

Broadband Outdoor Radiometer Calibration Shortwave

BORCAL-SW 2017-01

Customer

NREL-SRRL-BMS

Organization: NREL

Address: BMS, SRRL, Golden, CO 80401 USA

Phone: 303-384-6326

Calibration Facility

Solar Radiation Research Laboratory

Latitude: 39.742°N

Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Calibration date

05/04/2017

Report Date

May 8, 2017

NOTICE

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Broadband Outdoor Radiometer Calibration Report

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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

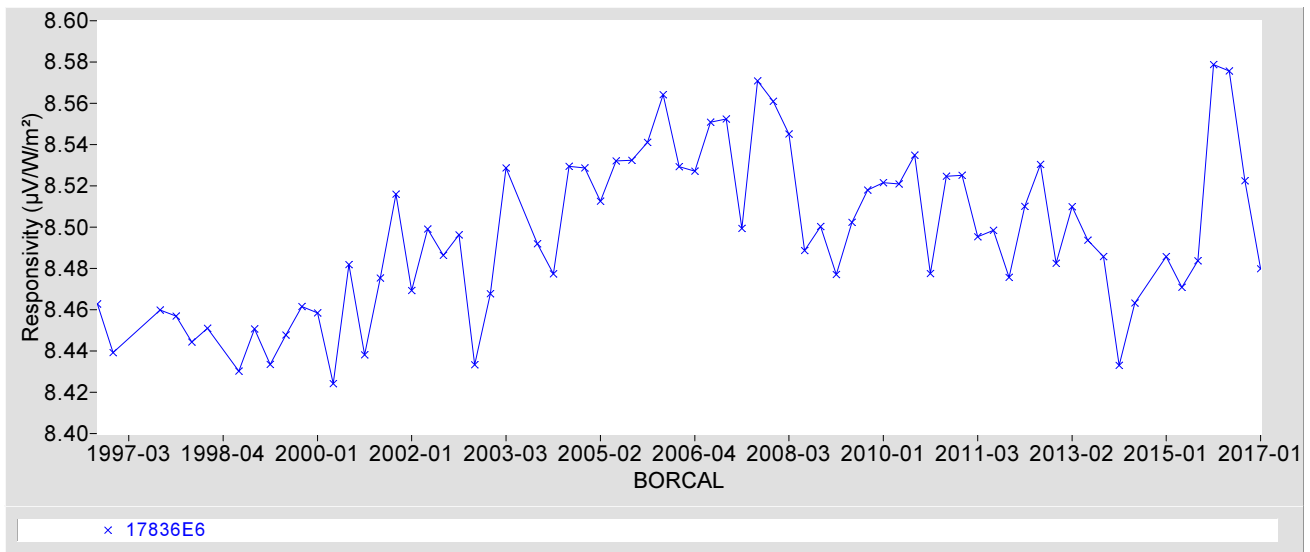
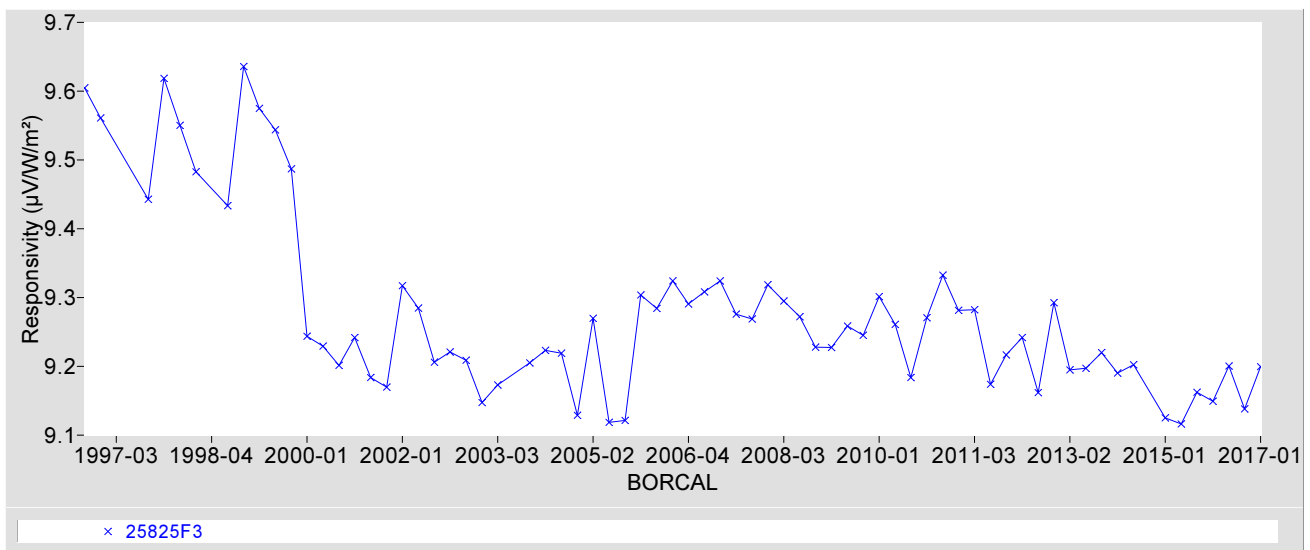


Figure 2. Eppley PSP Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	R@45 ¹ ($\mu\text{V}/\text{W}/\text{m}^2$)	CF@45 ¹ ($\text{W}/\text{m}^2/\text{mV}$)	U ² (%)	Rnet ³ ($\mu\text{V}/\text{W}/\text{m}^2$)	Page
010047 Kipp & Zonen CM22	9.6708	103.40	+1.2 / -1.2	0.087000	A1-2
014261 Kipp & Zonen CM3	21.693	46.097	+2.6 / -2.3	0.40000	A1-5
015189 Kipp & Zonen CM6B	10.788	92.699	+2.1 / -3.3	0.30000	A1-8
0212-2 Yankee TSP-700	2933.4	0.34090	+1.7 / -2.5	0	A1-11
080009 Kipp & Zonen CHP1	7.9476	125.82	+0.78 / -0.71	0	A1-14
080017 Kipp & Zonen CMP22	10.420	95.967	+1.5 / -1.6	0.087000	A1-17
100174 Kipp & Zonen CMP22	9.6731	103.38	+1.5 / -1.4	0.087000	A1-20
140043 Kipp & Zonen CMP22	8.9344	111.93	+1.6 / -1.1	0.087000	A1-23
140108 Kipp & Zonen CHP1	8.0544	124.16	+0.77 / -0.76	0	A1-26
140712 Kipp & Zonen CMP11	8.9512	111.72	+1.8 / -1.9	0.20500	A1-29
151027 Kipp & Zonen SP-LITE2	69.200	14.451	+2.6 / -2.0	0	A1-32
2516 Hukseflux SR25	11.146	89.717	+2.4 / -2.0	0.043000	A1-35
2529 Hukseflux SR25	9.2531	108.07	+1.5 / -1.4	0.043000	A1-38
28402F3 Eppley PSP	6.9722	143.43	+1.9 / -2.3	0.64000	A1-41
31137E6 Eppley NIP	8.4873	117.82	+1.4 / -1.1	0	A1-44
37831F3 Eppley GPP	8.3738	119.42	+2.3 / -3.1	0.15000	A1-47
37839F3 Eppley SPP	8.5464	117.01	+1.5 / -2.5	0.30000	A1-50
37882E6 Eppley sNIP	8.3664	119.53	+0.92 / -0.71	0	A1-53
40337 Apogee SP-110	185.08	5.4029	+1.8 / -1.7	0	A1-56
9206 Hukseflux DR02	11.031	90.657	+0.82 / -0.81	0	A1-59
A360 Delta-T SPN1	996.19	1.0038	+7.3 / -4.2	0	A1-62
F14077R EKO MS-802	6.9648	143.58	+2.1 / -2.6	0.18000	A1-65
P12022 EKO MS-56	7.2181	138.54	+0.96 / -0.78	0	A1-68
PY100360 Licor LI200R	10.879	91.921	+1.2 / -1.6	0	A1-71
PY28257 Licor LI200	13.619	73.424	+2.0 / -3.1	0	A1-74
PYHR101 Licor LI201SB	8.7989	113.65	+4.2 / -2.1	0	A1-77
S13071483 EKO MS-602	6.8491	146.01	+2.5 / -2.6	0.30000	A1-80
S13135063 EKO ML-01	40.045	24.972	+1.4 / -1.1	0	A1-83
S13144.085R EKO MS-410	9.1646	109.12	+1.3 / -1.3	0.20000	A1-86

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 A1-89.

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



Test Instrument:	Pyranometer (Ventilated)	Manufacturer:	Kipp & Zonen
Model:	CM22	Serial Number:	010047
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model 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: 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

010047 Kipp & Zonen CM22

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

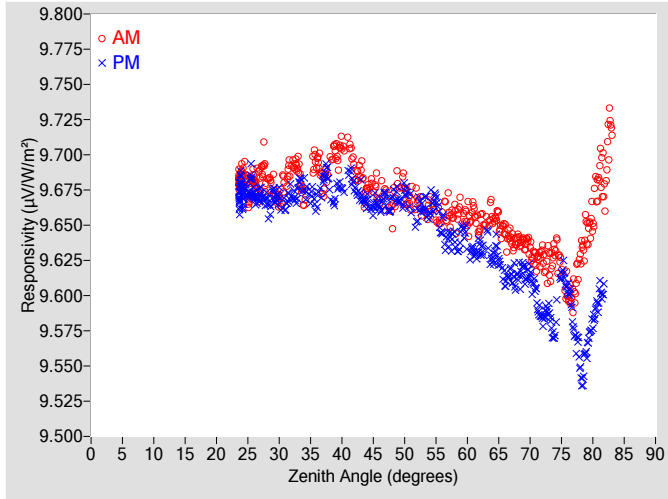


Figure 2. Responsivity vs Local Standard Time

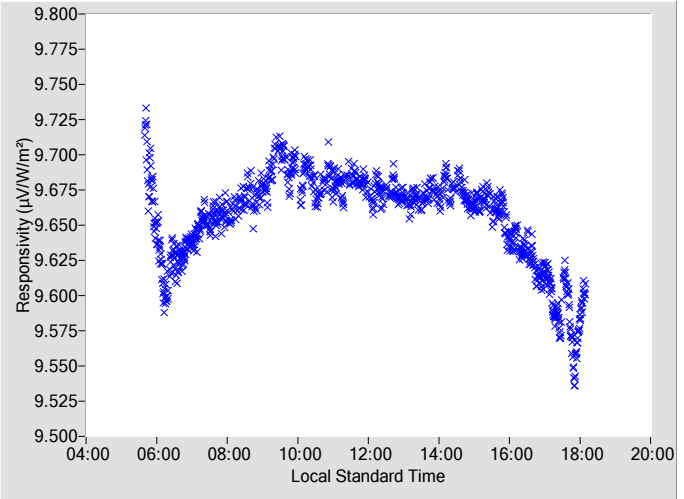


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.6667	0.34	107.50	9.6622	0.36	252.68
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.6626	0.34	105.12	9.6687	0.37	254.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6776	0.35	103.08	9.6735	0.38	257.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6701	0.36	100.96	9.6594	0.38	259.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.6656	0.36	99.04	9.6609	0.40	261.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6553	0.37	97.28	9.6503	0.41	263.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6561	0.38	95.33	9.6393	0.42	264.80
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.6542	0.39	93.58	9.6415	0.43	266.43
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6477	0.41	91.93	9.6352	0.45	268.26
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.6575	0.42	90.22	9.6264	0.47	269.97
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.6476	0.44	88.59	9.6111	0.50	271.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.6402	0.47	86.89	9.6162	0.53	273.30
24	9.6832	0.32	168.67	9.6762	0.31	192.02	70	9.6326	0.50	85.26	9.6152	0.57	274.89
26	9.6810	0.32	151.56	9.6714	0.32	208.43	72	9.6303	0.54	83.68	9.5835	0.62	276.46
28	9.6788	0.32	142.80	9.6661	0.32	217.65	74	9.6342	0.59	82.08	9.5779	N/A	278.07
30	9.6685	0.32	135.83	9.6683	0.32	224.46	76	9.6018	0.65	80.47	9.6044	N/A	279.67
32	9.6931	0.32	129.99	9.6729	0.33	229.79	78	9.6303	0.75	78.79	9.5463	N/A	281.32
34	9.6681	0.32	125.85	9.6753	0.33	234.31	80	9.6573	N/A	77.22	9.5814	N/A	282.97
36	9.6960	0.32	121.92	9.6671	0.33	238.23	82	9.6761	N/A	75.62	9.6085	N/A	284.37
38	9.6923	0.33	118.60	9.6774	0.34	241.62	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.7071	0.33	115.45	9.6763	0.34	244.77	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.6889	0.33	112.51	9.6773	0.35	247.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.6759	0.34	109.84	9.6667	0.35	250.16	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

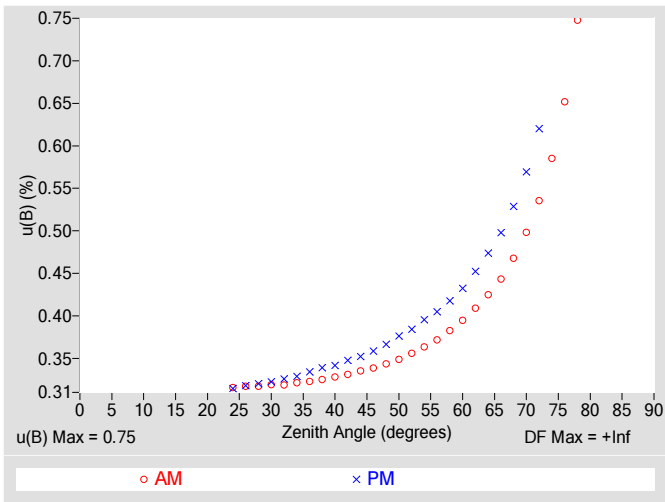


Figure 4. Residuals from Spline Interpolation

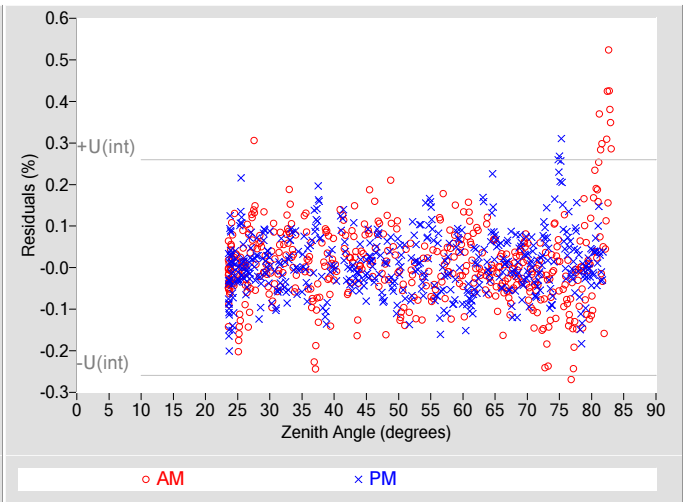


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.75
Type-A Interpolating Function, $u(int)$ (%)	± 0.13
Combined Standard Uncertainty, $u(c)$ (%)	± 0.76
Effective degrees of freedom, $DF(c)$	1007970
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

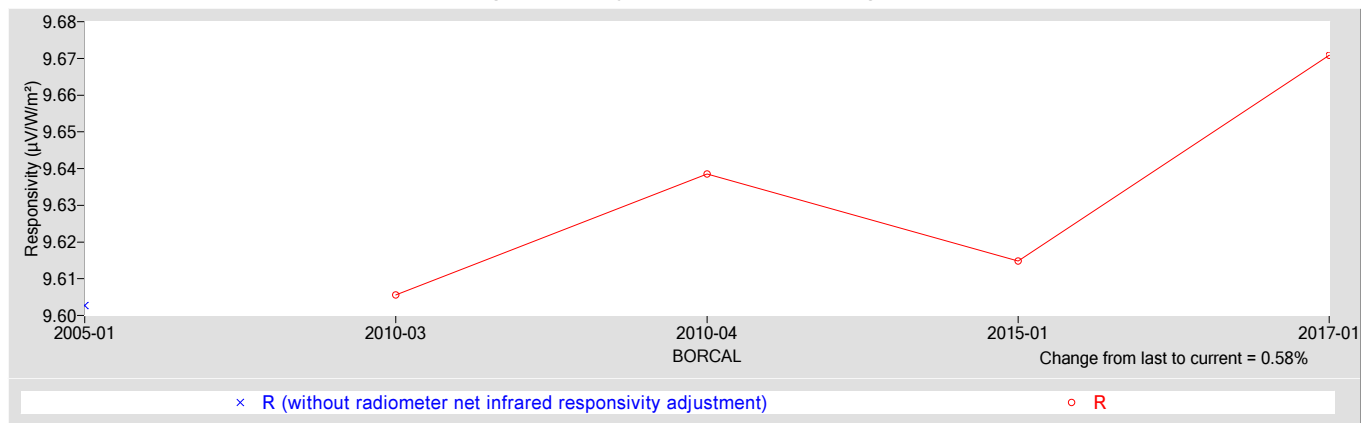
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
9.6708	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+0.37 / -0.33
Expanded Uncertainty, U (%)	+1.2 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	Kipp & Zonen
Model:	CM3	Serial Number:	014261
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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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Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

014261 Kipp & Zonen CM3

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

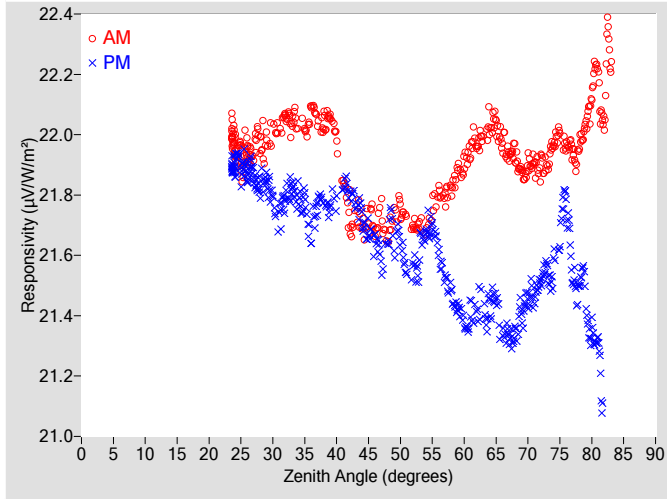


Figure 2. Responsivity vs Local Standard Time

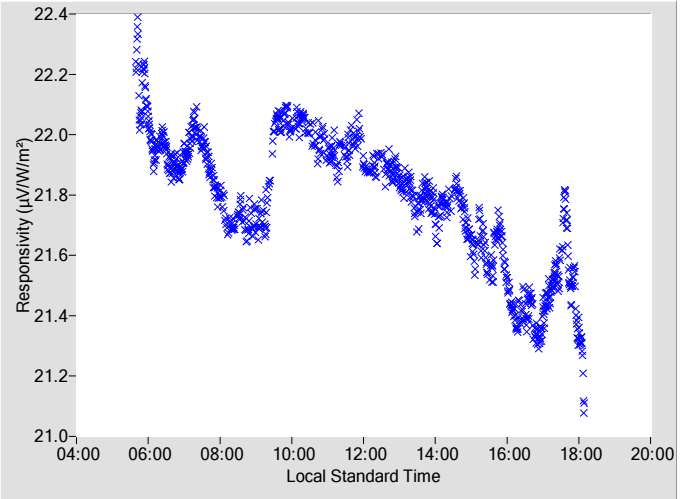


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	21.682	0.34	107.46	21.643	0.36	252.65
2	N/A	N/A	N/A	N/A	N/A	N/A	48	21.646	0.34	105.23	21.660	0.37	255.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	21.755	0.35	103.01	21.648	0.38	257.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	21.697	0.36	100.98	21.565	0.39	259.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	21.680	0.37	99.01	21.673	0.40	261.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	21.808	0.37	97.10	21.603	0.41	262.98
12	N/A	N/A	N/A	N/A	N/A	N/A	58	21.826	0.38	95.30	21.472	0.42	264.84
14	N/A	N/A	N/A	N/A	N/A	N/A	60	21.899	0.40	93.62	21.373	0.44	266.58
16	N/A	N/A	N/A	N/A	N/A	N/A	62	21.966	0.41	91.79	21.428	0.46	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	22.033	0.43	90.19	21.435	0.48	269.97
20	N/A	N/A	N/A	N/A	N/A	N/A	66	21.972	0.45	88.54	21.347	0.50	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	21.940	0.47	86.89	21.340	0.53	273.25
24	21.969	0.32	168.57	21.898	0.32	192.18	70	21.896	0.50	85.30	21.450	0.57	274.88
26	21.940	0.32	151.22	21.866	0.32	208.68	72	21.905	0.54	83.64	21.519	0.63	276.50
28	21.970	0.32	142.13	21.834	0.32	217.49	74	21.965	0.59	82.08	21.563	N/A	278.07
30	21.999	0.32	135.82	21.791	0.32	224.48	76	21.962	0.65	80.51	21.759	N/A	279.71
32	22.058	0.32	130.41	21.793	0.33	229.68	78	21.965	0.75	78.83	21.495	N/A	281.32
34	22.020	0.32	126.03	21.795	0.33	234.28	80	22.114	N/A	77.26	21.341	N/A	282.93
36	22.078	0.32	121.99	21.640	0.34	238.22	82	22.087	N/A	75.57	N/A	N/A	N/A
38	22.034	0.33	118.43	21.769	0.34	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	21.984	0.33	115.40	21.772	0.34	244.70	86	N/A	N/A	N/A	N/A	N/A	N/A
42	21.732	0.33	112.51	21.794	0.35	247.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	21.701	0.34	109.88	21.725	0.35	250.28	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

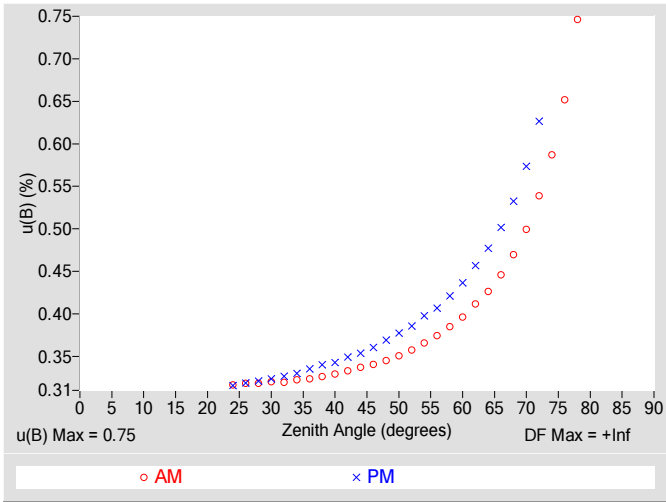


Figure 4. Residuals from Spline Interpolation

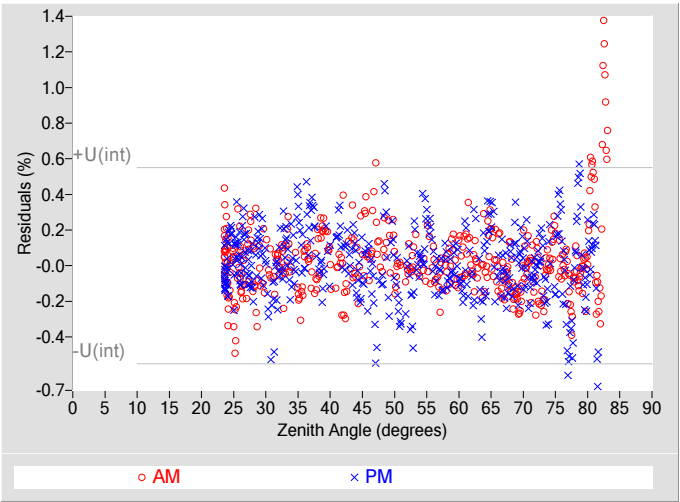


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.75
Type-A Interpolating Function, $u(int)$ (%)	± 0.28
Combined Standard Uncertainty, $u(c)$ (%)	± 0.80
Effective degrees of freedom, $DF(c)$	57722
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

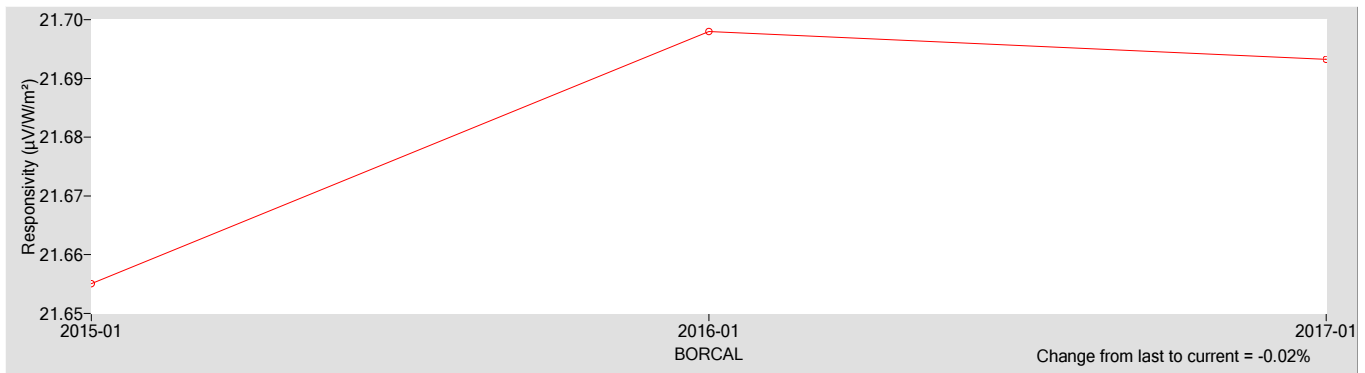
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
21.693	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.86
Offset Uncertainty, $U(off)$ (%)	+1.8 / -1.5
Expanded Uncertainty, U (%)	+2.6 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	Kipp & Zonen
Model:	CM6B	Serial Number:	015189
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

015189 Kipp & Zonen CM6B

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

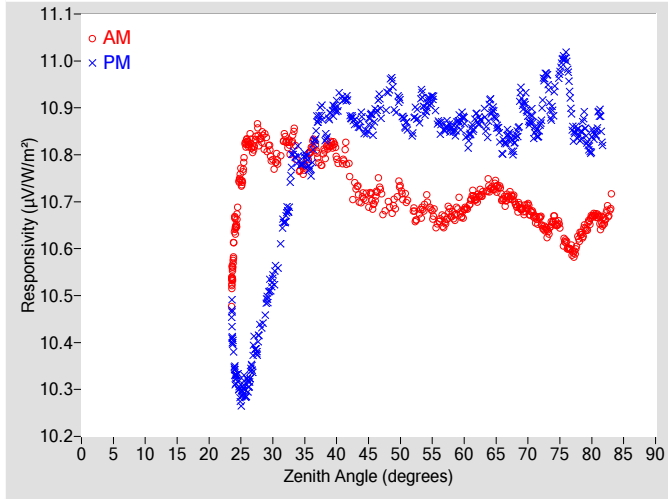


Figure 2. Responsivity vs Local Standard Time

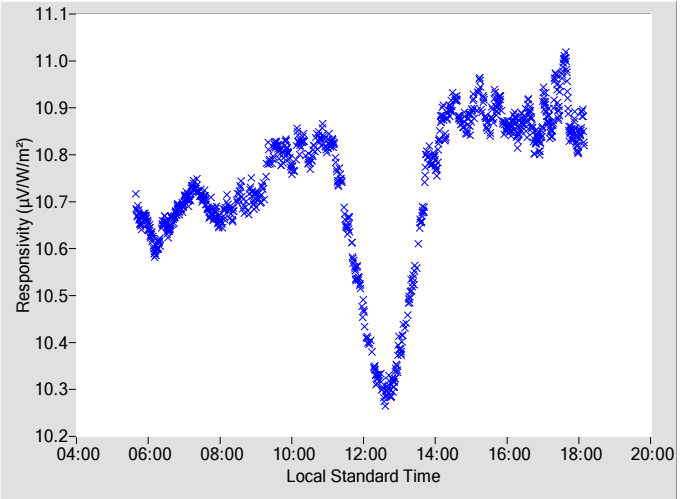


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith			AM			PM			Zenith			AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	R	u(B)	Azimuth	
(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.705	0.34	107.43	10.886	0.36	252.73				
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.694	0.35	104.95	10.925	0.37	254.96				
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.730	0.36	103.03	10.908	0.38	257.05				
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.682	0.36	100.86	10.861	0.39	259.18				
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.697	0.37	99.07	10.897	0.40	261.07				
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.658	0.38	97.11	10.863	0.41	262.99				
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.675	0.39	95.38	10.855	0.43	264.80				
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.681	0.40	93.58	10.869	0.44	266.54				
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.707	0.42	91.84	10.878	0.46	268.35				
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.732	0.43	90.20	10.900	0.49	269.97				
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.707	0.45	88.54	10.812	0.51	271.64				
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.698	0.48	86.89	10.832	0.54	273.25				
24	10.621	0.32	168.13	10.340	0.32	193.36	70	10.688	0.51	85.30	10.878	0.58	274.88				
26	10.825	0.32	151.22	10.302	0.32	208.69	72	10.661	0.55	83.68	10.879	0.64	276.51				
28	10.831	0.32	142.55	10.425	0.32	217.46	74	10.660	0.60	82.08	10.912	N/A	278.08				
30	10.782	0.32	135.72	10.530	0.33	224.35	76	10.610	0.67	80.47	10.998	N/A	279.72				
32	10.833	0.32	130.39	10.668	0.33	229.82	78	10.625	0.76	78.83	10.842	N/A	281.33				
34	10.766	0.33	125.40	10.799	0.33	234.07	80	10.666	N/A	77.27	10.826	N/A	282.93				
36	10.812	0.33	121.87	10.770	0.34	238.14	82	10.662	N/A	75.57	N/A	N/A	N/A				
38	10.804	0.33	118.29	10.864	0.34	241.66	84	N/A	N/A	N/A	N/A	N/A	N/A				
40	10.796	0.33	115.29	10.900	0.35	244.78	86	N/A	N/A	N/A	N/A	N/A	N/A				
42	10.768	0.34	112.51	10.879	0.35	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A				
44	10.708	0.34	109.81	10.872	0.36	250.22	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

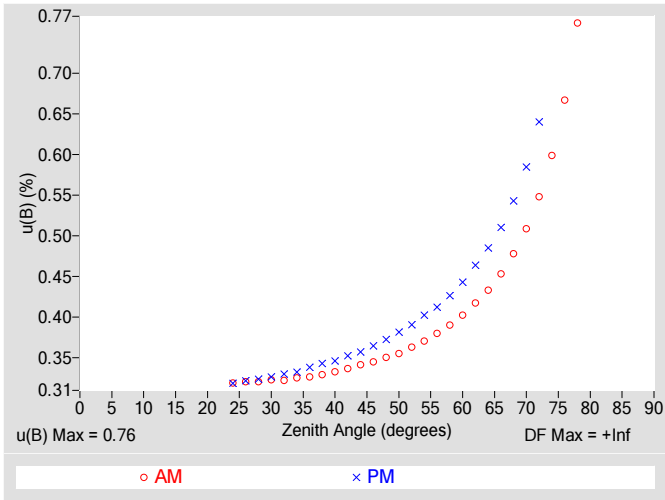


Figure 4. Residuals from Spline Interpolation

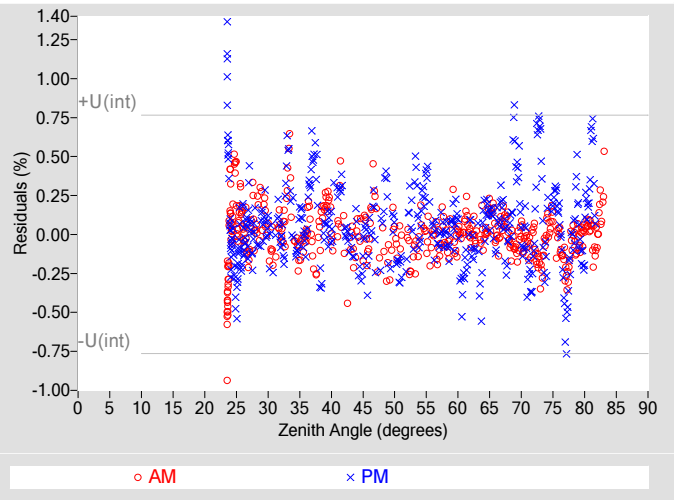


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.76
Type-A Interpolating Function, $u(int)$ (%)	± 0.38
Combined Standard Uncertainty, $u(c)$ (%)	± 0.85
Effective degrees of freedom, $DF(c)$	21034
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 1.7
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

