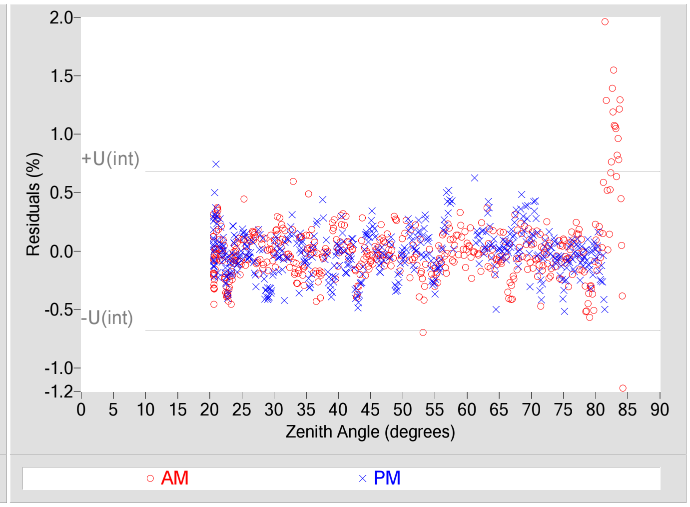


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.56
Effective degrees of freedom, DF(c)	5960
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

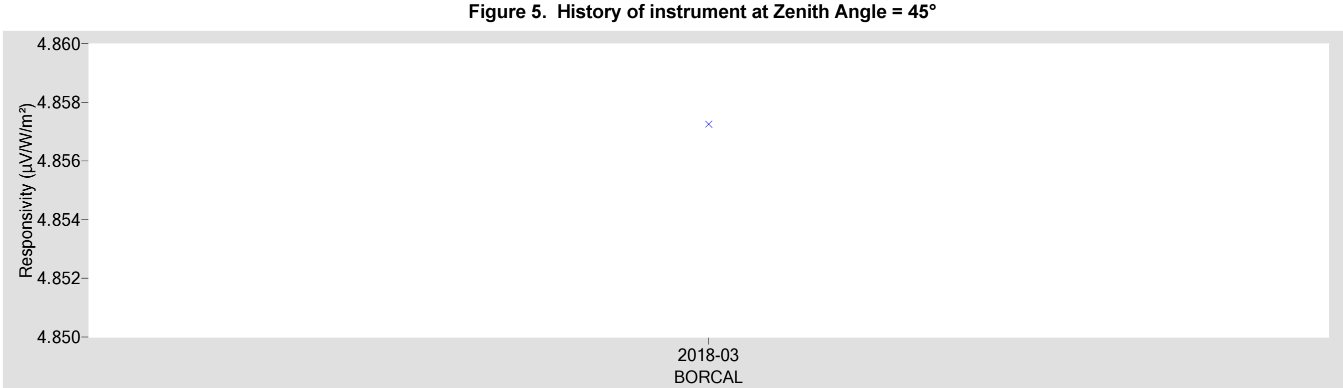
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
4.8573	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+1.4 / -0.76
Expanded Uncertainty, U (%)	+2.0 / -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

[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:**	S13135062
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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: 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

