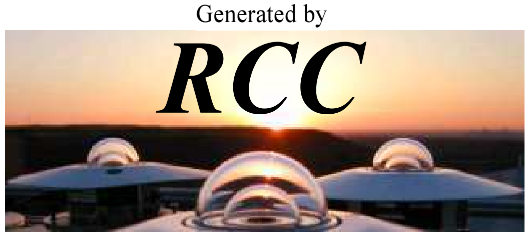
Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2018-04

Generated by



Radiometer Calibration and Characterization

<u>Customer</u>

NREL-SRRL-BMS

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

<u>Calibration Facility</u>

Solar Radiation Research Laboratory

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

Calibration date
05/25/2018 to 05/26/2018

Report Date
May 30, 2018

NOTICE

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

This report compiles the calibration results from a Broadband Outdoor Radiometer Calibration (BORCAL). The work was accomplished at the Radiometer Calibration Facility shown on the front of this report. The calibration results reported here are traceable to the International System (SI) Units of Measurement.

This report includes these sections:

- Control Instruments - a group of instruments included in each BORCAL event that provides a measure of process consistency.
- Results Summary - a table of all instruments included in this report summarizing their calibration results and uncertainty.
- Instrument Details - the calibration certificates for each instrument.
- Environmental and Sky Conditions - meteorological conditions and reference irradiance during the calibration event.

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

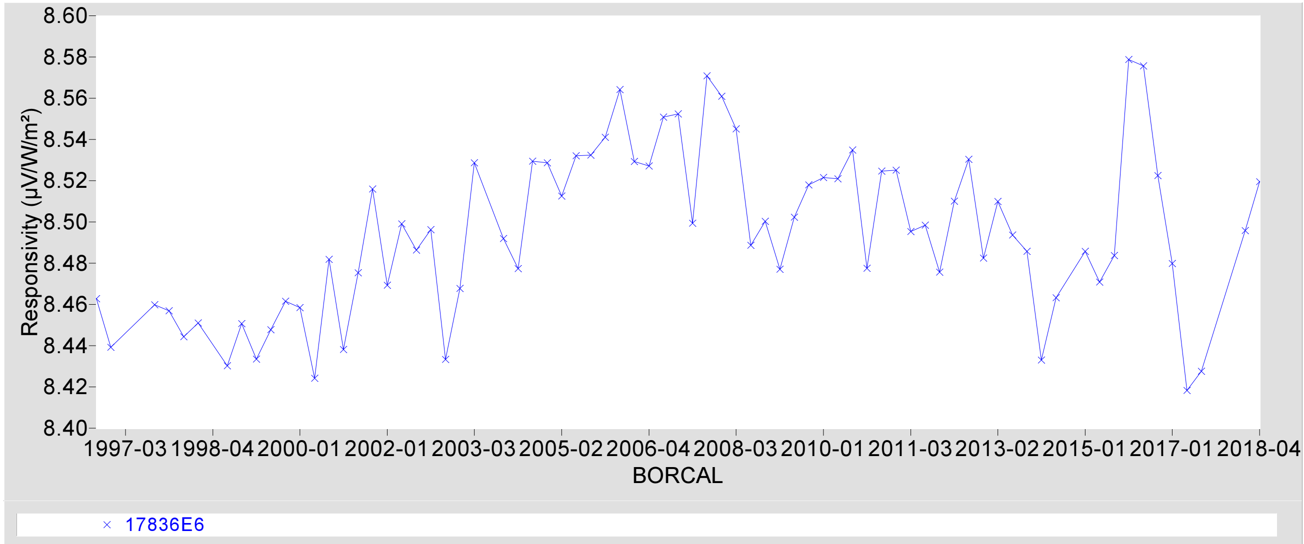
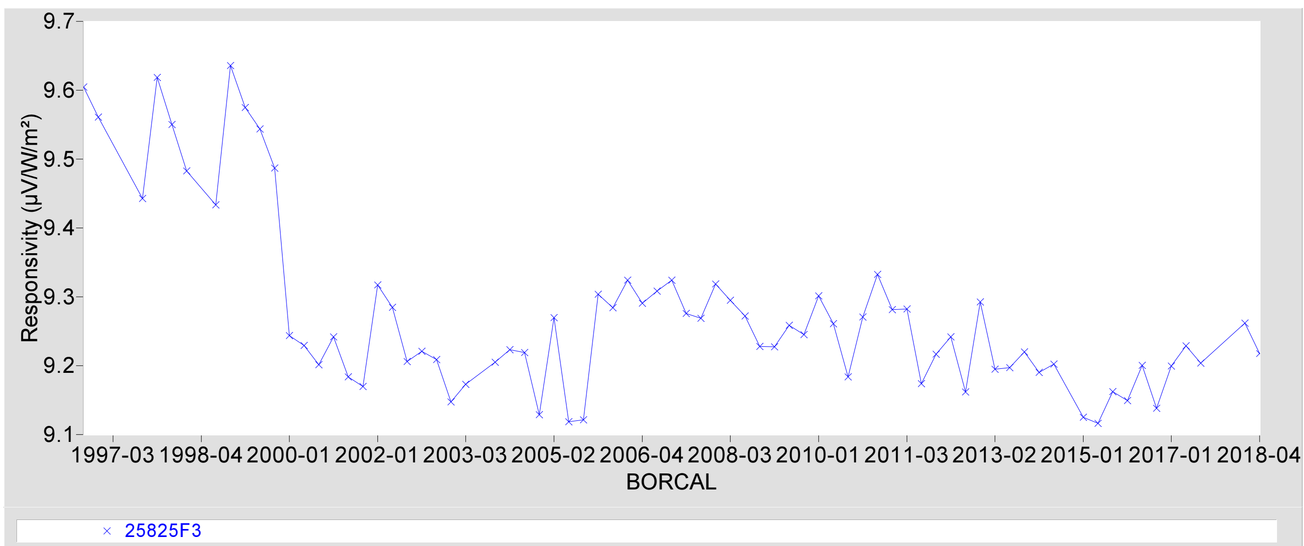


Figure 2. Eppley PSP Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	R@45 ¹ (µV/W/m²)	CF@45 ¹ (W/m²/mV)	U ² (%)	Rnet ³ (µV/W/m²)	Page
010034 Kipp & Zonen CM22	10.945	91.366	+2.5 / -1.6	0.087000	A1-2
010284-DW-CM3 Kipp & Zonen CM3	17.091	58.509	+2.3 / -2.2	0.40000	A1-5
140713 Kipp & Zonen CMP11	8.6085	116.16	+1.5 / -1.1	0.20500	A1-8
140911 Kipp & Zonen CMP11	8.6520	115.58	+1.6 / -1.6	0.20500	A1-11
18035F3 Eppley PSP	7.9144	126.35	+2.6 / -3.6	0.60000	A1-14
20068F3 Eppley PSP	9.3713	106.71	+2.4 / -3.3	0.60000	A1-17
31398F3 Eppley PSP	7.8009	128.19	+2.7 / -3.2	0.60000	A1-20
31401F3 Eppley PSP	8.2916	120.60	+2.3 / -3.1	0.60000	A1-23
PY1724 Licor LI200	11.453	87.315	+2.2 / -1.7	0	A1-26
PY1750 Licor LI200	13.400	74.629	+2.5 / -2.4	0	A1-29
PY28244 Licor LI200	12.949	77.228	+2.3 / -1.8	0	A1-32
PY28247 Licor LI200	12.919	77.405	+2.4 / -1.8	0	A1-35
PY28249 Licor LI200	12.111	82.571	+1.8 / -1.4	0	A1-38
PY28260 Licor LI200	12.814	78.042	+1.8 / -1.0	0	A1-41
PY66489 Licor LI200	9.3404	107.06	+2.2 / -2.0	0	A1-44

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

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

Appendix 1
Instrument Details

Calibration Certificates: 3 pages for each radiometer (4 including Environmental Conditions)
Environmental Conditions for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CM22	**Serial Number:**	010034
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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 CGR4, S/N 140021	06/05/2015	06/05/2019

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

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Mark Kutchenreiter, and RCC

________________________________ ________________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

010034 Kipp & Zonen CM22

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

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

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

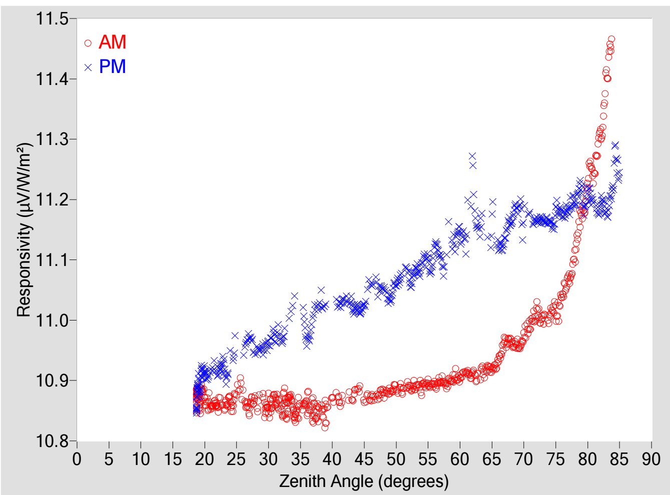


Figure 2. Responsivity vs Local Standard Time

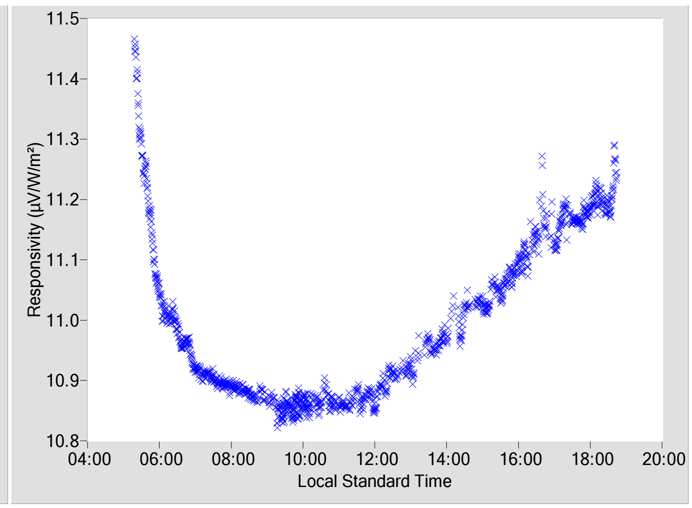


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.871	0.29	98.59	11.061	0.29	261.23
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.880	0.29	96.67	11.053	0.29	263.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.886	0.29	94.81	11.061	0.30	265.00
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.891	0.29	93.01	11.066	0.30	266.83
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.890	0.30	91.28	11.091	0.30	268.50
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.892	0.30	89.61	11.116	0.31	270.19
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.895	0.30	88.00	11.136	0.33	271.89
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.905	0.31	86.40	11.143	0.32	273.42
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.911	0.31	84.89	11.231	0.34	274.99
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.915	0.32	83.26	11.137	0.34	276.84
20	10.871	0.28	156.94	10.913	0.28	203.05	66	10.933	0.33	81.72	11.123	0.35	278.17
22	10.859	0.28	144.42	10.913	0.28	215.82	68	10.964	0.33	80.15	11.163	0.36	279.73
24	10.865	0.28	136.07	10.950	0.28	224.00	70	10.973	0.35	78.58	11.161	0.37	281.21
26	10.873	0.28	129.70	10.942	0.28	230.51	72	11.013	0.36	77.06	11.166	0.39	282.86
28	10.867	0.28	124.92	10.948	0.28	235.59	74	11.007	0.39	75.43	11.163	N/A	284.42
30	10.857	0.28	120.22	10.961	0.29	239.64	76	11.040	0.42	73.90	11.177	N/A	285.98
32	10.852	0.29	116.69	10.968	0.29	243.38	78	11.110	N/A	72.29	11.195	N/A	287.60
34	10.844	0.29	113.24	11.032	0.29	246.46	80	11.228	N/A	70.67	11.209	N/A	289.26
36	10.863	0.29	110.34	10.972	0.29	249.52	82	11.307	N/A	68.99	11.190	N/A	290.91
38	10.852	0.29	107.67	11.032	0.29	252.23	84	11.466	N/A	67.50	11.237	N/A	292.62
40	10.870	0.29	104.98	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	11.034	0.29	257.04	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.884	0.29	100.53	11.020	0.29	259.15	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

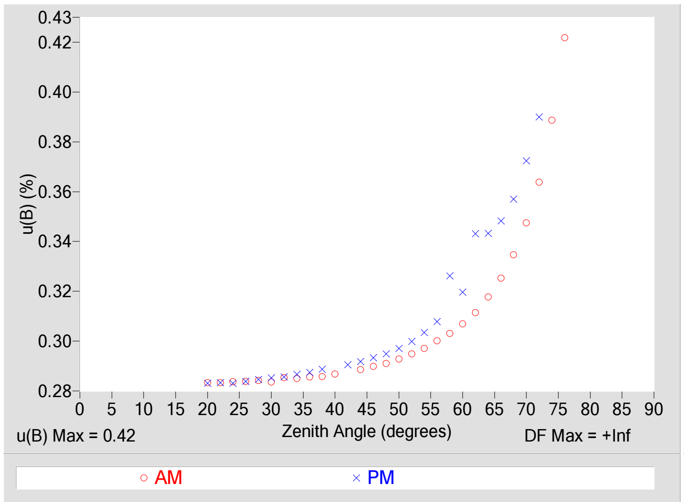


Figure 4. Residuals from Spline Interpolation

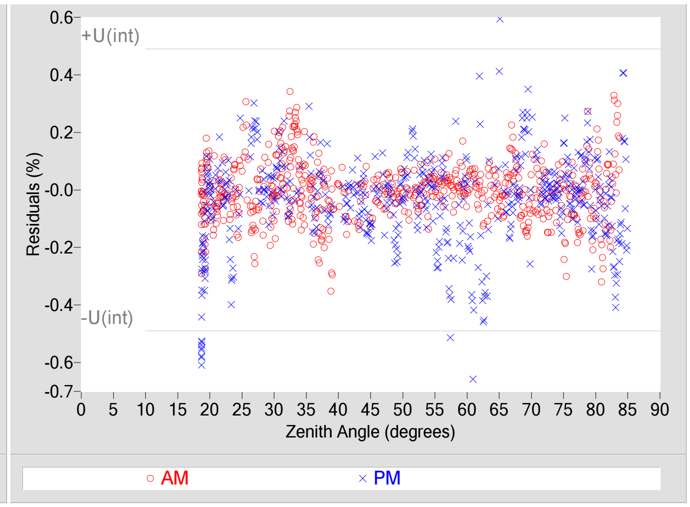


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	15640
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.96
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

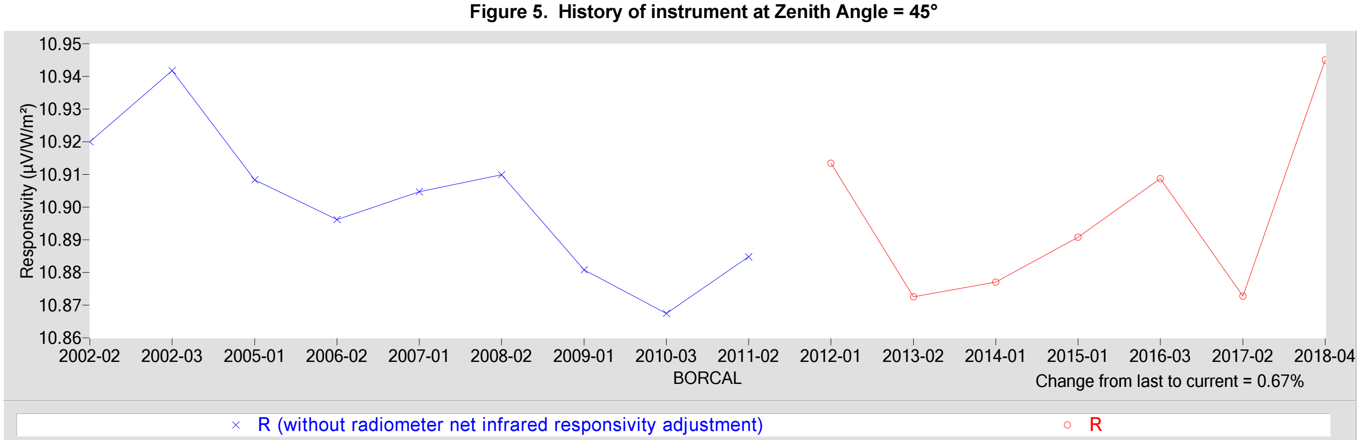
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.945	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.8 / -0.93
Expanded Uncertainty, U (%)	+2.5 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM3	**Serial Number:**	010284-DW-CM3
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Mark Kutchenreiter, and RCC

