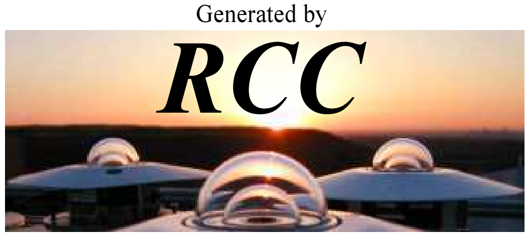
Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2018-03

Generated by



Radiometer Calibration and Characterization

<u>Customer</u>

NREL-SRRL-BMS

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

<u>Calibration Facility</u>

Solar Radiation Research Laboratory

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

Calibration date
05/15/2018 to 05/16/2018

Report Date
May 23, 2018

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

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

This report includes these sections:

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

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

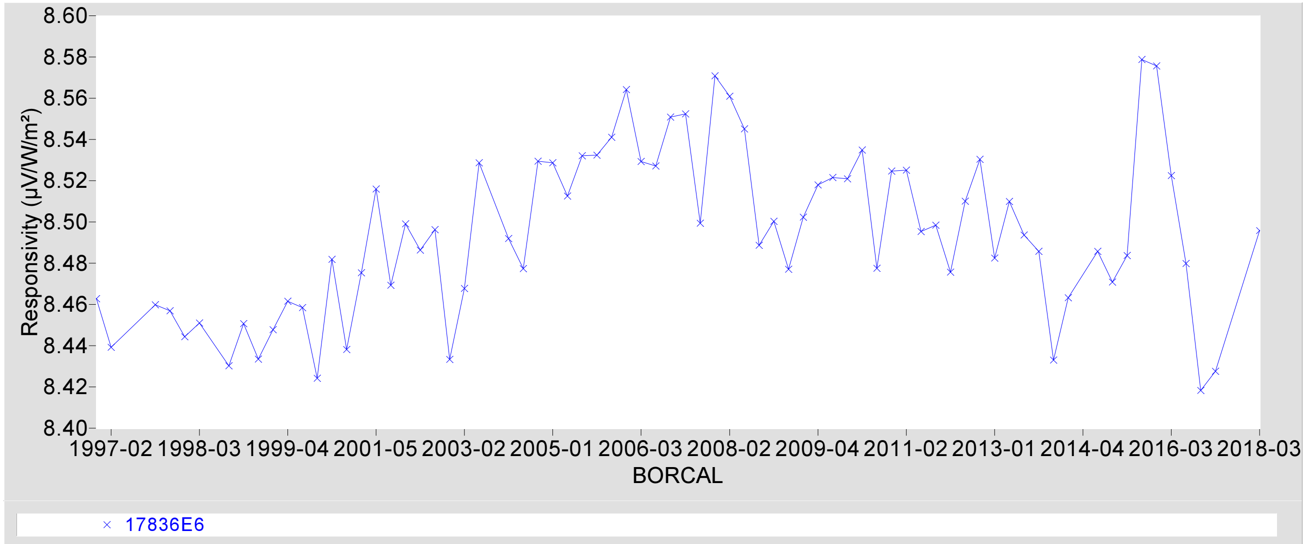
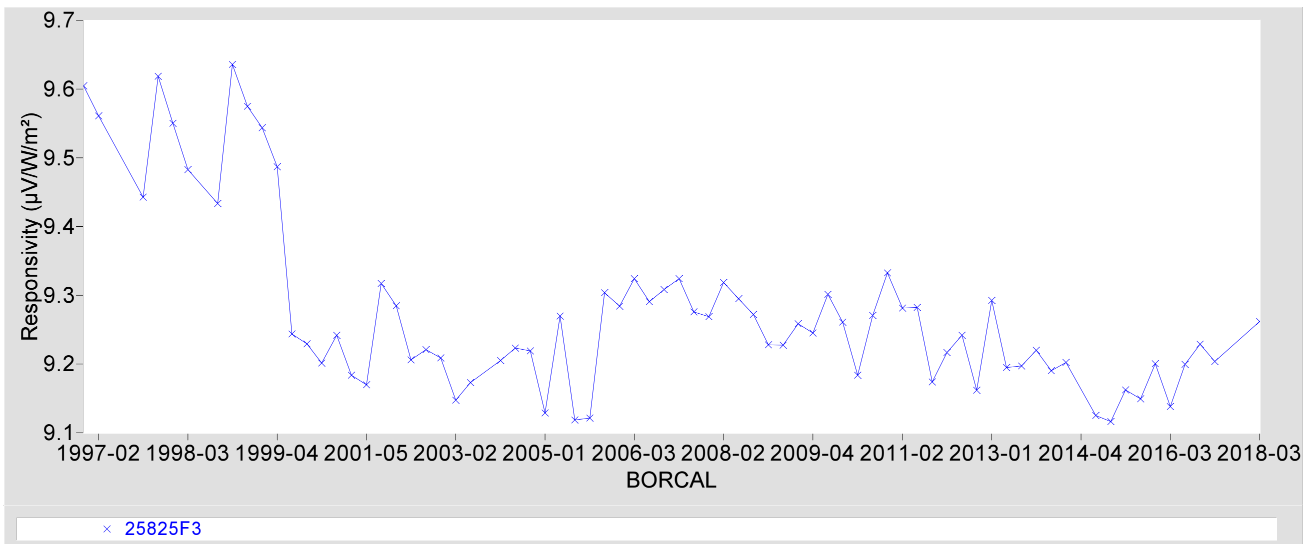