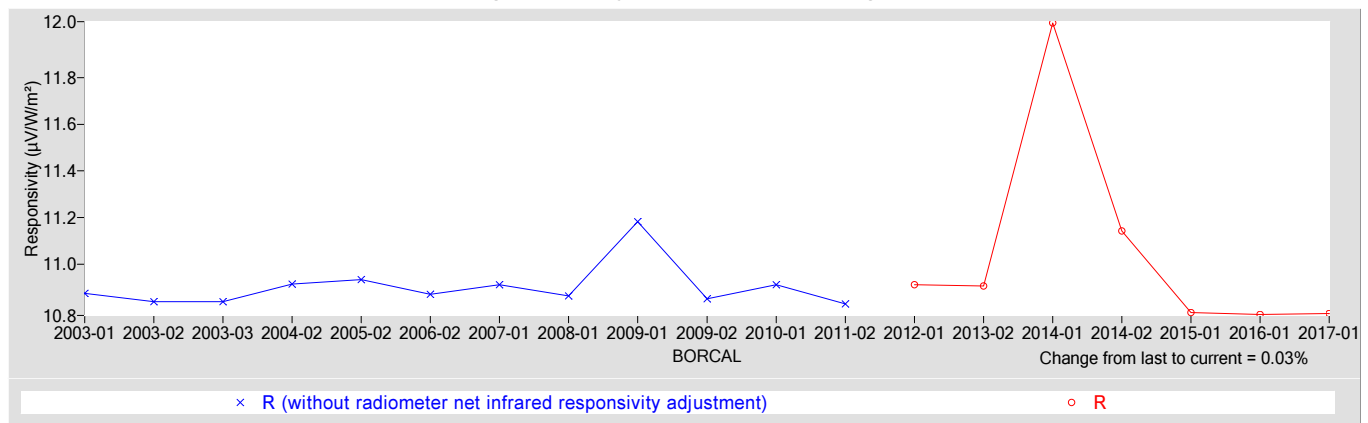
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
10.788	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.87
Offset Uncertainty, $U(off)$ (%)	+1.3 / -2.4
Expanded Uncertainty, U (%)	+2.1 / -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



Test Instrument:	Pyranometer (Ventilated)	Manufacturer:	Yankee
Model:	TSP-700	Serial Number:	0212-2
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

0212-2 Yankee TSP-700

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

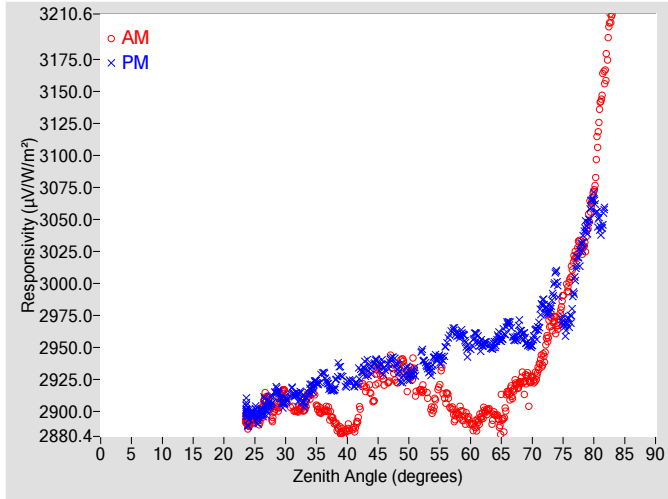


Figure 2. Responsivity vs Local Standard Time

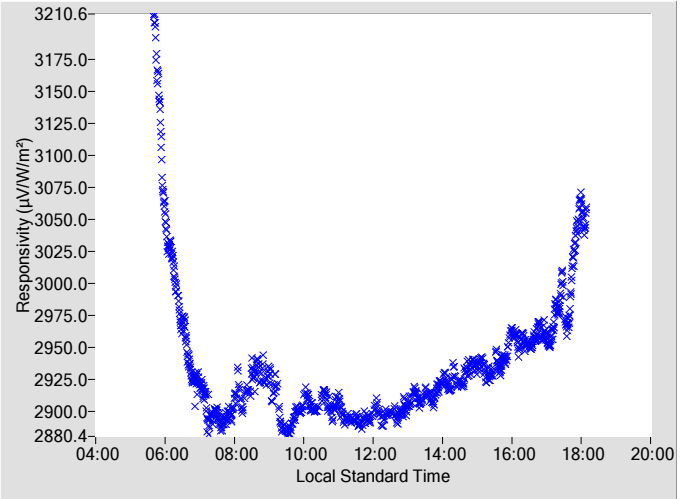


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	2924.5	0.34	107.63	2931.8	0.36	252.70
2	N/A	N/A	N/A	N/A	N/A	N/A	48	2924.9	0.34	105.14	2936.8	0.37	254.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	2925.5	0.35	103.08	2926.5	0.37	257.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	2916.9	0.35	100.96	2945.3	0.38	259.27
8	N/A	N/A	N/A	N/A	N/A	N/A	54	2904.2	0.36	98.98	2939.9	0.39	261.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	2911.7	0.37	97.10	2949.4	0.40	262.93
12	N/A	N/A	N/A	N/A	N/A	N/A	58	2897.1	0.38	95.33	2958.3	0.42	264.82
14	N/A	N/A	N/A	N/A	N/A	N/A	60	2890.0	0.39	93.57	2948.3	0.43	266.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	2897.8	0.41	91.88	2952.7	0.45	268.25
18	N/A	N/A	N/A	N/A	N/A	N/A	64	2897.7	0.42	90.24	2953.4	0.47	269.96
20	N/A	N/A	N/A	N/A	N/A	N/A	66	2911.8	0.44	88.54	2968.7	0.49	271.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	2922.2	0.46	86.89	2964.6	0.52	273.29
24	2892.5	0.31	168.19	2895.6	0.31	191.18	70	2925.1	0.49	85.25	2953.6	0.56	274.88
26	2898.1	0.32	151.17	2899.7	0.32	208.91	72	2944.9	0.53	83.68	2983.0	0.61	276.46
28	2895.9	0.32	142.52	2911.0	0.32	217.66	74	2966.4	0.58	82.08	3002.7	N/A	278.07
30	2913.1	0.32	135.64	2908.3	0.32	224.36	76	2999.9	0.65	80.47	2970.6	N/A	279.67
32	2901.2	0.32	130.21	2912.4	0.32	229.68	78	3027.0	0.73	78.87	3030.2	N/A	281.31
34	2913.6	0.32	125.93	2918.4	0.33	234.48	80	3073.0	N/A	77.22	3064.2	N/A	282.96
36	2899.5	0.32	122.11	2929.8	0.33	238.29	82	3167.1	N/A	75.64	3059.6	N/A	284.37
38	2891.1	0.32	118.47	2919.7	0.34	241.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	2886.2	0.33	115.38	2921.2	0.34	244.70	86	N/A	N/A	N/A	N/A	N/A	N/A
42	2900.2	0.33	112.55	2927.9	0.35	247.51	88	N/A	N/A	N/A	N/A	N/A	N/A
44	2909.8	0.33	109.77	2932.5	0.35	250.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

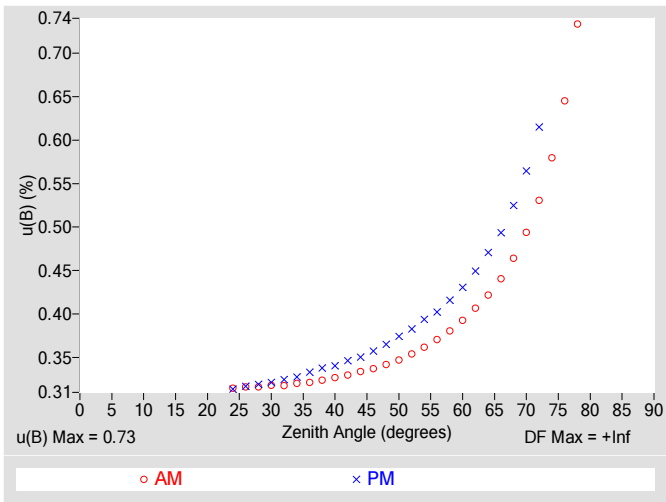


Figure 4. Residuals from Spline Interpolation

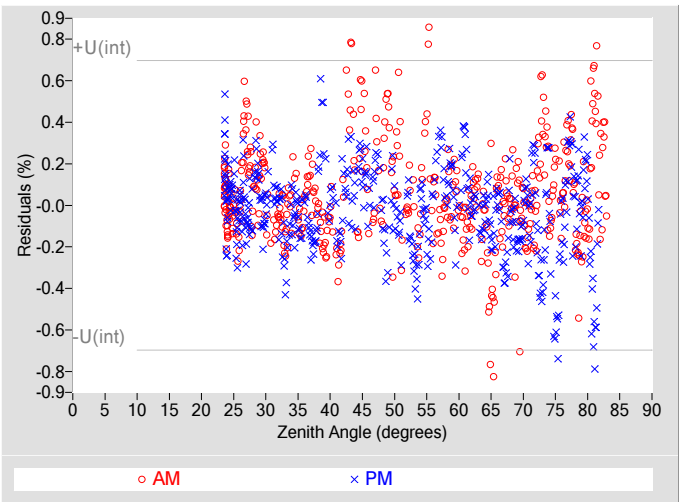


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.73
Type-A Interpolating Function, $u(int)$ (%)	± 0.35
Combined Standard Uncertainty, $u(c)$ (%)	± 0.81
Effective degrees of freedom, $DF(c)$	25983
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

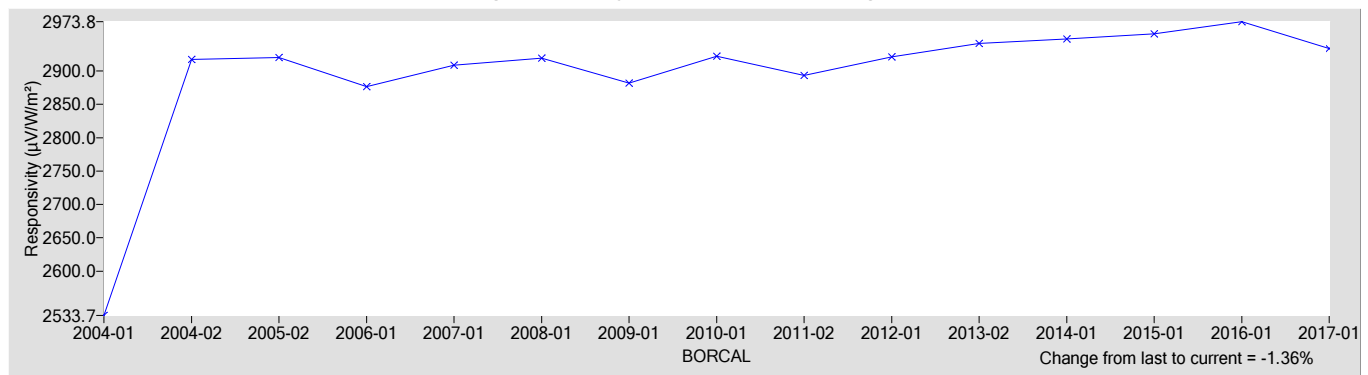
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
2933.4	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.84
Offset Uncertainty, $U(off)$ (%)	+0.85 / -1.6
Expanded Uncertainty, U (%)	+1.7 / -2.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyrheliometer	Manufacturer:	Kipp & Zonen
Model:	CHP1	Serial Number:	080009
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

080009 Kipp & Zonen CHP1

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

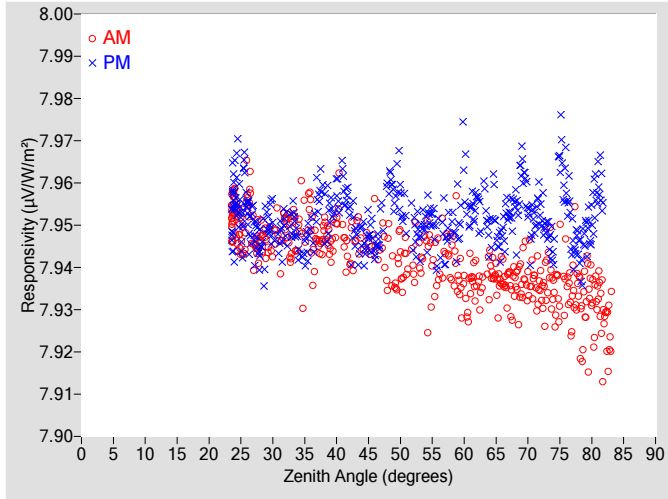


Figure 2. Responsivity vs Local Standard Time

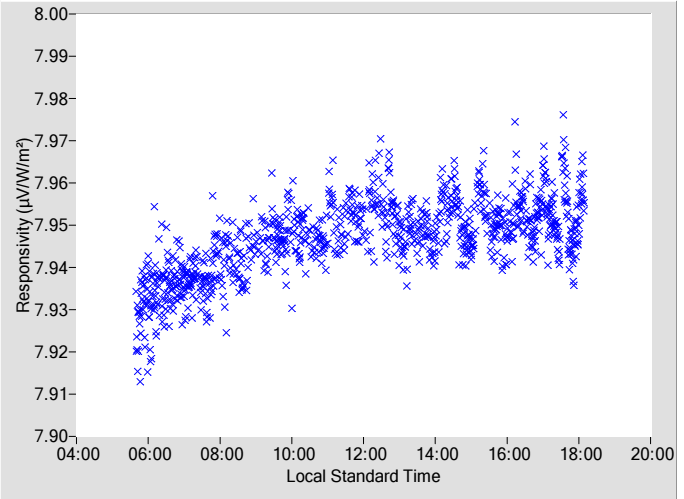


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9497	0.28	107.58	7.9438	0.28	252.73
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9422	0.28	105.16	7.9589	0.28	254.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9428	0.28	103.05	7.9571	0.28	257.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9421	0.28	100.91	7.9503	0.28	259.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9423	0.28	98.95	7.9503	0.28	261.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9408	0.28	97.13	7.9447	0.29	262.98
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9431	0.28	95.33	7.9499	0.29	264.90
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9356	0.28	93.53	7.9649	0.29	266.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9365	0.28	91.92	7.9568	0.29	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9394	0.29	90.16	7.9475	0.29	269.93
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9380	0.29	88.53	7.9488	0.29	271.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.9367	0.29	86.88	7.9534	0.29	273.32
24	7.9535	0.28	168.26	7.9548	0.28	191.43	70	7.9374	0.29	85.29	7.9546	0.30	274.87
26	7.9555	0.28	151.52	7.9530	0.28	208.81	72	7.9356	0.29	83.71	7.9517	0.30	276.49
28	7.9464	0.28	142.29	7.9443	0.28	217.82	74	7.9328	0.29	82.11	7.9445	N/A	278.02
30	7.9451	0.28	135.71	7.9493	0.28	224.24	76	7.9372	0.30	80.51	7.9595	N/A	279.70
32	7.9506	0.28	130.35	7.9494	0.28	229.78	78	7.9327	0.30	78.86	7.9437	N/A	281.35
34	7.9485	0.28	125.69	7.9441	0.28	234.32	80	7.9331	N/A	77.21	7.9504	N/A	282.96
36	7.9497	0.28	121.92	7.9494	0.28	237.97	82	7.9261	N/A	75.60	7.9553	N/A	284.36
38	7.9482	0.28	118.41	7.9542	0.28	241.76	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9507	0.28	115.28	7.9578	0.28	244.97	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9434	0.28	112.38	7.9549	0.28	247.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9456	0.28	109.88	7.9489	0.28	250.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

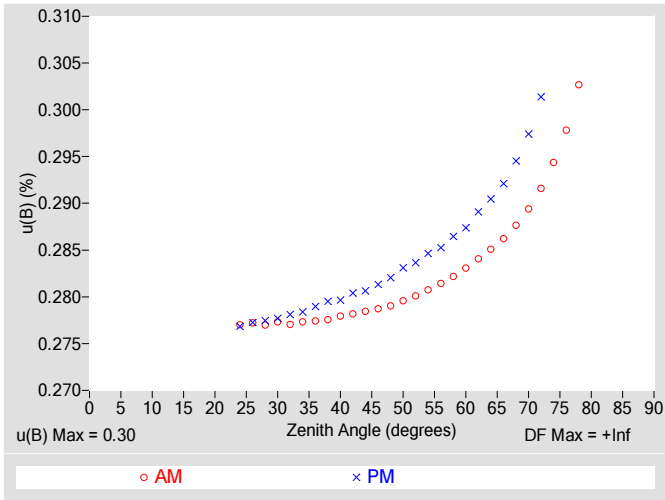


Figure 4. Residuals from Spline Interpolation

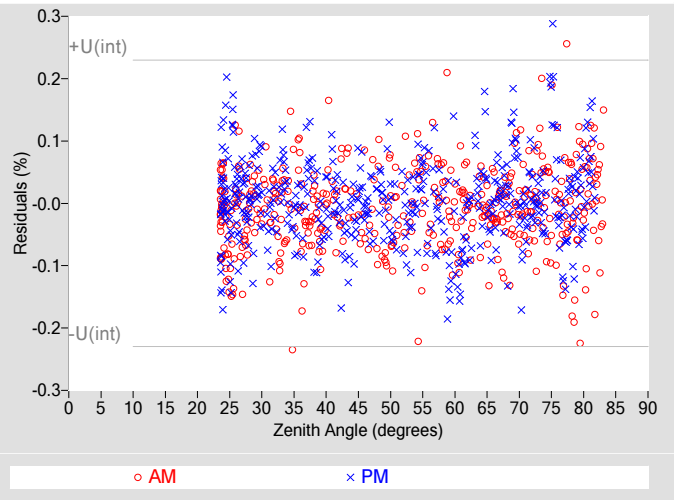


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.30
Type-A Interpolating Function, $u(int)$ (%)	± 0.11
Combined Standard Uncertainty, $u(c)$ (%)	± 0.32
Effective degrees of freedom, $DF(c)$	53537
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 0.63
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

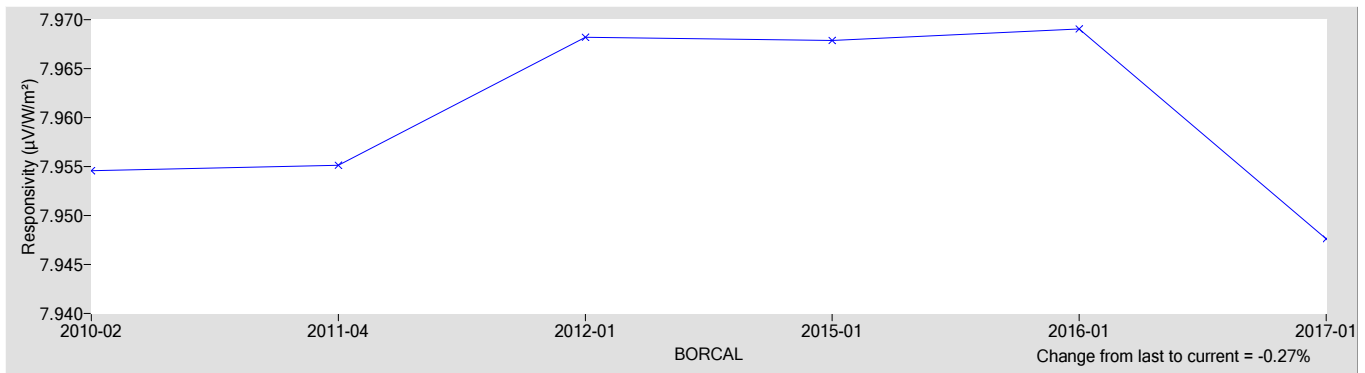
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
7.9476	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.56
Offset Uncertainty, $U(off)$ (%)	+0.22 / -0.15
Expanded Uncertainty, U (%)	+0.78 / -0.71
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 Pyrgometers. ARM 2008 Science Team Meeting (Poster).



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer (Ventilated)	Manufacturer:	Kipp & Zonen
Model:	CMP22	Serial Number:	080017
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model 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: 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

080017 Kipp & Zonen CMP22

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

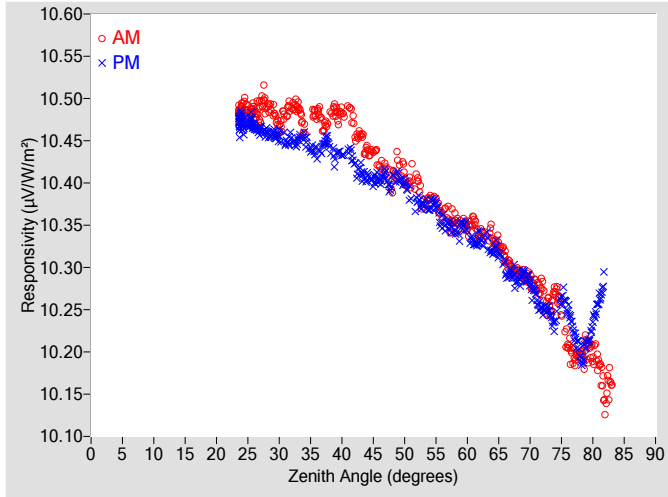


Figure 2. Responsivity vs Local Standard Time

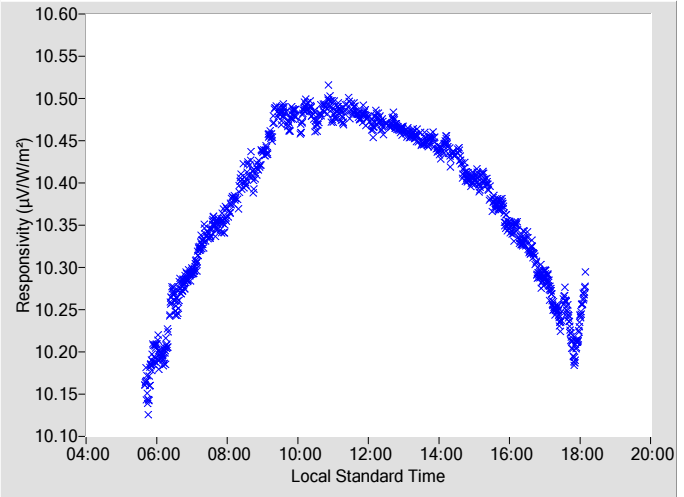


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.420	0.34	107.50	10.402	0.36	252.68
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.403	0.34	105.12	10.401	0.37	254.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.412	0.35	103.08	10.400	0.38	257.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.405	0.36	100.96	10.381	0.38	259.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.381	0.36	99.04	10.371	0.40	261.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.364	0.37	97.28	10.356	0.40	263.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.353	0.38	95.33	10.344	0.42	264.80
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.347	0.39	93.58	10.349	0.43	266.43
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.338	0.41	91.93	10.336	0.45	268.26
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.335	0.42	90.22	10.318	0.47	269.97
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.312	0.44	88.54	10.296	0.50	271.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.296	0.47	86.89	10.288	0.53	273.30
24	10.484	0.32	168.67	10.474	0.31	192.02	70	10.284	0.50	85.26	10.282	0.57	274.89
26	10.485	0.32	151.56	10.467	0.32	208.43	72	10.276	0.53	83.68	10.250	0.62	276.46
28	10.487	0.32	142.80	10.459	0.32	217.65	74	10.272	0.58	82.08	10.236	N/A	278.07
30	10.470	0.32	135.83	10.454	0.32	224.46	76	10.211	0.65	80.47	10.250	N/A	279.67
32	10.490	0.32	129.99	10.453	0.33	229.79	78	10.197	0.75	78.79	10.193	N/A	281.32
34	10.462	0.32	125.85	10.452	0.33	234.31	80	10.198	N/A	77.22	10.236	N/A	282.97
36	10.483	0.32	121.92	10.438	0.33	238.23	82	10.140	N/A	75.62	10.295	N/A	284.37
38	10.477	0.32	118.60	10.443	0.34	241.62	84	N/A	N/A	N/A	N/A	N/A	N/A
40	10.484	0.33	115.45	10.433	0.34	244.77	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.463	0.33	112.51	10.424	0.35	247.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.438	0.34	109.84	10.406	0.35	250.16	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

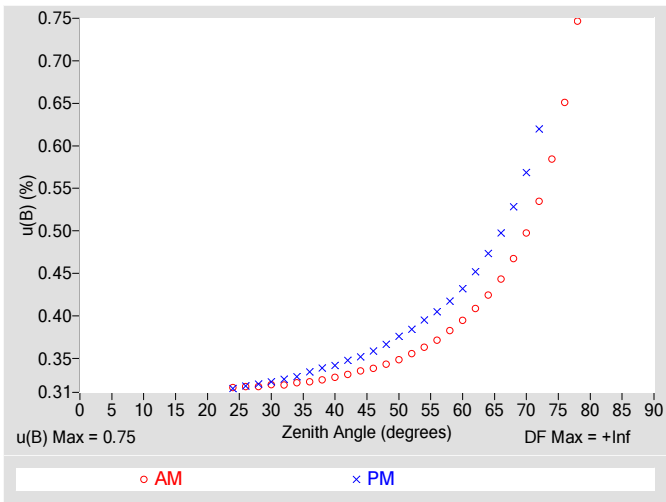


Figure 4. Residuals from Spline Interpolation

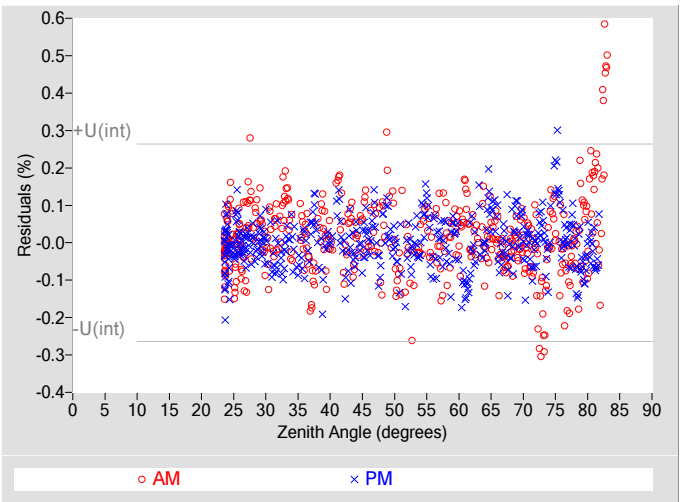


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.75
Type-A Interpolating Function, $u(int)$ (%)	± 0.13
Combined Standard Uncertainty, $u(c)$ (%)	± 0.76
Effective degrees of freedom, $DF(c)$	940769
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

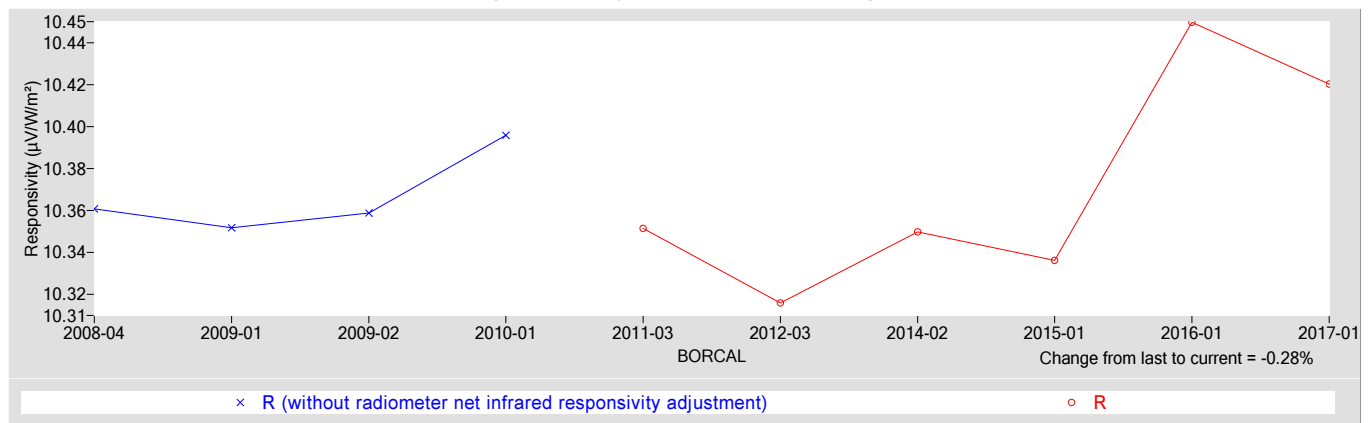
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
10.420	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+0.67 / -0.73
Expanded Uncertainty, U (%)	+1.5 / -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 Pyrgometers. ARM 2008 Science Team Meeting (Poster).



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	Kipp & Zonen
Model:	CMP22	Serial Number:	100174
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

100174 Kipp & Zonen CMP22

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

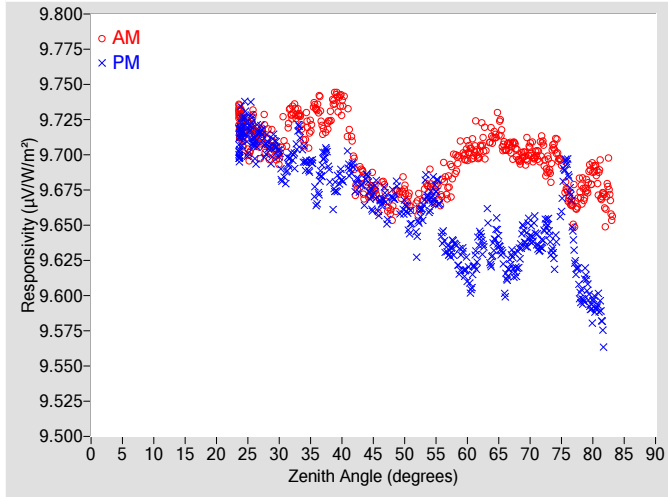


Figure 2. Responsivity vs Local Standard Time

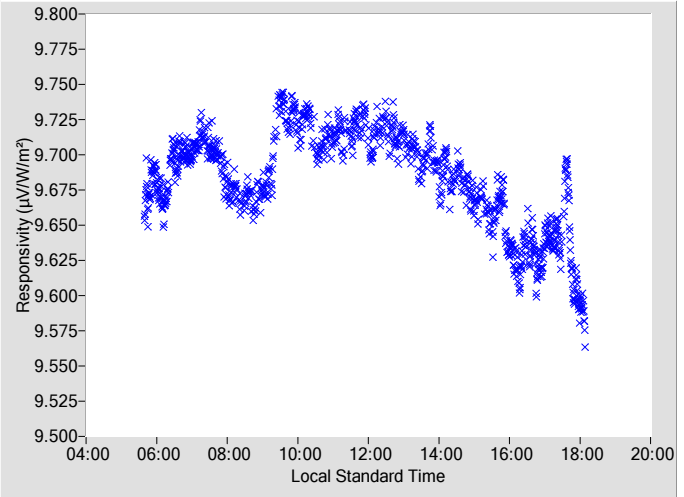


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.6654	0.34	107.45	9.6633	0.36	252.68
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.6593	0.34	105.21	9.6707	0.37	255.04
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6777	0.35	103.03	9.6622	0.38	257.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6657	0.36	100.93	9.6438	0.38	259.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.6795	0.36	99.05	9.6662	0.40	261.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6766	0.37	97.20	9.6424	0.40	262.96
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6939	0.38	95.27	9.6353	0.42	264.76
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7024	0.40	93.57	9.6190	0.43	266.50
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7057	0.41	91.83	9.6412	0.45	268.35
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7138	0.42	90.19	9.6292	0.47	269.96
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7054	0.44	88.54	9.6071	0.50	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.7000	0.47	86.94	9.6230	0.53	273.25
24	9.7195	0.32	167.90	9.7190	0.31	192.20	70	9.7033	0.50	85.30	9.6440	0.57	274.88
26	9.7192	0.32	151.21	9.7065	0.32	208.63	72	9.7049	0.54	83.68	9.6399	0.62	276.50
28	9.7102	0.32	142.20	9.7072	0.32	217.90	74	9.7066	0.59	82.08	9.6315	N/A	278.07
30	9.6987	0.32	135.88	9.6992	0.32	224.51	76	9.6719	0.65	80.47	9.6882	N/A	279.71
32	9.7299	0.32	130.34	9.6989	0.33	229.79	78	9.6740	0.74	78.83	9.6008	N/A	281.31
34	9.7093	0.32	125.78	9.6961	0.33	234.41	80	9.6866	N/A	77.26	9.5931	N/A	282.92
36	9.7324	0.32	121.82	9.6674	0.33	238.30	82	9.6657	N/A	75.56	N/A	N/A	N/A
38	9.7243	0.33	118.41	9.6873	0.34	241.60	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.7357	0.33	115.39	9.6837	0.34	244.73	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.6873	0.33	112.44	9.6816	0.35	247.65	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.6763	0.34	109.79	9.6823	0.35	250.27	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