____________________________________ ________________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

010284-DW-CM3 Kipp & Zonen CM3

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

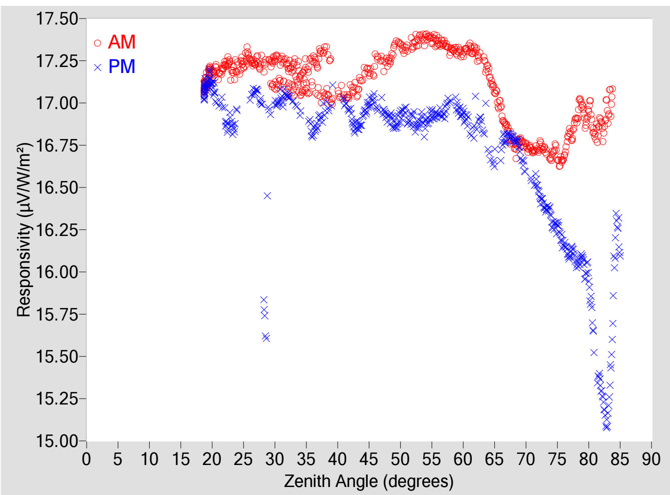


Figure 2. Responsivity vs Local Standard Time

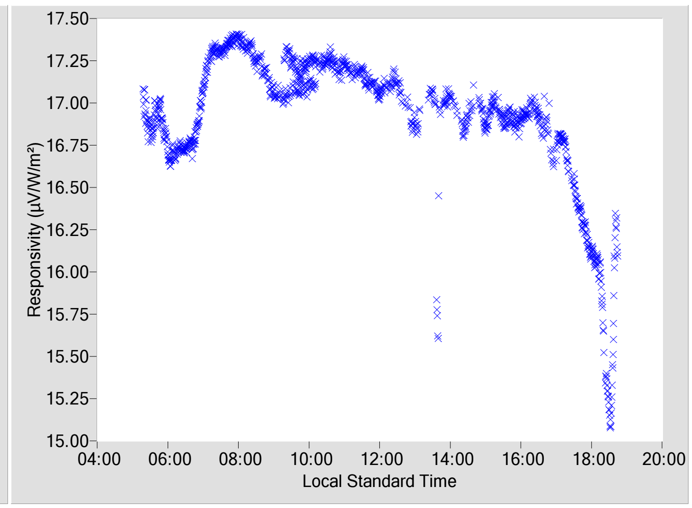


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	17.235	0.30	98.63	17.000	0.30	261.21
2	N/A	N/A	N/A	N/A	N/A	N/A	48	17.250	0.30	96.64	16.917	0.30	263.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	17.344	0.30	94.82	16.922	0.30	265.00
6	N/A	N/A	N/A	N/A	N/A	N/A	52	17.348	0.30	93.06	16.908	0.31	266.83
8	N/A	N/A	N/A	N/A	N/A	N/A	54	17.381	0.30	91.33	16.865	0.31	268.54
10	N/A	N/A	N/A	N/A	N/A	N/A	56	17.364	0.31	89.65	16.938	0.32	270.17
12	N/A	N/A	N/A	N/A	N/A	N/A	58	17.309	0.31	87.96	17.010	0.33	271.76
14	N/A	N/A	N/A	N/A	N/A	N/A	60	17.296	0.31	86.34	16.926	0.33	273.46
16	N/A	N/A	N/A	N/A	N/A	N/A	62	17.306	0.32	84.81	16.916	0.36	275.01
18	N/A	N/A	N/A	N/A	N/A	N/A	64	17.189	0.33	83.23	16.714	0.36	276.65
20	17.187	0.29	156.91	17.104	0.29	203.16	66	16.966	0.34	81.68	16.727	0.36	278.27
22	17.221	0.29	144.39	16.896	0.29	216.43	68	16.766	0.35	80.15	16.791	0.37	279.73
24	17.205	0.29	136.29	16.960	0.29	223.75	70	16.748	0.37	78.60	16.594	0.39	281.11
26	17.264	0.29	129.86	17.034	0.29	230.72	72	16.736	0.38	77.02	16.478	0.42	282.82
28	17.236	0.29	124.49	16.524	0.29	235.32	74	16.680	0.41	75.47	16.313	N/A	284.42
30	17.197	0.29	120.23	16.995	0.29	239.82	76	16.680	0.45	73.87	16.169	N/A	285.98
32	17.169	0.29	116.52	17.040	0.29	243.26	78	16.900	N/A	72.29	16.058	N/A	287.61
34	17.126	0.29	113.30	16.939	0.29	246.68	80	16.964	N/A	70.67	15.943	N/A	289.22
36	17.210	0.29	110.41	16.820	0.29	249.51	82	16.869	N/A	68.99	15.301	N/A	290.91
38	17.172	0.29	107.67	16.972	0.29	252.22	84	17.083	N/A	67.46	15.937	N/A	292.62
40	17.064	0.29	104.93	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	17.062	0.29	102.82	16.945	0.30	256.99	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.159	0.29	100.61	16.925	0.30	259.23	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

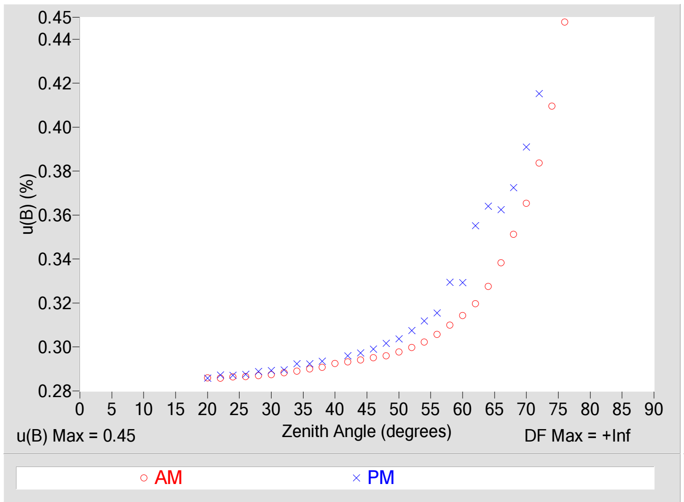


Figure 4. Residuals from Spline Interpolation

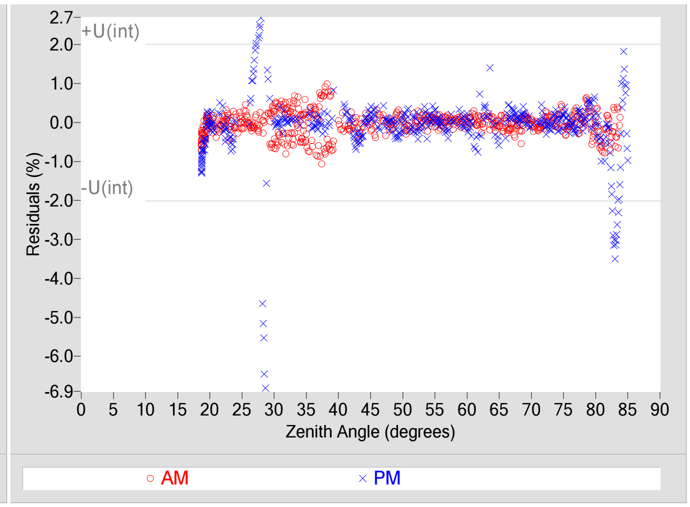


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±1.0
Combined Standard Uncertainty, u(c) (%)	±1.1
Effective degrees of freedom, DF(c)	1402
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±2.2
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

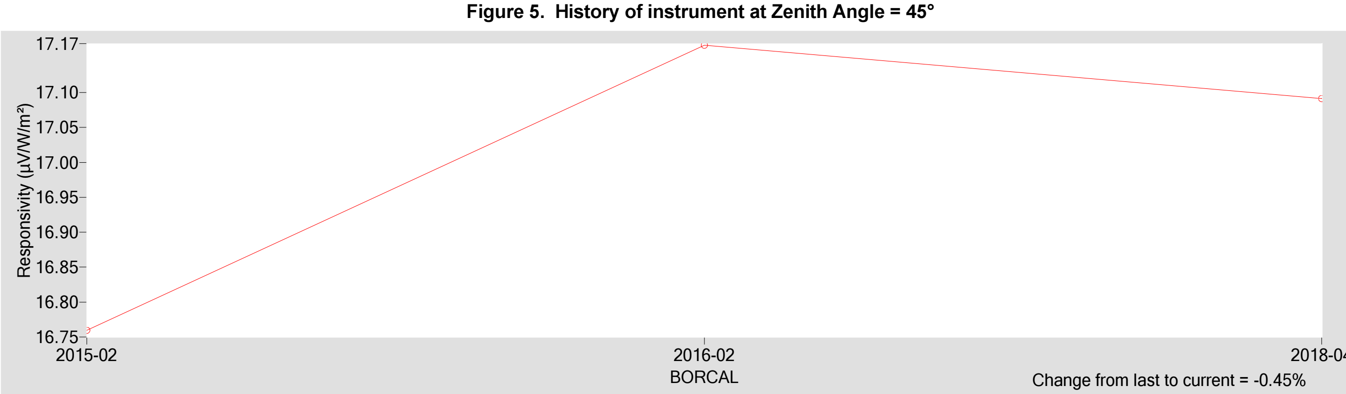
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
17.091	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+1.7 / -1.6
Expanded Uncertainty, U (%)	+2.3 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP11	**Serial Number:**	140713
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ ______________
Ibrahim Reda, Technical Manager Date

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

Calibration Results

140713 Kipp & Zonen CMP11

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

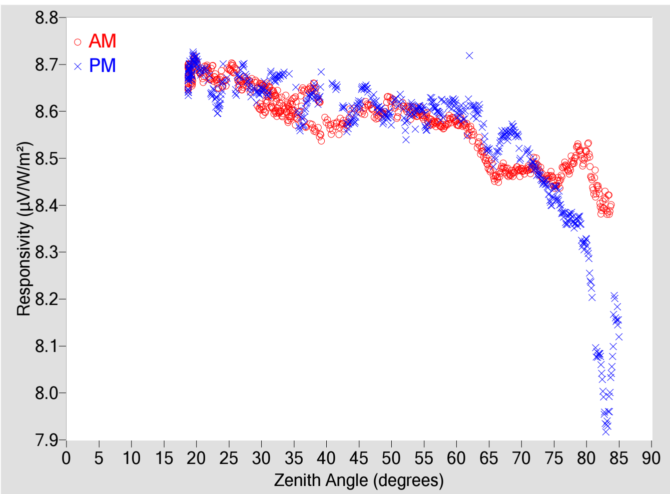


Figure 2. Responsivity vs Local Standard Time

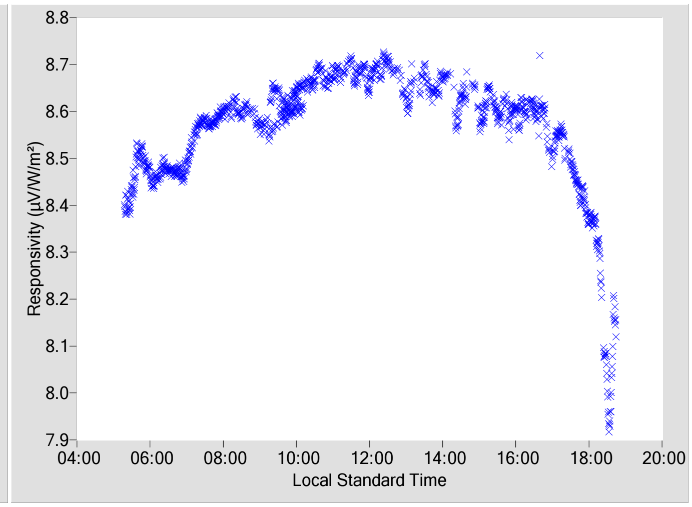


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A
20	8.7012	0.29	156.74	8.7054	0.29	202.78
22	8.6778	0.29	144.17	8.6542	0.29	216.02
24	8.6664	0.29	136.28	8.6607	0.29	223.72
26	8.6872	0.29	129.97	8.6489	0.29	230.53
28	8.6584	0.29	124.78	8.6580	0.29	235.33
30	8.6308	0.29	120.23	8.6437	0.29	239.62
32	8.6201	0.29	116.51	8.6695	0.29	243.37
34	8.6020	0.29	113.20	8.6797	0.29	247.02
36	8.6225	0.29	110.24	8.5723	0.29	249.57
38	8.6125	0.29	107.68	8.6430	0.29	252.20
40	8.5816	0.29	105.08	N/A	N/A	N/A
42	8.5683	0.29	102.66	N/A	N/A	N/A
44	8.6007	0.30	100.58	8.5892	0.30	259.19

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
46	8.6096	0.30	98.55	8.6508	0.30	261.19
48	8.5936	0.30	96.70	8.6054	0.30	263.14
50	8.6218	0.30	94.86	8.5921	0.30	264.94
52	8.6105	0.30	93.05	8.5733	0.31	266.82
54	8.5940	0.30	91.32	8.6071	0.31	268.54
56	8.5787	0.31	89.64	8.6204	0.32	270.23
58	8.5672	0.31	87.99	8.6068	0.33	271.77
60	8.5752	0.32	86.39	8.6045	0.33	273.45
62	8.5600	0.32	84.81	8.6525	0.36	275.02
64	8.5137	0.33	83.22	8.5584	0.36	276.69
66	8.4589	0.34	81.67	8.5077	0.37	278.21
68	8.4670	0.36	80.14	8.5504	0.38	279.72
70	8.4726	0.37	78.61	8.4981	0.39	281.10
72	8.4917	0.39	77.01	8.4812	0.42	282.84
74	8.4573	0.42	75.46	8.4371	N/A	284.40
76	8.4562	0.45	73.90	8.3989	N/A	286.01
78	8.4938	N/A	72.28	8.3632	N/A	287.62
80	8.5159	N/A	70.66	8.3148	N/A	289.25
82	8.4135	N/A	68.98	8.0783	N/A	290.90
84	8.3992	N/A	67.49	8.0975	N/A	292.61
86	N/A	N/A	N/A	N/A	N/A	N/A
88	N/A	N/A	N/A	N/A	N/A	N/A
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

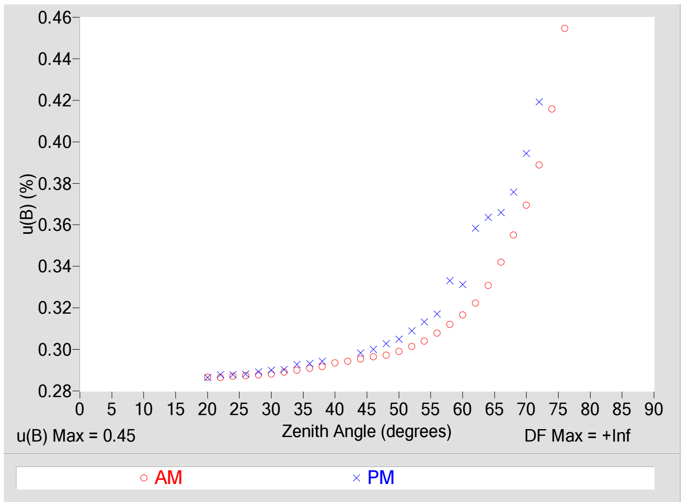


Figure 4. Residuals from Spline Interpolation

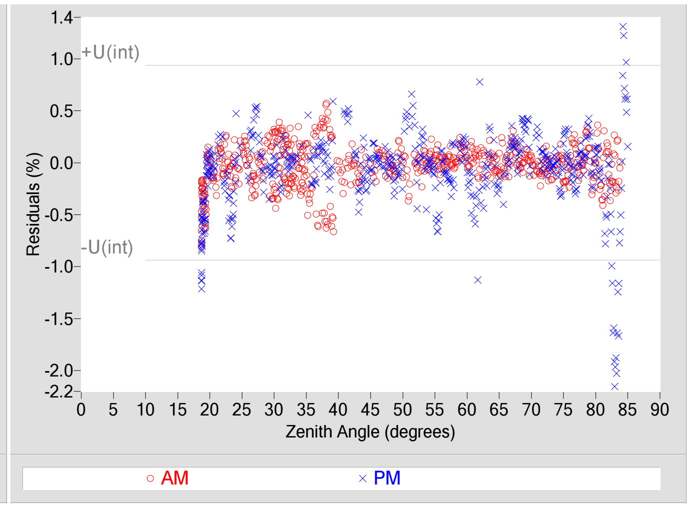


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.47
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	3792
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

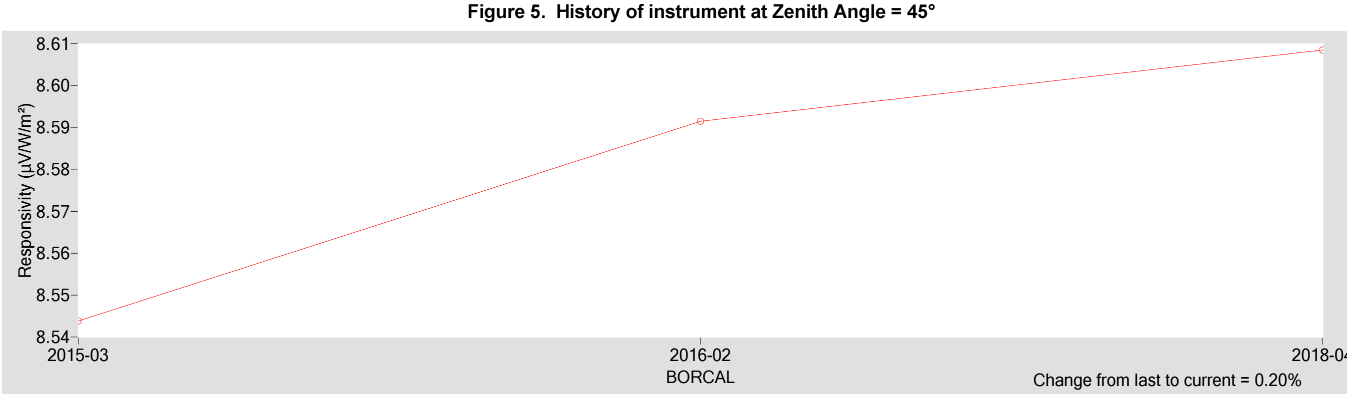
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6085	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+0.83 / -0.48
Expanded Uncertainty, U (%)	+1.5 / -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:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP11	**Serial Number:**	140911
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