S13135062 EKO ML-01

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

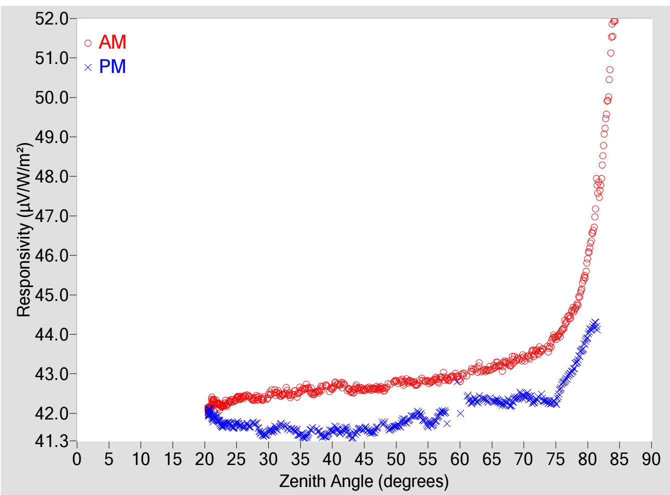


Figure 2. Responsivity vs Local Standard Time

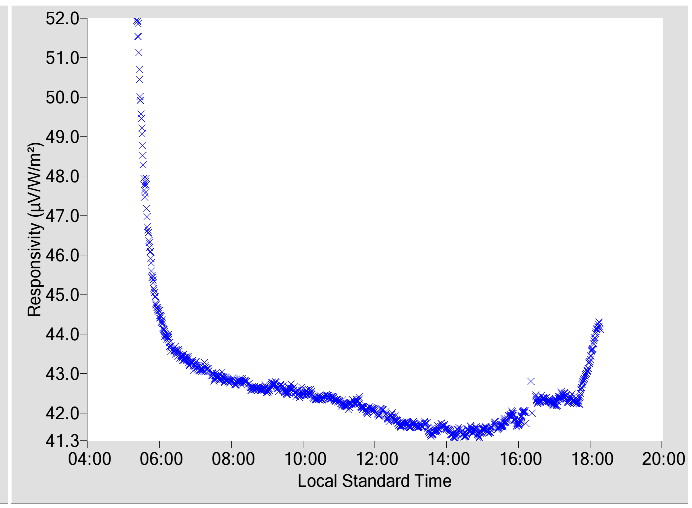


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	42.616	0.29	102.07	41.522	0.29	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	42.608	0.29	100.00	41.746	0.29	260.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	42.816	0.29	98.11	41.676	0.29	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	42.806	0.29	96.15	41.830	0.30	263.93
8	N/A	N/A	N/A	N/A	N/A	N/A	54	42.861	0.30	94.25	41.911	0.30	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	42.859	0.30	92.63	41.784	0.30	267.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	42.854	0.30	90.84	41.883	0.31	269.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	42.874	0.31	89.22	41.994	N/A	270.91
16	N/A	N/A	N/A	N/A	N/A	N/A	62	43.099	0.31	87.62	42.301	0.33	272.17
18	N/A	N/A	N/A	N/A	N/A	N/A	64	43.086	0.32	86.01	42.357	0.34	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	43.224	0.32	84.38	42.296	0.35	275.45
22	42.242	0.28	155.88	41.833	0.28	203.95	68	43.285	0.33	82.79	42.211	0.36	276.96
24	42.304	0.28	144.57	41.712	0.28	215.44	70	43.392	0.35	81.24	42.422	N/A	278.57
26	42.404	0.28	136.70	41.645	0.28	223.55	72	43.547	0.36	79.66	42.357	N/A	280.17
28	42.382	0.28	130.60	41.736	0.28	229.28	74	43.676	0.38	78.09	42.264	N/A	281.78
30	42.447	0.28	125.68	41.543	0.28	234.38	76	44.084	0.41	76.51	42.743	N/A	283.37
32	42.465	0.28	121.61	41.697	0.28	238.38	78	44.649	N/A	74.88	43.217	N/A	284.96
34	42.521	0.28	117.93	41.569	0.28	242.35	80	45.897	N/A	73.29	43.955	N/A	286.56
36	42.663	0.28	114.65	41.441	0.29	245.52	82	47.831	N/A	71.64	N/A	N/A	N/A
38	42.588	0.28	111.67	41.502	0.29	248.44	84	51.789	N/A	69.92	N/A	N/A	N/A
40	42.643	0.29	109.00	41.549	0.29	251.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	42.724	0.29	106.71	41.600	0.29	253.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	42.639	0.29	104.23	41.572	0.29	255.93	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