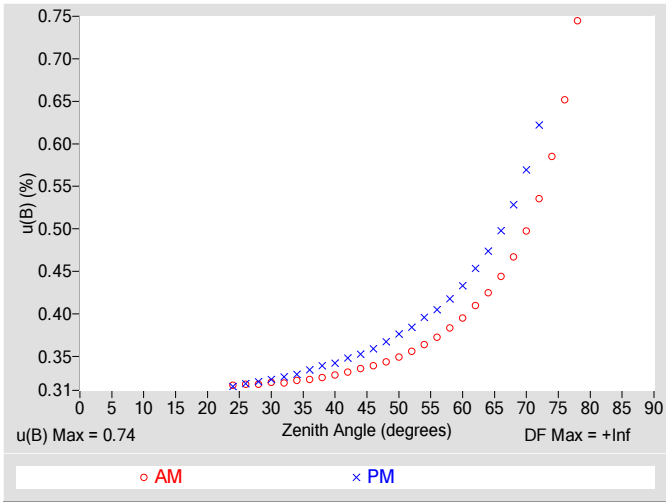


Figure 4. Residuals from Spline Interpolation

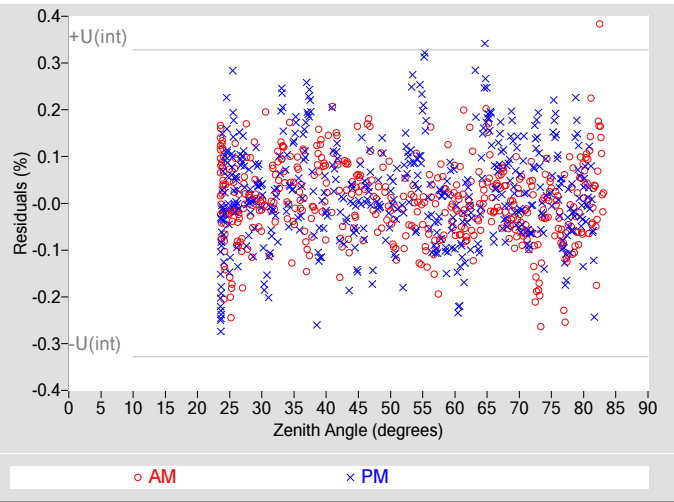


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.74
Type-A Interpolating Function, $u(int)$ (%)	± 0.16
Combined Standard Uncertainty, $u(c)$ (%)	± 0.76
Effective degrees of freedom, $DF(c)$	403619
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

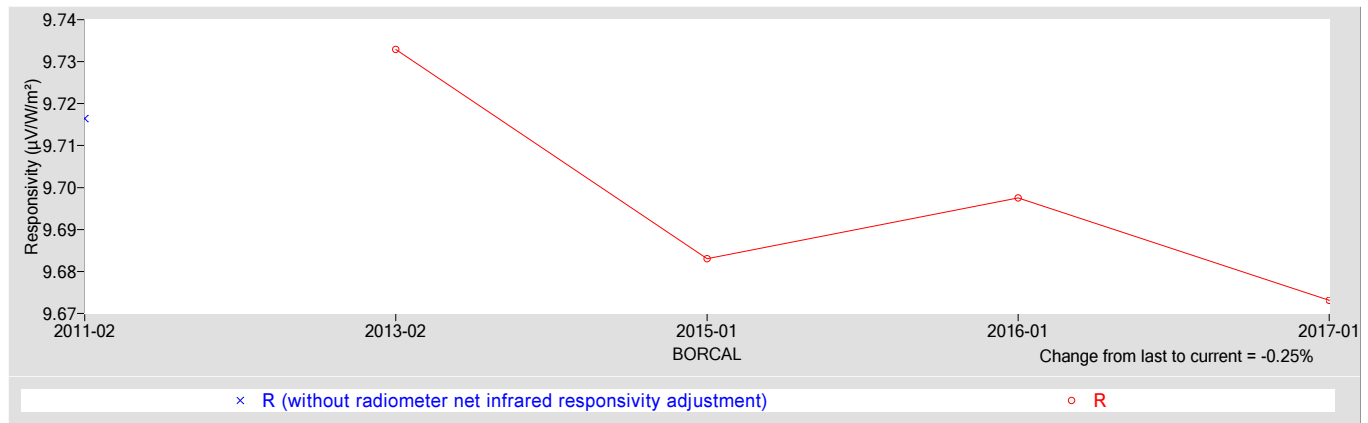
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
9.6731	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+0.65 / -0.56
Expanded Uncertainty, U (%)	+1.5 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	Kipp & Zonen
Model:	CMP22	Serial Number:	140043
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

140043 Kipp & Zonen CMP22

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

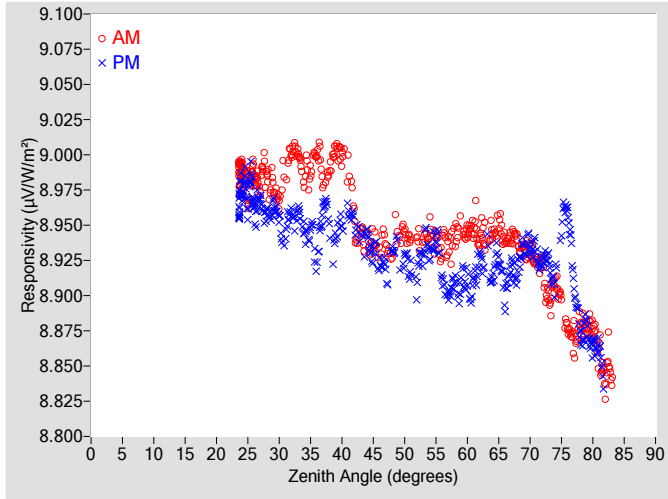


Figure 2. Responsivity vs Local Standard Time

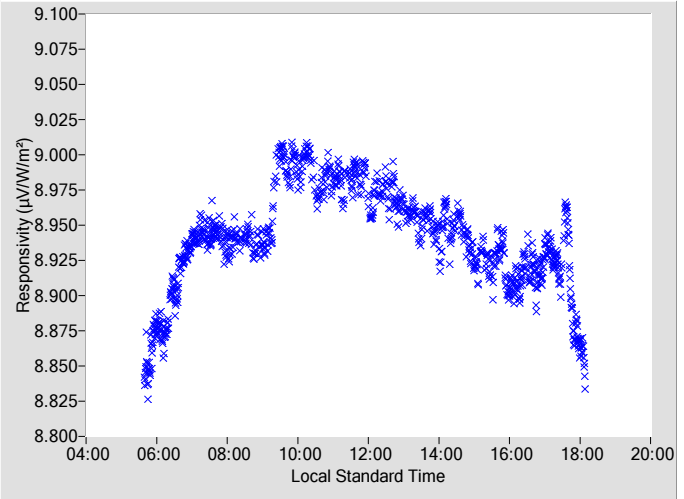


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9303	0.34	107.45	8.9213	0.36	252.68
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9276	0.34	105.21	8.9319	0.37	255.04
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9467	0.35	103.03	8.9259	0.38	257.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9421	0.36	100.93	8.9128	0.38	259.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9450	0.36	99.05	8.9303	0.40	261.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9348	0.37	97.20	8.9114	0.41	262.96
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9430	0.38	95.27	8.9098	0.42	264.76
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9455	0.40	93.57	8.9115	0.43	266.50
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9424	0.41	91.83	8.9269	0.45	268.35
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9461	0.43	90.19	8.9118	0.47	269.96
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9400	0.44	88.54	8.8990	0.50	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.9391	0.47	86.94	8.9169	0.53	273.25
24	8.9854	0.32	167.90	8.9753	0.31	192.20	70	8.9322	0.50	85.30	8.9353	0.57	274.88
26	8.9863	0.32	151.21	8.9621	0.32	208.63	72	8.9208	0.54	83.68	8.9248	0.62	276.50
28	8.9844	0.32	142.20	8.9583	0.32	217.90	74	8.9096	0.59	82.08	8.9123	N/A	278.07
30	8.9680	0.32	135.88	8.9535	0.32	224.51	76	8.8771	0.65	80.47	8.9560	N/A	279.71
32	9.0017	0.32	130.34	8.9587	0.33	229.79	78	8.8787	0.75	78.83	8.8724	N/A	281.31
34	8.9807	0.32	125.78	8.9446	0.33	234.41	80	8.8757	N/A	77.26	8.8657	N/A	282.92
36	8.9991	0.32	121.82	8.9241	0.33	238.30	82	8.8409	N/A	75.56	N/A	N/A	N/A
38	8.9884	0.33	118.41	8.9488	0.34	241.60	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9988	0.33	115.39	8.9507	0.34	244.73	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9510	0.33	112.44	8.9487	0.35	247.65	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9407	0.34	109.79	8.9422	0.35	250.27	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

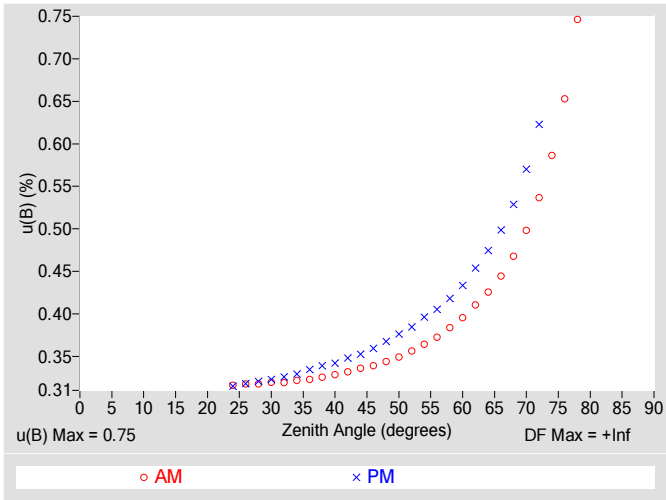


Figure 4. Residuals from Spline Interpolation

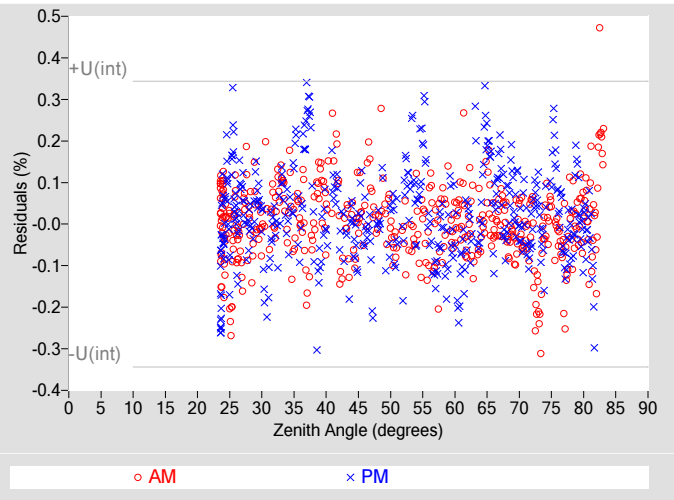


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.75
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	341755
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

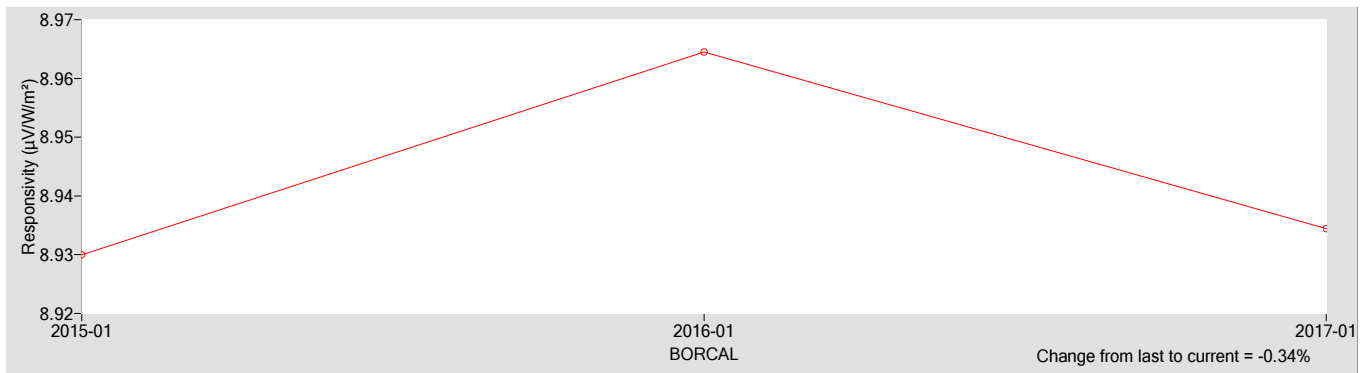
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.9344	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+0.75 / -0.28
Expanded Uncertainty, U (%)	+1.6 / -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



Test Instrument:	Pyrheliometer	Manufacturer:	Kipp & Zonen
Model:	CHP1	Serial Number:	140108
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

140108 Kipp & Zonen CHP1

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

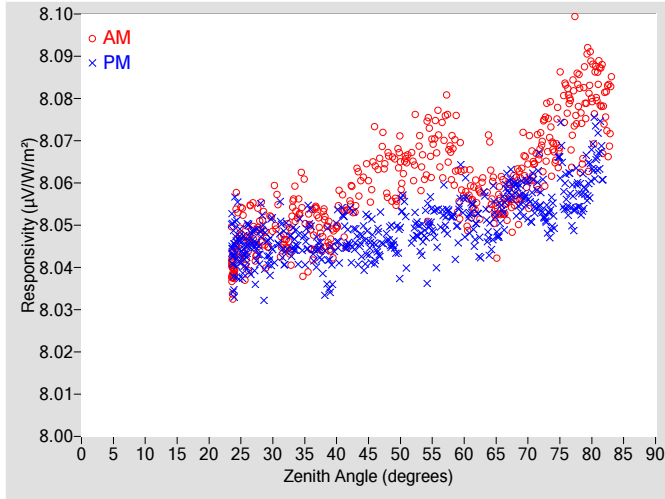


Figure 2. Responsivity vs Local Standard Time

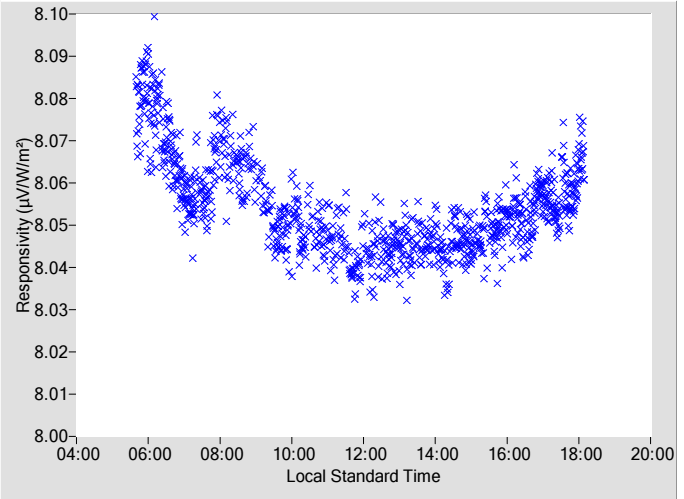


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0675	0.28	107.58	8.0436	0.28	252.73
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0619	0.28	105.16	8.0470	0.28	254.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0642	0.28	103.05	8.0498	0.28	257.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0667	0.28	100.91	8.0488	0.28	259.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0620	0.28	98.95	8.0480	0.28	261.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0708	0.28	97.13	8.0494	0.29	262.98
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0672	0.28	95.33	8.0521	0.29	264.90
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0593	0.28	93.53	8.0544	0.29	266.55
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0571	0.28	91.92	8.0516	0.29	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0626	0.29	90.16	8.0466	0.29	269.93
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0561	0.29	88.53	8.0534	0.29	271.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.0583	0.29	86.88	8.0579	0.29	273.32
24	8.0405	0.28	168.53	8.0430	0.28	191.43	70	8.0619	0.29	85.29	8.0579	0.30	274.87
26	8.0446	0.28	151.52	8.0453	0.28	208.81	72	8.0685	0.29	83.71	8.0547	0.30	276.49
28	8.0496	0.28	142.29	8.0475	0.28	217.82	74	8.0668	0.29	82.11	8.0526	N/A	278.02
30	8.0533	0.28	135.71	8.0444	0.28	224.24	76	8.0800	0.30	80.51	8.0573	N/A	279.70
32	8.0453	0.28	130.35	8.0440	0.28	229.78	78	8.0784	0.30	78.86	8.0564	N/A	281.35
34	8.0533	0.28	125.69	8.0463	0.28	234.32	80	8.0828	N/A	77.21	8.0647	N/A	282.96
36	8.0476	0.28	121.92	8.0513	0.28	237.97	82	8.0763	N/A	75.60	8.0608	N/A	284.36
38	8.0495	0.28	118.41	8.0386	0.28	241.76	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0497	0.28	115.28	8.0482	0.28	244.97	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0559	0.28	112.38	8.0486	0.28	247.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0609	0.28	109.88	8.0467	0.28	250.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

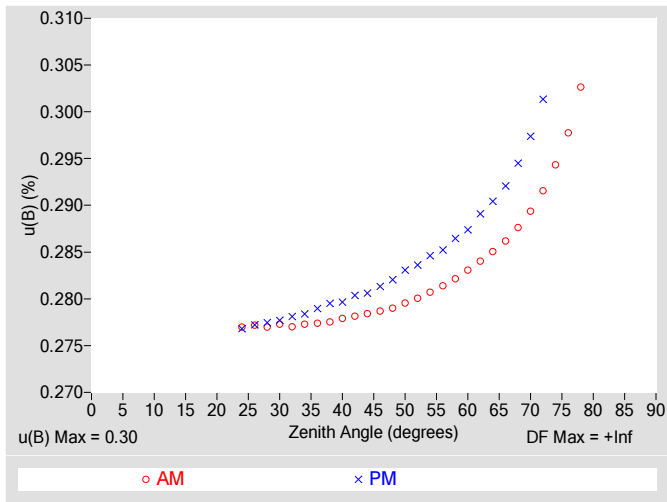


Figure 4. Residuals from Spline Interpolation

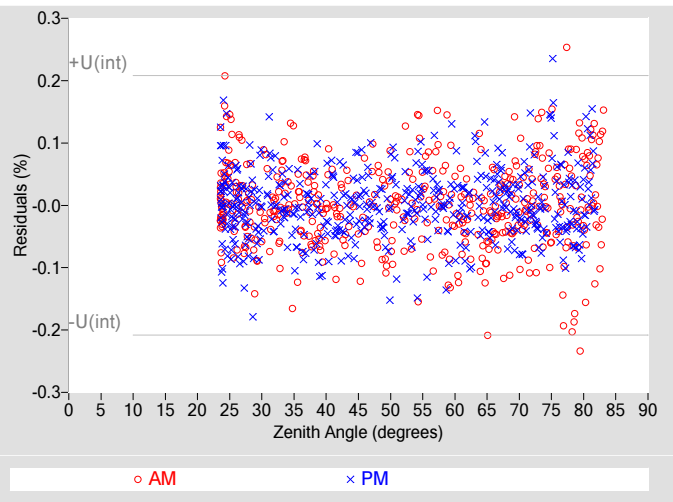


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.30
Type-A Interpolating Function, $u(int)$ (%)	± 0.10
Combined Standard Uncertainty, $u(c)$ (%)	± 0.32
Effective degrees of freedom, $DF(c)$	76004
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 0.63
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

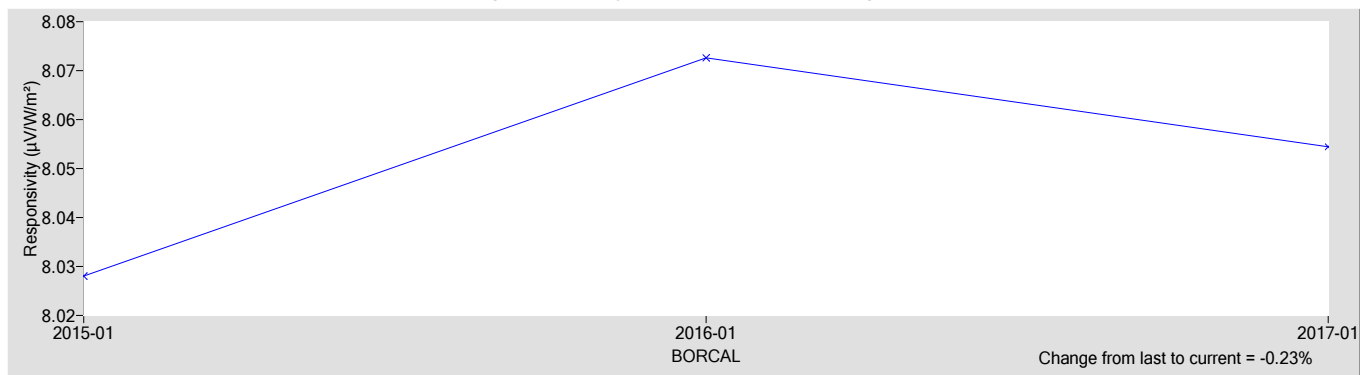
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
8.0544	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.56
Offset Uncertainty, $U(off)$ (%)	+0.20 / -0.20
Expanded Uncertainty, U (%)	+0.77 / -0.76
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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



Test Instrument:	Pyranometer	Manufacturer:	Kipp & Zonen
Model:	CMP11	Serial Number:	140712
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

140712 Kipp & Zonen CMP11

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

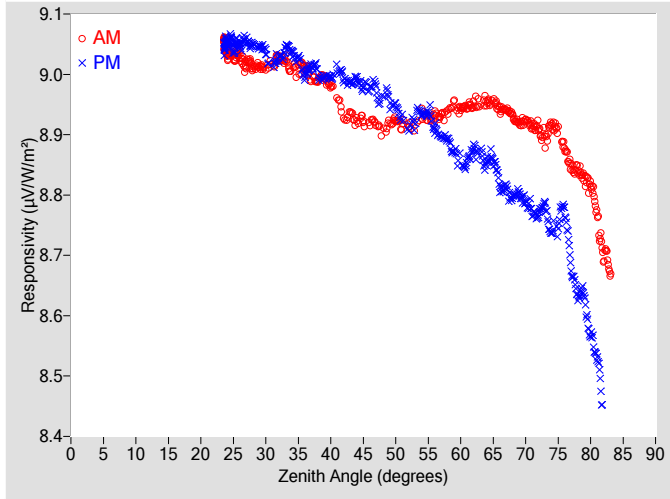


Figure 2. Responsivity vs Local Standard Time

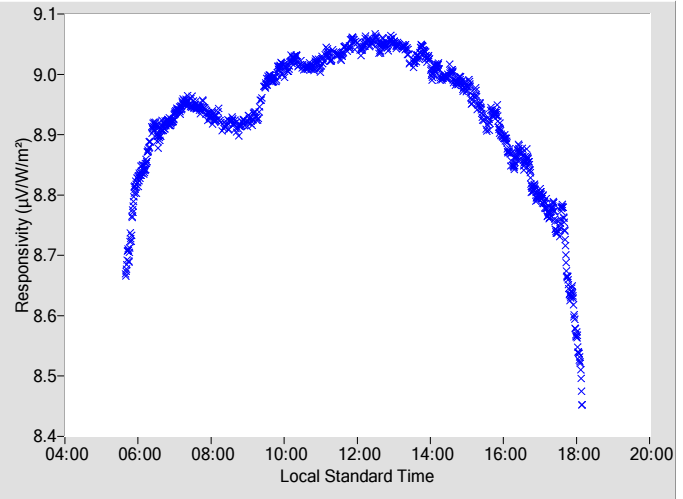


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9200	0.34	107.37	8.9757	0.36	252.61
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9044	0.35	105.22	8.9640	0.37	255.03
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9238	0.35	103.01	8.9486	0.38	257.06
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9160	0.36	100.92	8.9107	0.39	259.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9356	0.37	98.90	8.9327	0.40	261.16
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9318	0.38	97.12	8.9106	0.41	262.95
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9385	0.39	95.32	8.8918	0.42	264.78
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9427	0.40	93.57	8.8590	0.44	266.61
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9480	0.41	91.90	8.8768	0.46	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9560	0.43	90.16	8.8549	0.48	269.96
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9414	0.45	88.53	8.8152	0.51	271.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.9320	0.47	86.93	8.7967	0.54	273.24
24	9.0373	0.32	167.95	9.0533	0.32	191.76	70	8.9234	0.50	85.32	8.7880	0.58	274.88
26	9.0320	0.32	151.75	9.0476	0.32	209.01	72	8.9103	0.54	83.68	8.7690	0.64	276.49
28	9.0114	0.32	142.72	9.0496	0.32	217.47	74	8.9166	0.60	82.07	8.7413	N/A	278.11
30	9.0115	0.32	135.25	9.0375	0.33	224.35	76	8.8773	0.66	80.46	8.7706	N/A	279.71
32	9.0274	0.32	130.25	9.0284	0.33	230.05	78	8.8417	0.76	78.82	8.6340	N/A	281.31
34	9.0074	0.32	125.95	9.0361	0.33	234.38	80	8.8137	N/A	77.26	8.5688	N/A	282.92
36	9.0110	0.33	121.85	8.9989	0.34	238.26	82	8.7026	N/A	75.56	8.4523	N/A	284.40
38	8.9891	0.33	118.50	9.0001	0.34	241.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9811	0.33	115.38	8.9949	0.34	244.87	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9258	0.34	112.43	8.9934	0.35	247.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9211	0.34	109.88	8.9921	0.36	250.27	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

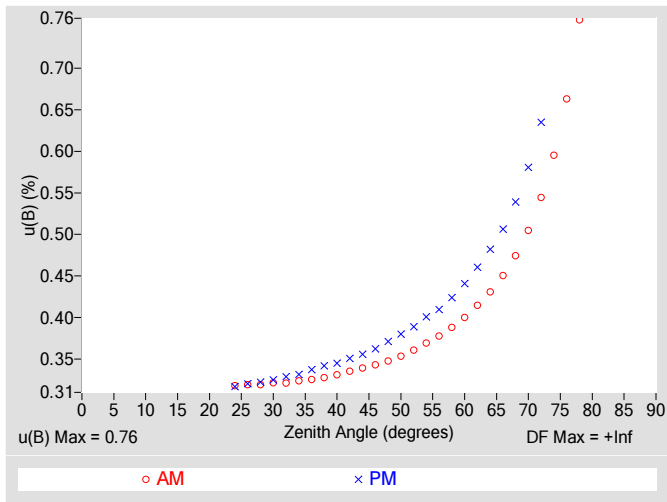


Figure 4. Residuals from Spline Interpolation

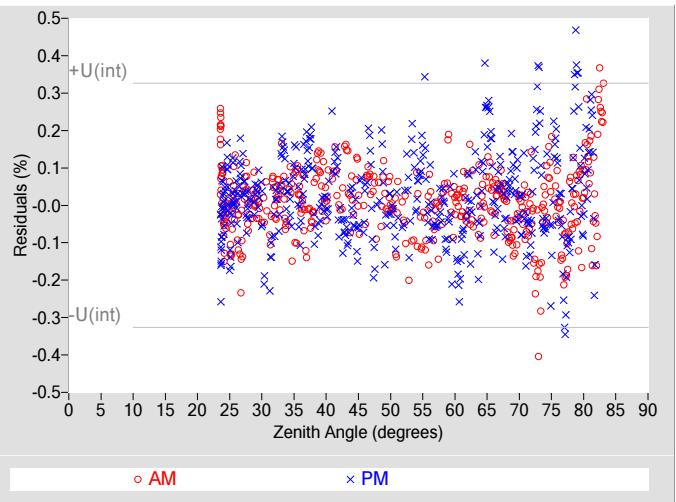


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.76
Type-A Interpolating Function, $u(int)$ (%)	± 0.16
Combined Standard Uncertainty, $u(c)$ (%)	± 0.78
Effective degrees of freedom, $DF(c)$	429859
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

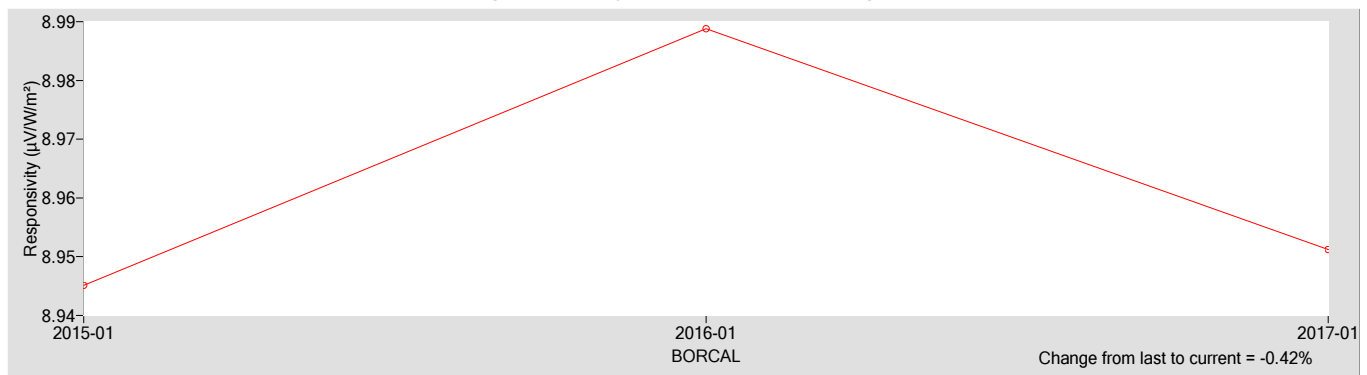
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
8.9512	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.86
Offset Uncertainty, $U(off)$ (%)	+0.96 / -1.0
Expanded Uncertainty, U (%)	+1.8 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument: Silicon Pyranometer
Manufacturer: Kipp & Zonen
Model: SP-LITE2
Serial Number: 151027
Calibration Date: 5/4/2017
Due Date: 5/4/2018
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/4

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

151027 Kipp & Zonen SP-LITE2

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

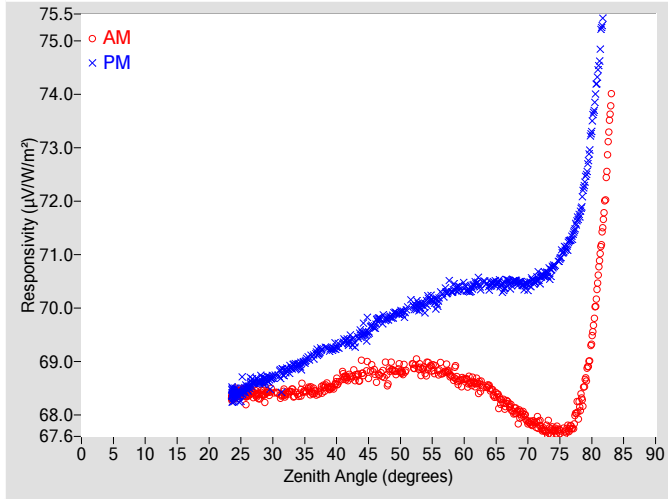


Figure 2. Responsivity vs Local Standard Time

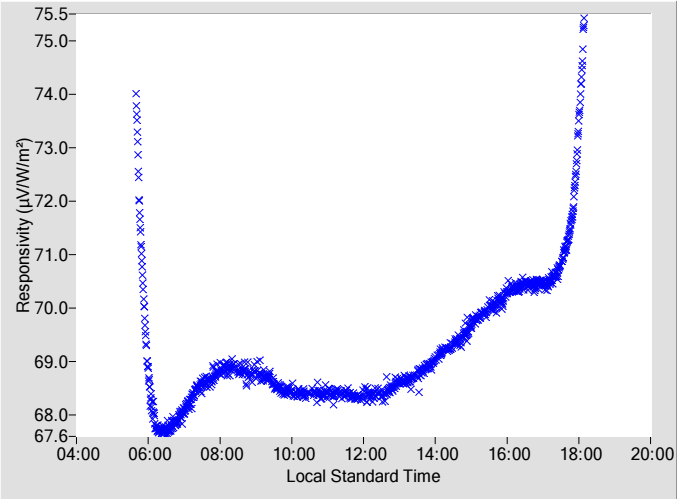


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	68.757	0.34	107.48	69.676	0.36	252.67
2	N/A	N/A	N/A	N/A	N/A	N/A	48	68.685	0.34	105.13	69.802	0.36	254.83
4	N/A	N/A	N/A	N/A	N/A	N/A	50	68.839	0.35	103.05	69.910	0.37	257.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	68.919	0.35	100.90	70.016	0.38	259.26
8	N/A	N/A	N/A	N/A	N/A	N/A	54	68.835	0.36	98.92	70.074	0.39	261.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	68.850	0.37	97.09	70.148	0.40	262.97
12	N/A	N/A	N/A	N/A	N/A	N/A	58	68.726	0.38	95.40	70.310	0.42	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	68.678	0.39	93.63	70.433	0.43	266.62
16	N/A	N/A	N/A	N/A	N/A	N/A	62	68.563	0.41	91.87	70.495	0.45	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	68.514	0.42	90.21	70.409	0.47	270.00
20	N/A	N/A	N/A	N/A	N/A	N/A	66	68.247	0.44	88.52	70.383	0.49	271.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	68.065	0.46	86.88	70.500	0.52	273.29
24	68.383	0.31	168.01	68.378	0.31	191.62	70	67.861	0.49	85.25	70.429	0.56	274.87
26	68.370	0.32	151.32	68.515	0.32	208.57	72	67.789	0.53	83.67	70.574	0.62	276.49
28	68.379	0.32	142.35	68.647	0.32	217.86	74	67.714	0.58	82.11	70.773	N/A	278.06
30	68.457	0.32	135.80	68.702	0.32	224.17	76	67.704	0.64	80.50	71.113	N/A	279.70
32	68.400	0.32	130.36	68.819	0.32	229.89	78	68.091	0.73	78.86	71.751	N/A	281.35
34	68.381	0.32	125.74	68.930	0.33	234.38	80	69.469	N/A	77.17	73.428	N/A	282.96
36	68.446	0.32	121.93	69.075	0.33	237.95	82	71.902	N/A	75.60	75.423	N/A	284.36
38	68.504	0.32	118.36	69.272	0.34	242.02	84	N/A	N/A	N/A	N/A	N/A	N/A
40	68.601	0.33	115.38	69.292	0.34	244.71	86	N/A	N/A	N/A	N/A	N/A	N/A
42	68.702	0.33	112.52	69.382	0.35	247.53	88	N/A	N/A	N/A	N/A	N/A	N/A
44	68.833	0.33	109.82	69.550	0.35	250.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