____   ________________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

140911 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

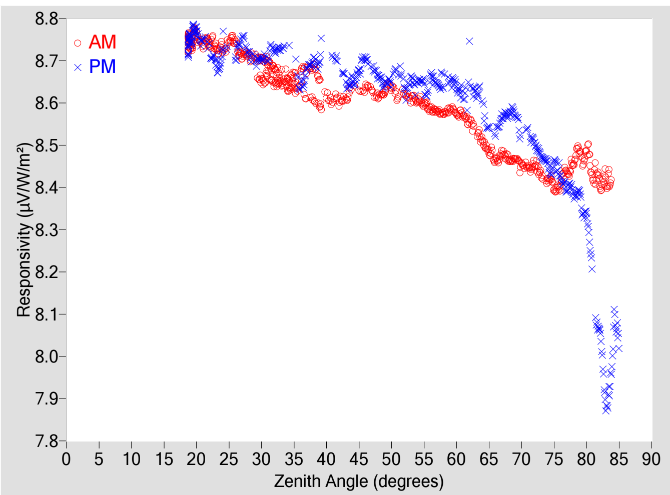


Figure 2. Responsivity vs Local Standard Time

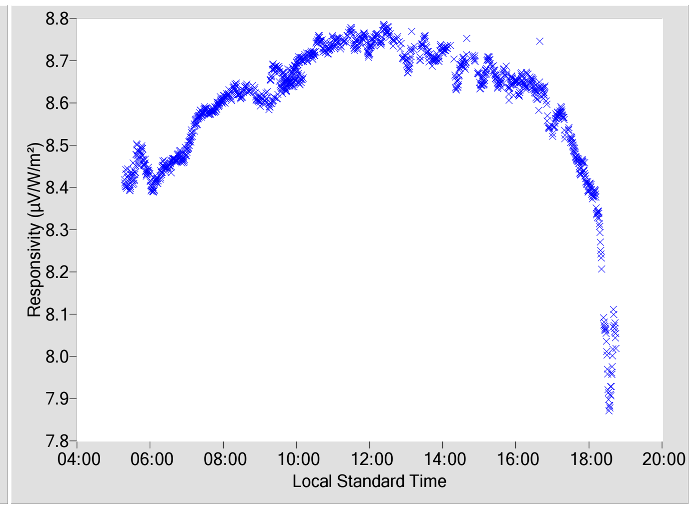


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6367	0.30	98.55	8.7038	0.30	261.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6166	0.30	96.70	8.6623	0.30	263.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6369	0.30	94.86	8.6517	0.30	264.94
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6224	0.30	93.05	8.6311	0.31	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6040	0.30	91.32	8.6512	0.31	268.54
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5863	0.31	89.64	8.6634	0.32	270.23
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5758	0.31	87.99	8.6526	0.33	271.77
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5738	0.32	86.39	8.6380	0.33	273.45
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5565	0.32	84.81	8.6781	0.36	275.02
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5102	0.33	83.22	8.5866	0.36	276.69
20	8.7604	0.29	156.74	8.7686	0.29	202.78	66	8.4654	0.34	81.67	8.5336	0.37	278.21
22	8.7409	0.29	144.17	8.7203	0.29	216.02	68	8.4664	0.36	80.14	8.5722	0.38	279.72
24	8.7314	0.29	136.28	8.7266	0.29	223.72	70	8.4504	0.37	78.61	8.5193	0.39	281.10
26	8.7438	0.29	129.97	8.7114	0.29	230.53	72	8.4559	0.39	77.01	8.5039	0.42	282.84
28	8.7118	0.29	124.78	8.7179	0.29	235.33	74	8.4167	0.42	75.46	8.4573	N/A	284.40
30	8.6804	0.29	120.23	8.7028	0.29	239.62	76	8.4081	0.46	73.90	8.4266	N/A	286.01
32	8.6661	0.29	116.51	8.7243	0.29	243.37	78	8.4574	N/A	72.28	8.3832	N/A	287.62
34	8.6474	0.29	113.20	8.7364	0.29	247.02	80	8.4866	N/A	70.66	8.3288	N/A	289.25
36	8.6625	0.29	110.24	8.6407	0.29	249.57	82	8.4132	N/A	68.98	8.0590	N/A	290.90
38	8.6499	0.29	107.68	8.6998	0.29	252.20	84	8.4145	N/A	67.49	8.0136	N/A	292.61
40	8.6209	0.29	105.08	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6035	0.29	102.66	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6363	0.30	100.58	8.6518	0.30	259.19	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

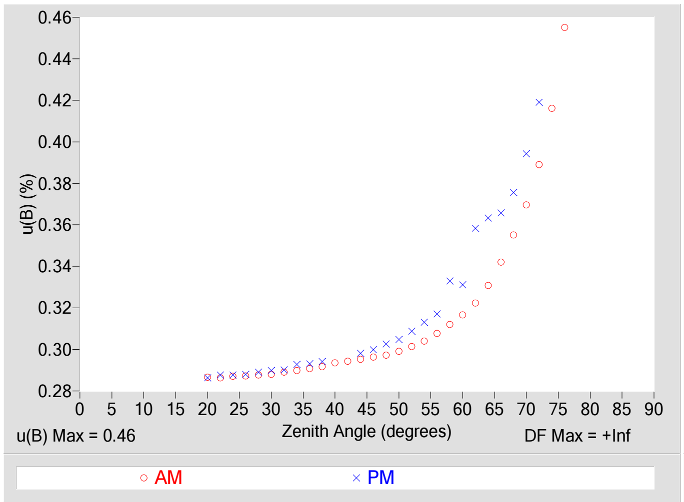


Figure 4. Residuals from Spline Interpolation

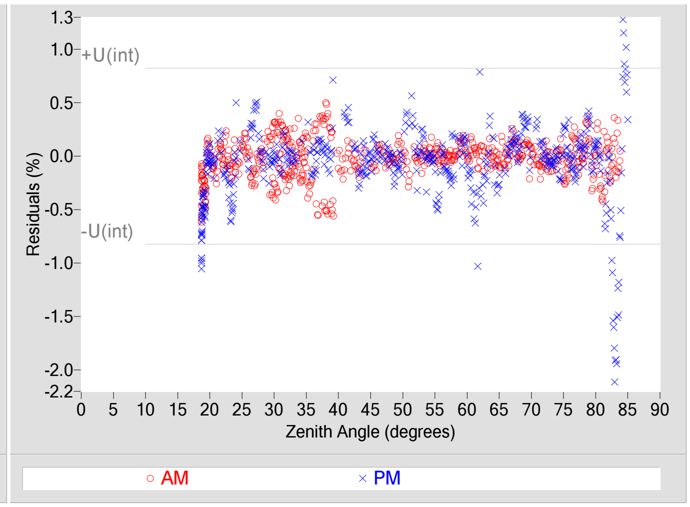


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.41
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	4961
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

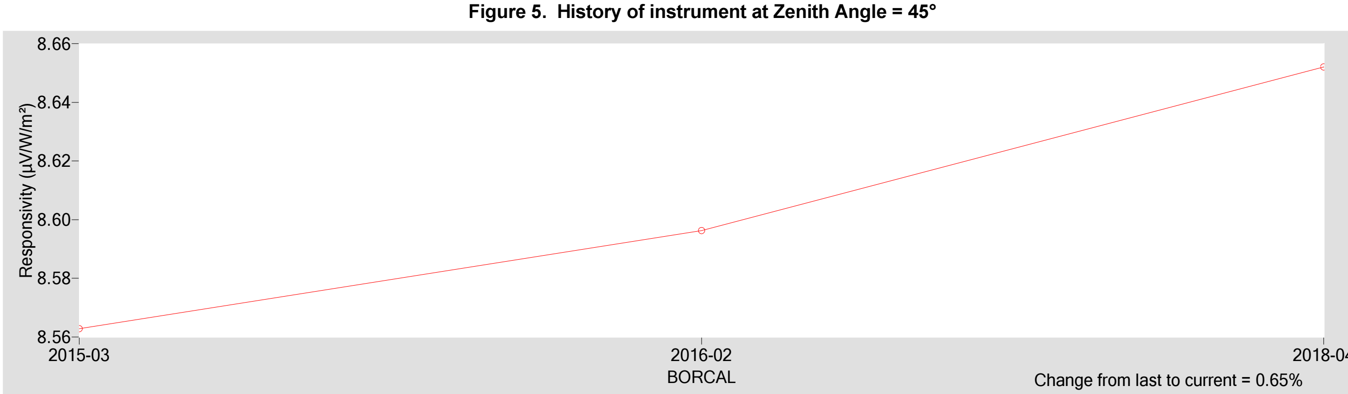
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6520	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+0.98 / -0.90
Expanded Uncertainty, U (%)	+1.6 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	18035F3
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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 ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31233F3	03/14/2017	03/14/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ ____________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

18035F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

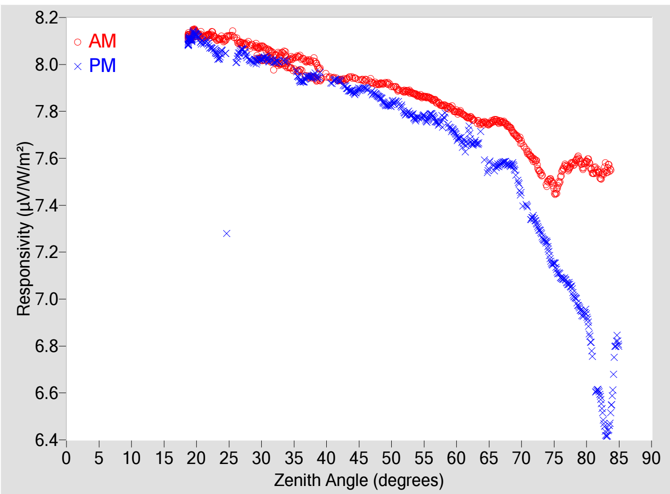


Figure 2. Responsivity vs Local Standard Time

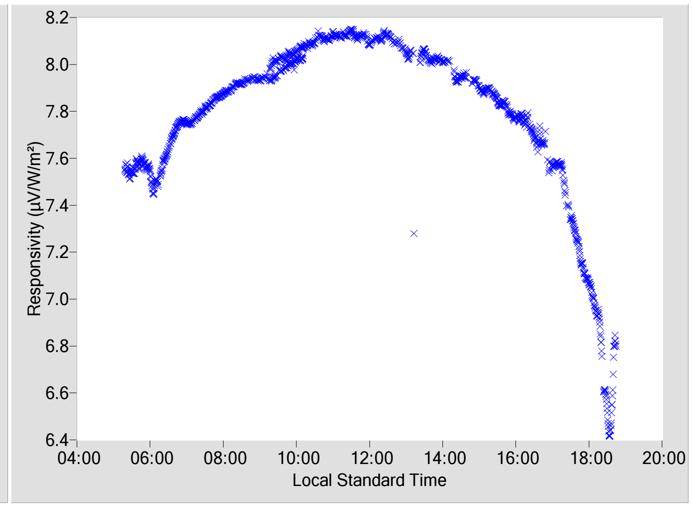


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9323	0.35	98.65	7.8987	0.36	261.17
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9166	0.36	96.60	7.8632	0.37	263.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9054	0.36	94.69	7.8318	0.38	264.96
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8855	0.37	93.02	7.7913	0.39	266.83
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8676	0.37	91.29	7.7713	0.40	268.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8545	0.38	89.61	7.7853	0.41	270.16
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8258	0.39	88.05	7.7699	0.42	271.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7983	0.41	86.40	7.6950	0.44	273.42
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7735	0.42	84.81	7.6957	0.48	275.01
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7491	0.44	83.28	7.6533	0.51	276.61
20	8.1329	0.31	156.80	8.1245	0.32	202.99	66	7.7620	0.47	81.73	7.5635	0.53	278.15
22	8.1246	0.32	144.35	8.0781	0.32	215.79	68	7.7358	0.49	80.11	7.5721	0.55	279.73
24	8.1074	0.32	135.76	8.0547	0.32	223.40	70	7.6728	0.52	78.66	7.4314	0.60	281.24
26	8.1115	0.32	129.75	8.0140	0.32	230.74	72	7.5928	0.56	77.07	7.3386	0.68	282.86
28	8.0848	0.32	124.59	8.0211	0.33	235.50	74	7.4979	0.62	75.44	7.2216	N/A	284.42
30	8.0498	0.33	120.29	8.0219	0.33	239.74	76	7.5140	0.69	73.91	7.0966	N/A	285.98
32	8.0173	0.33	116.42	8.0124	0.33	243.27	78	7.5773	N/A	72.30	7.0187	N/A	287.60
34	8.0047	0.33	113.25	8.0141	0.34	246.55	80	7.5864	N/A	70.67	6.9293	N/A	289.23
36	7.9997	0.34	110.43	7.9309	0.34	249.53	82	7.5305	N/A	69.00	6.5909	N/A	290.92
38	7.9719	0.34	107.56	7.9518	0.35	252.22	84	7.5502	N/A	67.50	6.6220	N/A	292.62
40	7.9540	0.35	105.11	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9328	0.35	102.77	7.9308	0.35	256.99	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9441	0.35	100.53	7.8836	0.36	259.15	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

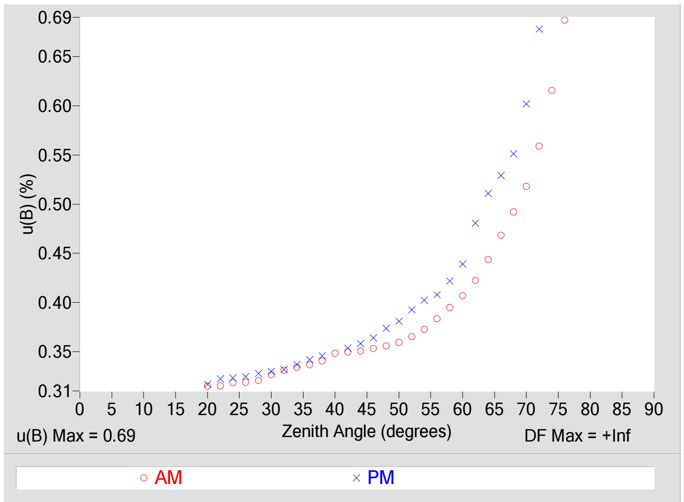


Figure 4. Residuals from Spline Interpolation

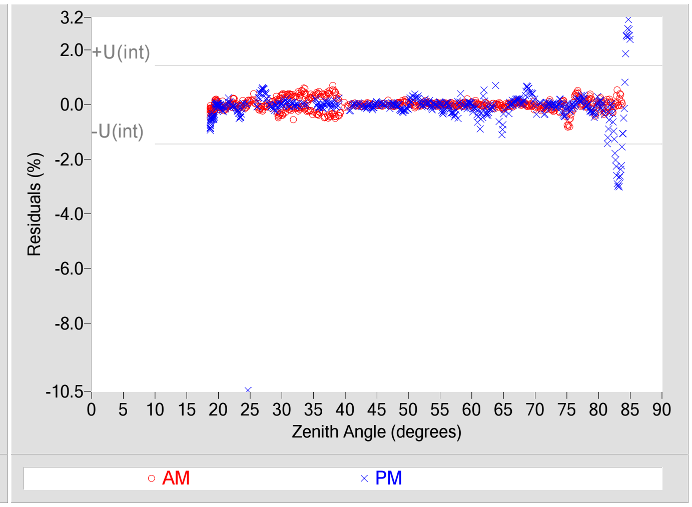


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.72
Combined Standard Uncertainty, u(c) (%)	±0.99
Effective degrees of freedom, DF(c)	3748
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.9
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

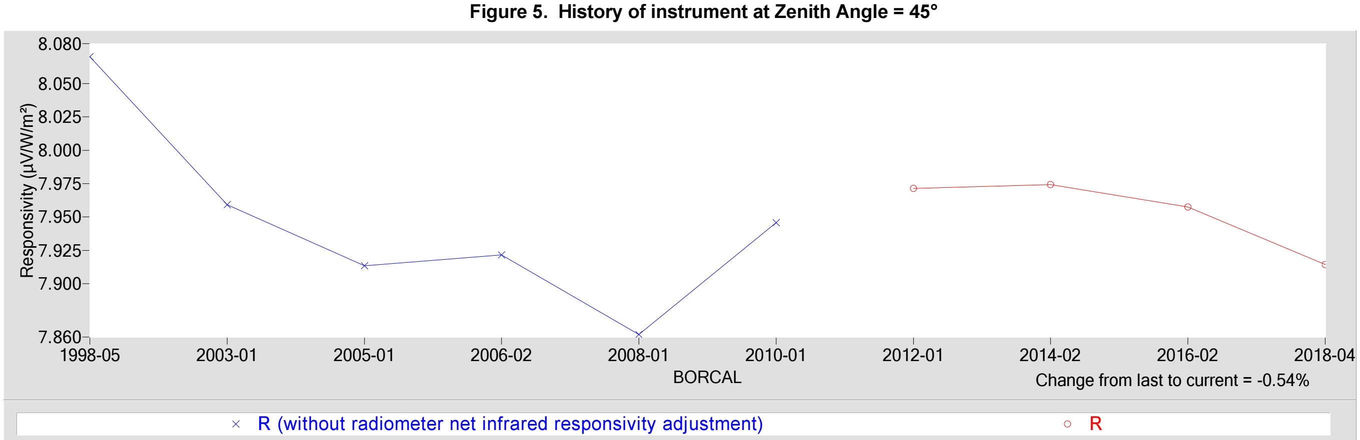
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9144	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.86
Offset Uncertainty, U(off) (%)	+1.7 / -2.8
Expanded Uncertainty, U (%)	+2.6 / -3.6
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:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	20068F3
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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 ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31233F3	03/14/2017	03/14/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ ____________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

20068F3 Eppley PSP

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

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

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

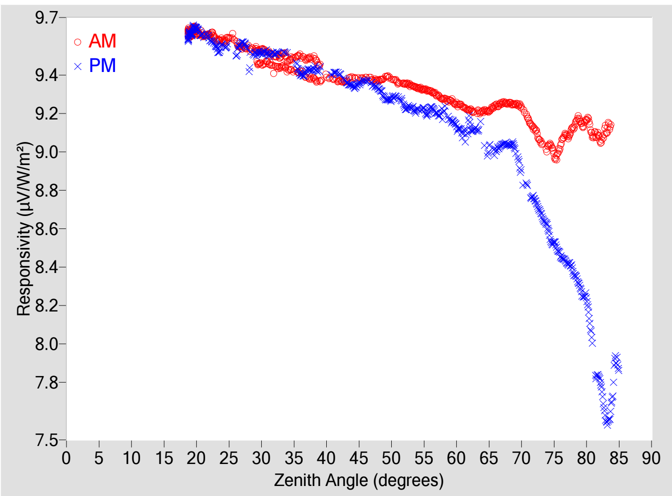


Figure 2. Responsivity vs Local Standard Time

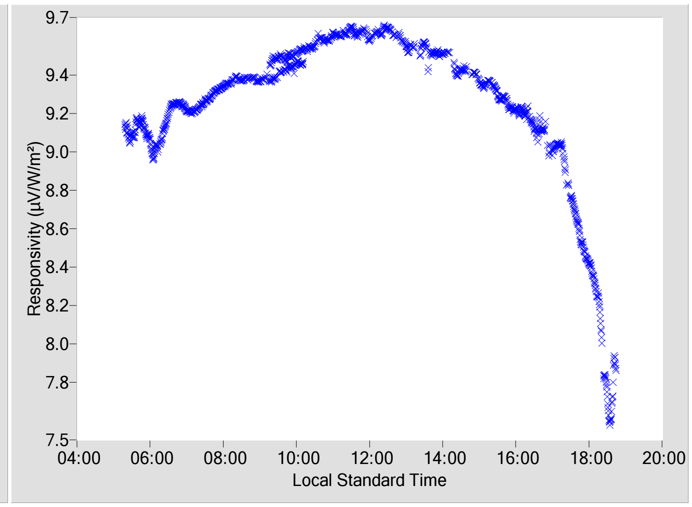


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.3823	0.34	98.65	9.3704	0.34	261.17
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.3735	0.34	96.60	9.3296	0.35	263.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3769	0.34	94.69	9.2764	0.36	264.96
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3553	0.35	93.02	9.2304	0.37	266.83
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3332	0.35	91.29	9.2179	0.38	268.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3151	0.36	89.61	9.2272	0.38	270.16
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2766	0.37	88.05	9.2106	0.40	271.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2474	0.38	86.40	9.1327	0.41	273.42
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2185	0.39	84.81	9.1421	0.44	275.01
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2096	0.41	83.28	9.0963	0.47	276.61
20	9.6288	0.31	156.80	9.6425	0.31	202.99	66	9.2406	0.43	81.73	9.0045	0.48	278.15
22	9.6098	0.31	144.35	9.5893	0.31	215.79	68	9.2537	0.45	80.11	9.0367	0.50	279.73
24	9.5798	0.31	135.76	9.5540	0.31	223.40	70	9.2363	0.47	78.66	8.8754	0.54	281.24
26	9.5768	0.31	129.75	9.5017	0.31	230.74	72	9.1205	0.51	77.07	8.7508	0.61	282.86
28	9.5403	0.31	124.59	9.4782	0.32	235.50	74	9.0249	0.55	75.44	8.6027	N/A	284.42
30	9.4966	0.31	120.29	9.5136	0.32	239.74	76	9.0300	0.62	73.91	8.4601	N/A	285.98
32	9.4632	0.32	116.42	9.5113	0.32	243.27	78	9.1273	N/A	72.30	8.3686	N/A	287.60
34	9.4519	0.32	113.25	9.5169	0.32	246.55	80	9.1669	N/A	70.67	8.2279	N/A	289.23
36	9.4545	0.32	110.43	9.4070	0.33	249.53	82	9.0719	N/A	69.00	7.8101	N/A	290.92
38	9.4232	0.33	107.56	9.4324	0.33	252.22	84	9.1422	N/A	67.50	7.7549	N/A	292.62
40	9.3966	0.33	105.11	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3697	0.33	102.77	9.4058	0.34	256.99	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3875	0.33	100.53	9.3446	0.34	259.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