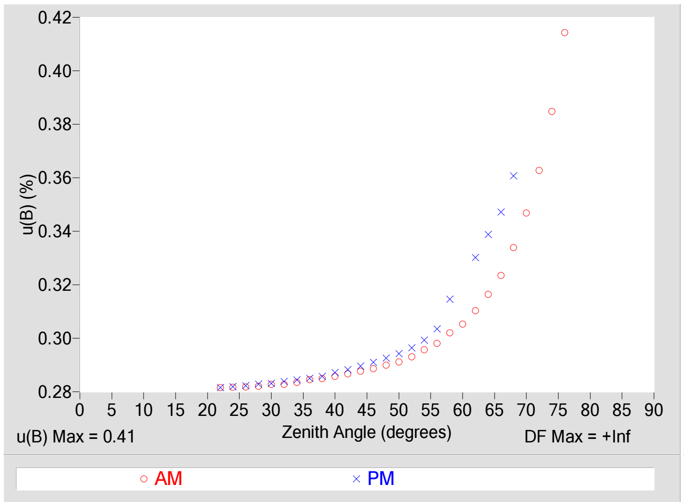


Figure 4. Residuals from Spline Interpolation

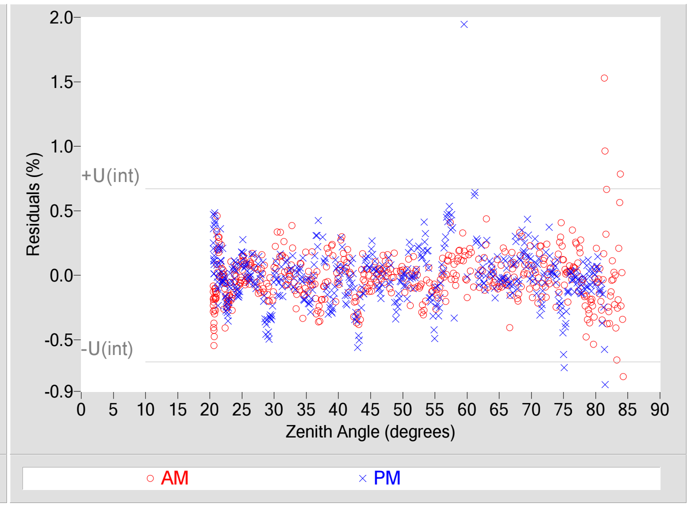


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	5292
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

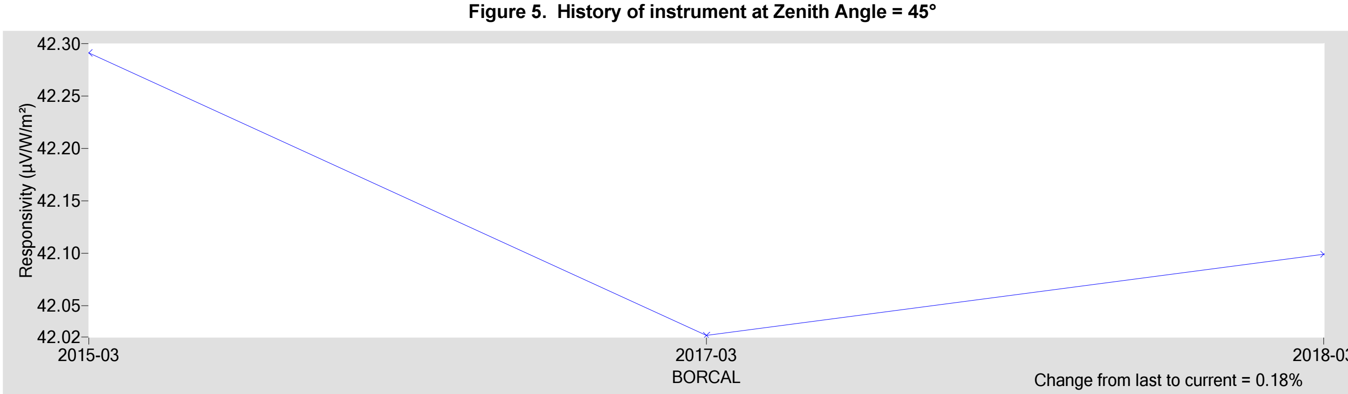
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
42.099	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+1.8 / -1.6
Expanded Uncertainty, U (%)	+2.5 / -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:**	EKO
Model:	MS-80	**Serial Number:**	S17096006
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	Mike Dooraghi	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
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	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: 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