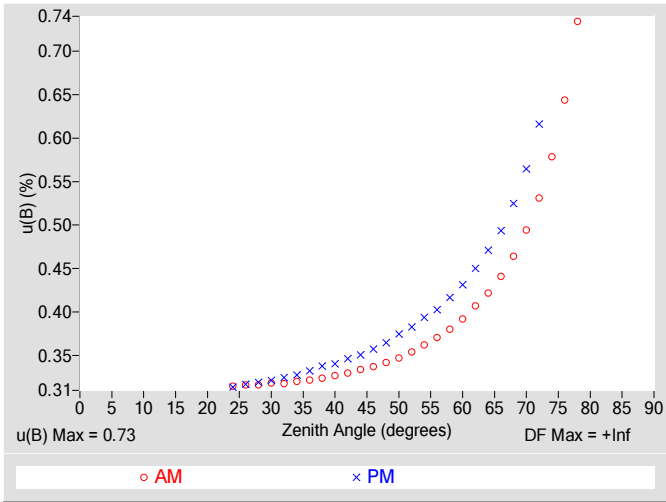


Figure 4. Residuals from Spline Interpolation

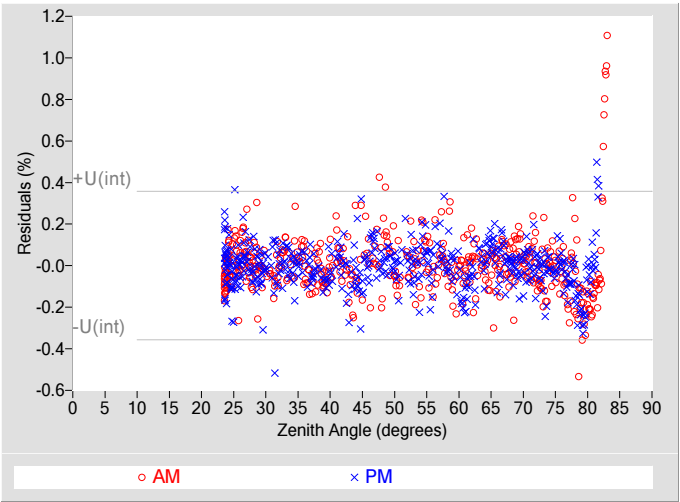


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.73
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	278990
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

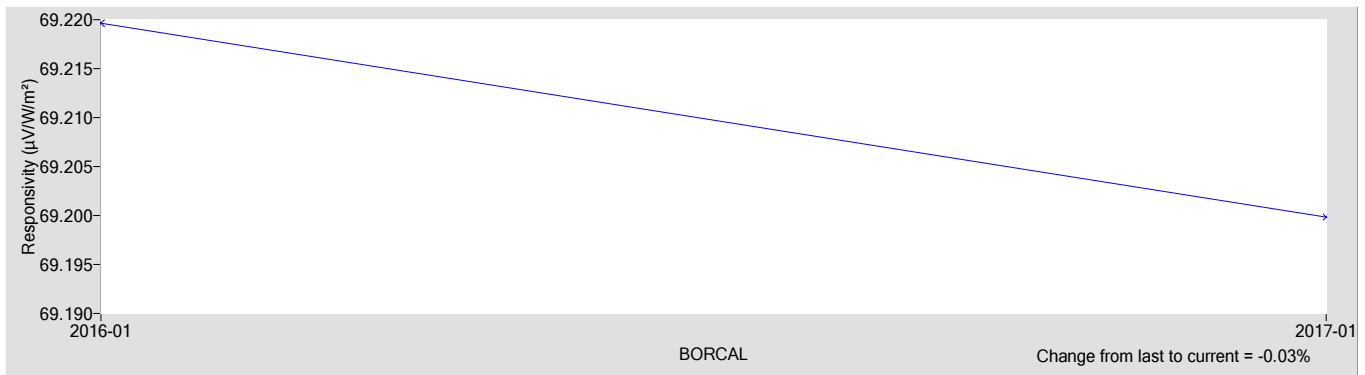
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
69.200	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+1.8 / -1.2
Expanded Uncertainty, U (%)	+2.6 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	Hukseflux
Model:	SR25	Serial Number:	2516
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

2516 Hukseflux SR25

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

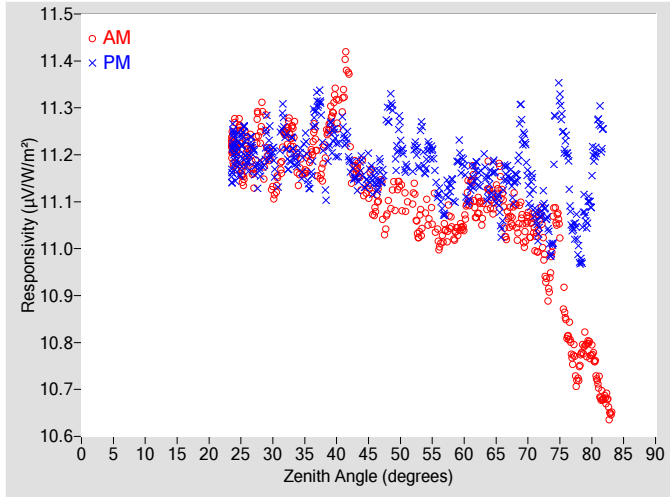


Figure 2. Responsivity vs Local Standard Time

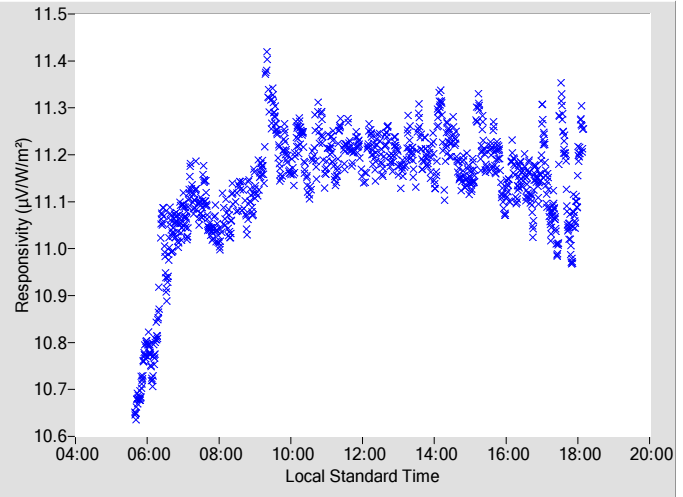


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	11.088	0.34	107.39	11.150	0.36	252.66
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.072	0.34	105.30	11.279	0.37	254.94
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.123	0.35	103.00	11.249	0.38	257.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.117	0.36	100.89	11.198	0.38	259.22
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.091	0.36	99.00	11.178	0.39	261.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.015	0.37	97.16	11.117	0.40	262.94
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.053	0.38	95.41	11.132	0.42	264.78
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.059	0.39	93.56	11.163	0.43	266.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.079	0.41	91.87	11.164	0.45	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.122	0.42	90.16	11.135	0.47	270.00
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.109	0.44	88.53	11.079	0.50	271.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	11.089	0.47	86.92	11.142	0.53	273.24
24	11.218	0.32	168.50	11.217	0.31	192.03	70	11.058	0.50	85.28	11.142	0.57	274.87
26	11.213	0.32	151.82	11.184	0.32	208.63	72	11.058	0.53	83.67	11.072	0.62	276.49
28	11.244	0.32	142.34	11.172	0.32	217.41	74	11.048	0.58	82.09	11.129	N/A	278.10
30	11.120	0.32	135.57	11.196	0.32	224.41	76	10.834	0.65	80.46	11.214	N/A	279.70
32	11.249	0.32	130.38	11.226	0.33	229.91	78	10.743	0.74	78.81	10.989	N/A	281.30
34	11.166	0.32	125.82	11.187	0.33	234.16	80	10.776	N/A	77.25	11.142	N/A	282.91
36	11.198	0.32	121.87	11.178	0.33	238.37	82	10.680	N/A	75.59	11.255	N/A	284.40
38	11.191	0.32	118.46	11.187	0.34	241.63	84	N/A	N/A	N/A	N/A	N/A	N/A
40	11.295	0.33	115.34	11.213	0.34	244.75	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.322	0.33	112.50	11.183	0.35	247.66	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.142	0.33	109.82	11.177	0.35	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

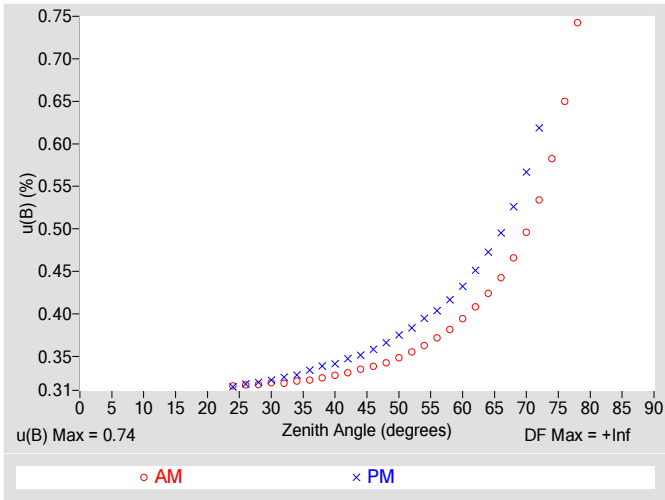


Figure 4. Residuals from Spline Interpolation

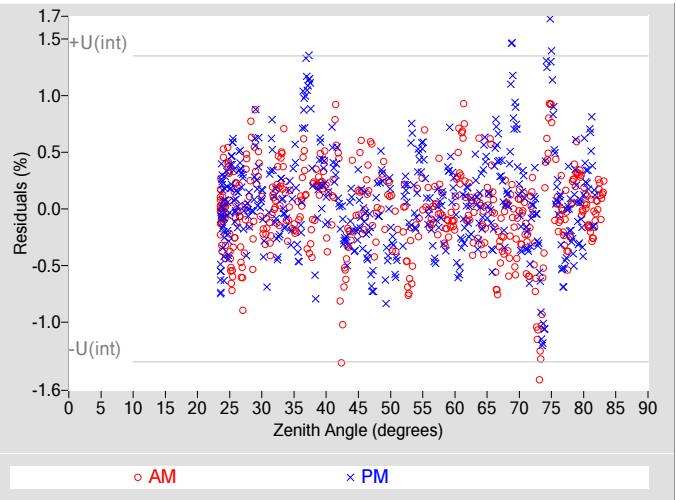


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.74
Type-A Interpolating Function, $u(int)$ (%)	± 0.67
Combined Standard Uncertainty, $u(c)$ (%)	± 1.0
Effective degrees of freedom, $DF(c)$	4264
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 2.0
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

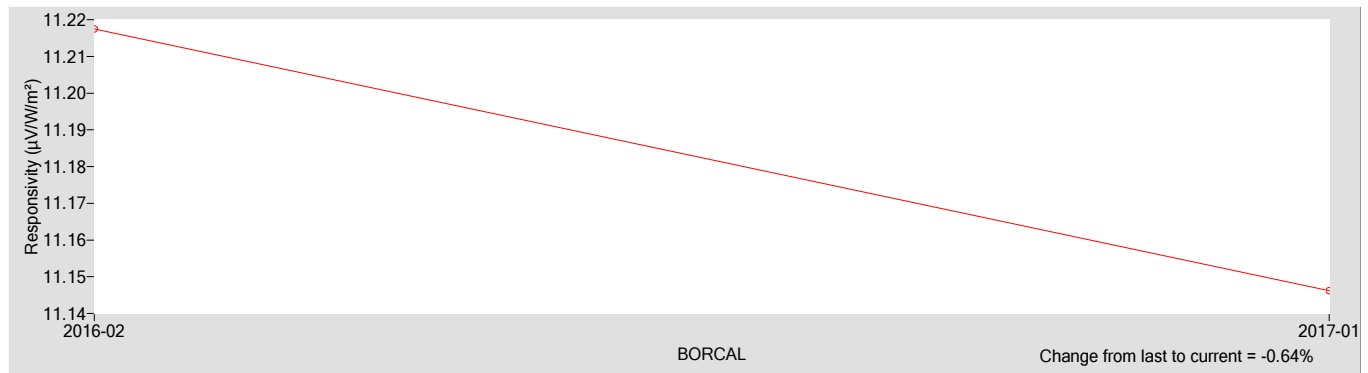
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
11.146	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+1.6 / -1.2
Expanded Uncertainty, U (%)	+2.4 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	Hukseflux
Model:	SR25	Serial Number:	2529
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

2529 Hukseflux SR25

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

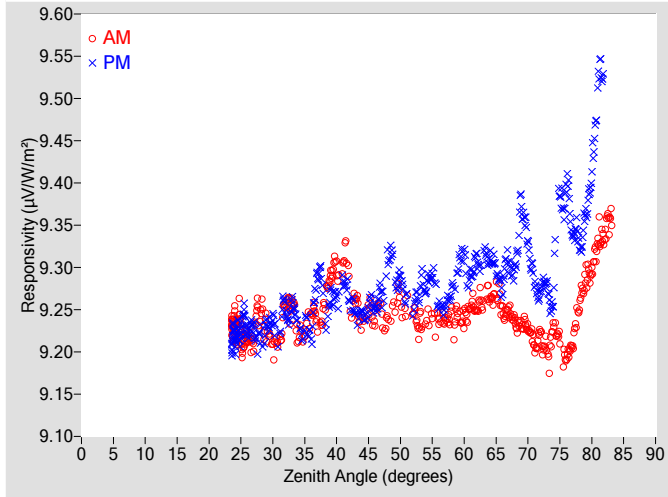


Figure 2. Responsivity vs Local Standard Time

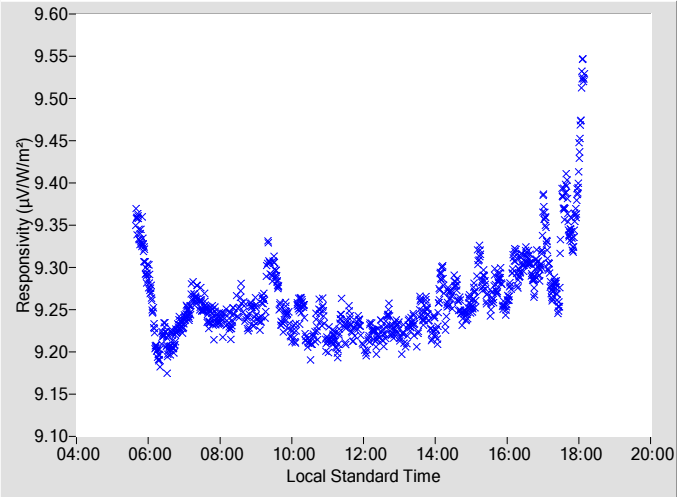


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2423	0.34	107.39	9.2521	0.36	252.66
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2373	0.34	105.30	9.3055	0.37	254.94
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2576	0.35	103.00	9.2904	0.38	257.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2486	0.36	100.89	9.2500	0.38	259.22
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2350	0.36	99.00	9.2735	0.40	261.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2395	0.37	97.16	9.2549	0.40	262.94
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2444	0.38	95.41	9.2716	0.42	264.78
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2413	0.39	93.56	9.3110	0.43	266.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2493	0.41	91.87	9.3092	0.45	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2655	0.42	90.16	9.3089	0.47	270.00
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2476	0.44	88.53	9.2769	0.50	271.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.2352	0.47	86.92	9.3013	0.53	273.24
24	9.2313	0.32	168.50	9.2210	0.31	192.03	70	9.2270	0.50	85.28	9.3281	0.57	274.87
26	9.2161	0.32	151.82	9.2226	0.32	208.63	72	9.2163	0.54	83.67	9.2735	0.62	276.49
28	9.2407	0.32	142.34	9.2218	0.32	217.41	74	9.2292	0.58	82.09	9.2821	N/A	278.10
30	9.2051	0.32	135.57	9.2347	0.32	224.41	76	9.1946	0.65	80.46	9.3920	N/A	279.70
32	9.2564	0.32	130.38	9.2489	0.33	229.91	78	9.2535	0.74	78.81	9.3288	N/A	281.30
34	9.2210	0.32	125.82	9.2337	0.33	234.16	80	9.2936	N/A	77.25	9.4121	N/A	282.91
36	9.2412	0.32	121.87	9.2254	0.33	238.37	82	9.3357	N/A	75.59	9.5290	N/A	284.40
38	9.2494	0.32	118.46	9.2605	0.34	241.63	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.2970	0.33	115.34	9.2632	0.34	244.75	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2797	0.33	112.50	9.2577	0.35	247.66	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2342	0.33	109.82	9.2477	0.35	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

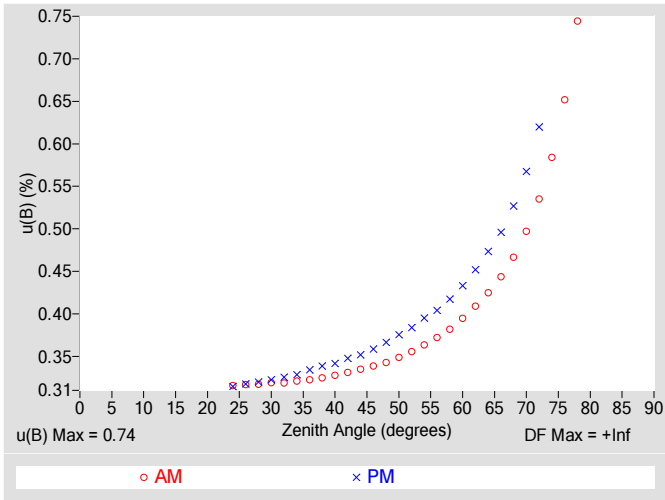


Figure 4. Residuals from Spline Interpolation

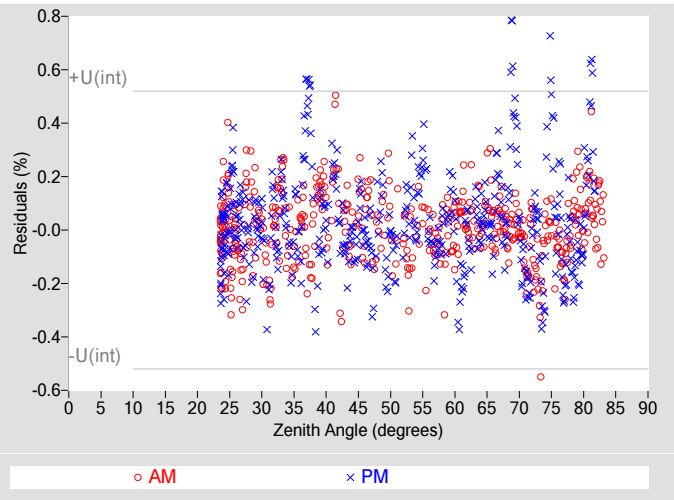


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.74
Type-A Interpolating Function, $u(int)$ (%)	± 0.26
Combined Standard Uncertainty, $u(c)$ (%)	± 0.79
Effective degrees of freedom, $DF(c)$	73607
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

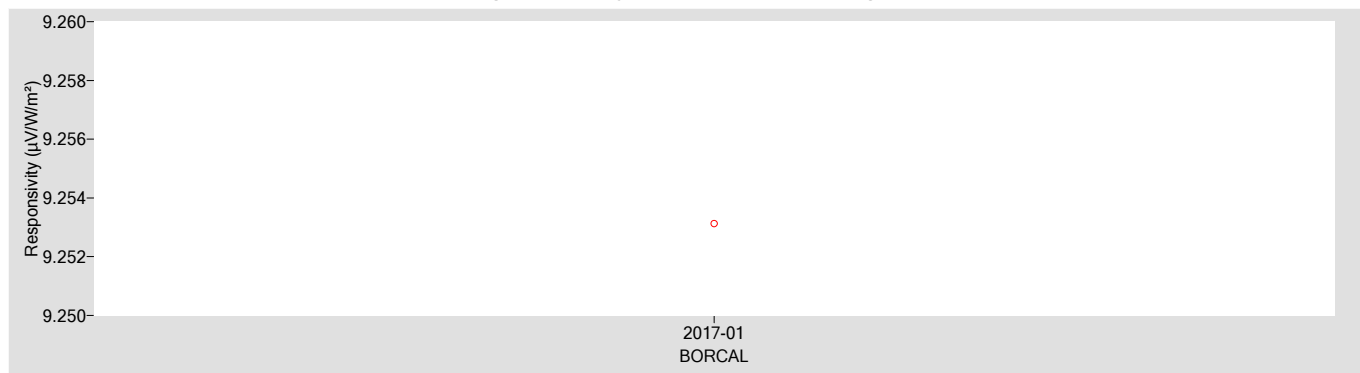
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
9.2531	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+0.63 / -0.52
Expanded Uncertainty, U (%)	+1.5 / -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



Test Instrument:	Precision Spectral Pyranometer (Ventilated)	Manufacturer:	Eppley
Model:	PSP	Serial Number:	28402F3
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 37757F3	08/17/2015	08/17/2019

† 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: 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

28402F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

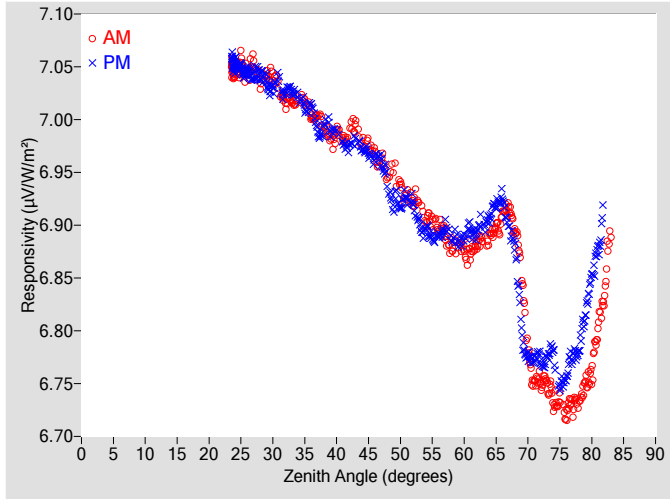


Figure 2. Responsivity vs Local Standard Time

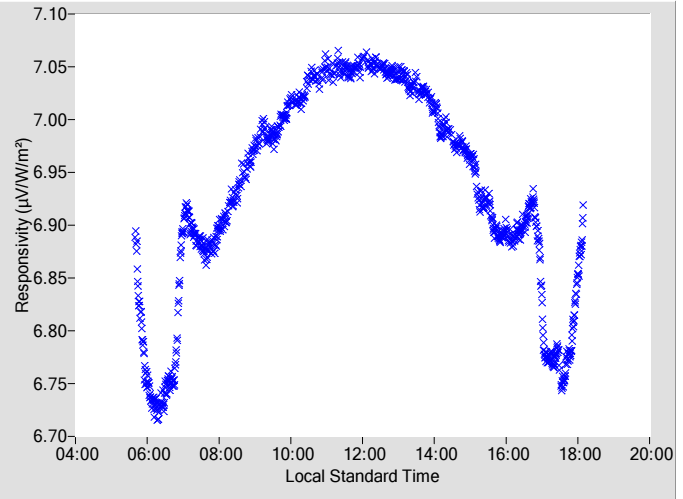


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith			AM			PM			Zenith			AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	R	u(B)	Azimuth	
(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	
0	N/A	N/A	N/A	N/A	N/A	N/A	46	6.9677	0.35	107.38	6.9637	0.38	252.64				
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.9445	0.36	105.14	6.9388	0.38	254.89				
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.9394	0.36	103.03	6.9172	0.40	257.07				
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.9216	0.37	100.98	6.9191	0.41	259.19				
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.9047	0.38	98.96	6.8974	0.42	261.19				
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.8983	0.39	97.22	6.8904	0.43	263.03				
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.8781	0.40	95.34	6.8864	0.45	264.81				
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.8772	0.42	93.54	6.8883	0.46	266.56				
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.8815	0.43	91.85	6.8939	0.49	268.27				
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.8889	0.45	90.18	6.9076	0.51	269.98				
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.9091	0.47	88.56	6.9244	0.54	271.65				
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.8937	0.50	86.91	6.8760	0.58	273.26				
24	7.0467	0.32	168.61	7.0517	0.32	191.82	70	6.7830	0.53	85.26	6.7759	0.63	274.85				
26	7.0461	0.33	151.29	7.0467	0.33	208.68	72	6.7478	0.58	83.61	6.7723	0.69	276.47				
28	7.0314	0.33	142.04	7.0429	0.33	217.67	74	6.7330	0.63	82.05	6.7765	N/A	278.09				
30	7.0412	0.33	135.64	7.0309	0.33	224.62	76	6.7196	0.71	80.48	6.7558	N/A	279.68				
32	7.0178	0.33	130.31	7.0272	0.34	229.83	78	6.7328	0.81	78.78	6.7825	N/A	281.29				
34	N/A	N/A	N/A	7.0208	0.34	234.24	80	6.7618	N/A	77.24	6.8531	N/A	282.98				
36	7.0045	0.33	121.89	7.0135	0.35	238.24	82	6.8329	N/A	75.62	6.9190	N/A	284.38				
38	6.9921	0.34	118.41	6.9937	0.35	241.76	84	N/A	N/A	N/A	N/A	N/A	N/A				
40	6.9871	0.34	115.35	6.9904	0.36	244.87	86	N/A	N/A	N/A	N/A	N/A	N/A				
42	6.9948	0.35	112.26	6.9740	0.36	247.56	88	N/A	N/A	N/A	N/A	N/A	N/A				
44	6.9782	0.35	109.82	6.9717	0.37	250.22	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

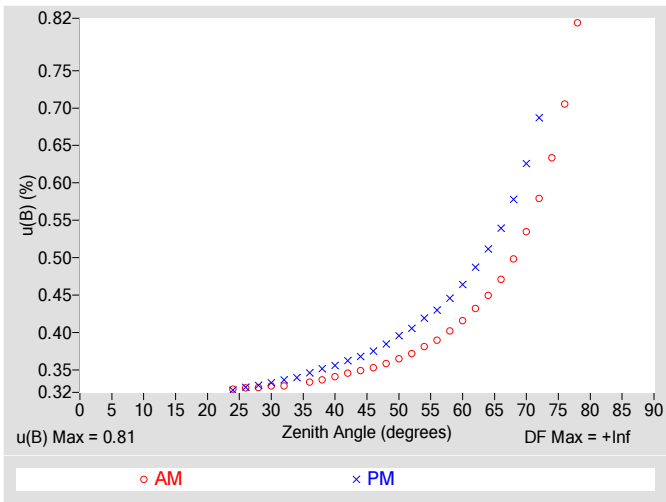


Figure 4. Residuals from Spline Interpolation

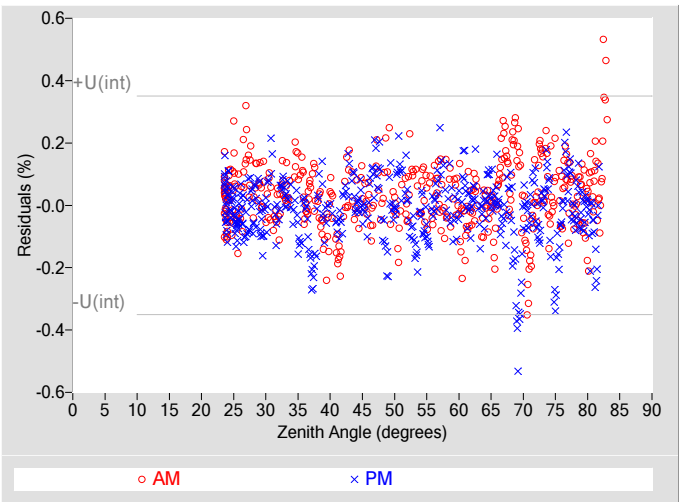


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.81
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.83
Effective degrees of freedom, $DF(c)$	435182
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

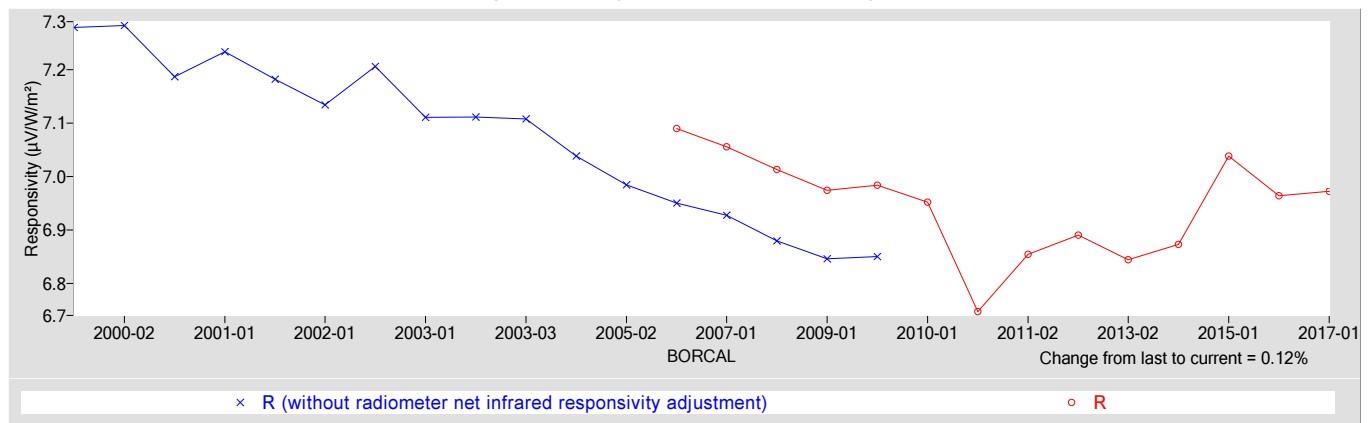
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
6.9722	0.64000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.91
Offset Uncertainty, $U(off)$ (%)	+0.99 / -1.4
Expanded Uncertainty, U (%)	+1.9 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Normal Incidence Pyrheliometer	Manufacturer:	Eppley
Model:	NIP	Serial Number:	31137E6
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

31137E6 Eppley NIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

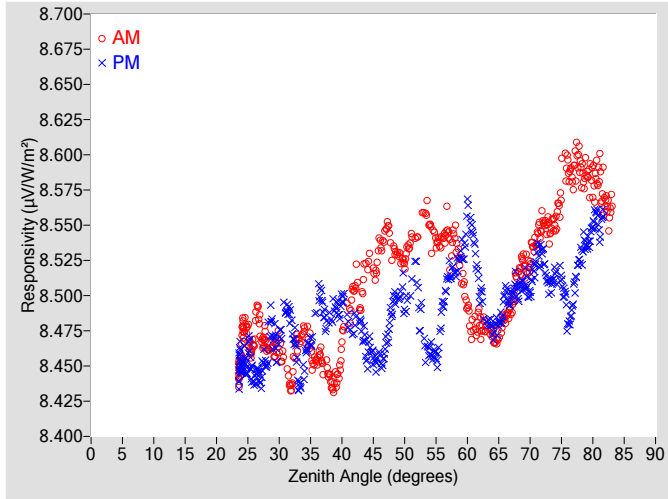


Figure 2. Responsivity vs Local Standard Time

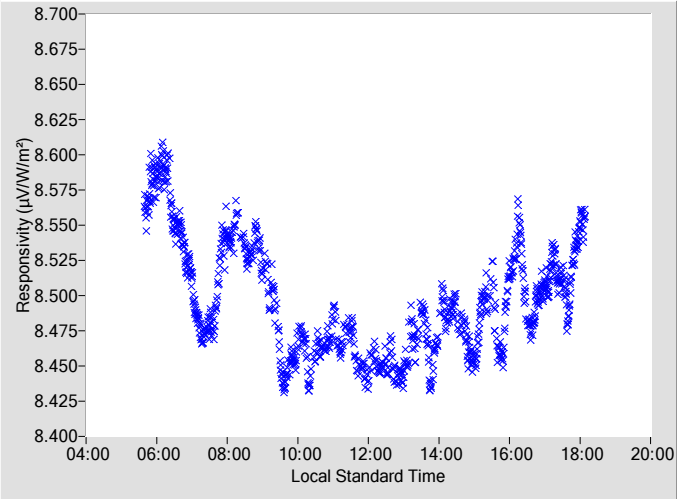


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5365	0.28	107.41	8.4567	0.28	252.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5326	0.28	105.17	8.4912	0.28	254.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5243	0.28	103.04	8.4965	0.28	257.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5415	0.28	100.93	8.5077	0.28	259.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5460	0.28	98.94	8.4611	0.28	261.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5388	0.28	97.19	8.4901	0.29	262.99
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5413	0.28	95.31	8.5155	0.29	264.87
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4922	0.28	93.55	8.5582	0.29	266.51
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4810	0.28	91.86	8.5029	0.29	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4731	0.28	90.19	8.4760	0.29	269.95
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4839	0.29	88.52	8.5018	0.29	271.62
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5143	0.29	86.87	8.5022	0.29	273.27
24	8.4638	0.28	167.50	8.4513	0.28	191.86	70	8.5242	0.29	85.28	8.5042	0.30	274.91
26	8.4718	0.28	151.26	8.4404	0.28	208.90	72	8.5513	0.29	83.71	8.5301	0.30	276.49
28	8.4651	0.28	142.52	8.4561	0.28	217.65	74	8.5500	0.29	82.10	8.5146	N/A	278.10
30	8.4676	0.28	135.83	8.4718	0.28	224.70	76	8.5892	0.30	80.49	8.4820	N/A	279.70
32	8.4395	0.28	130.37	8.4785	0.28	229.80	78	8.5929	0.30	78.89	8.5271	N/A	281.34
34	8.4757	0.28	126.04	8.4516	0.28	234.43	80	8.5799	N/A	77.20	8.5518	N/A	282.95
36	8.4537	0.28	121.81	8.4945	0.28	238.18	82	8.5647	N/A	75.59	8.5560	N/A	284.35
38	8.4417	0.28	118.40	8.4838	0.28	241.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4634	0.28	115.37	8.4976	0.28	244.88	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5050	0.28	112.50	8.4811	0.28	247.72	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5219	0.28	109.83	8.4582	0.28	250.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