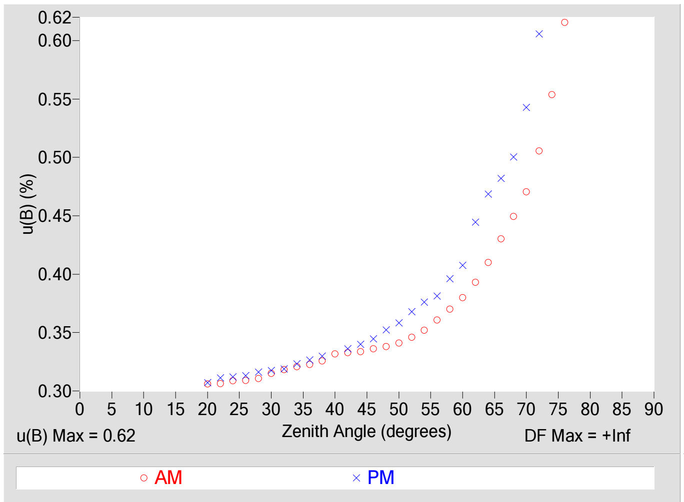


Figure 4. Residuals from Spline Interpolation

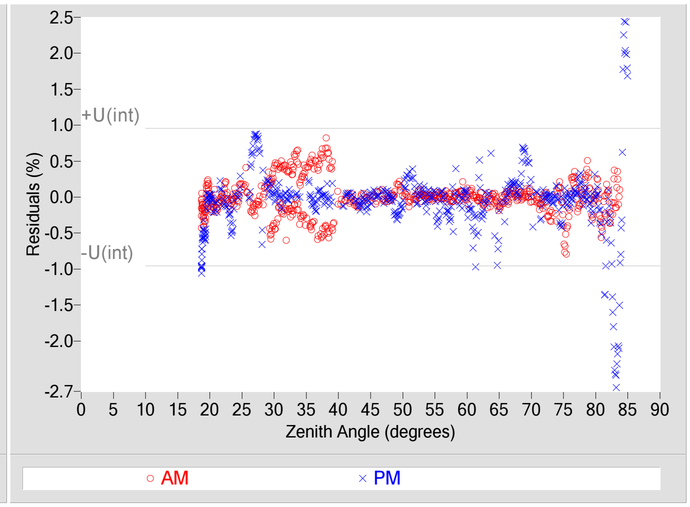


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.48
Combined Standard Uncertainty, u(c) (%)	±0.78
Effective degrees of freedom, DF(c)	7247
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

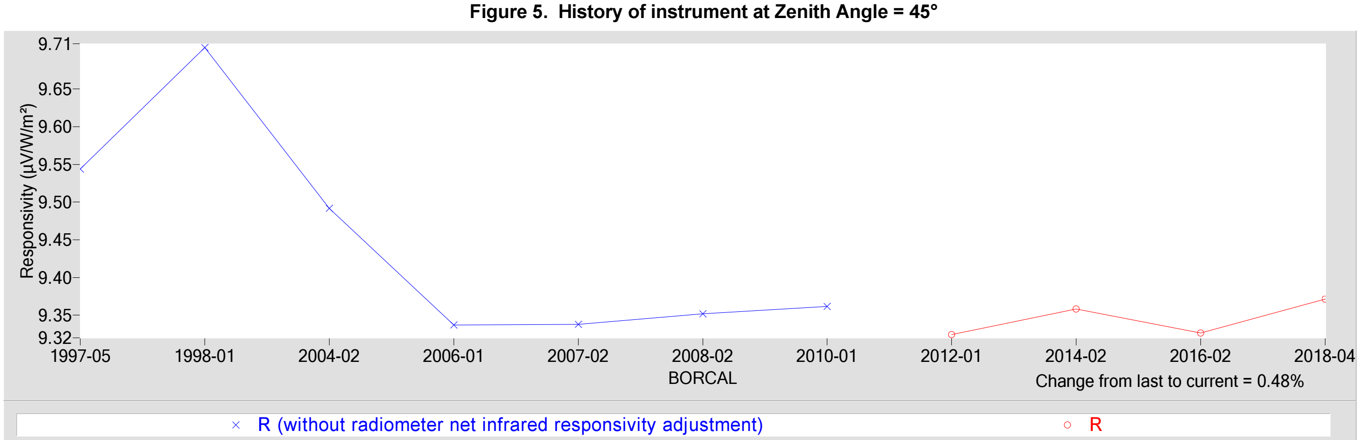
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.3713	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+1.6 / -2.5
Expanded Uncertainty, U (%)	+2.4 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31398F3
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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 ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31233F3	03/14/2017	03/14/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ _______________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

31398F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

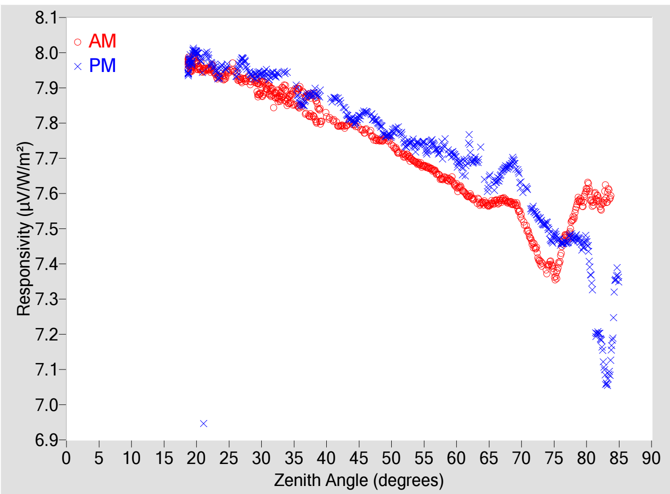


Figure 2. Responsivity vs Local Standard Time

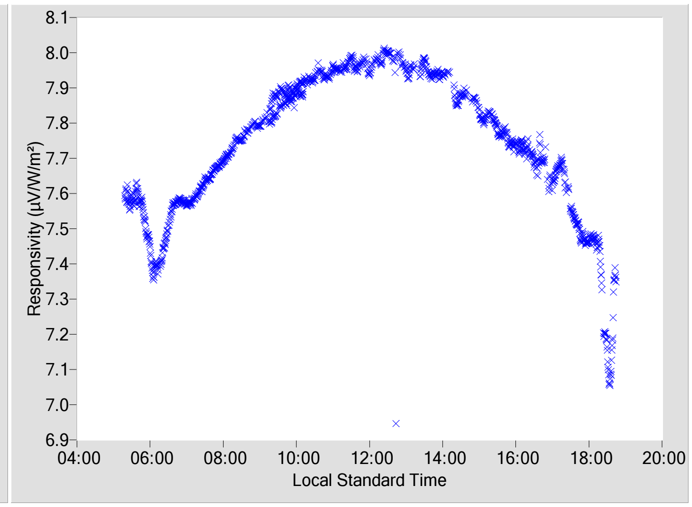


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7768	0.36	98.65	7.8319	0.37	261.17
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7521	0.36	96.60	7.7995	0.37	263.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7362	0.36	94.69	7.7689	0.38	264.96
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7080	0.37	93.02	7.7401	0.39	266.83
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6858	0.38	91.29	7.7383	0.40	268.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6698	0.39	89.61	7.7427	0.41	270.16
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6426	0.40	88.05	7.7330	0.42	271.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6190	0.41	86.40	7.6950	0.44	273.42
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5925	0.43	84.81	7.7257	0.48	275.01
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5722	0.45	83.28	7.6856	0.51	276.61
20	7.9696	0.32	156.80	8.0007	0.32	202.99	66	7.5774	0.47	81.73	7.6292	0.53	278.15
22	7.9531	0.32	144.35	7.9776	0.32	215.79	68	7.5753	0.50	80.11	7.6771	0.55	279.73
24	7.9303	0.32	135.76	7.9599	0.32	223.40	70	7.5378	0.52	78.66	7.6170	0.59	281.24
26	7.9425	0.32	129.75	7.9360	0.33	230.74	72	7.4494	0.57	77.07	7.5486	0.66	282.86
28	7.9222	0.32	124.59	7.9450	0.33	235.50	74	7.3897	0.62	75.44	7.5045	N/A	284.42
30	7.8991	0.33	120.29	7.9374	0.33	239.74	76	7.4190	0.69	73.91	7.4621	N/A	285.98
32	7.8748	0.33	116.42	7.9371	0.33	243.27	78	7.5310	N/A	72.30	7.4703	N/A	287.60
34	7.8663	0.34	113.25	7.9442	0.34	246.55	80	7.6111	N/A	70.67	7.4629	N/A	289.23
36	7.8689	0.34	110.43	7.8571	0.34	249.53	82	7.5725	N/A	69.00	7.1955	N/A	290.92
38	7.8404	0.34	107.56	7.8849	0.35	252.22	84	7.5936	N/A	67.50	7.2106	N/A	292.62
40	7.8239	0.35	105.11	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7917	0.35	102.77	7.8633	0.35	256.99	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7976	0.35	100.53	7.8094	0.36	259.15	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

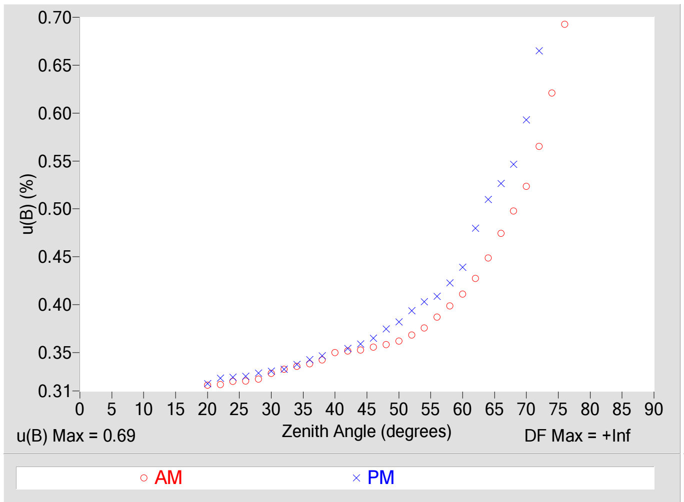


Figure 4. Residuals from Spline Interpolation

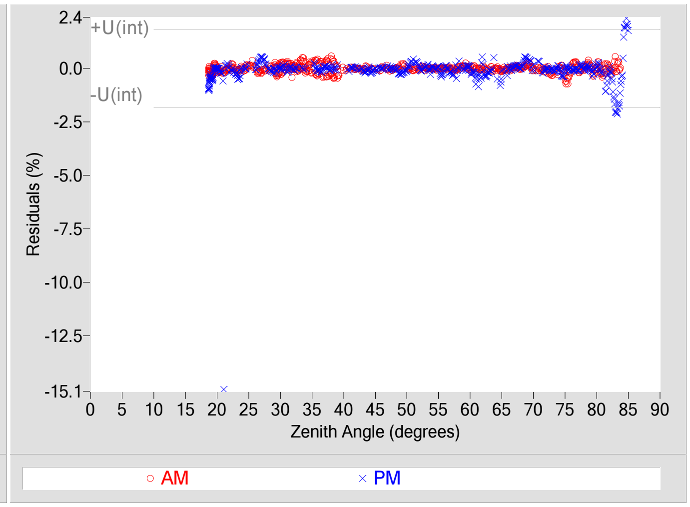


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.91
Combined Standard Uncertainty, u(c) (%)	±1.1
Effective degrees of freedom, DF(c)	2549
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±2.2
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

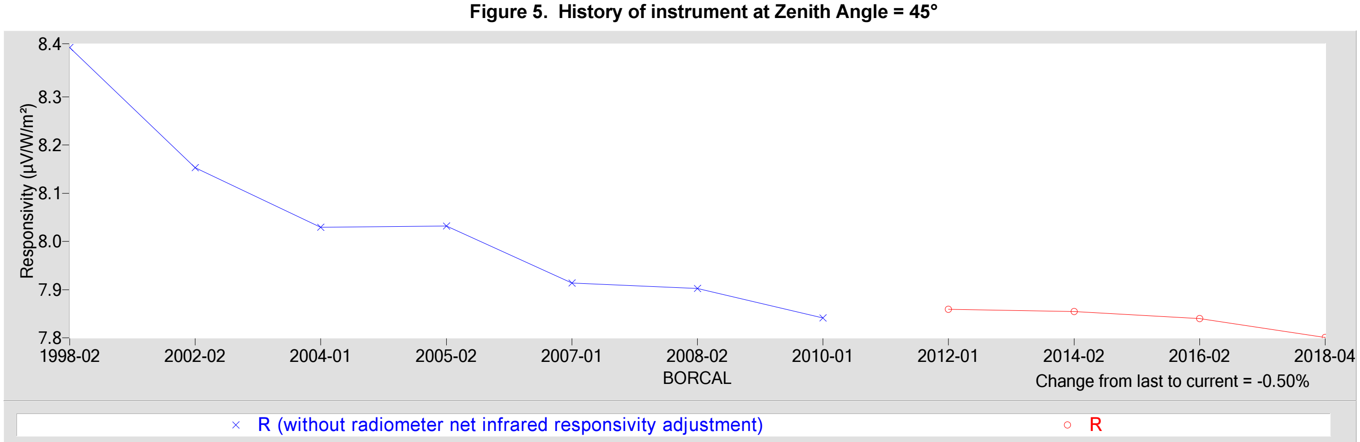
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8009	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.86
Offset Uncertainty, U(off) (%)	+1.8 / -2.3
Expanded Uncertainty, U (%)	+2.7 / -3.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31401F3
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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 ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 31233F3	03/14/2017	03/14/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ ______________
Ibrahim Reda, Technical Manager Date

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

Calibration Results

31401F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

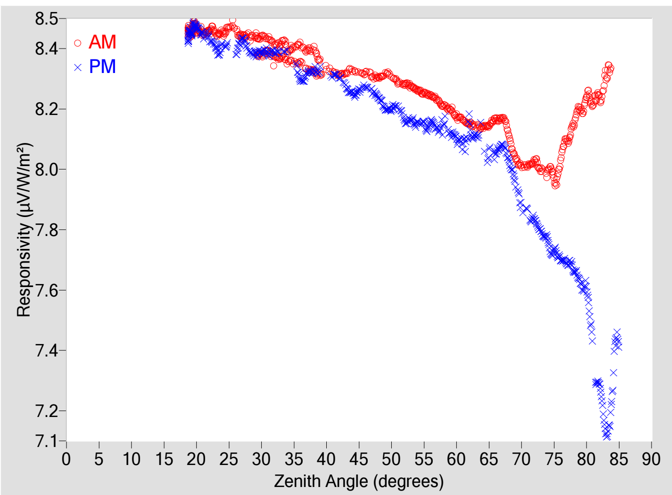


Figure 2. Responsivity vs Local Standard Time

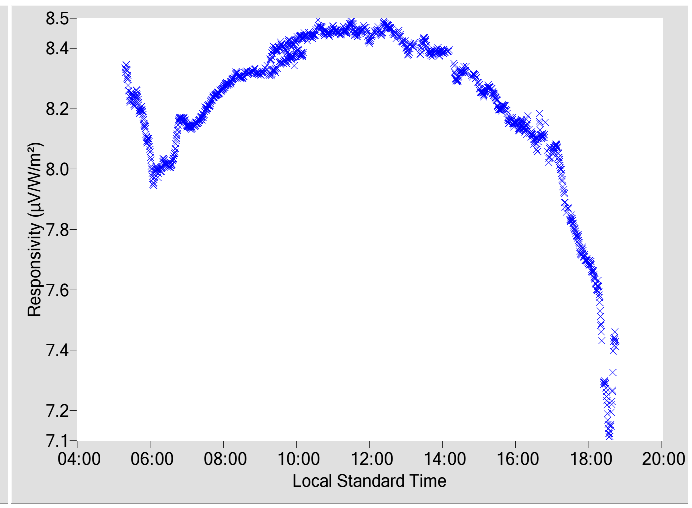


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.3191	0.35	98.65	8.2730	0.36	261.17
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3056	0.35	96.60	8.2375	0.37	263.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3031	0.35	94.69	8.2018	0.37	264.96
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2823	0.36	93.02	8.1591	0.39	266.83
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2619	0.37	91.29	8.1527	0.39	268.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2444	0.38	89.61	8.1555	0.40	270.16
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2114	0.39	88.05	8.1498	0.41	271.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1743	0.40	86.40	8.1009	0.43	273.42
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1514	0.41	84.81	8.1397	0.47	275.01
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1392	0.43	83.28	8.1073	0.50	276.61
20	8.4685	0.31	156.80	8.4722	0.31	202.99	66	8.1664	0.46	81.73	8.0518	0.51	278.15
22	8.4590	0.31	144.35	8.4326	0.32	215.79	68	8.1146	0.48	80.11	8.0288	0.53	279.73
24	8.4520	0.32	135.76	8.4110	0.32	223.40	70	8.0127	0.51	78.66	7.8729	0.58	281.24
26	8.4640	0.32	129.75	8.3845	0.32	230.74	72	8.0269	0.54	77.07	7.8333	0.65	282.86
28	8.4415	0.32	124.59	8.3929	0.32	235.50	74	7.9929	0.59	75.44	7.7633	N/A	284.42
30	8.4102	0.32	120.29	8.3874	0.33	239.74	76	8.0225	0.66	73.91	7.7032	N/A	285.98
32	8.3866	0.33	116.42	8.3878	0.33	243.27	78	8.1480	N/A	72.30	7.6649	N/A	287.60
34	8.3754	0.33	113.25	8.3946	0.33	246.55	80	8.2388	N/A	70.67	7.6012	N/A	289.23
36	8.3799	0.33	110.43	8.2989	0.34	249.53	82	8.2380	N/A	69.00	7.2784	N/A	290.92
38	8.3543	0.34	107.56	8.3275	0.34	252.22	84	8.3353	N/A	67.50	7.2841	N/A	292.62
40	8.3377	0.34	105.11	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3144	0.34	102.77	8.3046	0.35	256.99	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3275	0.35	100.53	8.2531	0.35	259.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