S17096006 EKO MS-80

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),
  = $Win - Wout$ = $Win - \sigma * Tc\hat{}4$
  - 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

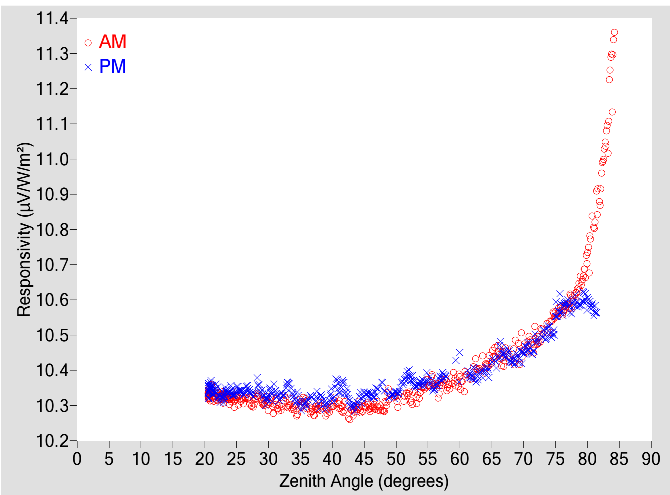


Figure 2. Responsivity vs Local Standard Time

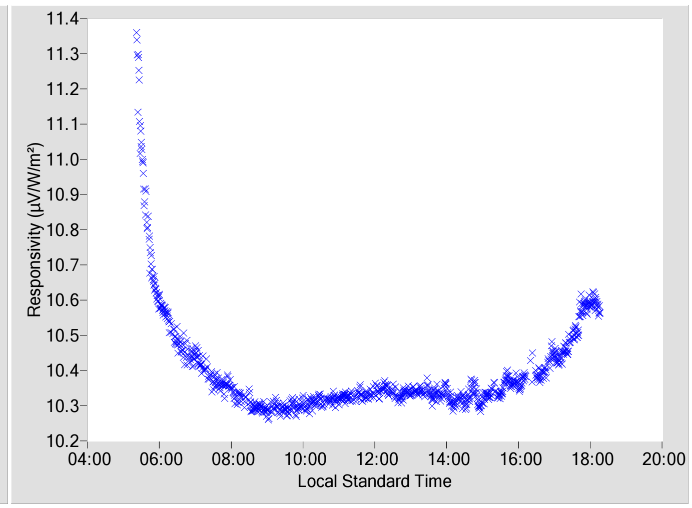


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.291	0.29	102.01	10.329	0.29	258.03
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.290	0.29	99.95	10.353	0.29	260.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.314	0.29	98.01	10.336	0.30	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.327	0.29	96.13	10.383	0.30	263.99
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.342	0.30	94.44	10.366	0.30	265.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.360	0.30	92.56	10.349	0.30	267.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.353	0.30	90.80	10.382	0.31	269.05
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.368	0.31	89.25	10.409	N/A	270.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.390	0.31	87.67	10.391	0.33	272.23
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.410	0.32	85.96	10.401	0.34	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.451	0.33	84.35	10.437	0.35	275.43
22	10.327	0.28	155.86	10.337	0.28	203.07	68	10.431	0.34	82.98	10.425	0.36	277.02
24	10.318	0.28	144.64	10.342	0.28	215.62	70	10.457	0.35	81.26	10.455	N/A	278.62
26	10.314	0.28	137.12	10.336	0.28	223.10	72	10.494	0.37	79.67	10.486	N/A	280.13
28	10.321	0.28	130.74	10.358	0.28	229.58	74	10.518	0.39	78.06	10.515	N/A	281.74
30	10.306	0.28	125.72	10.333	0.28	234.33	76	10.569	0.42	76.52	10.573	N/A	283.33
32	10.296	0.28	121.37	10.327	0.28	238.51	78	10.606	N/A	74.93	10.594	N/A	284.92
34	10.296	0.28	117.99	10.320	0.29	242.27	80	10.718	N/A	73.25	10.592	N/A	286.61
36	10.308	0.29	114.65	10.311	0.29	245.44	82	10.906	N/A	71.59	N/A	N/A	N/A
38	10.295	0.29	111.68	10.314	0.29	248.46	84	11.286	N/A	69.93	N/A	N/A	N/A
40	10.299	0.29	109.01	10.326	0.29	251.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.292	0.29	106.72	10.346	0.29	253.60	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.293	0.29	104.17	10.311	0.29	255.87	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