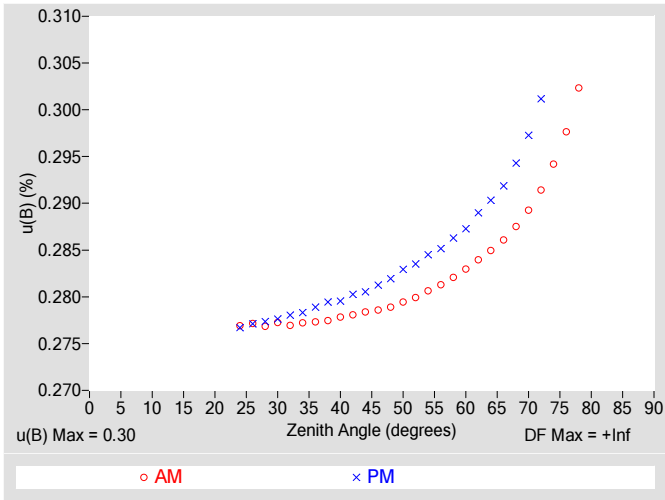


Figure 4. Residuals from Spline Interpolation

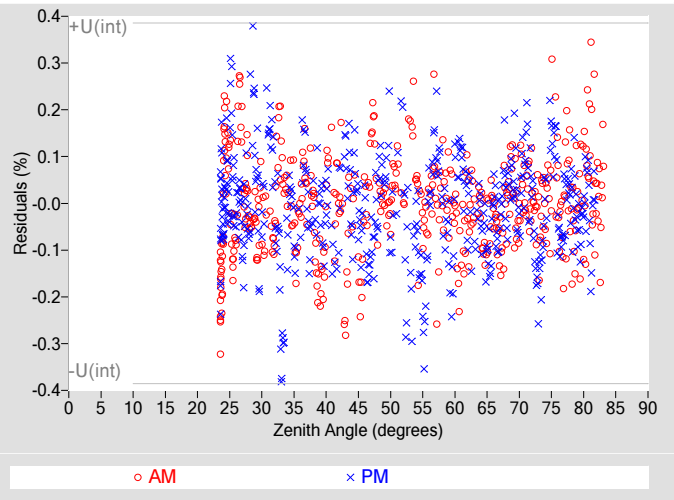


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.30
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.36
Effective degrees of freedom, $DF(c)$	10571
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.70
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

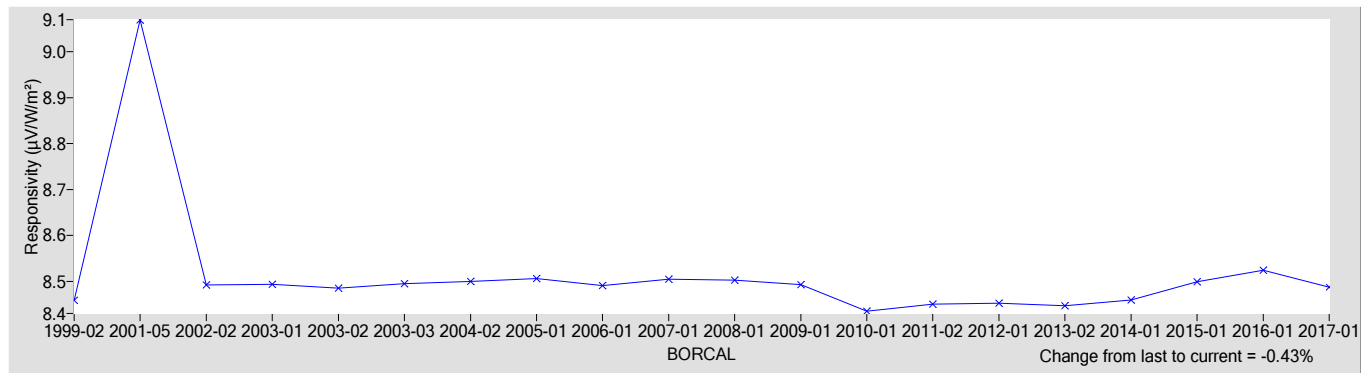
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
8.4873	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.56
Offset Uncertainty, $U(off)$ (%)	+0.84 / -0.56
Expanded Uncertainty, U (%)	+1.4 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	GPP Pyranometer	Manufacturer:	Eppley
Model:	GPP	Serial Number:	37831F3
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

37831F3 Eppley GPP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

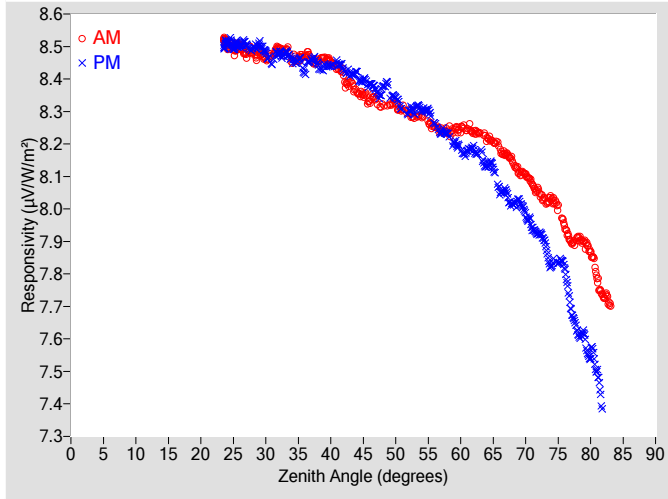


Figure 2. Responsivity vs Local Standard Time

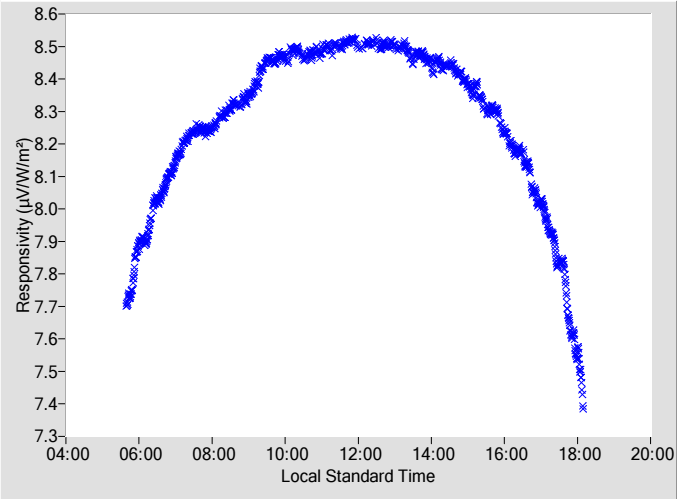


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3312	0.34	107.47	8.3831	0.36	252.72
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3182	0.35	105.23	8.3706	0.37	254.90
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3235	0.35	102.98	8.3431	0.38	257.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2997	0.36	101.02	8.2982	0.39	259.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2845	0.37	98.99	8.3013	0.40	261.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2536	0.38	97.21	8.2639	0.41	262.92
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2450	0.39	95.33	8.2302	0.42	264.75
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2475	0.40	93.53	8.1821	0.44	266.60
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2354	0.41	91.86	8.1832	0.46	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2170	0.43	90.13	8.1327	0.48	269.99
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1828	0.45	88.50	8.0561	0.50	271.62
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.1482	0.47	86.94	8.0147	0.53	273.23
24	8.5086	0.32	168.19	8.5113	0.32	191.90	70	8.1050	0.50	85.28	7.9816	0.58	274.86
26	8.4992	0.32	151.40	8.5015	0.32	208.57	72	8.0536	0.54	83.68	7.9230	0.63	276.49
28	8.4822	0.32	142.57	8.4944	0.32	217.65	74	8.0309	0.59	82.06	7.8287	N/A	278.10
30	8.4612	0.32	135.94	8.4789	0.32	224.37	76	7.9470	0.66	80.45	7.8131	N/A	279.70
32	8.4965	0.32	130.40	8.4789	0.33	229.85	78	7.9107	0.76	78.81	7.6202	N/A	281.30
34	8.4533	0.32	125.63	8.4597	0.33	234.23	80	7.8639	N/A	77.25	7.5516	N/A	282.91
36	8.4701	0.32	121.75	8.4208	0.34	238.06	82	7.7290	N/A	75.59	7.3844	N/A	284.39
38	8.4545	0.33	118.40	8.4425	0.34	241.70	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4532	0.33	115.30	8.4405	0.34	244.81	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4058	0.33	112.49	8.4281	0.35	247.67	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3594	0.34	109.78	8.4207	0.35	250.13	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

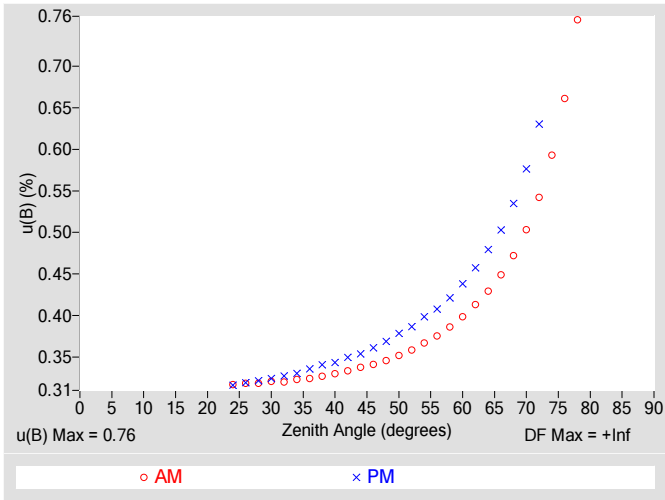


Figure 4. Residuals from Spline Interpolation

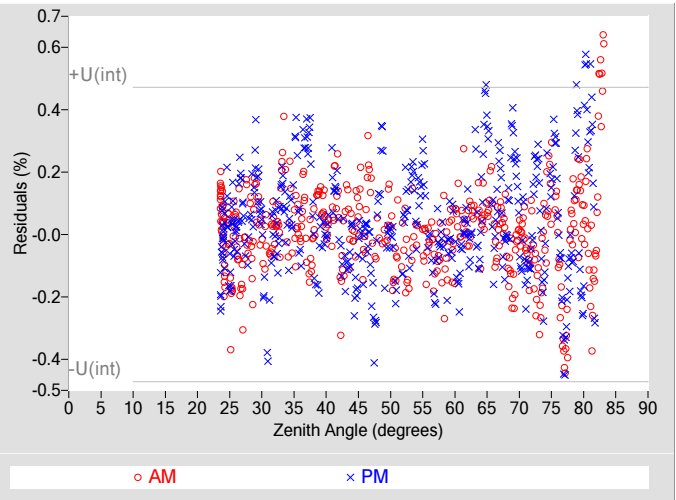


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.76
Type-A Interpolating Function, $u(int)$ (%)	± 0.24
Combined Standard Uncertainty, $u(c)$ (%)	± 0.79
Effective degrees of freedom, $DF(c)$	108713
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

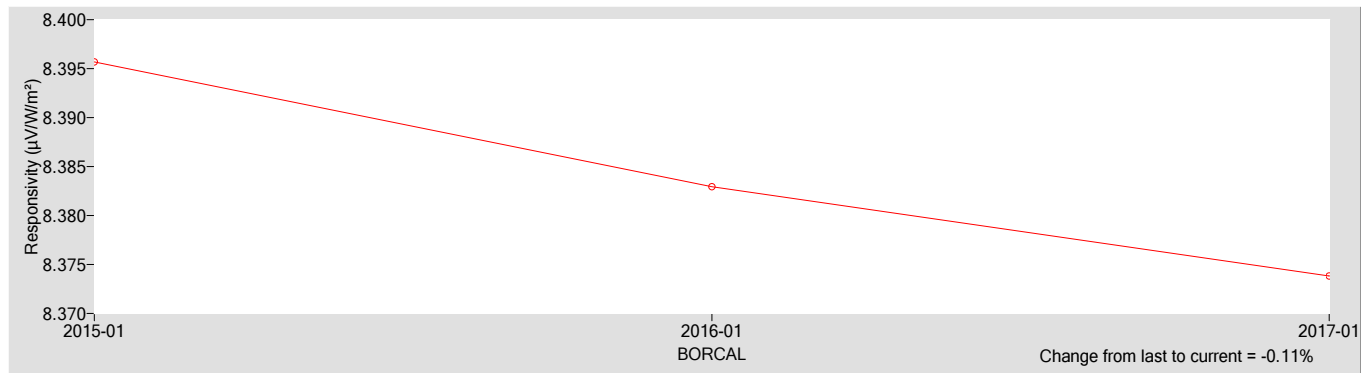
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
8.3738	0.15000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.86
Offset Uncertainty, $U(off)$ (%)	+1.5 / -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



Test Instrument:	Standard Precision Pyranometer (Ventilated)	Manufacturer:	Eppley
Model:	SPP	Serial Number:	37839F3
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 37757F3	08/17/2015	08/17/2019

† 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: 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

37839F3 Eppley SPP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

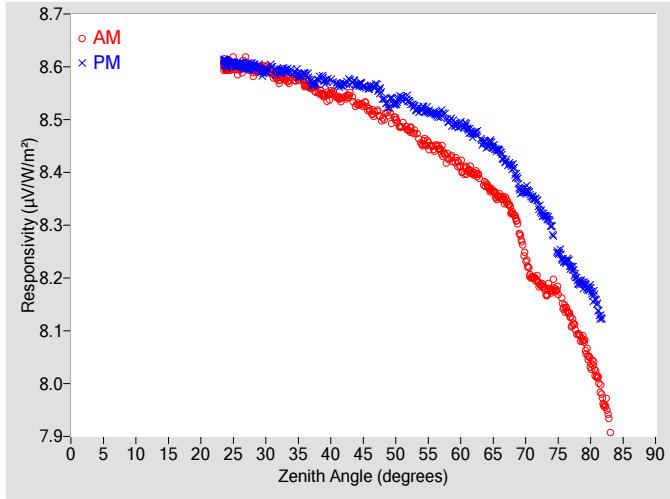


Figure 2. Responsivity vs Local Standard Time

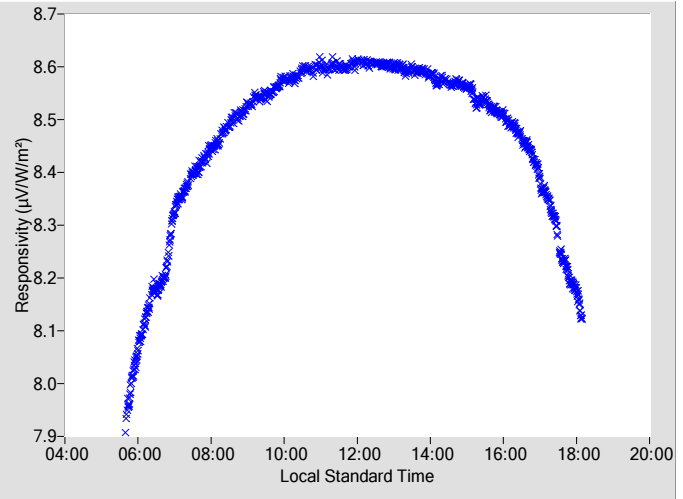


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5161	0.35	107.38	8.5613	0.37	252.64
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4999	0.35	105.14	8.5430	0.38	254.89
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5004	0.36	103.03	8.5304	0.39	257.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4801	0.36	100.98	8.5356	0.40	259.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4547	0.37	98.96	8.5215	0.41	261.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4464	0.38	97.22	8.5110	0.42	263.03
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4259	0.39	95.34	8.4971	0.43	264.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4112	0.41	93.54	8.4907	0.45	266.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3976	0.42	91.85	8.4730	0.47	268.27
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3758	0.44	90.18	8.4518	0.50	269.98
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3551	0.46	88.56	8.4393	0.52	271.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.3222	0.48	86.91	8.4101	0.56	273.26
24	8.5991	0.32	168.61	8.6069	0.32	191.82	70	8.2354	0.52	85.26	8.3679	0.60	274.85
26	8.5979	0.32	151.29	8.6047	0.32	208.68	72	8.1912	0.56	83.65	8.3368	0.66	276.47
28	8.5851	0.32	142.04	8.6013	0.33	217.67	74	8.1792	0.61	82.05	8.2941	N/A	278.09
30	8.5998	0.32	135.64	8.5932	0.33	224.62	76	8.1428	0.68	80.48	8.2309	N/A	279.68
32	8.5777	0.32	130.31	8.5935	0.33	229.83	78	8.0929	0.79	78.78	8.1948	N/A	281.29
34	N/A	N/A	N/A	8.5901	0.33	234.24	80	8.0404	N/A	77.24	8.1757	N/A	282.98
36	8.5673	0.33	121.89	8.5866	0.34	238.24	82	7.9648	N/A	75.62	8.1224	N/A	284.38
38	8.5509	0.33	118.41	8.5753	0.35	241.76	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5483	0.34	115.35	8.5761	0.35	244.87	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5427	0.34	112.26	8.5664	0.36	247.56	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5282	0.34	109.82	8.5658	0.36	250.22	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

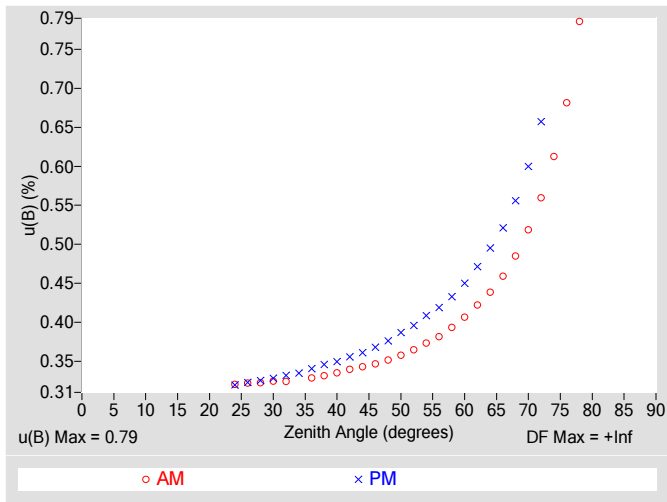


Figure 4. Residuals from Spline Interpolation

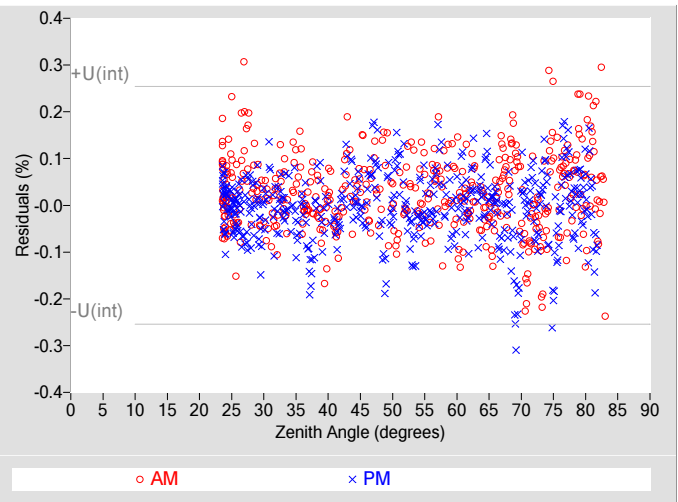


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.79
Type-A Interpolating Function, $u(int)$ (%)	± 0.13
Combined Standard Uncertainty, $u(c)$ (%)	± 0.80
Effective degrees of freedom, $DF(c)$	1306867
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

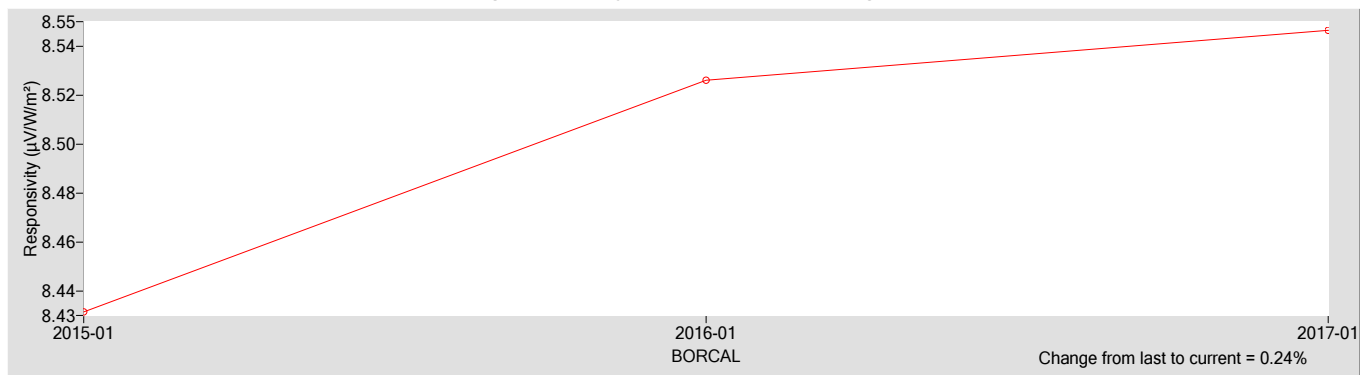
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
8.5464	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.88
Offset Uncertainty, $U(off)$ (%)	+0.62 / -1.6
Expanded Uncertainty, U (%)	+1.5 / -2.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Short Normal Incidence Pyrheliometer	Manufacturer:	Eppley
Model:	sNIP	Serial Number:	37882E6
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

37882E6 Eppley sNIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

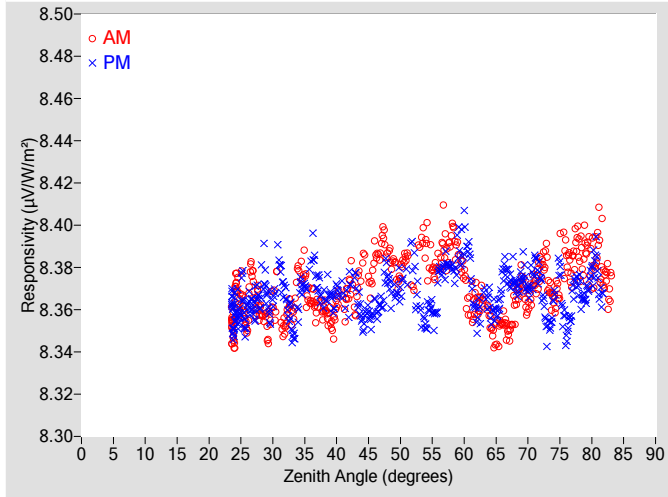


Figure 2. Responsivity vs Local Standard Time

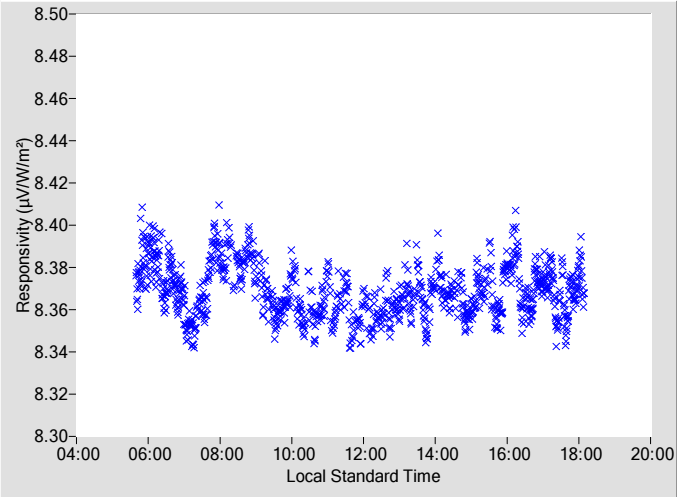


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3862	0.28	107.41	8.3629	0.28	252.76
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3865	0.28	105.17	8.3763	0.28	254.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3767	0.28	103.04	8.3709	0.28	257.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3700	0.28	100.93	8.3845	0.28	259.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3888	0.28	98.94	8.3543	0.28	261.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3817	0.28	97.19	8.3746	0.29	262.99
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3963	0.28	95.31	8.3803	0.29	264.87
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3773	0.28	93.55	8.3944	0.29	266.51
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3647	0.28	91.86	8.3561	0.29	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3566	0.28	90.19	8.3624	0.29	269.95
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3542	0.29	88.52	8.3750	0.29	271.62
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.3631	0.29	86.87	8.3720	0.29	273.27
24	8.3583	0.28	167.50	8.3555	0.28	191.86	70	8.3619	0.29	85.28	8.3694	0.30	274.91
26	8.3569	0.28	151.26	8.3610	0.28	208.90	72	8.3802	0.29	83.71	8.3732	0.30	276.49
28	8.3592	0.28	142.52	8.3667	0.28	217.65	74	8.3637	0.29	82.10	8.3641	N/A	278.10
30	8.3651	0.28	135.83	8.3656	0.28	224.70	76	8.3832	0.30	80.49	8.3485	N/A	279.70
32	8.3540	0.28	130.37	8.3680	0.28	229.80	78	8.3880	0.30	78.89	8.3707	N/A	281.34
34	8.3779	0.28	126.04	8.3634	0.28	234.43	80	8.3800	N/A	77.20	8.3791	N/A	282.95
36	8.3648	0.28	121.81	8.3861	0.28	238.18	82	8.3748	N/A	75.59	8.3677	N/A	284.35
38	8.3597	0.28	118.40	8.3649	0.28	241.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3616	0.28	115.37	8.3691	0.28	244.88	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3701	0.28	112.50	8.3695	0.28	247.72	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3808	0.28	109.83	8.3547	0.28	250.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

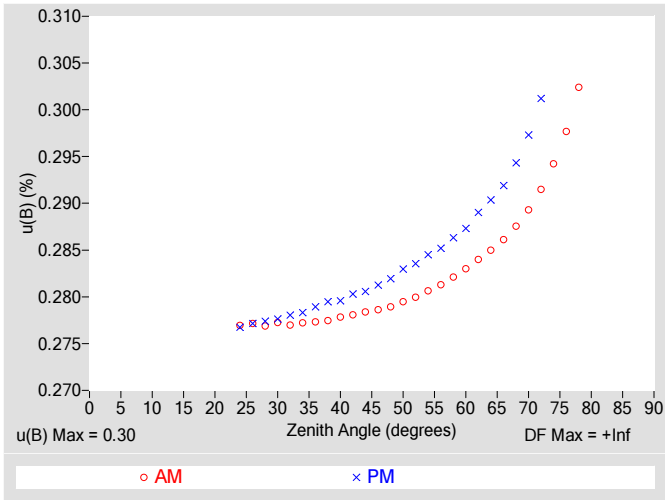


Figure 4. Residuals from Spline Interpolation

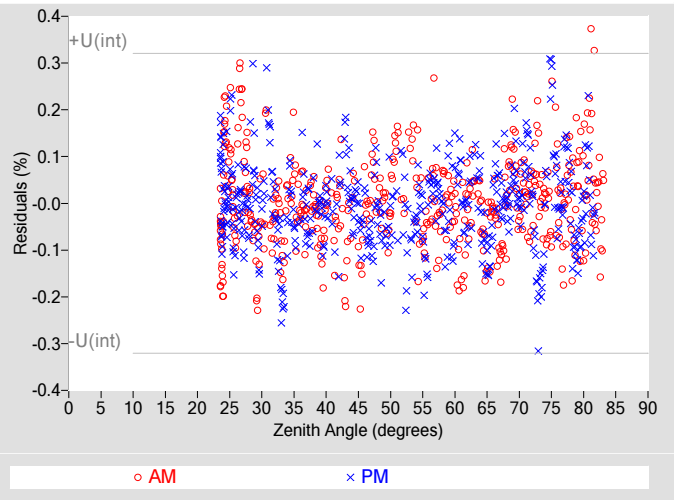


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.30
Type-A Interpolating Function, $u(int)$ (%)	± 0.16
Combined Standard Uncertainty, $u(c)$ (%)	± 0.34
Effective degrees of freedom, $DF(c)$	18357
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.67
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

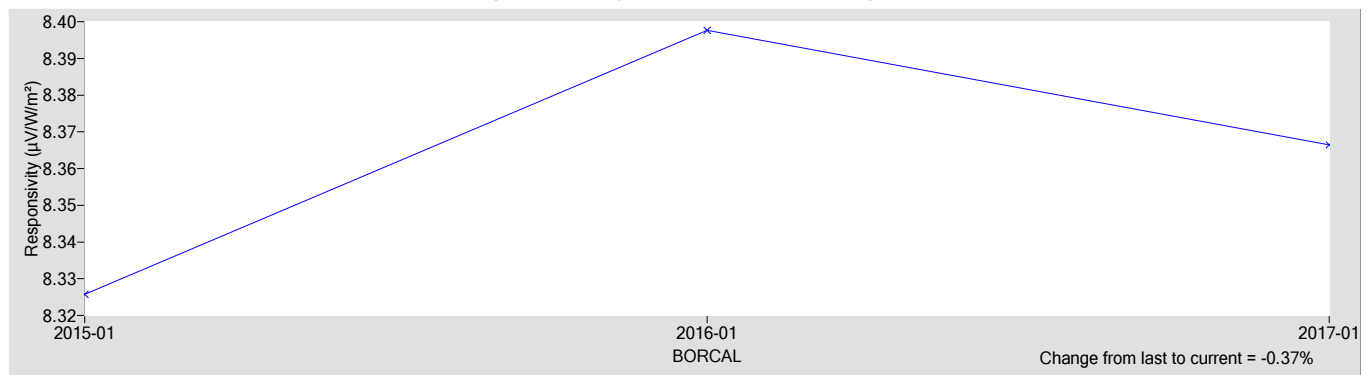
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
8.3664	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.56
Offset Uncertainty, $U(off)$ (%)	+0.36 / -0.15
Expanded Uncertainty, U (%)	+0.92 / -0.71
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



Test Instrument:	Si pyranometer	Manufacturer:	Apogee
Model:	SP-110	Serial Number:	40337
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

40337 Apogee SP-110

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

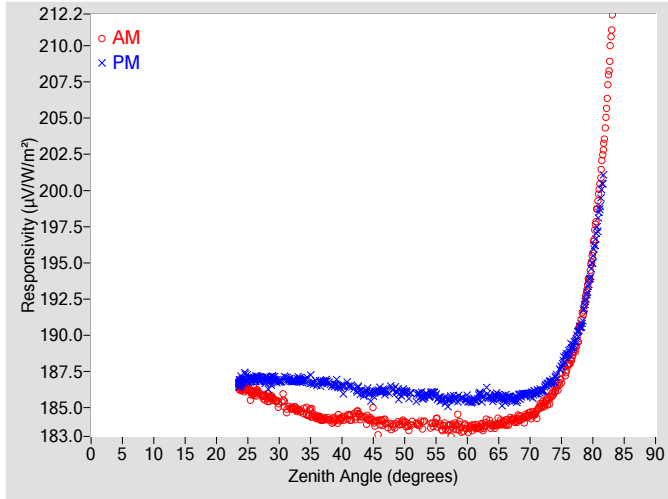


Figure 2. Responsivity vs Local Standard Time

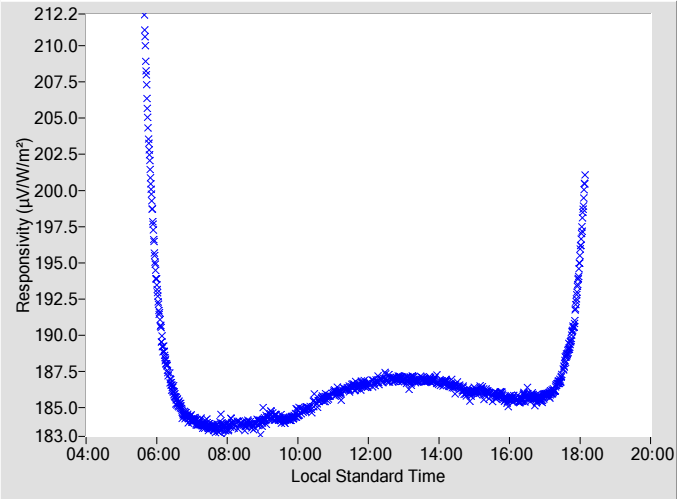


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	184.03	0.34	107.36	186.19	0.36	252.70
2	N/A	N/A	N/A	N/A	N/A	N/A	48	183.66	0.34	105.11	186.33	0.37	254.94
4	N/A	N/A	N/A	N/A	N/A	N/A	50	183.94	0.35	103.04	186.11	0.37	257.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	183.86	0.35	100.93	185.79	0.38	259.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	183.74	0.36	98.88	185.85	0.39	261.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	183.62	0.37	97.16	185.59	0.40	262.95
12	N/A	N/A	N/A	N/A	N/A	N/A	58	183.70	0.38	95.35	185.65	0.41	264.71
14	N/A	N/A	N/A	N/A	N/A	N/A	60	183.52	0.39	93.63	185.54	0.43	266.56
16	N/A	N/A	N/A	N/A	N/A	N/A	62	183.66	0.41	91.85	185.85	0.45	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	183.72	0.42	90.18	185.60	0.47	269.98
20	N/A	N/A	N/A	N/A	N/A	N/A	66	183.96	0.44	88.52	185.57	0.49	271.61
22	N/A	N/A	N/A	N/A	N/A	N/A	68	184.17	0.46	86.90	185.69	0.52	273.26
24	186.47	0.31	168.45	186.81	0.31	191.41	70	184.46	0.49	85.31	185.95	0.56	274.89
26	186.08	0.32	151.34	186.95	0.32	208.79	72	185.18	0.53	83.69	186.19	0.62	276.51
28	185.70	0.32	142.41	186.83	0.32	217.65	74	186.22	0.58	82.09	187.02	N/A	278.08
30	185.14	0.32	136.07	186.80	0.32	224.50	76	187.79	0.64	80.48	188.74	N/A	279.72
32	184.95	0.32	130.17	186.82	0.32	229.93	78	190.48	0.73	78.93	190.57	N/A	281.33
34	184.76	0.32	125.96	186.89	0.33	234.30	80	195.70	N/A	77.28	195.36	N/A	282.94
36	184.33	0.32	121.88	186.69	0.33	237.99	82	204.71	N/A	75.58	N/A	N/A	N/A
38	184.20	0.32	118.38	186.66	0.34	241.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	184.20	0.33	115.39	186.37	0.34	244.85	86	N/A	N/A	N/A	N/A	N/A	N/A
42	184.37	0.33	112.32	186.23	0.35	247.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	184.18	0.33	109.85	186.12	0.35	250.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