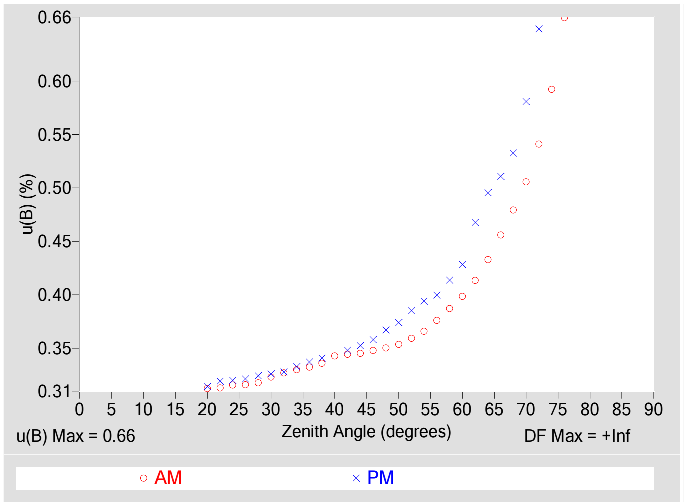


Figure 4. Residuals from Spline Interpolation

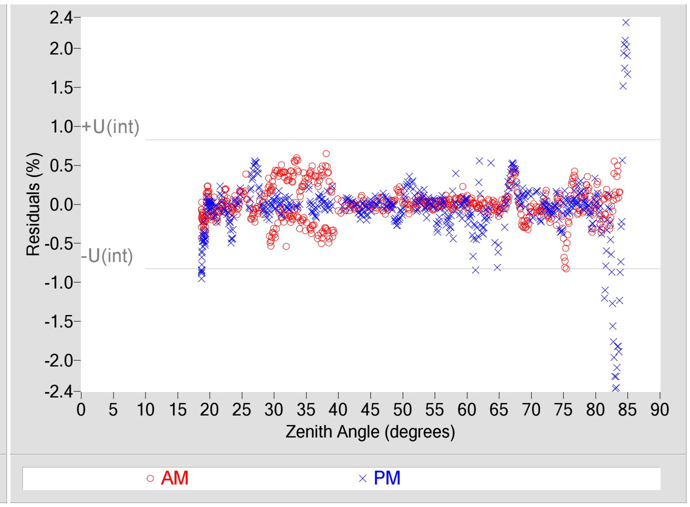


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.66
Type-A Interpolating Function, u(int) (%)	±0.41
Combined Standard Uncertainty, u(c) (%)	±0.78
Effective degrees of freedom, DF(c)	12804
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

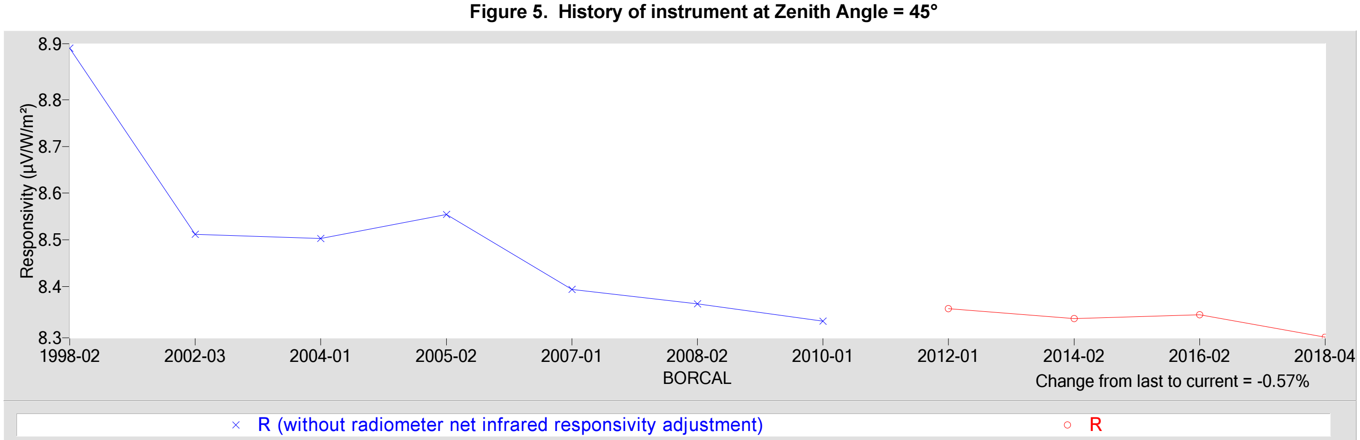
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.2916	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.84
Offset Uncertainty, U(off) (%)	+1.4 / -2.3
Expanded Uncertainty, U (%)	+2.3 / -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

[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

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY1724
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

____ ________________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

PY1724 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

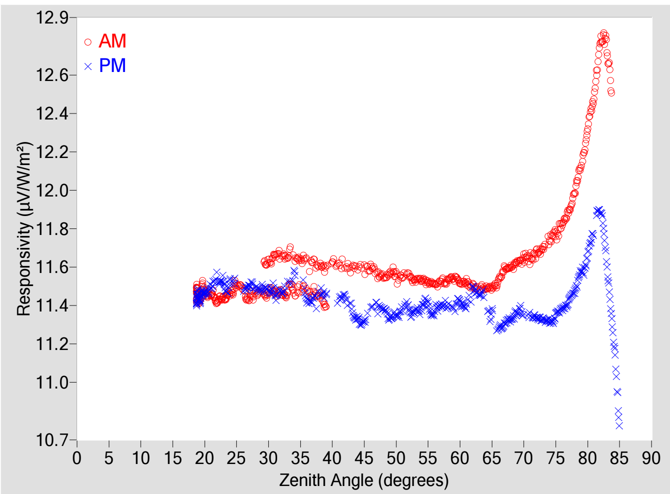


Figure 2. Responsivity vs Local Standard Time

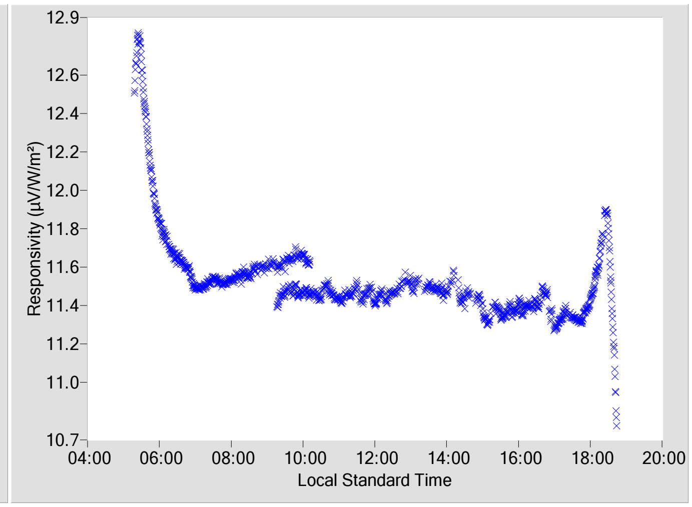


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	11.594	0.29	98.53	11.393	0.29	261.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.549	0.29	96.64	11.381	0.29	263.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.551	0.29	94.82	11.350	0.30	264.99
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.557	0.29	92.98	11.376	0.30	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.534	0.30	91.28	11.396	0.30	268.59
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.512	0.30	89.64	11.370	0.31	270.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.526	0.30	88.04	11.401	0.32	271.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.520	0.31	86.43	11.417	0.32	273.45
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.504	0.31	84.84	11.475	0.34	275.07
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.490	0.32	83.27	11.368	0.34	276.84
20	11.473	0.28	156.68	11.468	0.28	203.25	66	11.525	0.32	81.72	11.280	0.35	278.17
22	11.424	0.28	144.15	11.532	0.28	216.04	68	11.601	0.33	80.14	11.329	0.35	279.72
24	11.465	0.28	135.98	11.518	0.28	223.73	70	11.649	0.35	78.58	11.348	0.37	281.14
26	11.481	0.28	129.69	11.473	0.28	230.49	72	11.673	0.36	77.06	11.335	0.39	282.85
28	11.464	0.28	124.77	11.491	0.28	235.57	74	11.741	0.39	75.43	11.318	N/A	284.41
30	11.547	0.28	120.22	11.475	0.28	239.74	76	11.824	0.42	73.90	11.383	N/A	285.98
32	11.528	0.28	116.58	11.470	0.29	243.38	78	12.000	N/A	72.29	11.481	N/A	287.59
34	11.534	0.28	113.27	11.561	0.29	246.56	80	12.317	N/A	70.67	11.662	N/A	289.22
36	11.565	0.29	110.41	11.432	0.29	249.58	82	12.762	N/A	68.99	11.884	N/A	290.91
38	11.538	0.29	107.66	11.474	0.29	252.27	84	12.507	N/A	67.49	11.227	N/A	292.65
40	11.629	0.29	104.97	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.599	0.29	102.64	11.444	0.29	257.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.597	0.29	100.62	11.329	0.29	259.14	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

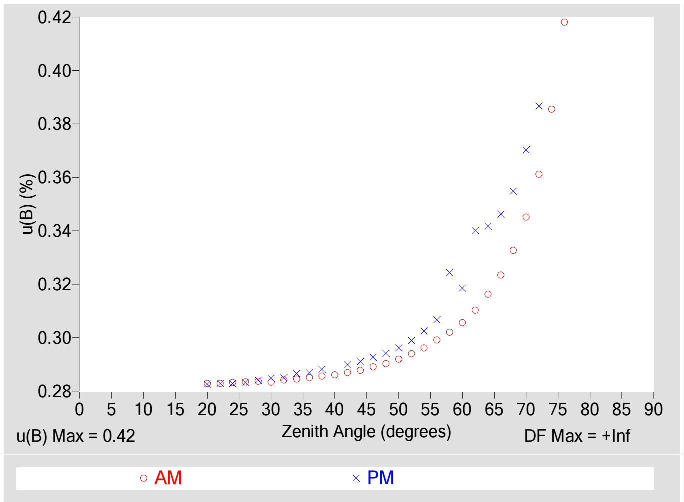


Figure 4. Residuals from Spline Interpolation

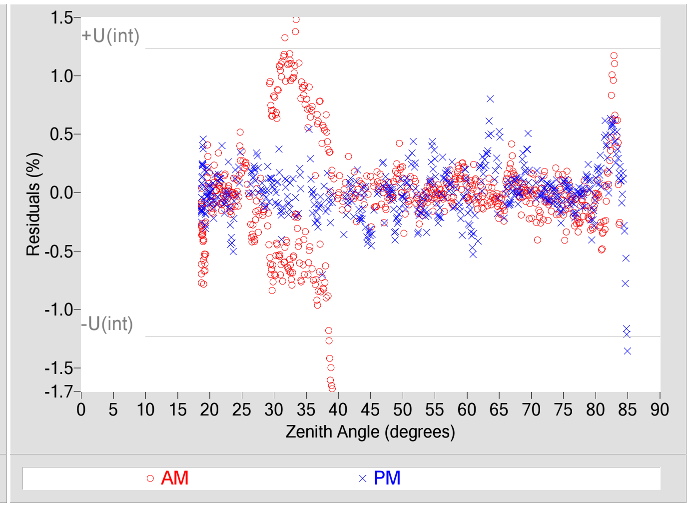


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.62
Combined Standard Uncertainty, u(c) (%)	±0.74
Effective degrees of freedom, DF(c)	2194
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

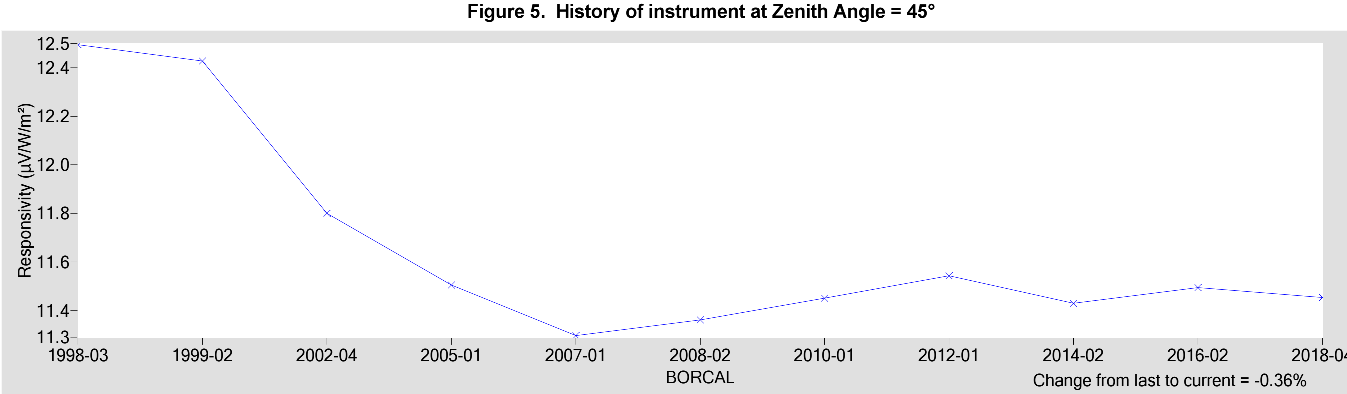
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.453	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.5 / -1.1
Expanded Uncertainty, U (%)	+2.2 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY1750
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ _______________

Ibrahim Reda, Technical Manager — Date

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

Calibration Results

PY1750 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

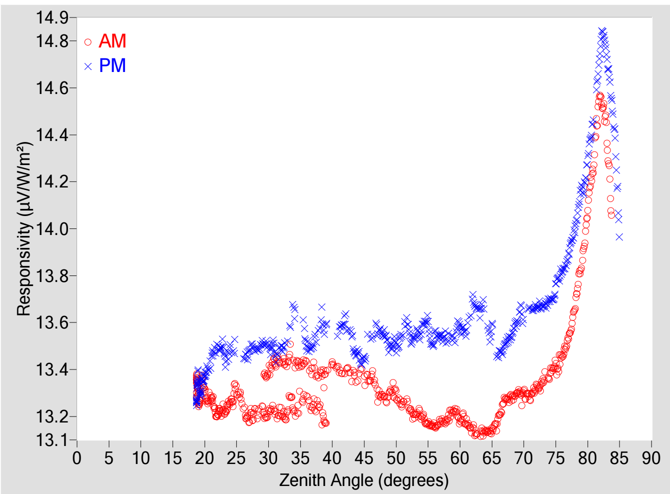


Figure 2. Responsivity vs Local Standard Time

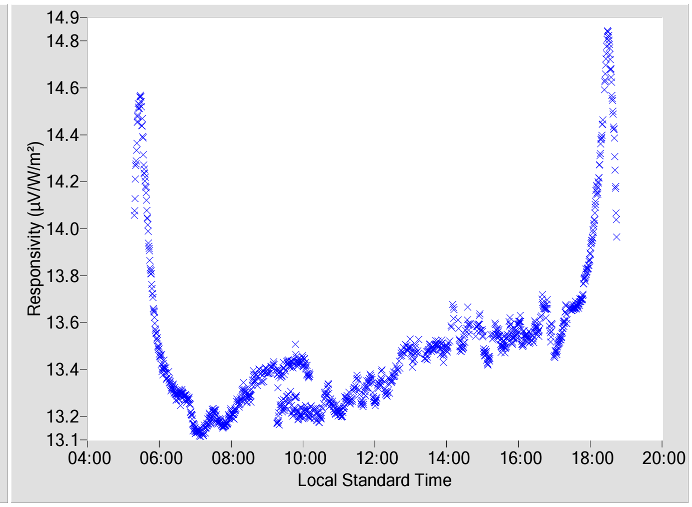


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	13.366	0.29	98.53	13.538	0.29	261.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.287	0.29	96.64	13.551	0.29	263.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.289	0.29	94.82	13.506	0.30	264.99
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.237	0.29	92.98	13.560	0.30	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.200	0.30	91.28	13.579	0.30	268.59
10	N/A	N/A	N/A	N/A	N/A	N/A	56	13.158	0.30	89.64	13.530	0.31	270.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.185	0.30	88.04	13.536	0.32	271.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.184	0.31	86.43	13.578	0.32	273.45
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.149	0.31	84.84	13.680	0.34	275.07
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.136	0.32	83.27	13.586	0.34	276.84
20	13.302	0.28	156.68	13.373	0.28	203.25	66	13.185	0.32	81.72	13.465	0.35	278.17
22	13.210	0.28	144.15	13.489	0.28	216.04	68	13.279	0.33	80.14	13.543	0.35	279.72
24	13.263	0.28	135.98	13.477	0.28	223.73	70	13.295	0.34	78.58	13.605	0.37	281.14
26	13.242	0.28	129.69	13.446	0.28	230.49	72	13.323	0.36	77.06	13.665	0.39	282.85
28	13.218	0.28	124.77	13.487	0.28	235.57	74	13.377	0.38	75.43	13.694	N/A	284.41
30	13.302	0.28	120.22	13.488	0.28	239.74	76	13.458	0.42	73.90	13.821	N/A	285.98
32	13.284	0.28	116.58	13.491	0.28	243.38	78	13.673	N/A	72.29	14.001	N/A	287.59
34	13.298	0.28	113.27	13.653	0.29	246.56	80	14.076	N/A	70.67	14.292	N/A	289.22
36	13.361	0.28	110.41	13.502	0.29	249.58	82	14.548	N/A	68.99	14.777	N/A	290.91
38	13.321	0.29	107.66	13.585	0.29	252.27	84	14.058	N/A	67.49	14.458	N/A	292.65
40	13.424	0.29	104.97	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	13.392	0.29	102.64	13.603	0.29	257.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	13.359	0.29	100.62	13.466	0.29	259.14	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