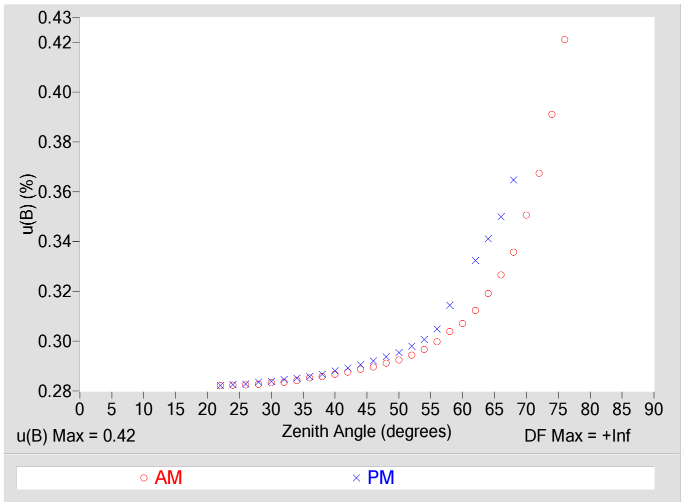


Figure 4. Residuals from Spline Interpolation

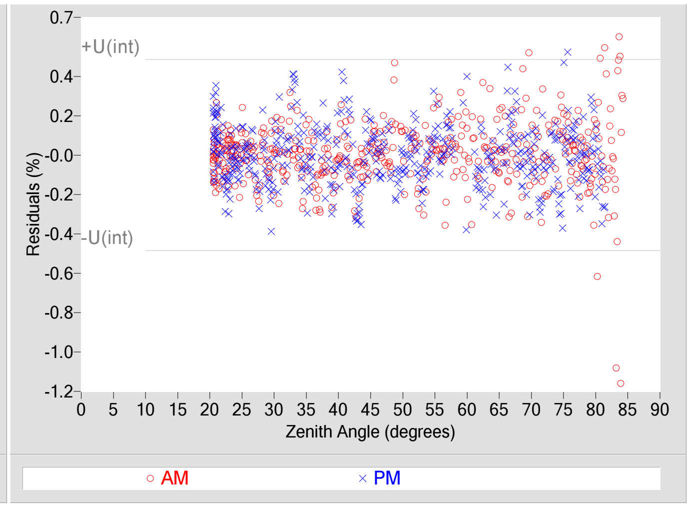


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	13078
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.95
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