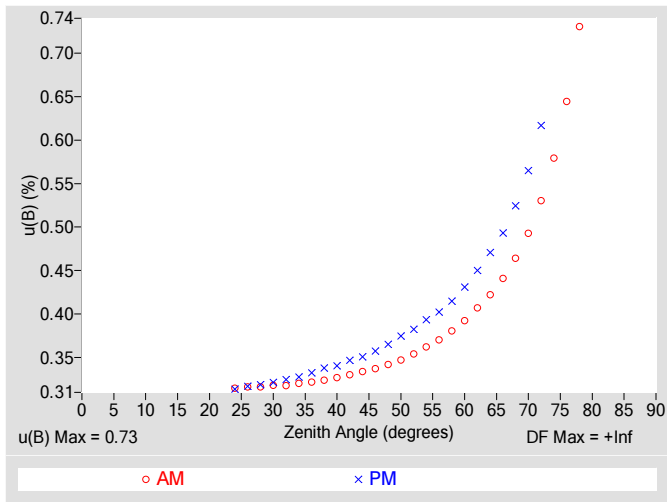


Figure 4. Residuals from Spline Interpolation

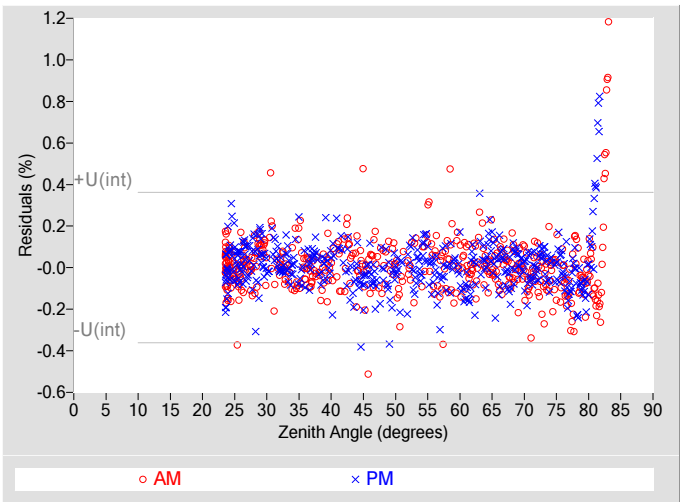


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.73
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	260662
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

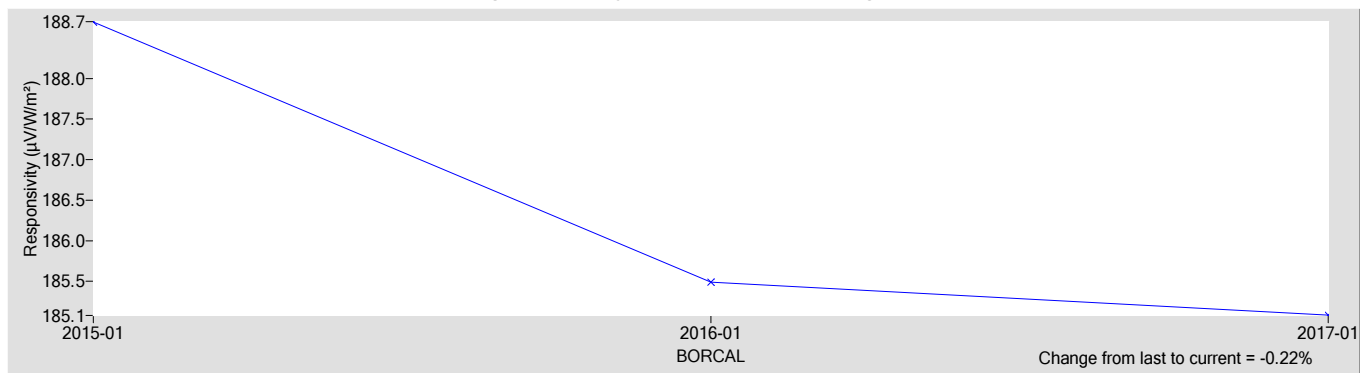
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
185.08	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.84
Offset Uncertainty, U(off) (%)	+0.97 / -0.84
Expanded Uncertainty, U (%)	+1.8 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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



Test Instrument: Pyrheliometer
Model: DR02
Calibration Date: 5/4/2017
Customer: NREL-SRRL-BMS
Test Dates: 5/4

Manufacturer: Hukseflux
Serial Number: 9206
Due Date: 5/4/2018
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: 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

9206 Hukseflux DR02

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

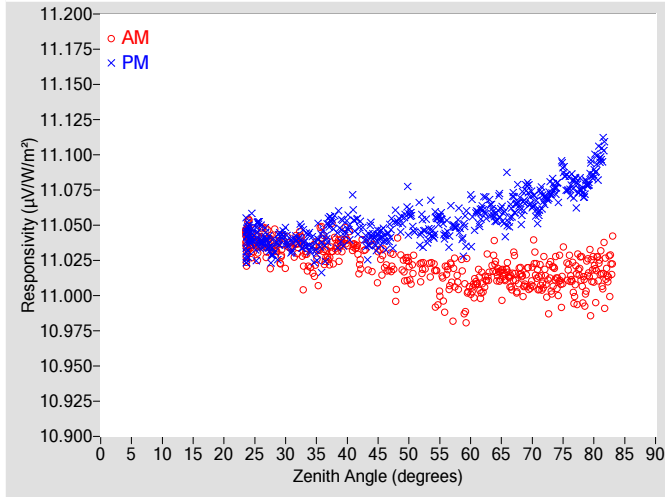


Figure 2. Responsivity vs Local Standard Time

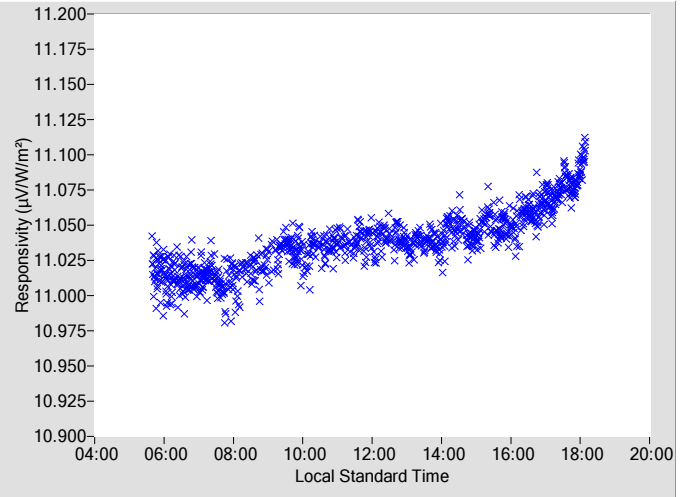


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	11.027	0.28	107.62	11.041	0.28	252.62
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.014	0.28	105.17	11.055	0.28	255.00
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.019	0.28	103.10	11.059	0.28	257.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.018	0.28	100.99	11.045	0.28	259.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.011	0.28	98.84	11.046	0.28	261.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.011	0.28	97.16	11.045	0.28	262.98
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.009	0.28	95.43	11.052	0.29	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.003	0.28	93.56	11.058	0.29	266.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.007	0.28	91.89	11.063	0.29	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.024	0.28	90.20	11.055	0.29	269.95
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.017	0.29	88.53	11.050	0.29	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	11.015	0.29	86.87	11.061	0.29	273.28
24	11.042	0.28	167.31	11.042	0.28	191.90	70	11.017	0.29	85.28	11.067	0.30	274.87
26	11.040	0.28	151.20	11.039	0.28	208.86	72	11.014	0.29	83.71	11.068	0.30	276.49
28	11.037	0.28	142.33	11.032	0.28	217.49	74	11.011	0.29	82.11	11.075	N/A	278.10
30	11.031	0.28	135.34	11.041	0.28	224.63	76	11.017	0.30	80.50	11.077	N/A	279.72
32	11.038	0.28	130.38	11.040	0.28	230.01	78	11.014	0.30	78.90	11.075	N/A	281.35
34	11.020	0.28	126.08	11.037	0.28	234.33	80	11.015	N/A	77.20	11.089	N/A	282.95
36	11.037	0.28	121.83	11.036	0.28	237.98	82	11.012	N/A	75.60	11.109	N/A	284.35
38	11.034	0.28	118.44	11.052	0.28	241.40	84	N/A	N/A	N/A	N/A	N/A	N/A
40	11.038	0.28	115.37	11.051	0.28	244.96	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.022	0.28	112.51	11.048	0.28	247.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.031	0.28	109.92	11.045	0.28	250.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

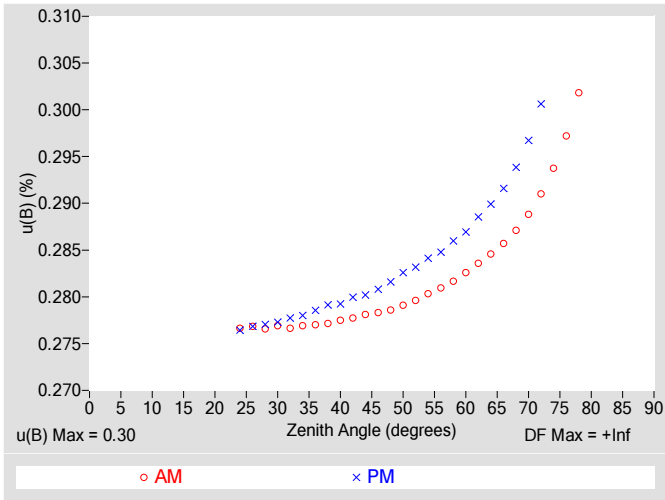


Figure 4. Residuals from Spline Interpolation

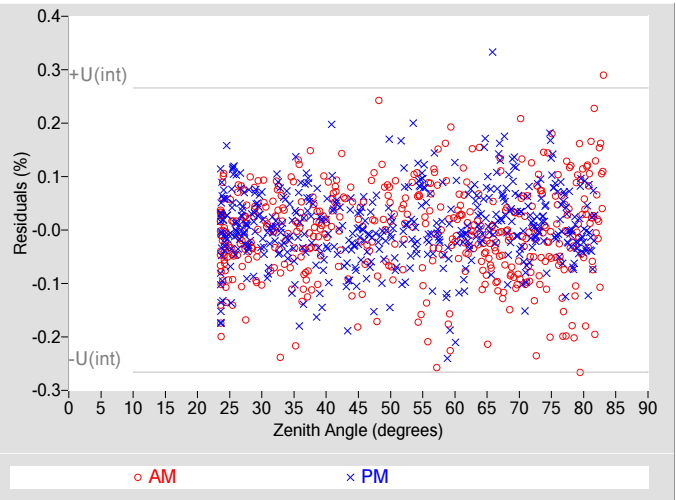


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.30
Type-A Interpolating Function, $u(int)$ (%)	± 0.13
Combined Standard Uncertainty, $u(c)$ (%)	± 0.33
Effective degrees of freedom, $DF(c)$	32216
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.65
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

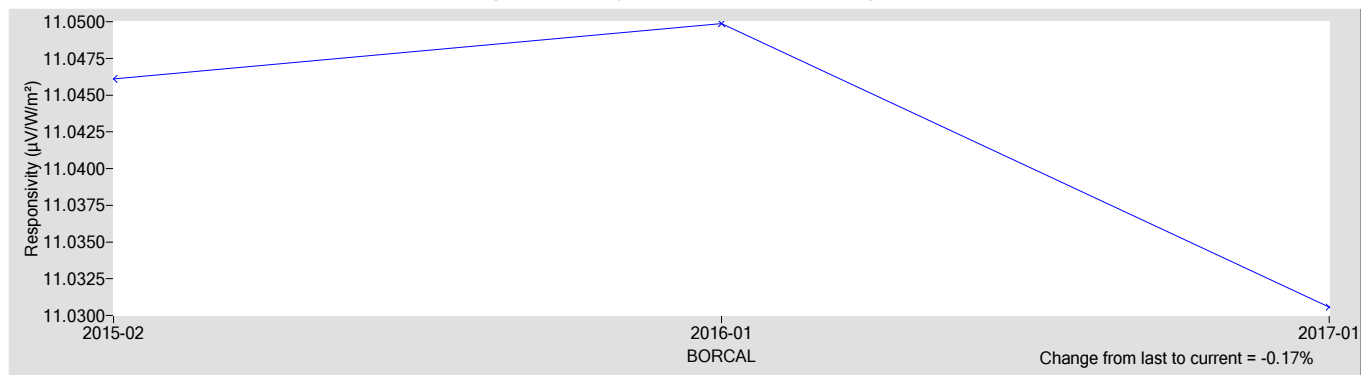
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
11.031	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.56
Offset Uncertainty, $U(off)$ (%)	+0.26 / -0.25
Expanded Uncertainty, U (%)	+0.82 / -0.81
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 Pyrgometers.* ARM 2008 Science Team Meeting (Poster).



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Sunshine Pyranometer - Global Output	Manufacturer:	Delta-T
Model:	SPN1	Serial Number:	A360
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

A360 Delta-T SPN1

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 where, $G = B * \text{COS}(Z) + D$,
 Z = zenith angle (degrees),
 D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

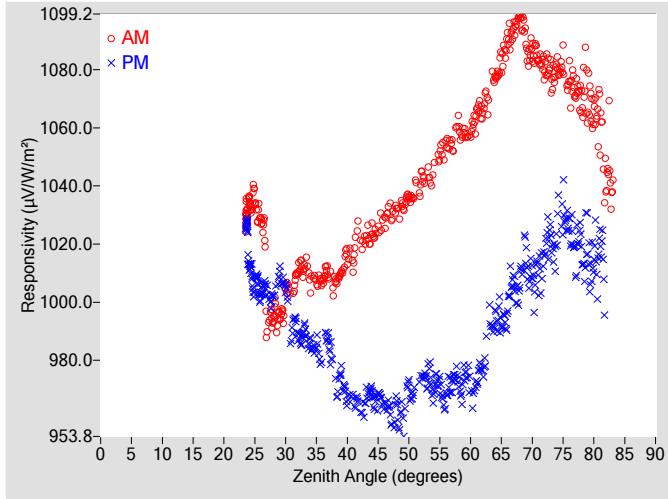


Figure 2. Responsivity vs Local Standard Time

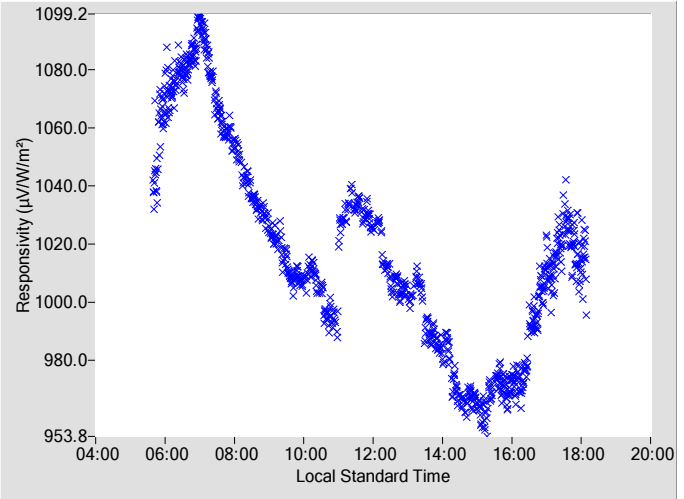


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	1028.0	0.34	107.40	964.48	0.36	252.70
2	N/A	N/A	N/A	N/A	N/A	N/A	48	1032.1	0.34	105.17	963.27	0.37	255.00
4	N/A	N/A	N/A	N/A	N/A	N/A	50	1036.1	0.35	103.03	969.83	0.37	257.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	1041.7	0.35	100.98	973.94	0.38	259.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	1045.9	0.36	99.03	968.73	0.39	261.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	1055.1	0.37	97.05	966.17	0.40	262.99
12	N/A	N/A	N/A	N/A	N/A	N/A	58	1060.9	0.38	95.32	973.26	0.42	264.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	1058.8	0.39	93.52	969.11	0.43	266.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	1066.2	0.41	91.86	977.17	0.45	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	1077.0	0.42	90.19	993.31	0.47	269.94
20	N/A	N/A	N/A	N/A	N/A	N/A	66	1090.8	0.44	88.51	996.46	0.49	271.61
22	N/A	N/A	N/A	N/A	N/A	N/A	68	1098.3	0.46	86.91	1007.2	0.52	273.26
24	1032.6	0.31	168.00	1017.2	0.31	191.96	70	1086.6	0.49	85.31	1008.3	0.57	274.90
26	1028.1	0.32	151.43	1002.9	0.32	208.79	72	1080.2	0.53	83.70	1017.4	0.62	276.52
28	995.25	0.32	142.32	1002.4	0.32	217.43	74	1080.6	0.58	82.09	1025.9	N/A	278.09
30	1005.3	0.32	135.35	1004.3	0.32	224.55	76	1074.9	0.64	80.48	1024.5	N/A	279.73
32	1010.6	0.32	130.38	988.54	0.32	229.94	78	1068.2	0.73	78.89	1018.1	N/A	281.33
34	1007.5	0.32	125.88	985.63	0.33	234.31	80	1063.8	N/A	77.24	1017.5	N/A	282.94
36	1007.3	0.32	121.86	979.28	0.33	237.83	82	1041.8	N/A	75.58	N/A	N/A	N/A
38	1006.6	0.32	118.41	970.50	0.34	241.99	84	N/A	N/A	N/A	N/A	N/A	N/A
40	1016.1	0.33	115.40	966.73	0.34	244.68	86	N/A	N/A	N/A	N/A	N/A	N/A
42	1024.6	0.33	112.60	964.00	0.35	247.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	1023.3	0.33	109.88	968.28	0.35	250.30	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

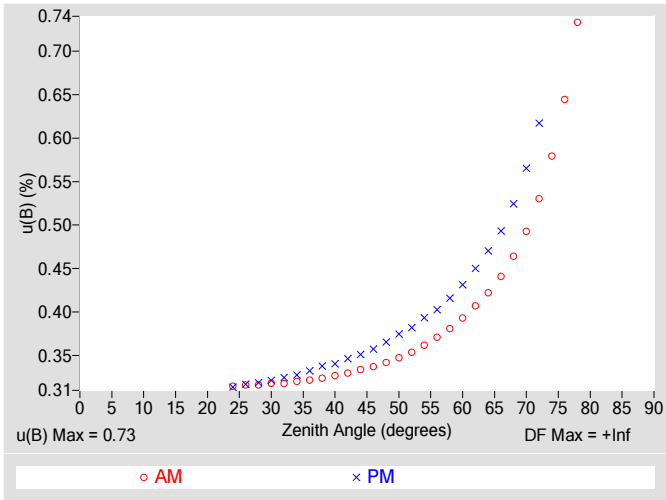


Figure 4. Residuals from Spline Interpolation

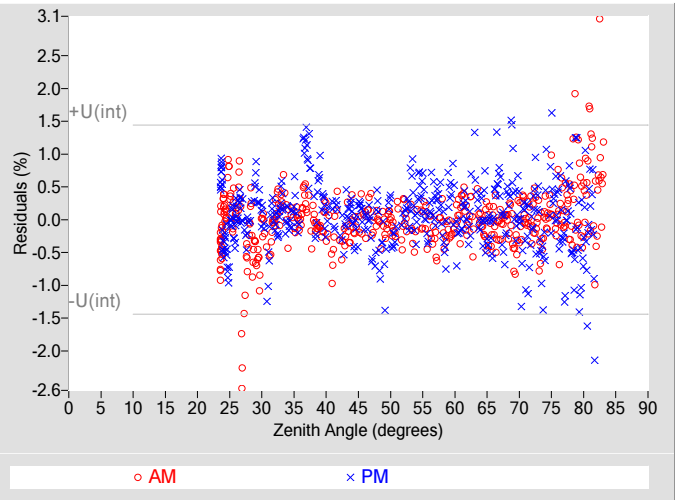


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.73
Type-A Interpolating Function, $u(int)$ (%)	± 0.72
Combined Standard Uncertainty, $u(c)$ (%)	± 1.0
Effective degrees of freedom, $DF(c)$	3579
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 2.0
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

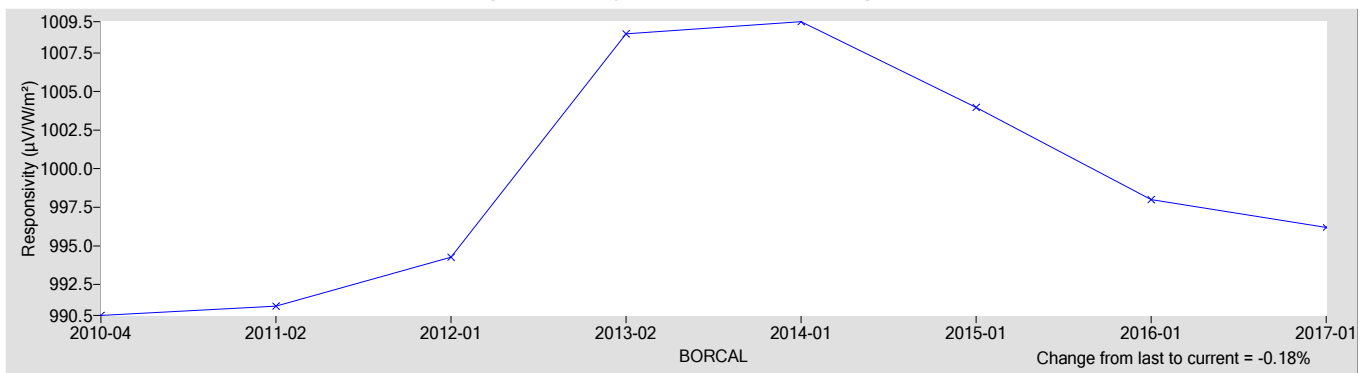
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
996.19	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+6.5 / -3.3
Expanded Uncertainty, U (%)	+7.3 / -4.2
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 Pyrgometers. ARM 2008 Science Team Meeting (Poster).



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	EKO
Model:	MS-802	Serial Number:	F14077R
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

F14077R EKO MS-802

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

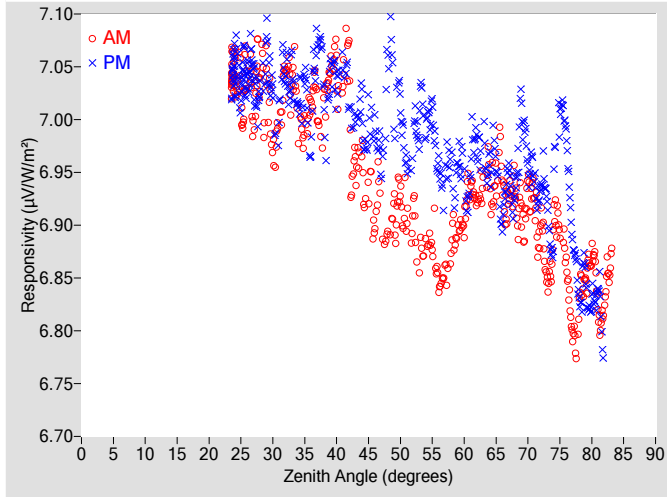


Figure 2. Responsivity vs Local Standard Time

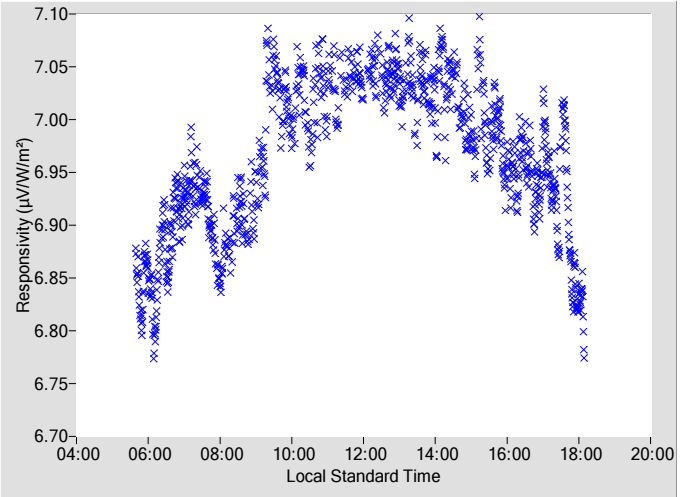


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	6.9018	0.34	107.50	6.9861	0.36	252.68
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.8902	0.35	105.30	7.0510	0.37	254.90
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.9244	0.36	102.99	7.0143	0.38	257.07
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.9077	0.36	100.99	6.9862	0.39	259.22
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.8836	0.37	98.94	6.9948	0.40	261.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.8473	0.38	97.15	6.9538	0.41	262.99
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.8870	0.39	95.28	6.9552	0.43	264.75
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9049	0.40	93.55	6.9482	0.44	266.57
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9231	0.42	91.86	6.9779	0.46	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9440	0.43	90.19	6.9546	0.49	269.99
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.9410	0.45	88.52	6.9051	0.51	271.62
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.9329	0.48	86.91	6.9312	0.54	273.23
24	7.0431	0.32	168.51	7.0495	0.32	191.44	70	6.9324	0.51	85.28	6.9551	0.58	274.86
26	7.0448	0.32	151.99	7.0393	0.32	208.90	72	6.8972	0.55	83.66	6.9339	0.64	276.48
28	7.0341	0.32	142.49	7.0249	0.32	217.15	74	6.8971	0.60	82.06	6.9207	N/A	278.10
30	6.9707	0.32	135.71	7.0231	0.33	224.20	76	6.8606	0.67	80.45	6.9815	N/A	279.70
32	7.0470	0.32	130.48	7.0437	0.33	229.84	78	6.8257	0.76	78.81	6.8337	N/A	281.30
34	6.9941	0.33	125.98	7.0172	0.33	234.24	80	6.8675	N/A	77.24	6.8302	N/A	282.95
36	7.0120	0.33	121.89	6.9888	0.34	238.24	82	6.8238	N/A	75.62	6.7743	N/A	284.39
38	7.0107	0.33	118.35	7.0143	0.34	241.70	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.0411	0.33	115.22	7.0317	0.35	244.81	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0285	0.34	112.48	7.0113	0.35	247.67	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.9536	0.34	109.74	7.0031	0.36	250.25	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

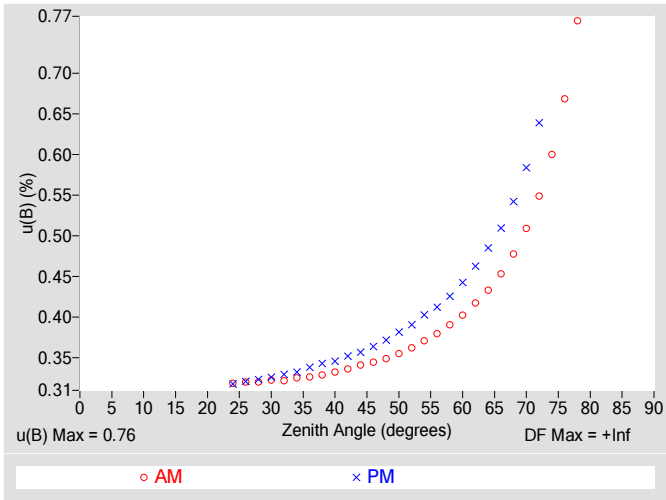


Figure 4. Residuals from Spline Interpolation

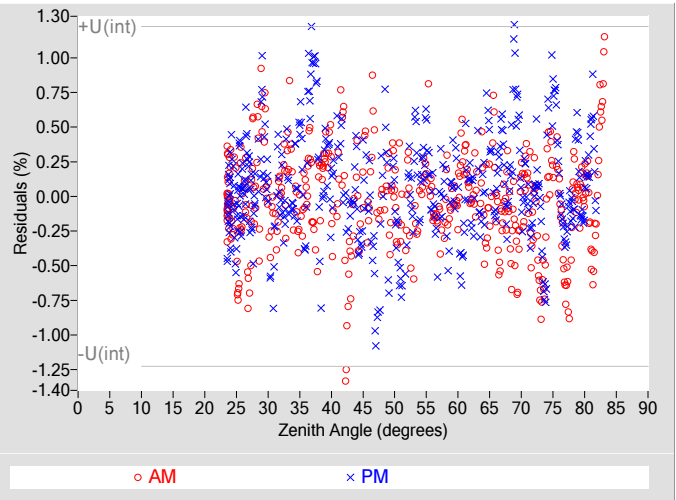


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.76
Type-A Interpolating Function, $u(int)$ (%)	± 0.61
Combined Standard Uncertainty, $u(c)$ (%)	± 0.98
Effective degrees of freedom, $DF(c)$	5716
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 1.9
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

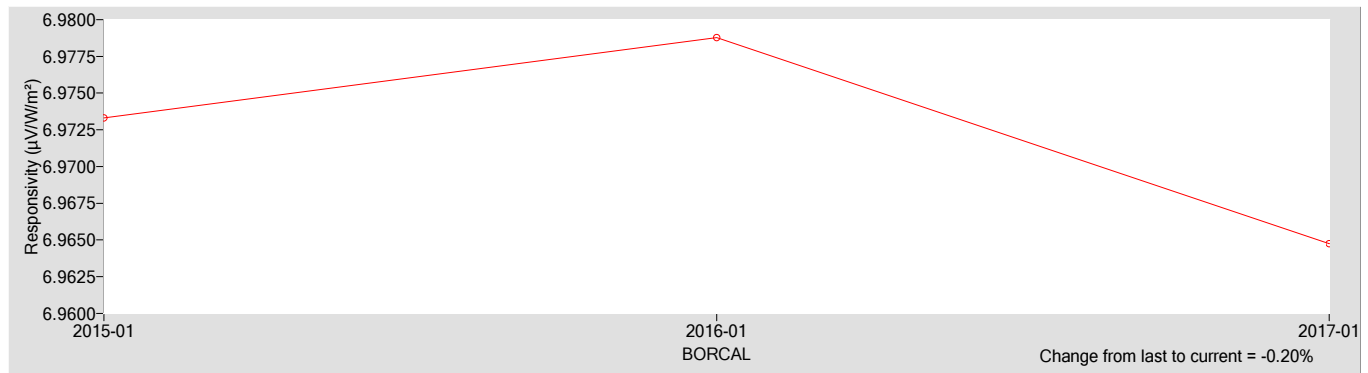
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
6.9648	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.87
Offset Uncertainty, $U(off)$ (%)	+1.2 / -1.7
Expanded Uncertainty, U (%)	+2.1 / -2.6
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 Pyrheliometers. ARM 2008 Science Team Meeting (Poster).