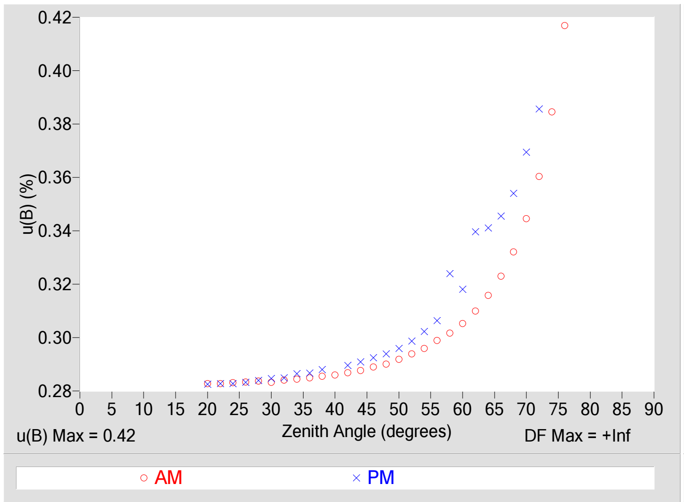


Figure 4. Residuals from Spline Interpolation

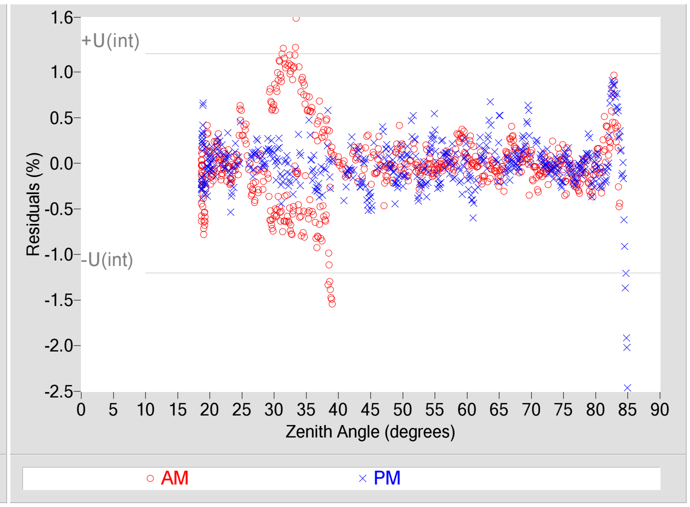


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.60
Combined Standard Uncertainty, u(c) (%)	±0.73
Effective degrees of freedom, DF(c)	2258
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

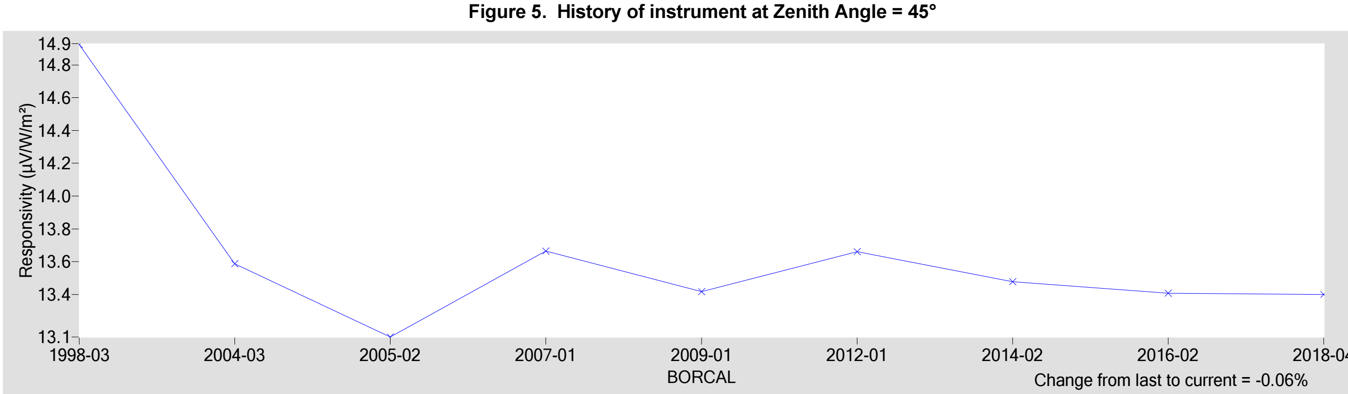
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
13.400	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.9 / -1.8
Expanded Uncertainty, U (%)	+2.5 / -2.4
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:**	Licor
Model:	LI200	**Serial Number:**	PY28244
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

____ ________________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

PY28244 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 - 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

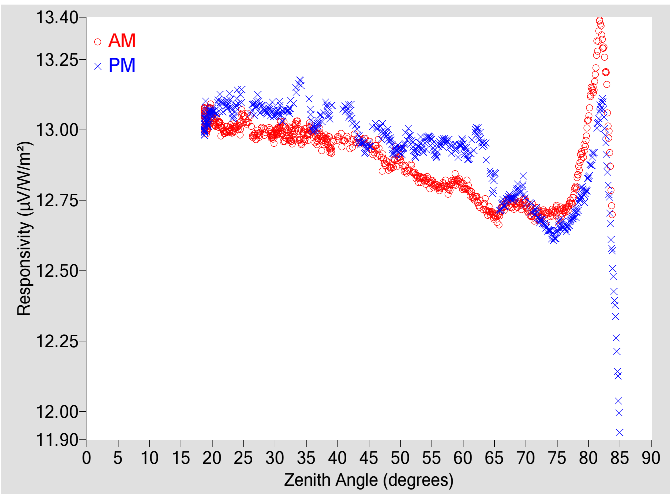


Figure 2. Responsivity vs Local Standard Time

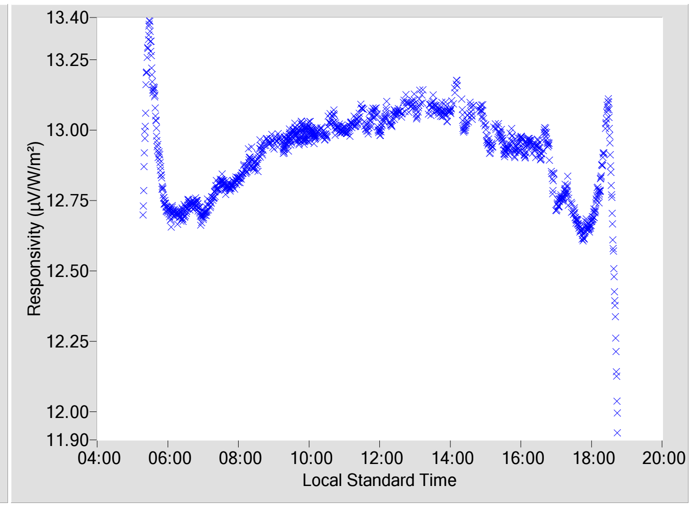


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	12.929	0.29	98.53	13.011	0.29	261.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.875	0.29	96.64	12.980	0.29	263.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.904	0.29	94.82	12.928	0.30	264.99
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.853	0.29	92.98	12.935	0.30	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.822	0.30	91.28	12.957	0.30	268.59
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.796	0.30	89.64	12.929	0.31	270.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.800	0.30	88.04	12.942	0.32	271.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.799	0.31	86.43	12.945	0.32	273.45
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.760	0.31	84.84	12.985	0.34	275.07
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.711	0.32	83.27	12.854	0.34	276.84
20	13.046	0.28	156.68	13.064	0.28	203.25	66	12.703	0.32	81.72	12.725	0.35	278.17
22	12.995	0.28	144.15	13.086	0.28	216.04	68	12.737	0.33	80.14	12.758	0.35	279.72
24	13.011	0.28	135.98	13.103	0.28	223.73	70	12.732	0.34	78.58	12.745	0.37	281.14
26	13.030	0.28	129.69	13.056	0.28	230.49	72	12.703	0.36	77.06	12.686	0.39	282.85
28	13.007	0.28	124.77	13.079	0.28	235.57	74	12.705	0.38	75.43	12.634	N/A	284.41
30	12.986	0.28	120.22	13.056	0.28	239.74	76	12.713	0.42	73.90	12.655	N/A	285.98
32	12.981	0.28	116.58	13.066	0.28	243.38	78	12.808	N/A	72.29	12.710	N/A	287.59
34	12.971	0.28	113.27	13.169	0.29	246.56	80	13.054	N/A	70.67	12.831	N/A	289.22
36	12.998	0.28	110.41	13.010	0.29	249.58	82	13.353	N/A	68.99	13.088	N/A	290.91
38	12.966	0.29	107.66	13.083	0.29	252.27	84	12.699	N/A	67.49	12.442	N/A	292.65
40	12.970	0.29	104.97	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.947	0.29	102.64	13.058	0.29	257.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.963	0.29	100.62	12.950	0.29	259.14	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

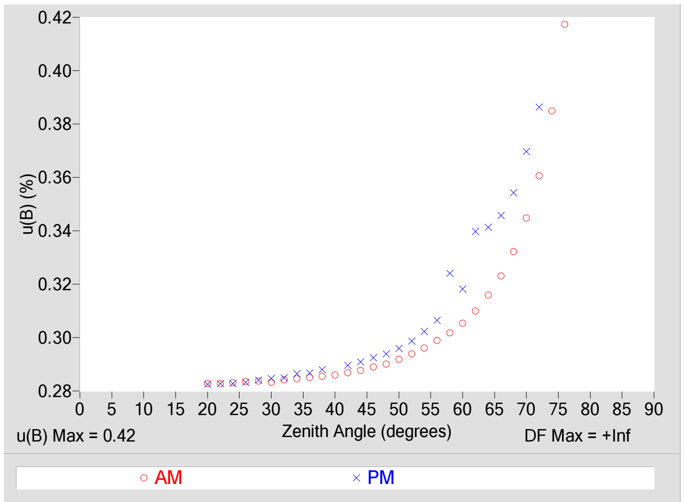


Figure 4. Residuals from Spline Interpolation

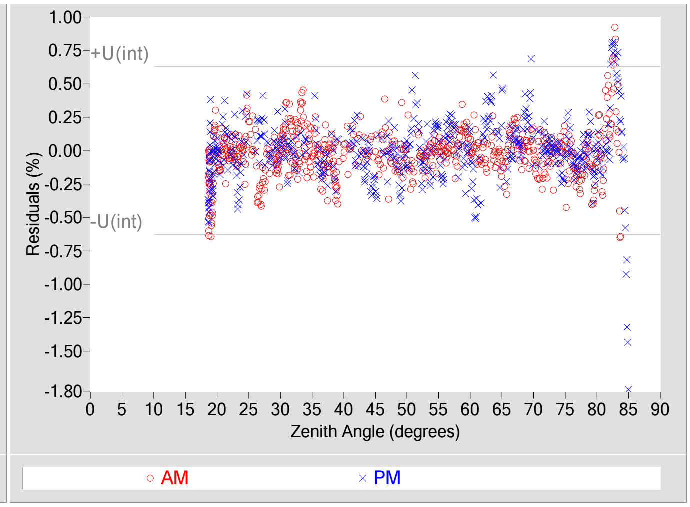


Table 3. Uncertainty using Spline Interpolation

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)	7838
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

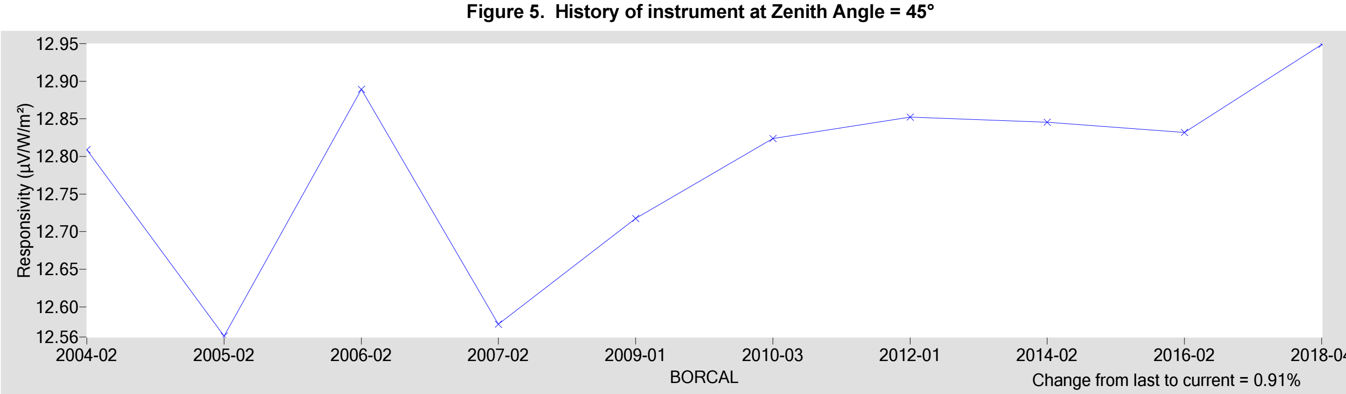
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
12.949	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.7 / -1.2
Expanded Uncertainty, U (%)	+2.3 / -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:**	PY28247
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

_____________________________ _____________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

PY28247 Licor LI200

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

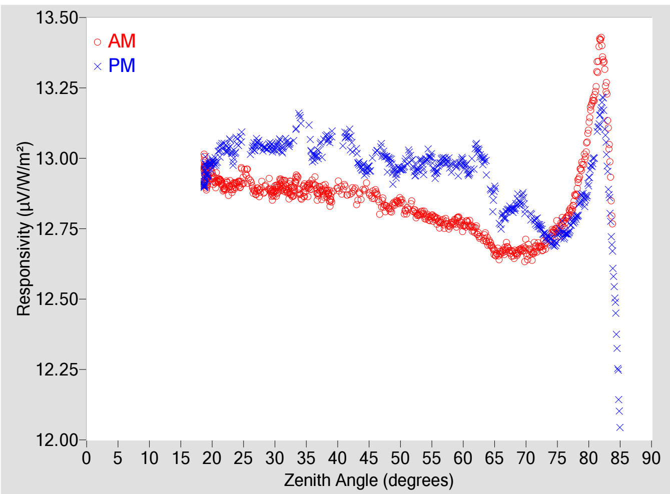


Figure 2. Responsivity vs Local Standard Time

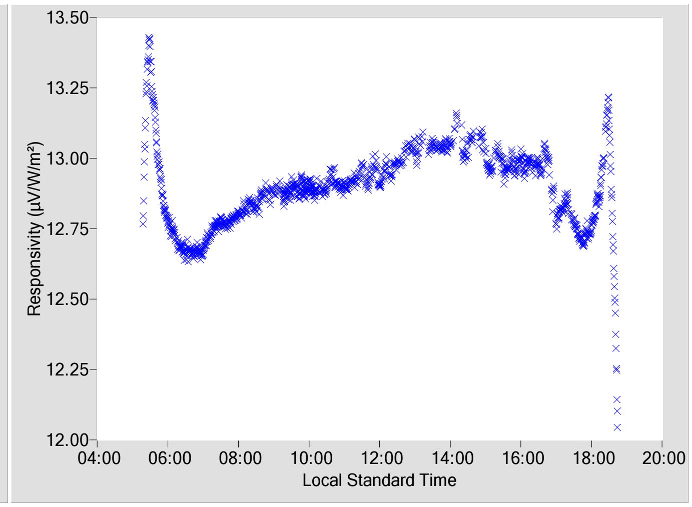


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	12.875	0.29	98.53	13.026	0.29	261.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.825	0.29	96.64	12.991	0.29	263.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.849	0.29	94.82	12.963	0.30	264.99
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.821	0.29	92.98	12.969	0.30	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.795	0.30	91.28	12.993	0.30	268.59
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.773	0.30	89.64	12.965	0.31	270.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.763	0.30	88.04	12.975	0.32	271.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.762	0.31	86.43	12.984	0.32	273.45
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.747	0.31	84.84	13.025	0.34	275.07
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.703	0.32	83.27	12.890	0.34	276.84
20	12.936	0.28	156.68	12.983	0.28	203.25	66	12.662	0.32	81.72	12.776	0.35	278.17
22	12.896	0.28	144.15	13.036	0.28	216.04	68	12.661	0.33	80.14	12.819	0.35	279.72
24	12.910	0.28	135.98	13.053	0.28	223.73	70	12.654	0.34	78.57	12.810	0.37	281.14
26	12.921	0.28	129.69	13.014	0.28	230.49	72	12.684	0.36	77.06	12.763	0.39	282.85
28	12.896	0.28	124.77	13.038	0.28	235.57	74	12.727	0.38	75.43	12.708	N/A	284.41
30	12.885	0.28	120.22	13.033	0.28	239.74	76	12.771	0.42	73.90	12.728	N/A	286.01
32	12.880	0.28	116.58	13.052	0.28	243.38	78	12.882	N/A	72.29	12.789	N/A	287.59
34	12.873	0.28	113.35	13.145	0.29	246.56	80	13.117	N/A	70.67	12.917	N/A	289.22
36	12.908	0.28	110.41	13.009	0.29	249.58	82	13.401	N/A	68.99	13.184	N/A	290.91
38	12.883	0.29	107.66	13.078	0.29	252.27	84	12.767	N/A	67.49	12.549	N/A	292.65
40	12.898	0.29	104.97	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.874	0.29	102.64	13.069	0.29	257.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.876	0.29	100.62	12.963	0.29	259.14	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