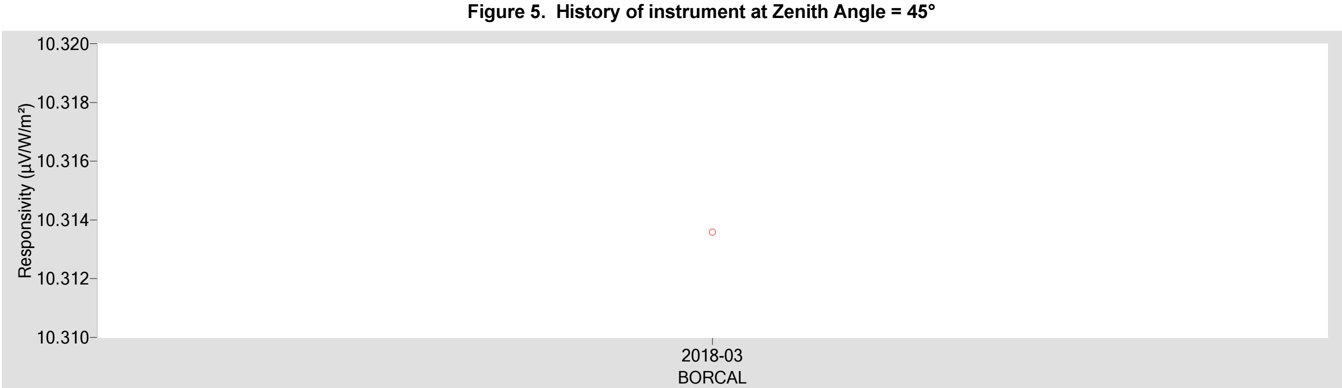
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.314	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.93 / -0.23
Expanded Uncertainty, U (%)	+1.5 / -0.84
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Environmental and Sky Conditions for BORCAL-SW 2018-03

Calibration Facility: Solar Radiation Research Laboratory

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

Reference Irradiance:

Figure 6. Reference Irradiance

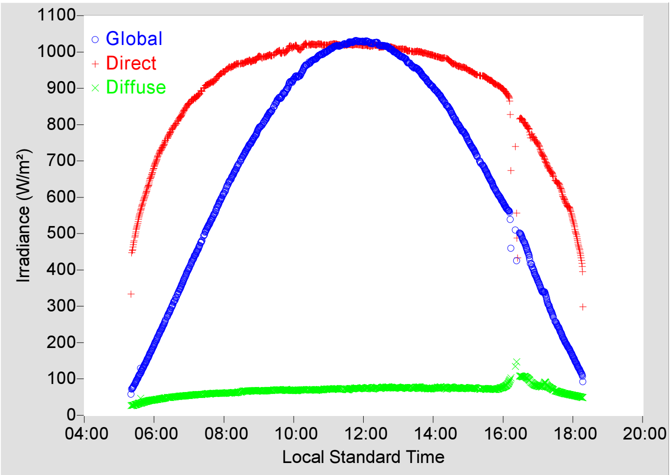
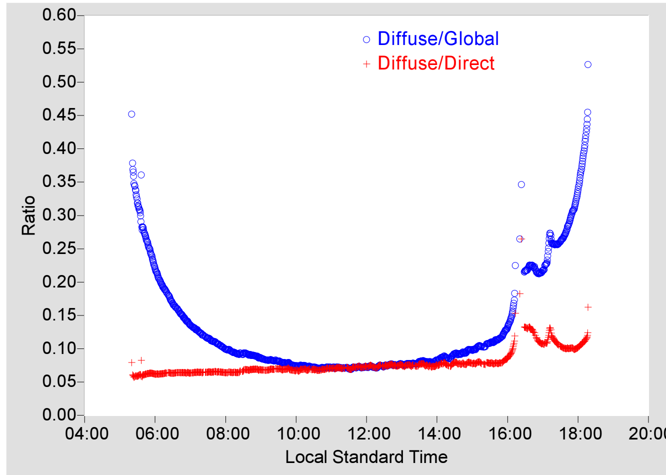