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyrheliometer	Manufacturer:	EKO
Model:	MS-56	Serial Number:	P12022
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

P12022 EKO MS-56

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 where, $G = B * \text{COS}(Z) + D$,
 Z = zenith angle (degrees),
 D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

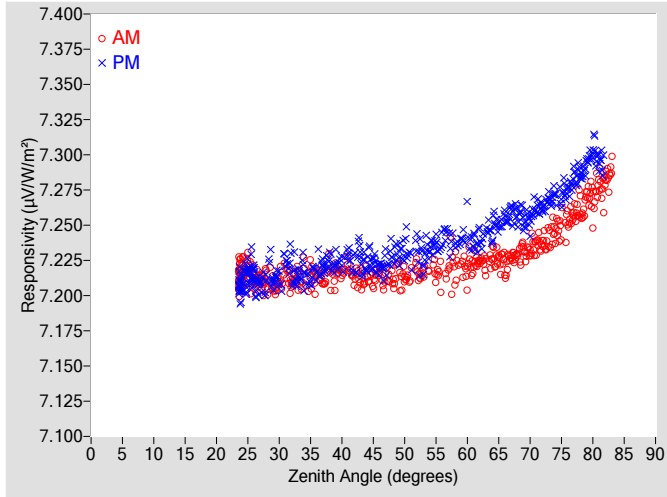


Figure 2. Responsivity vs Local Standard Time

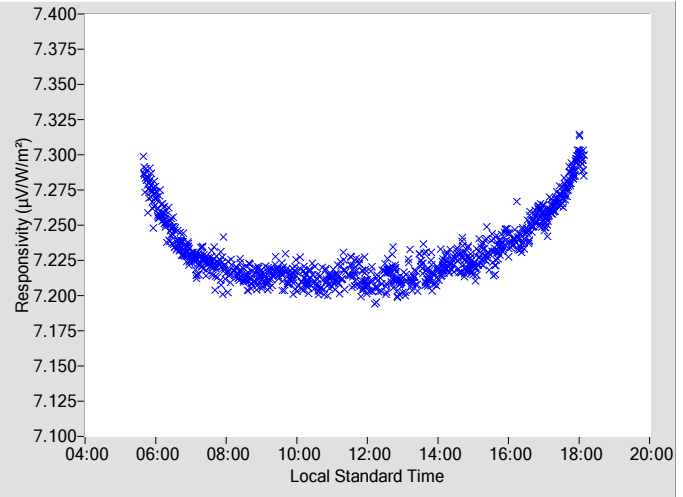


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.2179	0.28	107.41	7.2206	0.28	252.71
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2107	0.28	105.03	7.2317	0.28	254.84
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2137	0.28	103.04	7.2363	0.28	257.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2192	0.28	101.01	7.2339	0.28	259.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2175	0.28	99.19	7.2325	0.28	261.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2022	0.28	97.34	7.2406	0.29	263.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2187	0.28	95.34	7.2356	0.29	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2191	0.28	93.60	7.2471	0.29	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2248	0.28	91.90	7.2427	0.29	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2277	0.29	90.19	7.2463	0.29	269.95
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.2203	0.29	88.52	7.2561	0.29	271.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.2293	0.29	86.96	7.2555	0.29	273.27
24	7.2176	0.28	167.97	7.2065	0.28	191.97	70	7.2299	0.29	85.23	7.2524	0.30	274.90
26	7.2130	0.28	151.47	7.2130	0.28	208.64	72	7.2378	0.29	83.70	7.2618	0.30	276.48
28	7.2106	0.28	142.68	7.2094	0.28	217.14	74	7.2460	0.29	82.10	7.2717	N/A	278.09
30	7.2127	0.28	135.65	7.2110	0.28	224.52	76	7.2510	0.30	80.49	7.2749	N/A	279.73
32	7.2077	0.28	130.36	7.2186	0.28	229.83	78	7.2618	0.30	78.89	7.2864	N/A	281.33
34	7.2178	0.28	125.77	7.2162	0.28	234.29	80	7.2647	N/A	77.24	7.3048	N/A	282.95
36	7.2132	0.28	122.07	7.2198	0.28	238.13	82	7.2789	N/A	75.58	N/A	N/A	N/A
38	7.2167	0.28	118.47	7.2262	0.28	241.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.2148	0.28	115.32	7.2221	0.28	244.85	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2110	0.28	112.60	7.2229	0.28	247.77	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2144	0.28	109.83	7.2229	0.28	250.27	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

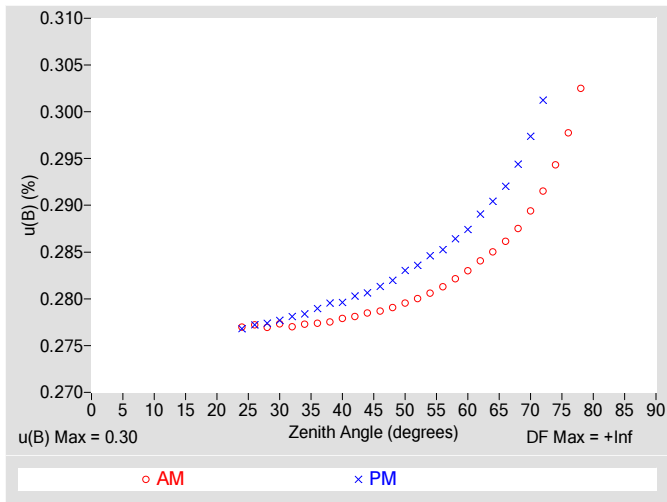


Figure 4. Residuals from Spline Interpolation

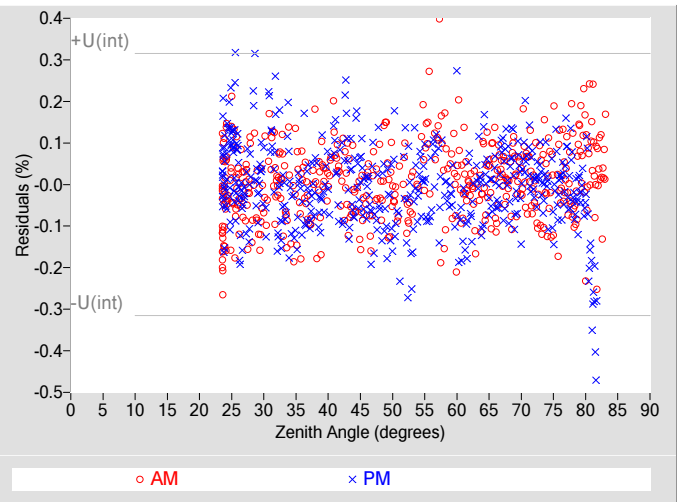


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.30
Type-A Interpolating Function, $u(int)$ (%)	± 0.16
Combined Standard Uncertainty, $u(c)$ (%)	± 0.34
Effective degrees of freedom, $DF(c)$	19471
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.67
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

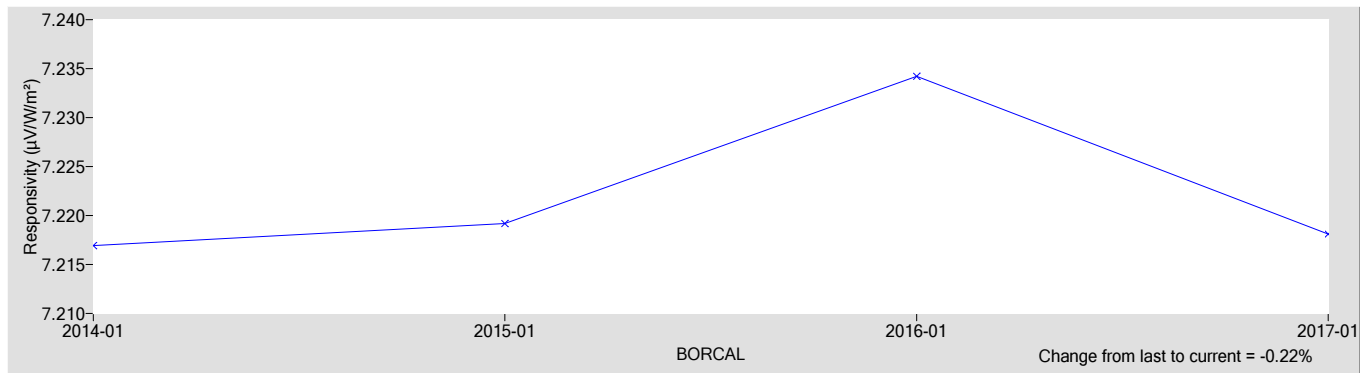
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
7.2181	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.56
Offset Uncertainty, $U(off)$ (%)	+0.40 / -0.22
Expanded Uncertainty, U (%)	+0.96 / -0.78
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

[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



Test Instrument: Revised Silicon Pyranometer
Manufacturer: Licor
Model: LI200R
Serial Number: PY100360
Calibration Date: 5/4/2017
Due Date: 5/4/2018
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/4

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: 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

PY100360 Licor LI200R

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

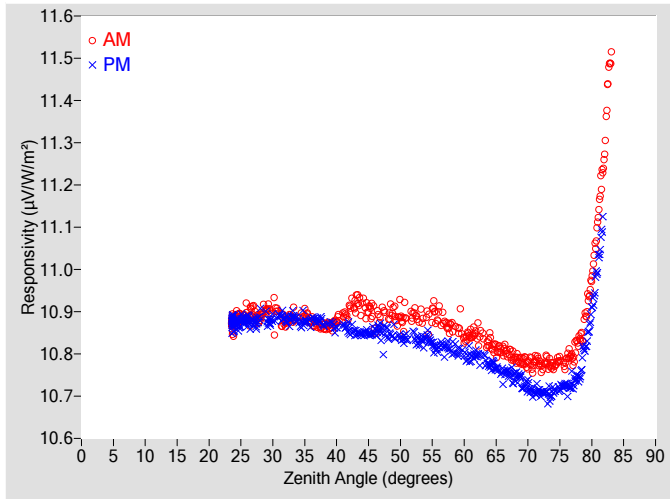


Figure 2. Responsivity vs Local Standard Time

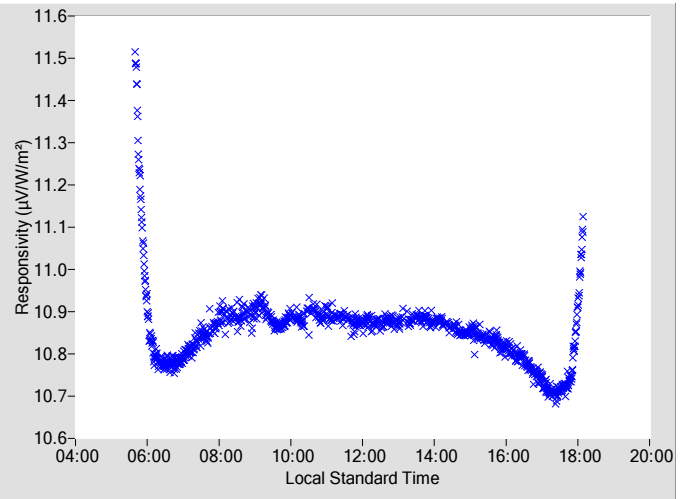


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.874	0.34	107.51	10.850	0.36	252.71
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.890	0.34	104.94	10.850	0.37	254.92
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.893	0.35	103.06	10.839	0.38	257.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.893	0.35	100.96	10.847	0.38	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.894	0.36	98.90	10.843	0.39	261.17
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.893	0.37	97.21	10.813	0.40	262.98
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.867	0.38	95.34	10.812	0.42	264.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.833	0.39	93.52	10.800	0.43	266.61
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.846	0.41	91.87	10.800	0.45	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.829	0.42	90.21	10.771	0.47	269.96
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.808	0.44	88.52	10.758	0.50	271.62
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.789	0.47	86.89	10.749	0.53	273.29
24	10.882	0.32	168.59	10.874	0.31	191.94	70	10.774	0.49	85.34	10.724	0.57	274.87
26	10.891	0.32	151.25	10.880	0.32	208.44	72	10.772	0.53	83.68	10.709	0.62	276.45
28	10.883	0.32	142.27	10.888	0.32	217.31	74	10.771	0.58	82.09	10.711	N/A	278.07
30	10.891	0.32	135.51	10.885	0.32	224.05	76	10.782	0.65	80.50	10.721	N/A	279.71
32	10.874	0.32	130.29	10.882	0.33	229.90	78	10.831	0.74	78.86	10.743	N/A	281.31
34	10.887	0.32	126.10	10.874	0.33	234.56	80	10.982	N/A	77.21	10.906	N/A	282.96
36	10.879	0.32	121.93	10.884	0.33	238.20	82	11.278	N/A	75.60	11.125	N/A	284.36
38	10.867	0.32	118.45	10.868	0.34	241.57	84	N/A	N/A	N/A	N/A	N/A	N/A
40	10.880	0.33	115.31	10.858	0.34	244.64	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.904	0.33	112.46	10.855	0.35	247.53	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.914	0.33	109.89	10.847	0.35	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

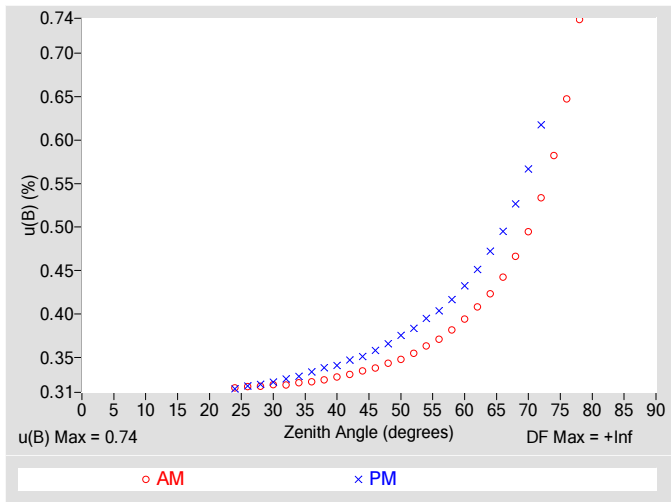


Figure 4. Residuals from Spline Interpolation

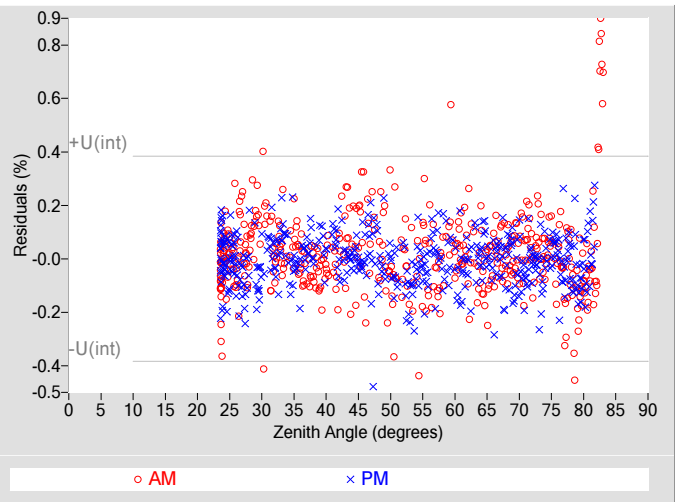


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	211078
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

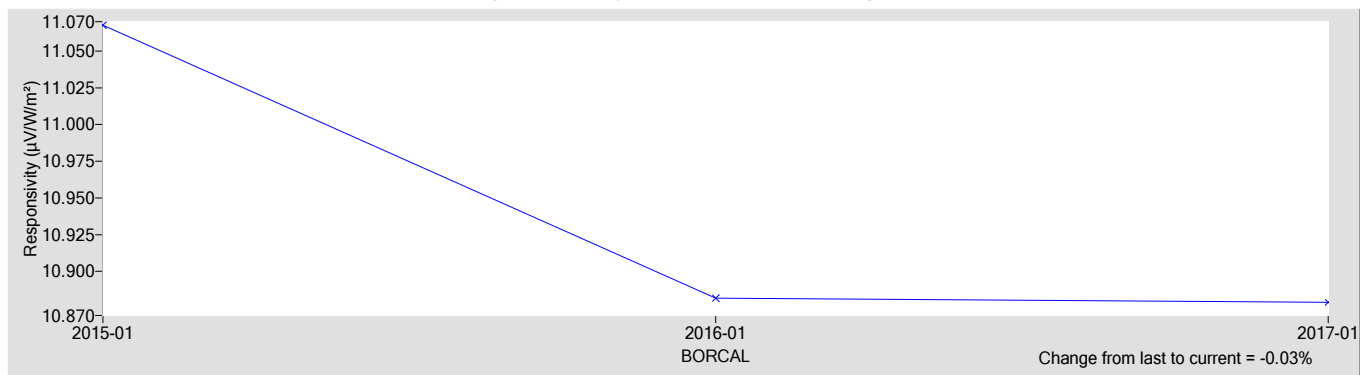
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.879	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+0.33 / -0.73
Expanded Uncertainty, U (%)	+1.2 / -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 Pyrgometers. ARM 2008 Science Team Meeting (Poster).



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Silicon Pyranometer	Manufacturer:	Licor
Model:	LI200	Serial Number:	PY28257
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: 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

PY28257 Licor LI200

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{in} - W_{out} = W_{in} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \text{COS}(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

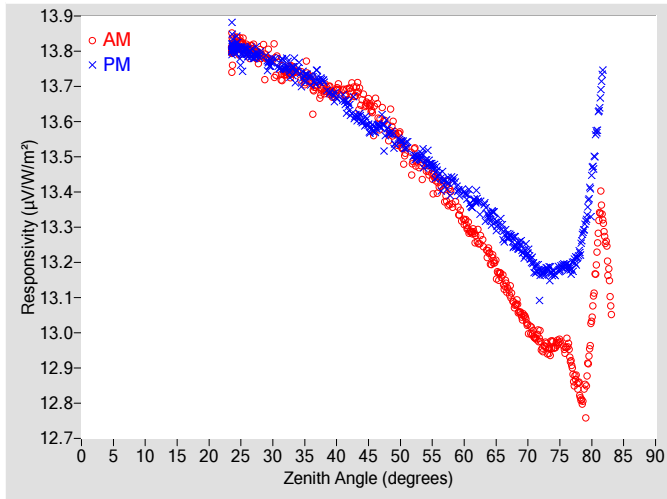


Figure 2. Responsivity vs Local Standard Time

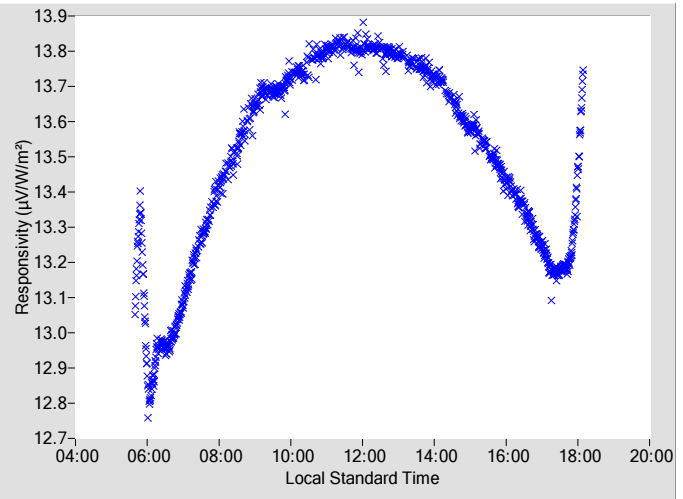


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	13.623	0.34	107.51	13.577	0.36	252.71
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.556	0.34	104.94	13.583	0.37	254.92
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.552	0.35	103.06	13.546	0.38	257.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.493	0.35	100.96	13.499	0.38	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.470	0.36	98.90	13.491	0.39	261.17
10	N/A	N/A	N/A	N/A	N/A	N/A	56	13.419	0.37	97.21	13.448	0.40	262.98
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.383	0.38	95.34	13.424	0.42	264.81
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.318	0.39	93.52	13.397	0.43	266.61
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.268	0.41	91.87	13.380	0.45	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.219	0.42	90.21	13.325	0.47	269.96
20	N/A	N/A	N/A	N/A	N/A	N/A	66	13.150	0.44	88.52	13.289	0.49	271.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	13.082	0.47	86.89	13.256	0.53	273.29
24	13.814	0.32	168.70	13.808	0.31	191.94	70	13.018	0.49	85.34	13.226	0.57	274.87
26	13.809	0.32	151.25	13.795	0.32	208.44	72	12.975	0.53	83.68	13.172	0.62	276.48
28	13.786	0.32	142.27	13.789	0.32	217.31	74	12.966	0.58	82.09	13.169	N/A	278.07
30	13.774	0.32	135.51	13.772	0.32	224.05	76	12.959	0.65	80.50	13.189	N/A	279.71
32	13.736	0.32	130.29	13.757	0.33	229.90	78	12.839	0.74	78.86	13.223	N/A	281.31
34	13.741	0.32	126.10	13.752	0.33	234.56	80	13.041	N/A	77.21	13.433	N/A	282.96
36	13.717	0.32	122.01	13.722	0.33	238.16	82	13.285	N/A	75.60	13.746	N/A	284.36
38	13.693	0.32	118.45	13.715	0.34	241.57	84	N/A	N/A	N/A	N/A	N/A	N/A
40	13.689	0.33	115.31	13.672	0.34	244.64	86	N/A	N/A	N/A	N/A	N/A	N/A
42	13.684	0.33	112.46	13.638	0.35	247.53	88	N/A	N/A	N/A	N/A	N/A	N/A
44	13.662	0.33	109.89	13.604	0.35	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

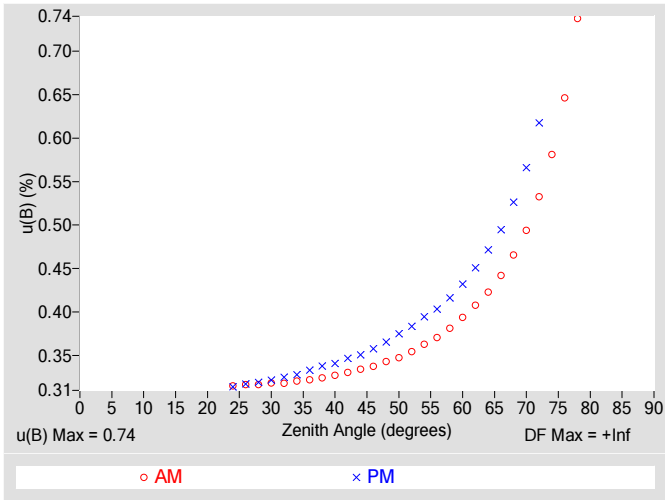


Figure 4. Residuals from Spline Interpolation

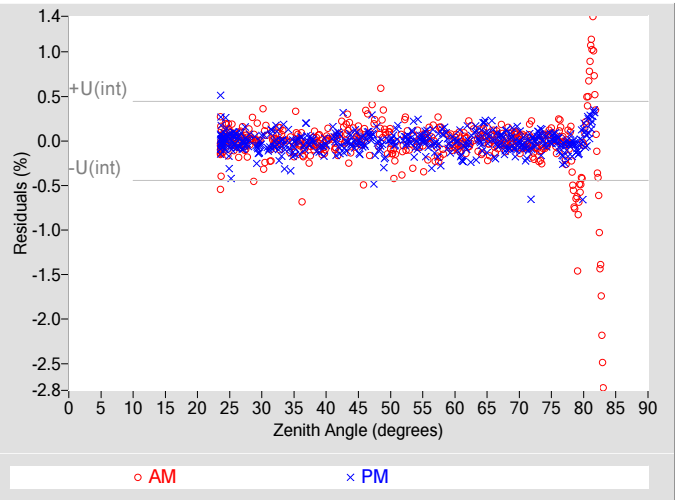


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.74
Type-A Interpolating Function, $u(int)$ (%)	± 0.22
Combined Standard Uncertainty, $u(c)$ (%)	± 0.77
Effective degrees of freedom, $DF(c)$	123097
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

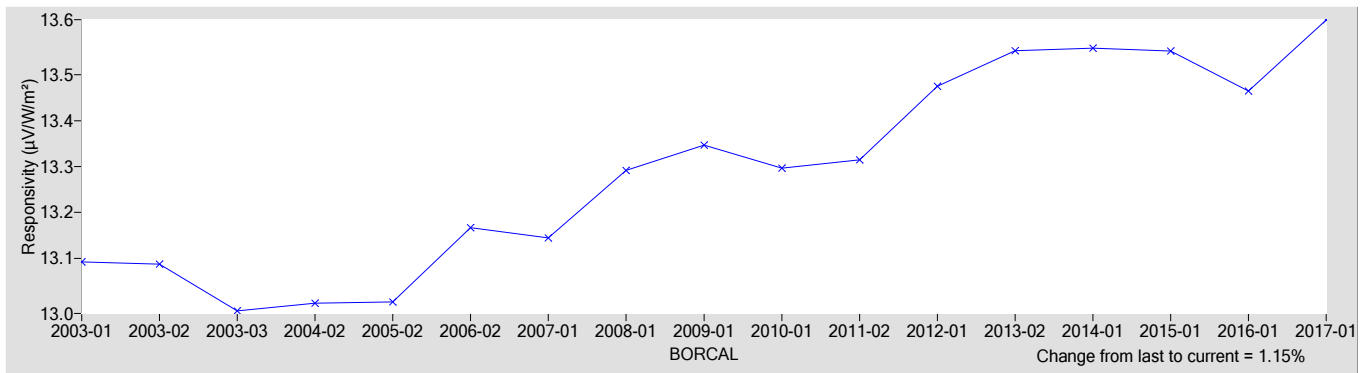
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
13.619	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+1.1 / -2.2
Expanded Uncertainty, U (%)	+2.0 / -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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Semiconductor Pyrheliometer	Manufacturer:	Licor
Model:	LI201SB	Serial Number:	PYHR101
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

PYHR101 Licor LI201SB

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
- R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
- W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
- = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
- where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
- T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
- where, $G = B * \text{COS}(Z) + D$,
- Z = zenith angle (degrees),
- D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

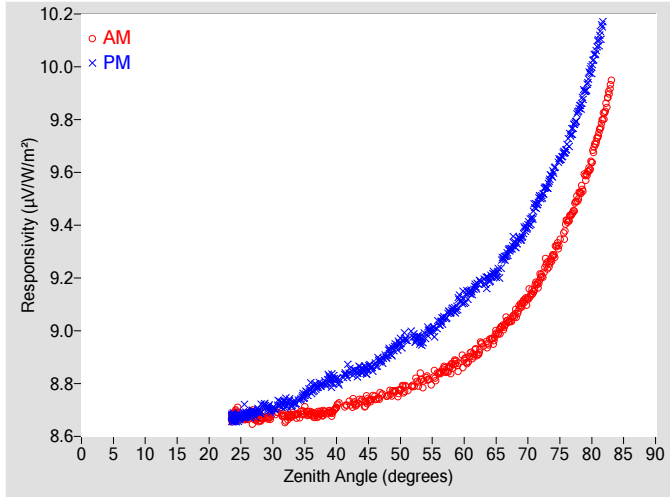


Figure 2. Responsivity vs Local Standard Time

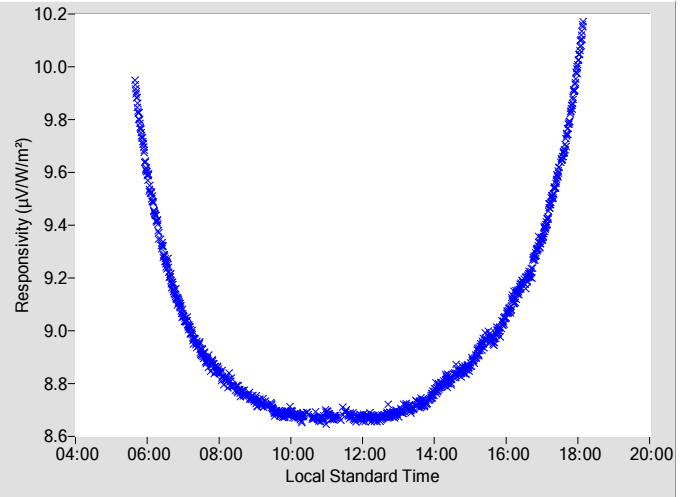


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7491	0.28	107.51	8.8725	0.28	252.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7535	0.28	105.19	8.9133	0.28	254.93
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7735	0.28	103.11	8.9526	0.28	257.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7901	0.28	101.03	8.9744	0.28	259.27
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8219	0.28	98.86	8.9907	0.28	261.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8394	0.28	97.09	9.0253	0.29	263.01
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8611	0.28	95.34	9.0764	0.29	264.79
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8900	0.28	93.60	9.1213	0.29	266.54
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9177	0.28	91.87	9.1720	0.29	268.23
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9594	0.28	90.23	9.1983	0.29	269.96
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0138	0.29	88.54	9.2688	0.29	271.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.0613	0.29	86.93	9.3274	0.29	273.29
24	8.6823	0.28	168.35	8.6704	0.28	191.55	70	9.1242	0.29	85.30	9.3980	0.30	274.88
26	8.6753	0.28	151.17	8.6836	0.28	208.37	72	9.2052	0.29	83.68	9.5071	0.30	276.46
28	8.6619	0.28	142.31	8.6978	0.28	217.68	74	9.2835	0.29	82.07	9.6020	N/A	278.07
30	N/A	N/A	N/A	8.7047	0.28	224.39	76	9.3959	0.30	80.51	9.6887	N/A	279.67
32	8.6653	0.28	130.30	8.7247	0.28	229.87	78	9.5123	0.30	78.86	9.8424	N/A	281.31
34	8.6803	0.28	125.93	8.7383	0.28	234.57	80	9.6481	N/A	77.21	10.005	N/A	282.96
36	8.6873	0.28	122.02	8.7778	0.28	238.26	82	9.8244	N/A	75.61	10.171	N/A	284.37
38	8.6872	0.28	118.52	8.8031	0.28	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7114	0.28	115.39	8.8149	0.28	244.91	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7256	0.28	112.37	8.8565	0.28	247.49	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7351	0.28	109.85	8.8471	0.28	250.14	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

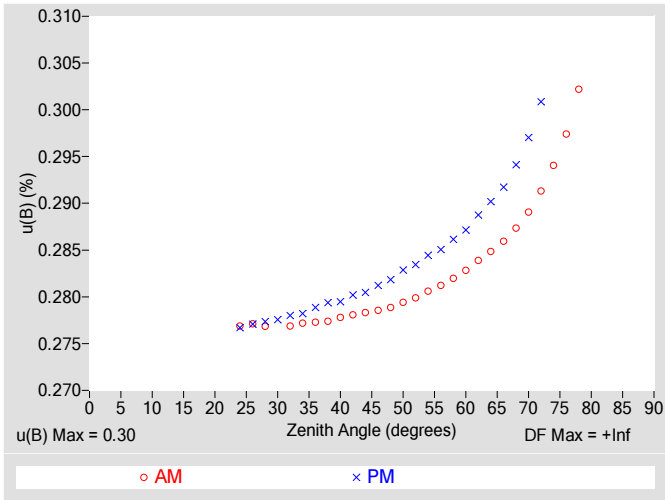


Figure 4. Residuals from Spline Interpolation

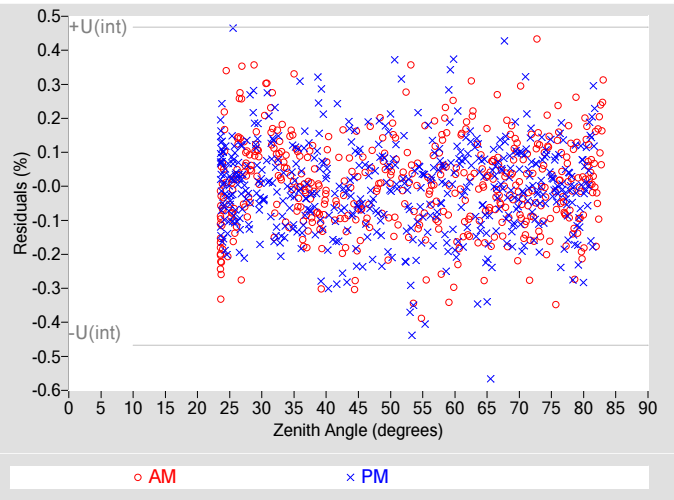


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	6236
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

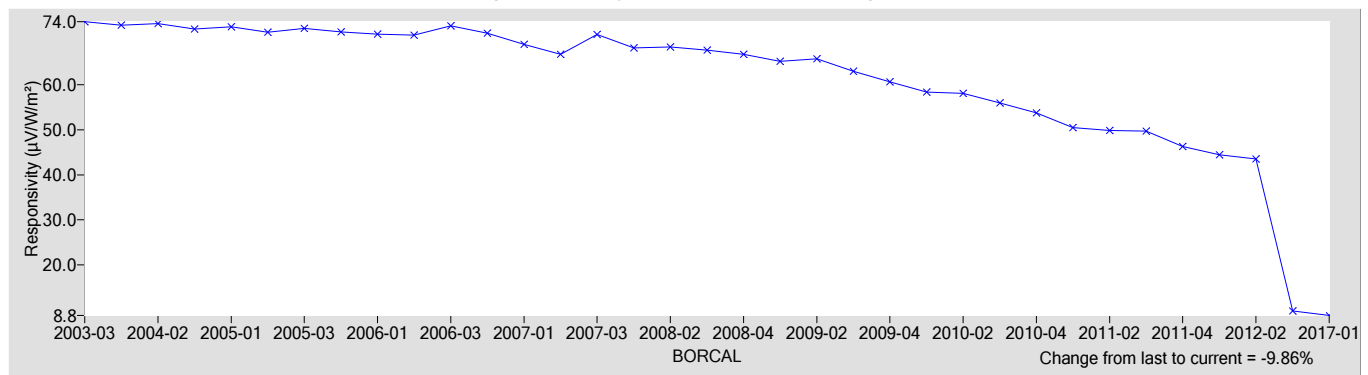
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7989	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.56
Offset Uncertainty, U(off) (%)	+3.7 / -1.5
Expanded Uncertainty, U (%)	+4.2 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	EKO
Model:	MS-602	Serial Number:	S13071483
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