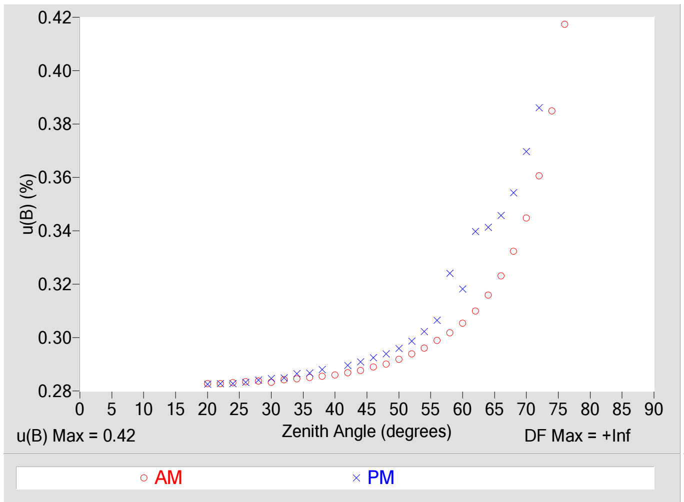


Figure 4. Residuals from Spline Interpolation

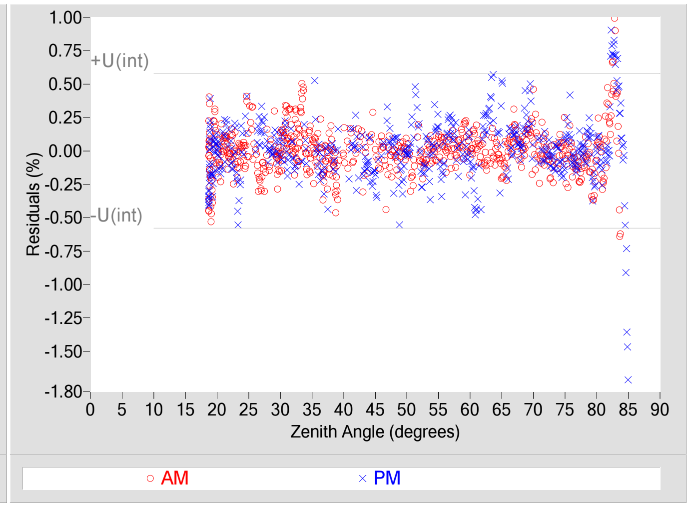


Table 3. Uncertainty using Spline Interpolation

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)	9687
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

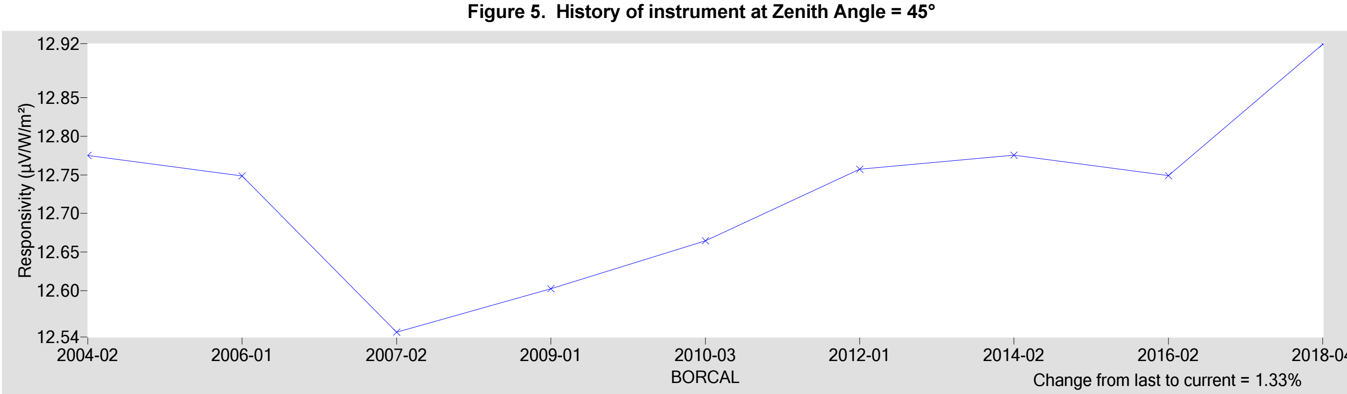
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
12.919	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.8 / -1.2
Expanded Uncertainty, U (%)	+2.4 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

[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:**	PY28249
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ ____________

Ibrahim Reda, Technical Manager   Date

For questions or comments, please contact the technical manager at:

ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

PY28249 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

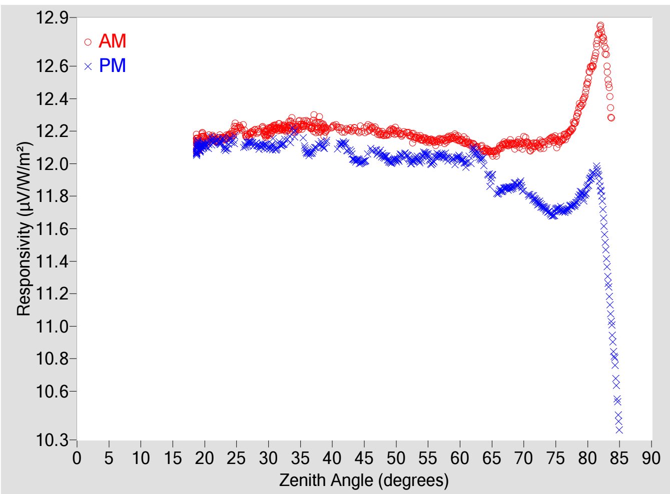


Figure 2. Responsivity vs Local Standard Time

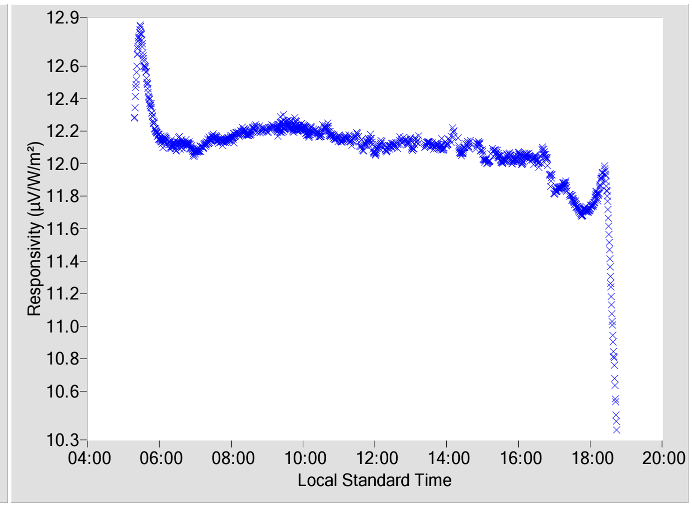


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	12.218	0.29	98.53	12.084	0.29	261.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.183	0.29	96.64	12.045	0.29	263.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.199	0.29	94.82	12.025	0.30	264.99
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.181	0.29	92.98	12.029	0.30	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.153	0.30	91.28	12.044	0.30	268.59
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.135	0.30	89.64	12.027	0.31	270.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.150	0.30	88.04	12.039	0.32	271.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.149	0.31	86.43	12.034	0.32	273.45
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.120	0.31	84.84	12.067	0.34	275.07
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.081	0.32	83.27	11.935	0.34	276.84
20	12.149	0.28	156.68	12.115	0.28	203.25	66	12.084	0.32	81.72	11.824	0.35	278.17
22	12.142	0.28	144.15	12.138	0.28	216.04	68	12.124	0.33	80.14	11.852	0.35	279.72
24	12.179	0.28	135.98	12.141	0.28	223.73	70	12.130	0.34	78.58	11.831	0.37	281.14
26	12.218	0.28	129.69	12.100	0.28	230.49	72	12.119	0.36	77.06	11.765	0.39	282.85
28	12.201	0.28	124.77	12.119	0.28	235.57	74	12.144	0.39	75.43	11.698	N/A	284.41
30	12.197	0.28	120.22	12.097	0.28	239.74	76	12.152	0.42	73.90	11.714	N/A	285.98
32	12.216	0.28	116.58	12.115	0.29	243.38	78	12.259	N/A	72.29	11.751	N/A	287.59
34	12.215	0.28	113.27	12.196	0.29	246.56	80	12.506	N/A	70.67	11.861	N/A	289.22
36	12.251	0.29	110.41	12.070	0.29	249.58	82	12.814	N/A	68.99	11.845	N/A	290.91
38	12.228	0.29	107.66	12.126	0.29	252.27	84	12.282	N/A	67.49	10.868	N/A	292.65
40	12.228	0.29	104.97	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.206	0.29	102.64	12.115	0.29	257.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.199	0.29	100.62	12.020	0.29	259.14	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

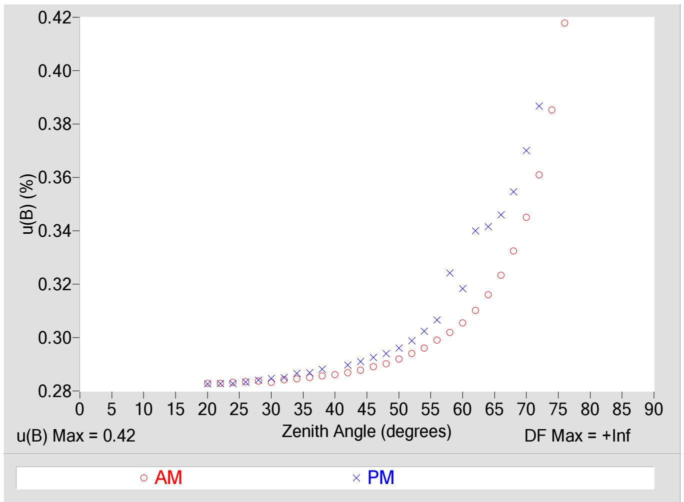


Figure 4. Residuals from Spline Interpolation

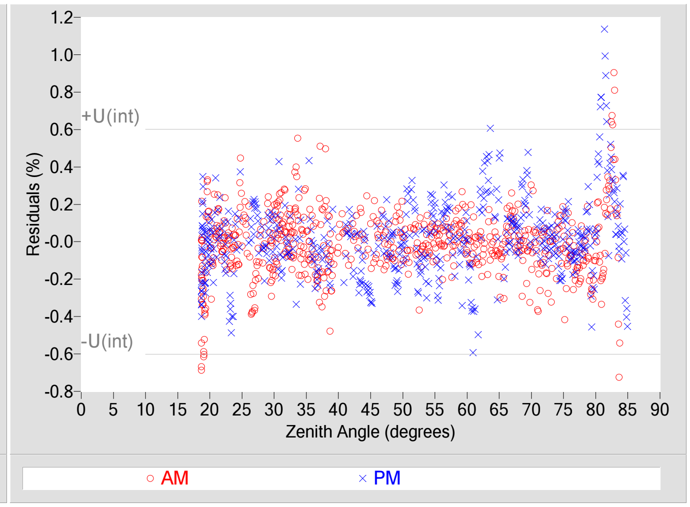


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	8837
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

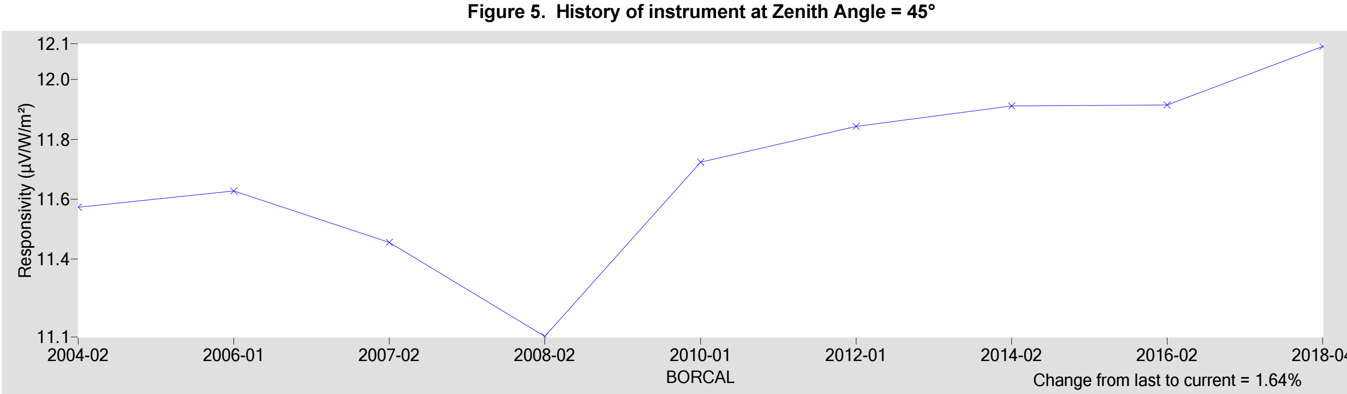
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
12.111	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.2 / -0.75
Expanded Uncertainty, U (%)	+1.8 / -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:**	Licor
Model:	LI200	**Serial Number:**	PY28260
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ ____________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

PY28260 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

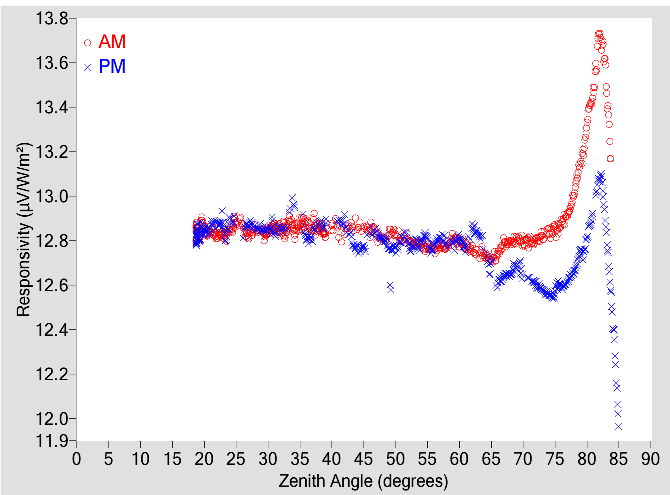


Figure 2. Responsivity vs Local Standard Time

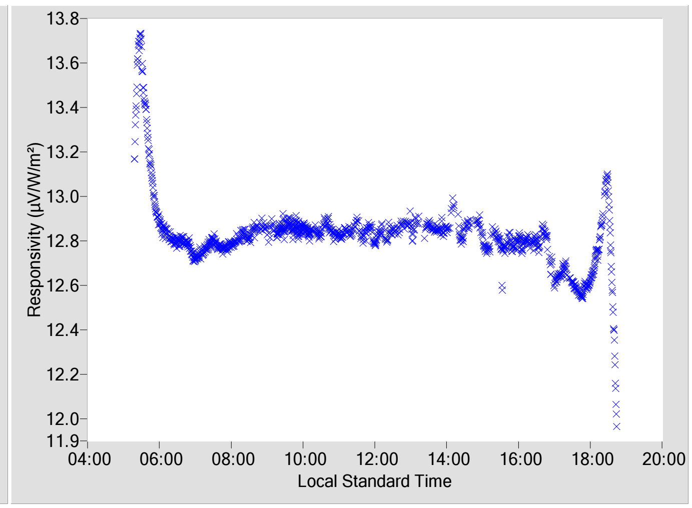


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	12.848	0.29	98.53	12.840	0.29	261.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.812	0.29	96.64	12.807	0.29	263.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.824	0.29	94.82	12.770	0.30	264.99
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.805	0.29	92.98	12.781	0.30	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.786	0.30	91.28	12.801	0.30	268.59
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.762	0.30	89.64	12.778	0.31	270.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.773	0.30	88.04	12.790	0.32	271.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.789	0.31	86.43	12.807	0.32	273.45
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.761	0.31	84.84	12.846	0.34	275.07
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.731	0.32	83.27	12.729	0.34	276.84
20	12.854	0.28	156.68	12.846	0.28	203.25	66	12.735	0.32	81.72	12.609	0.35	278.17
22	12.817	0.28	144.15	12.871	0.28	216.04	68	12.794	0.33	80.14	12.649	0.35	279.72
24	12.848	0.28	135.98	12.883	0.28	223.73	70	12.794	0.34	78.58	12.637	0.37	281.14
26	12.866	0.28	129.69	12.812	0.28	230.49	72	12.802	0.36	77.06	12.599	0.39	282.85
28	12.852	0.28	124.77	12.858	0.28	235.57	74	12.839	0.38	75.43	12.558	N/A	284.41
30	12.843	0.28	120.22	12.850	0.28	239.74	76	12.879	0.42	73.90	12.594	N/A	285.98
32	12.851	0.28	116.58	12.854	0.28	243.38	78	13.019	N/A	72.29	12.663	N/A	287.59
34	12.843	0.28	113.27	12.966	0.29	246.56	80	13.320	N/A	70.67	12.812	N/A	289.22
36	12.887	0.28	110.41	12.815	0.29	249.58	82	13.709	N/A	68.99	13.082	N/A	290.91
38	12.856	0.29	107.66	12.872	0.29	252.27	84	13.167	N/A	67.49	12.444	N/A	292.65
40	12.859	0.29	104.97	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.847	0.29	102.64	12.877	0.29	257.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.870	0.29	100.62	12.766	0.29	259.14	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

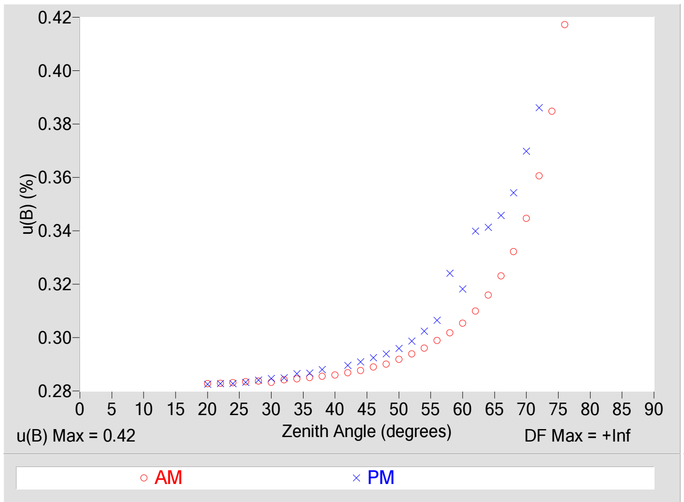


Figure 4. Residuals from Spline Interpolation

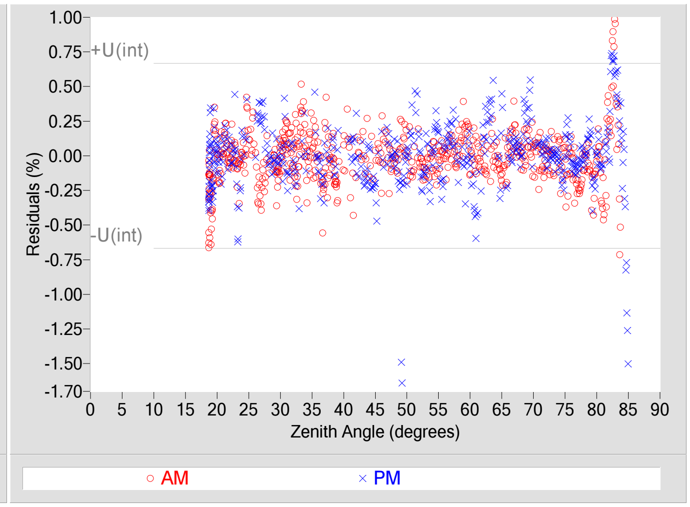


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	6747
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