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

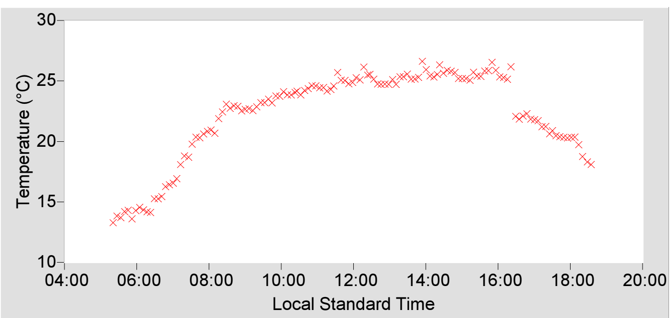


Figure 9. Humidity

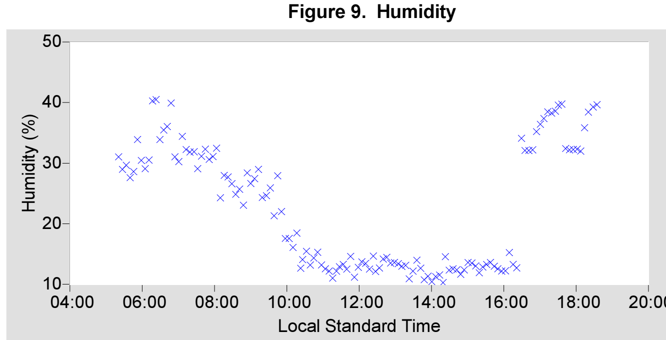


Figure 10. Pressure

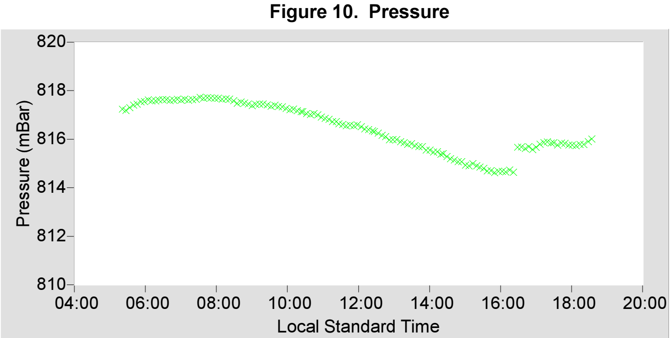


Figure 11. Effective Net Infrared

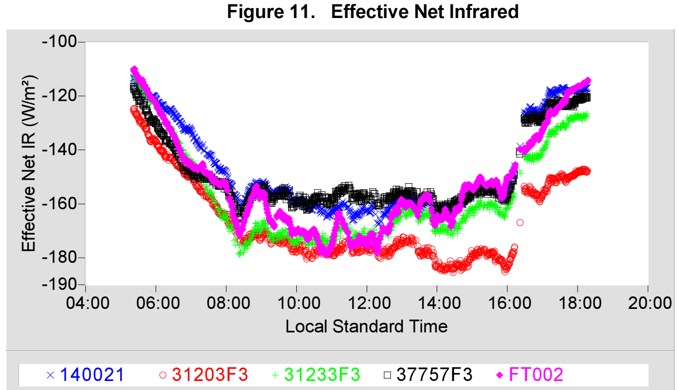


Figure 12. Estimated Broadband Aerosol Optical Depth

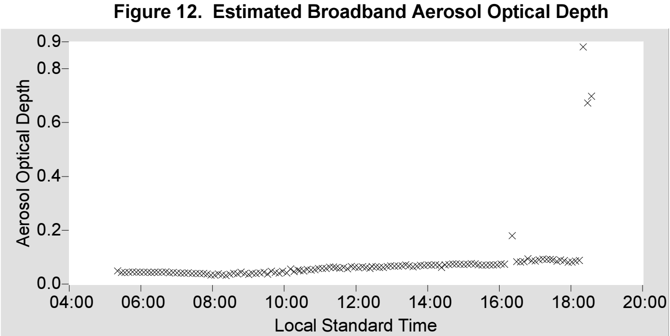


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	22.28	13.28	26.62
Humidity (%)	22.49	10.29	40.50
Pressure (mBar)	816.4	814.6	817.7
Est. Aerosol Optical Depth (BB)	0.077	0.032	0.881

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

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