S13071483 EKO MS-602

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

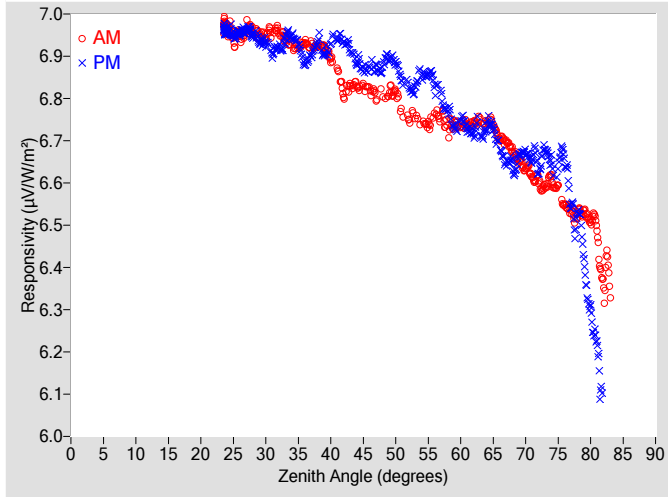


Figure 2. Responsivity vs Local Standard Time

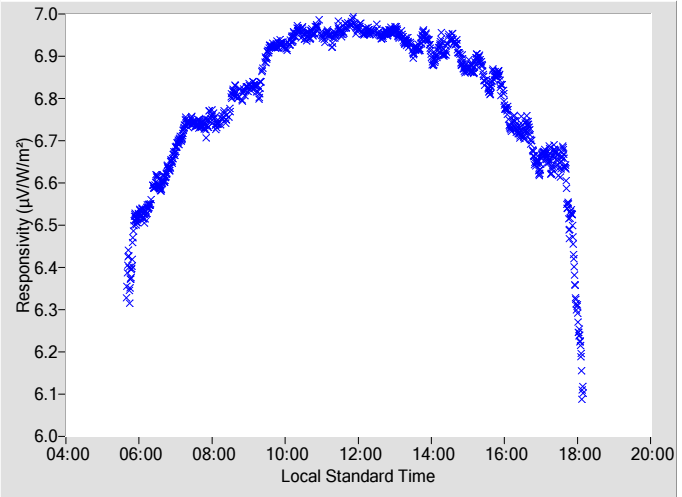


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	6.8174	0.36	107.38	6.8761	0.37	252.65
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.8130	0.36	105.32	6.8725	0.38	254.94
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.8144	0.37	103.07	6.8846	0.39	257.04
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.7505	0.37	100.99	6.8252	0.40	259.27
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.7418	0.38	99.04	6.8544	0.42	261.25
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.7603	0.39	97.17	6.8273	0.43	262.93
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.7300	0.40	95.32	6.7722	0.44	264.84
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.7365	0.42	93.50	6.7502	0.46	266.53
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.7449	0.43	91.84	6.7195	0.48	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.7411	0.45	90.19	6.7364	0.51	269.99
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.7046	0.47	88.52	6.6851	0.54	271.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.6755	0.50	86.91	6.6343	0.57	273.27
24	6.9628	0.32	167.55	6.9582	0.32	191.61	70	6.6331	0.53	85.28	6.6714	0.61	274.86
26	6.9515	0.33	151.79	6.9563	0.33	208.61	72	6.6048	0.57	83.66	6.6310	0.68	276.48
28	6.9571	0.33	142.39	6.9481	0.33	217.26	74	6.6067	0.63	82.06	6.6428	N/A	278.09
30	6.9463	0.33	135.65	6.9328	0.33	224.19	76	6.5473	0.70	80.45	6.6528	N/A	279.69
32	6.9604	0.33	130.51	6.9215	0.34	229.74	78	6.5288	0.80	78.80	6.5217	N/A	281.29
34	6.9232	0.33	125.53	6.9463	0.34	234.29	80	6.5084	N/A	77.24	6.2877	N/A	282.99
36	6.9317	0.33	121.88	6.8834	0.35	238.19	82	6.3556	N/A	75.63	6.1022	N/A	284.39
38	6.9249	0.34	118.46	6.9374	0.35	241.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	6.8926	0.34	115.29	6.9350	0.35	244.92	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.8092	0.35	112.60	6.9315	0.36	247.61	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.8317	0.35	109.85	6.8872	0.37	250.24	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

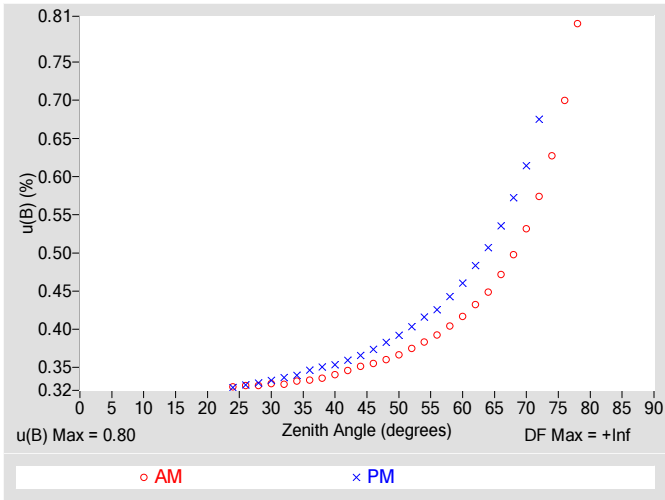


Figure 4. Residuals from Spline Interpolation

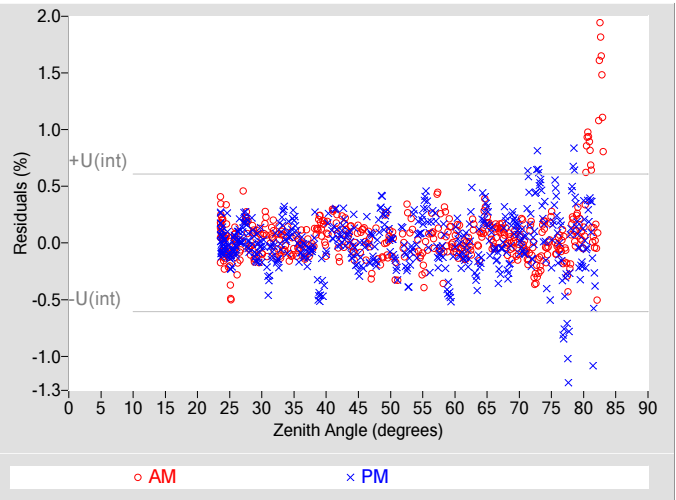


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.80
Type-A Interpolating Function, $u(int)$ (%)	± 0.30
Combined Standard Uncertainty, $u(c)$ (%)	± 0.86
Effective degrees of freedom, $DF(c)$	55296
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.7
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

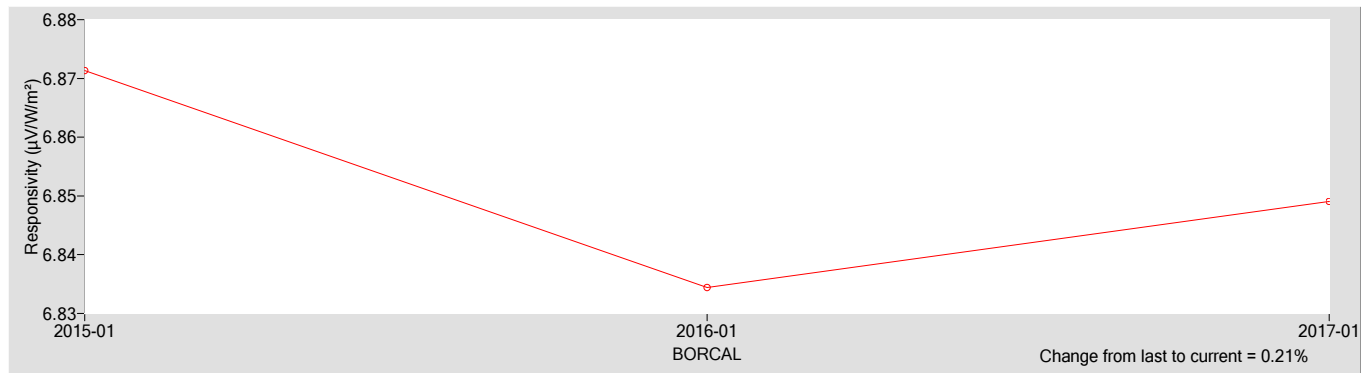
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
6.8491	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.90
Offset Uncertainty, $U(off)$ (%)	+1.6 / -1.7
Expanded Uncertainty, U (%)	+2.5 / -2.6
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



Test Instrument: Silicon Pyranometer
Manufacturer: EKO

Model: ML-01
Serial Number: S13135063

Calibration Date: 5/4/2017
Due Date: 5/4/2018

Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4

Test Dates: 5/4

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

S13135063 EKO ML-01

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

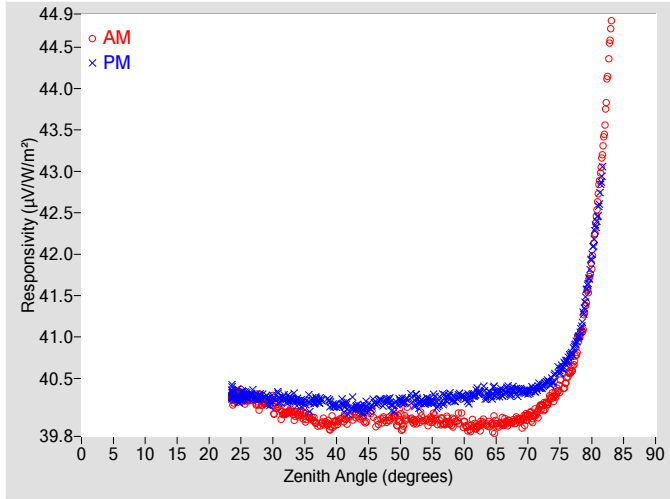


Figure 2. Responsivity vs Local Standard Time

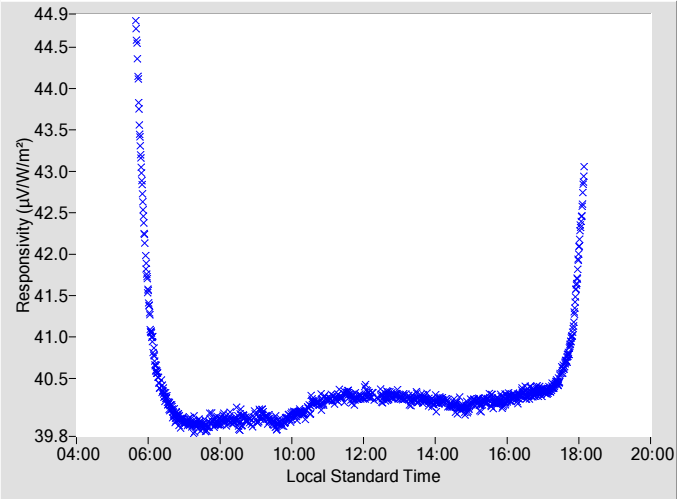


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	39.976	0.34	107.52	40.215	0.36	252.58
2	N/A	N/A	N/A	N/A	N/A	N/A	48	39.995	0.34	105.06	40.245	0.37	255.00
4	N/A	N/A	N/A	N/A	N/A	N/A	50	39.998	0.35	103.03	40.236	0.37	257.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	39.987	0.35	100.98	40.206	0.38	259.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	40.003	0.36	98.88	40.231	0.39	261.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	39.970	0.37	97.19	40.208	0.40	262.93
12	N/A	N/A	N/A	N/A	N/A	N/A	58	39.953	0.38	95.36	40.271	0.42	264.86
14	N/A	N/A	N/A	N/A	N/A	N/A	60	39.950	0.39	93.57	40.276	0.43	266.49
16	N/A	N/A	N/A	N/A	N/A	N/A	62	39.913	0.41	91.86	40.339	0.45	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	39.943	0.42	90.23	40.303	0.47	269.94
20	N/A	N/A	N/A	N/A	N/A	N/A	66	39.961	0.44	88.51	40.327	0.49	271.61
22	N/A	N/A	N/A	N/A	N/A	N/A	68	39.982	0.46	86.89	40.346	0.52	273.27
24	40.294	0.31	167.70	40.277	0.31	190.72	70	40.046	0.49	85.32	40.336	0.57	274.90
26	40.262	0.32	151.32	40.279	0.32	208.69	72	40.158	0.53	83.70	40.385	0.62	276.48
28	40.202	0.32	142.59	40.268	0.32	217.58	74	40.283	0.58	82.09	40.492	N/A	278.09
30	40.180	0.32	135.71	40.270	0.32	224.52	76	40.458	0.64	80.51	40.714	N/A	279.73
32	40.078	0.32	130.42	40.252	0.32	229.79	78	40.968	0.73	78.89	41.031	N/A	281.33
34	40.074	0.32	125.84	40.221	0.33	234.31	80	41.864	N/A	77.28	41.979	N/A	282.94
36	40.020	0.32	121.98	40.203	0.33	238.07	82	43.552	N/A	75.58	N/A	N/A	N/A
38	39.976	0.32	118.47	N/A	N/A	N/A	84	N/A	N/A	N/A	N/A	N/A	N/A
40	39.962	0.33	115.37	40.174	0.34	244.80	86	N/A	N/A	N/A	N/A	N/A	N/A
42	40.043	0.33	112.46	40.116	0.35	247.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	40.064	0.33	109.88	40.118	0.35	250.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

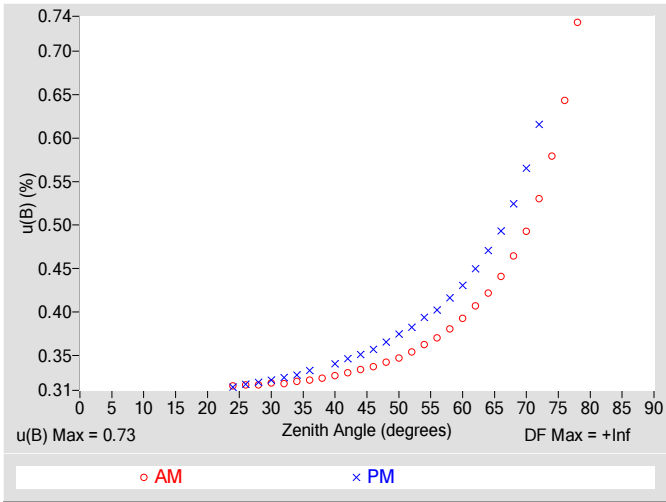


Figure 4. Residuals from Spline Interpolation

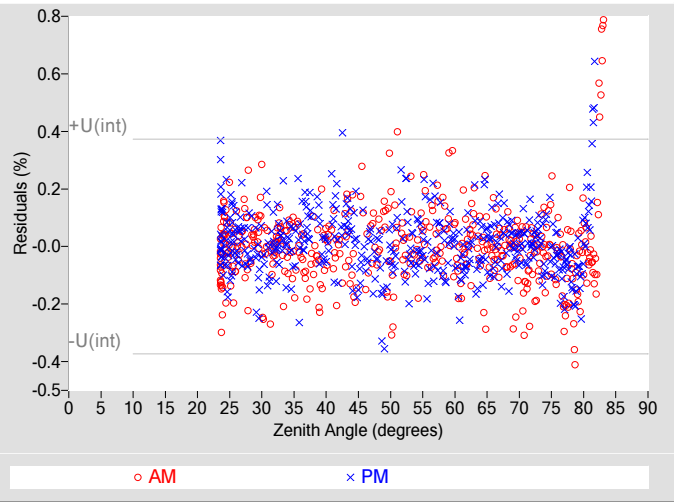


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.73
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.76
Effective degrees of freedom, $DF(c)$	230490
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.5
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

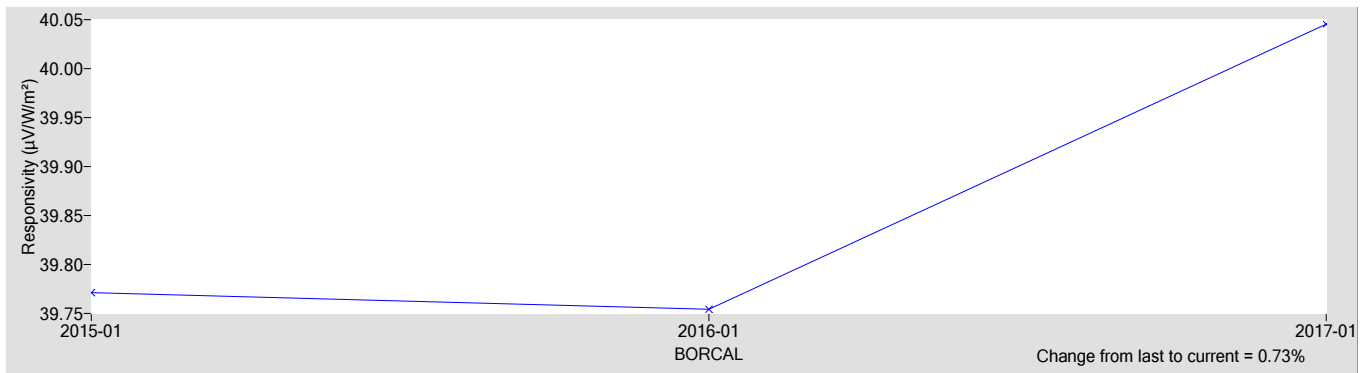
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
40.045	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.84
Offset Uncertainty, $U(off)$ (%)	+0.57 / -0.24
Expanded Uncertainty, U (%)	+1.4 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate



Test Instrument:	Pyranometer	Manufacturer:	EKO
Model:	MS-410	Serial Number:	S13144.085R
Calibration Date:	5/4/2017	Due Date:	5/4/2018
Customer:	NREL-SRRL-BMS	Environmental Conditions:	see page 4
Test Dates:	5/4		

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/26/2016	09/26/2017
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32858	03/10/2016	03/10/2018
Diffuse Irradiance †	Eppley Black and White Pyranometer Model 8-48, S/N 32871	03/10/2016	03/10/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	06/05/2015	06/05/2019

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: 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

S13144.085R EKO MS-410

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

- V = radiometer output voltage (microvolts),
 - R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 - W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 - = $W_{in} - W_{out} = W_{in} - \sigma * T_c^4$
 - where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 - T_c = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m^2), beam (B) or global (G)
 - where, $G = B * \text{COS}(Z) + D$,
 - Z = zenith angle (degrees),
 - D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

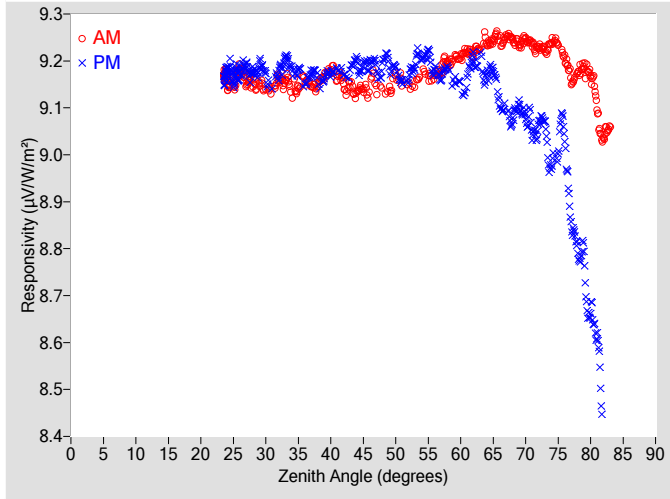


Figure 2. Responsivity vs Local Standard Time

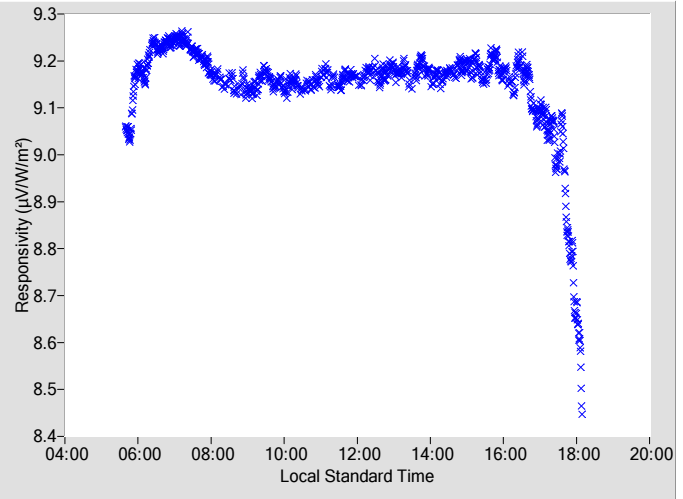


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1535	0.34	107.30	9.1918	0.36	252.71
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1422	0.35	105.37	9.1887	0.37	254.89
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1672	0.35	102.99	9.1867	0.38	257.03
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1477	0.36	100.93	9.1699	0.39	259.25
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1825	0.37	98.78	9.2039	0.40	261.19
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1692	0.38	97.13	9.1796	0.41	262.98
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1958	0.39	95.32	9.1844	0.42	264.84
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2064	0.40	93.57	9.1495	0.44	266.49
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2154	0.41	91.86	9.2006	0.46	268.27
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2374	0.43	90.19	9.1680	0.48	269.98
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2453	0.45	88.56	9.1065	0.51	271.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.2452	0.47	86.91	9.0751	0.54	273.27
24	9.1606	0.32	168.07	9.1754	0.32	191.63	70	9.2463	0.50	85.27	9.0797	0.58	274.85
26	9.1763	0.32	151.31	9.1731	0.32	208.73	72	9.2291	0.54	83.65	9.0604	0.63	276.48
28	9.1491	0.32	142.42	9.1770	0.32	217.65	74	9.2391	0.59	82.09	8.9821	N/A	278.09
30	9.1394	0.32	135.64	9.1643	0.33	224.58	76	9.2043	0.66	80.49	9.0330	N/A	279.69
32	9.1627	0.32	130.35	9.1777	0.33	229.85	78	9.1742	0.76	78.80	8.7962	N/A	281.29
34	9.1272	0.32	125.88	9.1815	0.33	234.11	80	9.1675	N/A	77.24	8.6645	N/A	282.98
36	9.1594	0.33	121.98	9.1499	0.34	238.33	82	9.0348	N/A	75.63	8.4469	N/A	284.39
38	9.1462	0.33	118.50	9.1629	0.34	241.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1792	0.33	115.21	9.1732	0.34	244.94	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1525	0.33	112.53	9.1705	0.35	247.70	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1317	0.34	109.85	9.1982	0.36	250.24	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

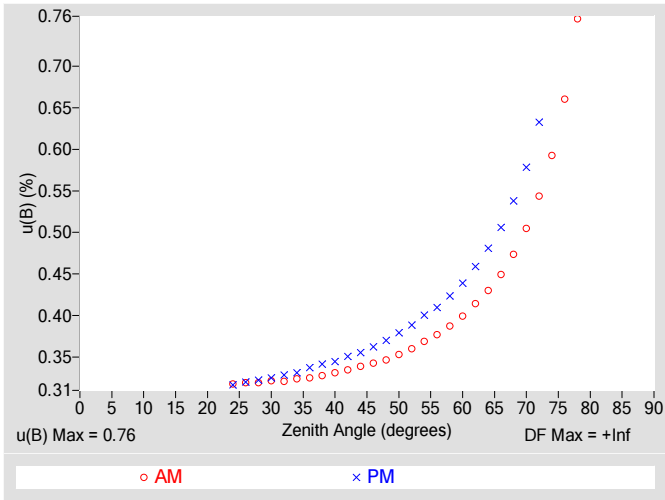


Figure 4. Residuals from Spline Interpolation

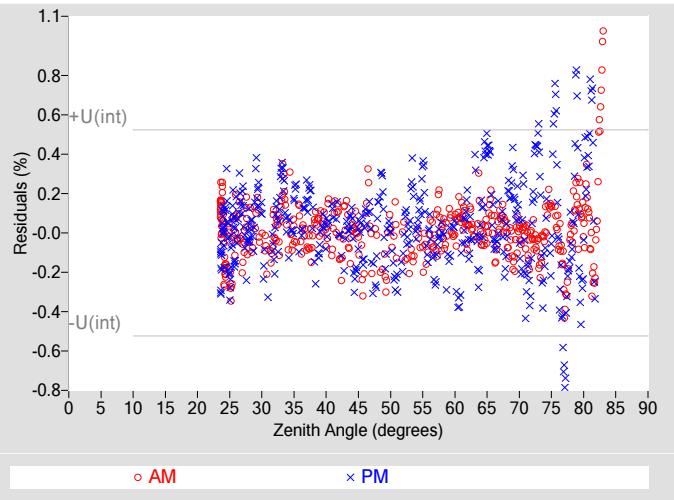


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.76
Type-A Interpolating Function, $u(int)$ (%)	± 0.26
Combined Standard Uncertainty, $u(c)$ (%)	± 0.80
Effective degrees of freedom, $DF(c)$	74241
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 72°

Table 4. Calibration Label Values

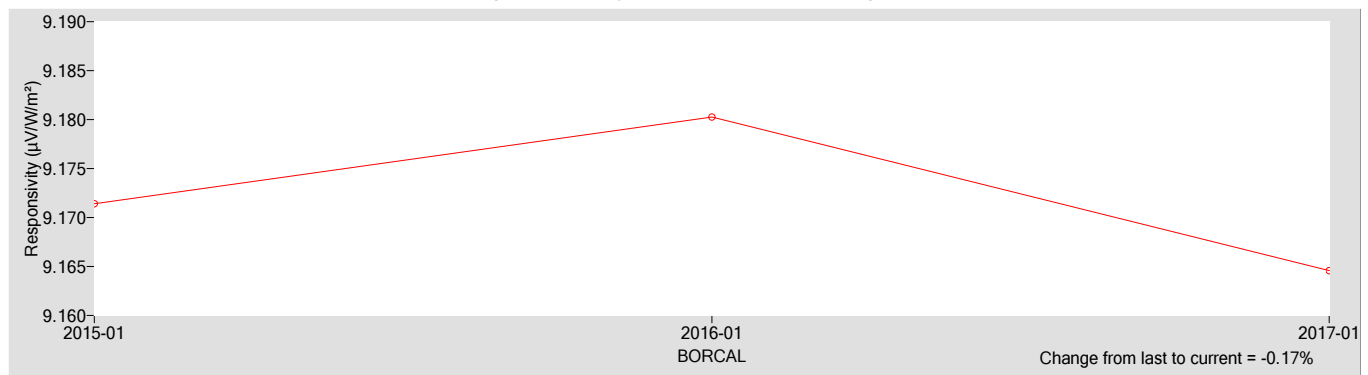
R @ 45° ($\mu V/W/m^2$)	Rnet ($\mu V/W/m^2$) †
9.1646	0.20000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.86
Offset Uncertainty, $U(off)$ (%)	+0.46 / -0.41
Expanded Uncertainty, U (%)	+1.3 / -1.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Environmental and Sky Conditions for BORCAL-SW 2017-01

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

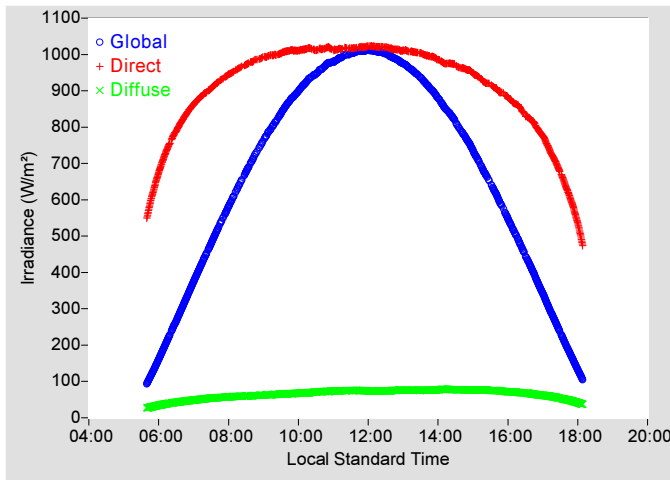
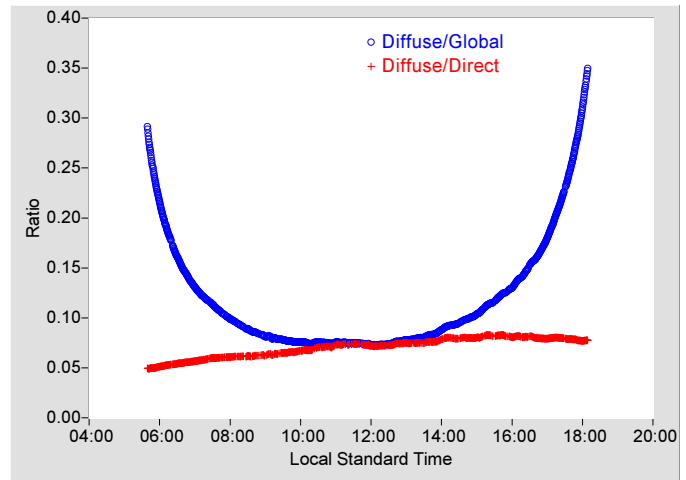


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

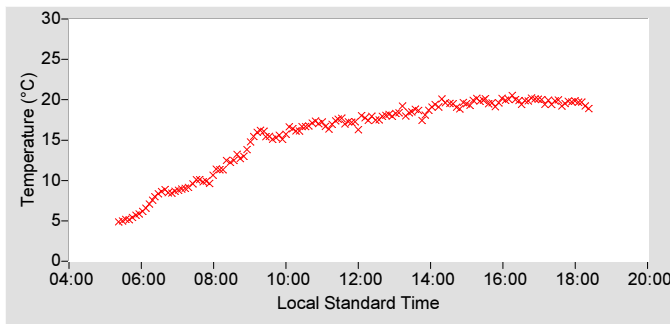


Figure 9. Humidity

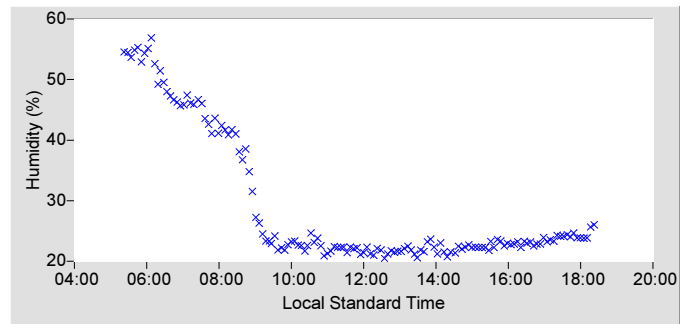


Figure 10. Pressure

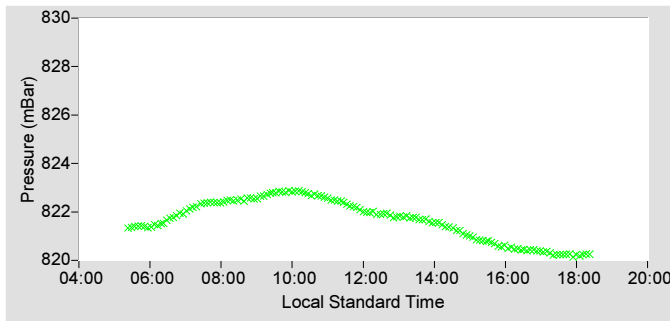


Figure 11. Effective Net Infrared

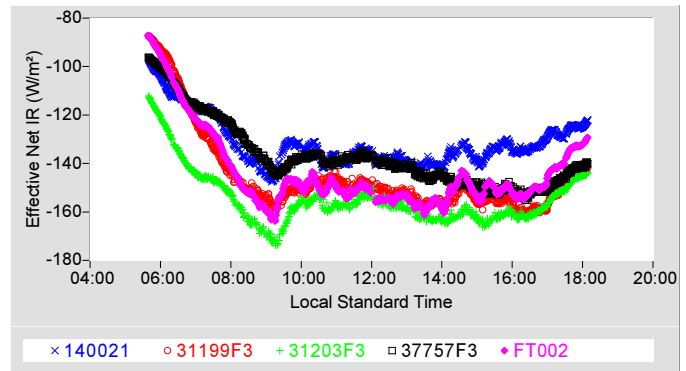


Figure 12. Estimated Broadband Aerosol Optical Depth

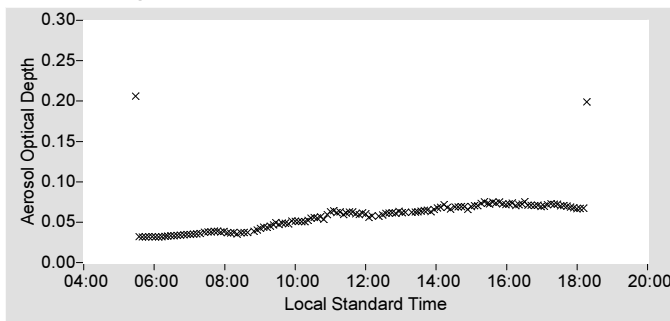


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	15.76	4.87	20.52
Humidity (%)	29.18	20.48	56.90
Pressure (mBar)	821.7	820.1	822.9
Est. Aerosol Optical Depth (BB)	0.058	0.032	0.206

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

Appendix 2

BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Solar Radiation Research Laboratory

Comments:

Avg. Station Pressure & Temperature is for Denver, CO, which is used for the Solar Position Algorithm (SPA).