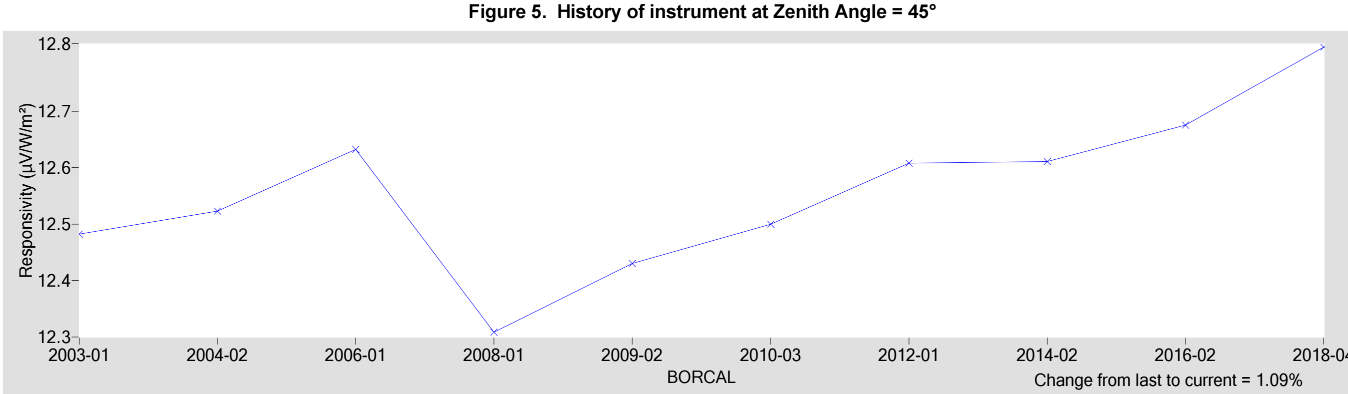
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
12.814	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.2 / -0.40
Expanded Uncertainty, U (%)	+1.8 / -1.0
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:**	PY66489
Calibration Date:	5/26/2018	**Due Date:**	5/26/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/25-26		

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: Afshin Andreas, Mark Kutchenreiter, and RCC

______________________________ ______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

PY66489 Licor LI200

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

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

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - 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

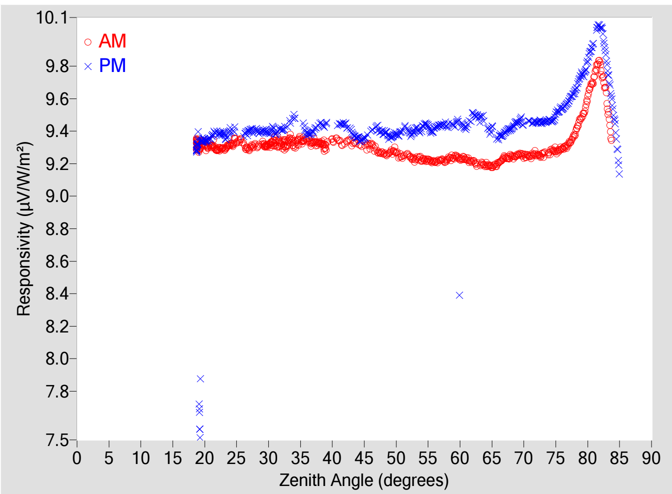


Figure 2. Responsivity vs Local Standard Time

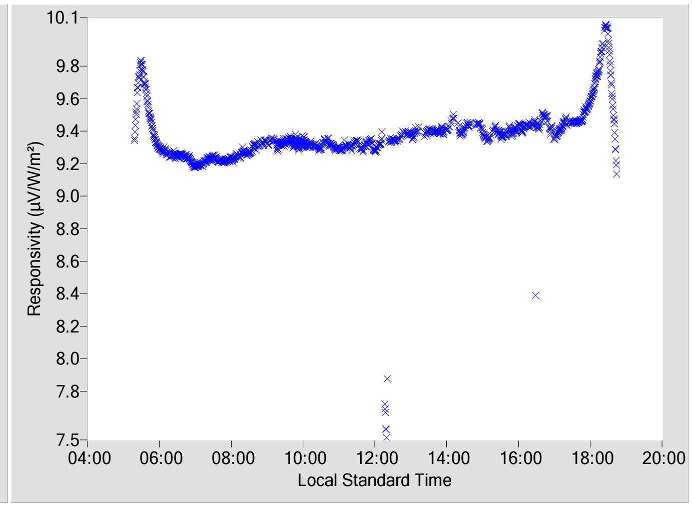


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.3139	0.29	98.53	9.4061	0.29	261.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2651	0.29	96.64	9.3925	0.29	263.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2761	0.29	94.82	9.3812	0.30	264.99
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2491	0.29	92.98	9.3956	0.30	266.82
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2265	0.30	91.28	9.4221	0.30	268.59
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2127	0.30	89.64	9.4133	0.31	270.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2234	0.30	88.04	9.4370	0.32	271.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2301	0.31	86.43	9.4451	0.32	273.50
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2165	0.31	84.84	9.4993	0.34	275.07
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1918	0.32	83.27	9.4160	0.34	276.84
20	9.3180	0.28	156.68	9.3434	0.28	203.25	66	9.2013	0.32	81.72	9.3611	0.35	278.17
22	9.2858	0.28	144.15	9.3876	0.28	216.04	68	9.2435	0.33	80.14	9.4162	0.36	279.72
24	9.3182	0.28	135.98	9.4000	0.28	223.73	70	9.2488	0.35	78.58	9.4379	0.37	281.14
26	9.3250	0.28	129.69	9.3664	0.28	230.49	72	9.2583	0.36	77.06	9.4538	0.39	282.85
28	9.3127	0.28	124.77	9.4063	0.28	235.57	74	9.2680	0.39	75.43	9.4667	N/A	284.41
30	9.3141	0.28	120.22	9.3903	0.28	239.74	76	9.2932	0.42	73.90	9.5399	N/A	285.98
32	9.3191	0.28	116.58	9.4105	0.29	243.38	78	9.3863	N/A	72.29	9.6474	N/A	287.59
34	9.3180	0.28	113.27	9.4861	0.29	246.56	80	9.6064	N/A	70.67	9.8322	N/A	289.22
36	9.3471	0.29	110.41	9.3886	0.29	249.58	82	9.7934	N/A	68.99	10.040	N/A	290.91
38	9.3245	0.29	107.66	9.4460	0.29	252.27	84	9.3436	N/A	67.49	9.5115	N/A	292.65
40	9.3427	0.29	104.97	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3304	0.29	102.64	9.4394	0.29	257.00	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3297	0.29	100.62	9.3576	0.29	259.14	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

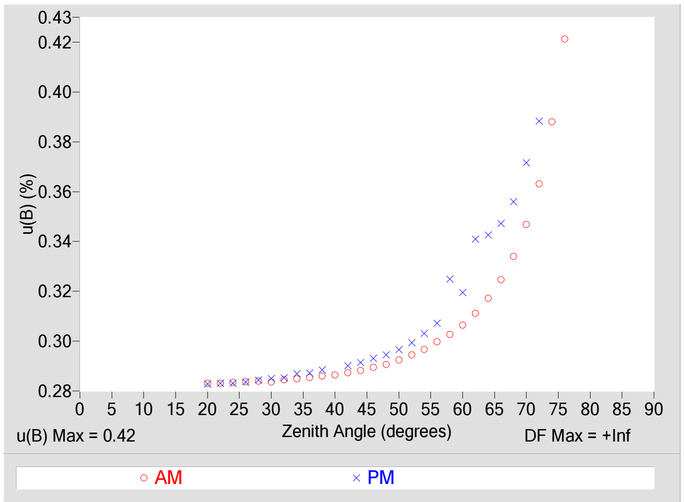


Figure 4. Residuals from Spline Interpolation

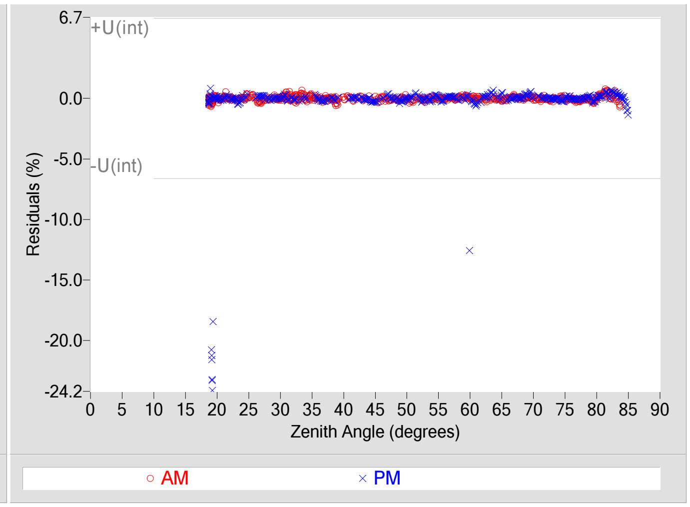


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±3.3
Combined Standard Uncertainty, u(c) (%)	±3.3
Effective degrees of freedom, DF(c)	1056
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±6.6
AM Valid zenith angle range	20° to 76°
PM Valid zenith angle range	20° to 72°

Table 4. Calibration Label Values

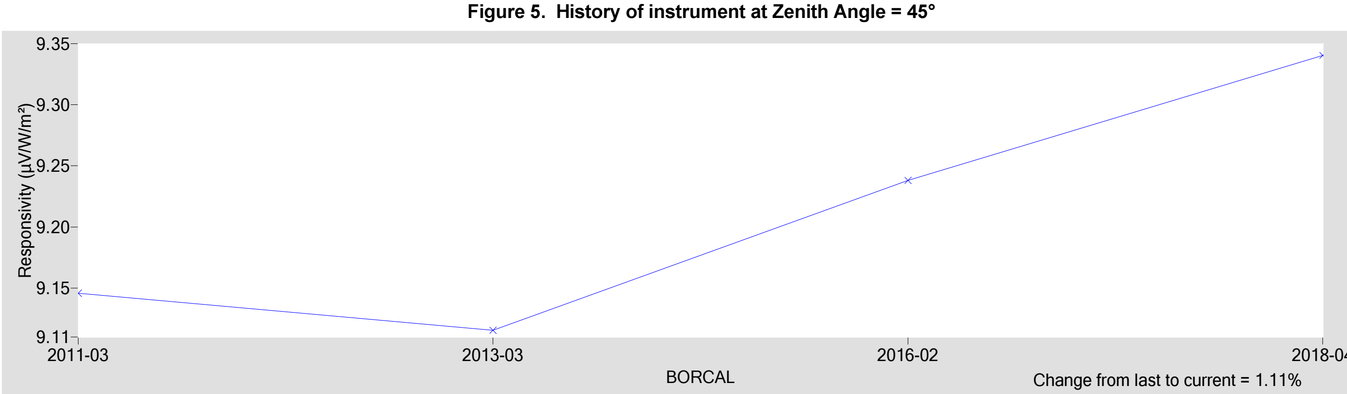
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3404	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.6 / -1.4
Expanded Uncertainty, U (%)	+2.2 / -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

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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

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

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

Environmental and Sky Conditions for BORCAL-SW 2018-04

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

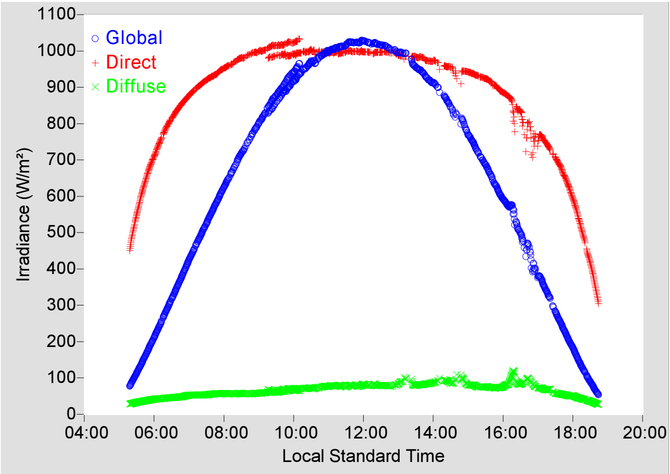
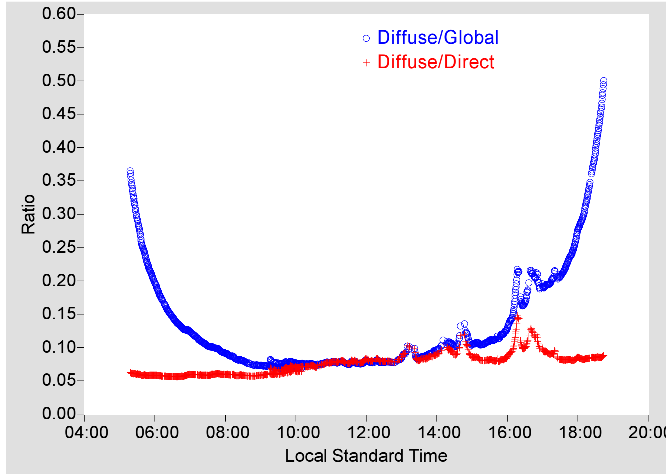


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

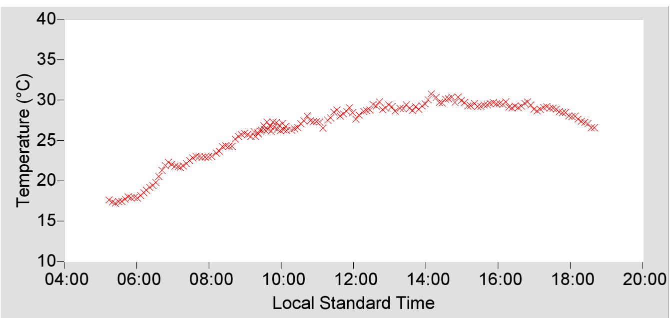


Figure 9. Humidity

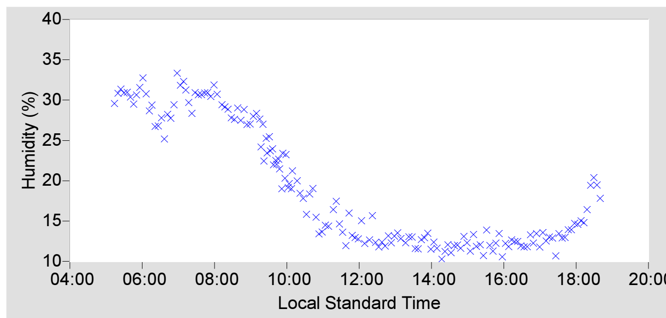


Figure 10. Pressure

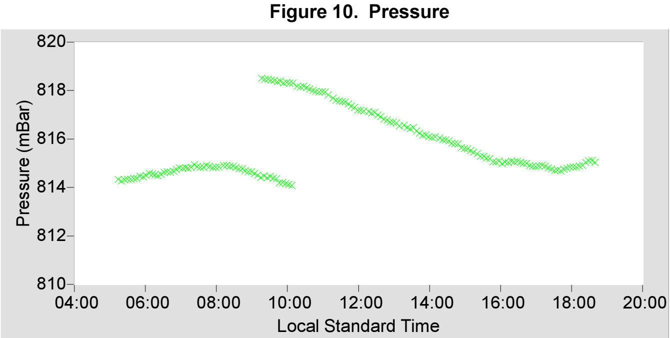


Figure 11. Effective Net Infrared

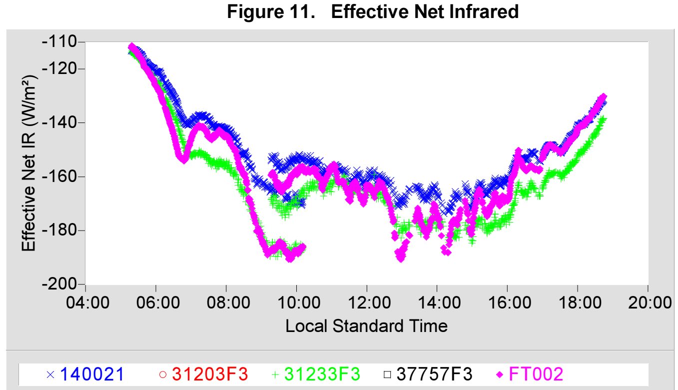


Figure 12. Estimated Broadband Aerosol Optical Depth

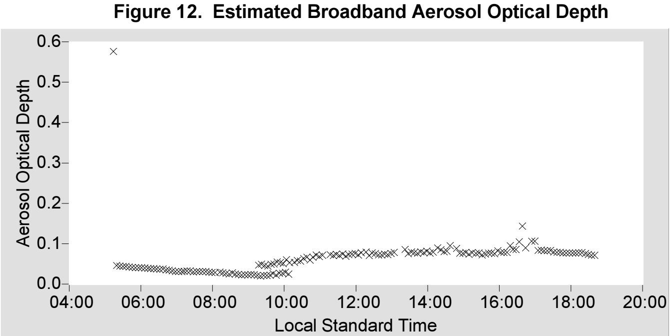


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	26.40	17.22	30.75
Humidity (%)	19.29	10.28	33.34
Pressure (mBar)	815.7	814.1	818.5
Est. Aerosol Optical Depth (BB)	0.063	0.020	0.576

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

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

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

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