Figure 2. Eppley PSP Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	R@45 ¹ (µV/W/m²)	CF@45 ¹ (W/m²/mV)	U ² (%)	Rnet ³ (µV/W/m²)	Page
010046 Kipp & Zonen CM22	9.3631	106.80	+4.1 / -1.1	0.087000	A1-2
014261 Kipp & Zonen CM3	22.006	45.441	+0.92 / -1.5	0.40000	A1-5
015189 Kipp & Zonen CM6B	10.932	91.477	+2.2 / -1.7	0.30000	A1-8
0212-2 Yankee TSP-700	2978.9	0.33570	+3.2 / -1.2	0	A1-11
080009 Kipp & Zonen CHP1	7.9348	126.03	+0.78 / -1.4	0	A1-14
080017 Kipp & Zonen CMP22	10.530	94.963	+3.3 / -1.3	0.087000	A1-17
100174 Kipp & Zonen CMP22	9.7895	102.15	+1.0 / -1.1	0.087000	A1-20
1171 Apogee SP-510	53.960	18.532	+2.7 / -4.0	2.5000	A1-23
140043 Kipp & Zonen CMP22	9.0413	110.60	+1.0 / -0.95	0.087000	A1-26
140108 Kipp & Zonen CHP1	8.0489	124.24	+0.86 / -1.9	0	A1-29
140712 Kipp & Zonen CMP11	9.0321	110.72	+1.6 / -1.7	0.20500	A1-32
151027 Kipp & Zonen SP-LITE2	69.655	14.356	+3.1 / -2.0	0	A1-35
170515 Kipp & Zonen CMP22	9.3270	107.22	+1.0 / -1.5	0.087000	A1-38
21096 Eppley 8-48	11.292	88.561	+2.7 / -1.4	0	A1-41
2530 Hukseflux SR25	11.059	90.422	+1.6 / -1.7	0.043000	A1-44
2543 Hukseflux SR25	9.4984	105.28	+1.6 / -1.1	0.043000	A1-47
28402F3 Eppley PSP	7.0189	142.47	+2.1 / -2.1	0.64000	A1-50
31137E6 Eppley NIP	8.4532	118.30	+2.2 / -0.97	0	A1-53
37831F3 Eppley GPP	8.4910	117.77	+1.6 / -2.7	0.15000	A1-56
37839F3 Eppley SPP	8.5992	116.29	+1.7 / -1.7	0.30000	A1-59
37882E6 Eppley sNIP	8.3647	119.55	+1.1 / -0.73	0	A1-62
40337 Apogee SP-110	185.18	5.4001	+1.8 / -2.7	0	A1-65
9206 Hukseflux DR02	11.052	90.485	+0.78 / -0.75	0	A1-68
A360 Delta-T SPN1	1020.1	0.98032	+7.5 / -5.1	0	A1-71
F14077R EKO MS-802	7.0798	141.25	+2.0 / -2.3	0.18000	A1-74
P12022 EKO MS-56	7.2231	138.44	+0.91 / -1.5	0	A1-77
PY100360 Licor LI200R	10.866	92.034	+1.2 / -0.95	0	A1-80
PY102023 Licor LI200R	10.048	99.527	+1.3 / -1.1	0	A1-83
PY28257 Licor LI200	13.711	72.936	+2.1 / -2.6	0	A1-86
PYHR101 Licor LI201SB	7.5910	131.74	+4.6 / -1.7	0	A1-89
S13071483 EKO MS-602	6.9713	143.45	+1.9 / -2.0	0.30000	A1-92
S13135063 EKO ML-01	40.557	24.656	+1.7 / -1.0	0	A1-95
S13144.085R EKO MS-410	9.2482	108.13	+1.7 / -1.2	0.20000	A1-98
S17096005 EKO MS-80	10.669	93.727	+2.7 / -0.97	0.043000	A1-101

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 A1-104.

Appendix 1
Instrument Details

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CM22	**Serial Number:**	010046
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model 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: 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

010046 Kipp & Zonen CM22

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

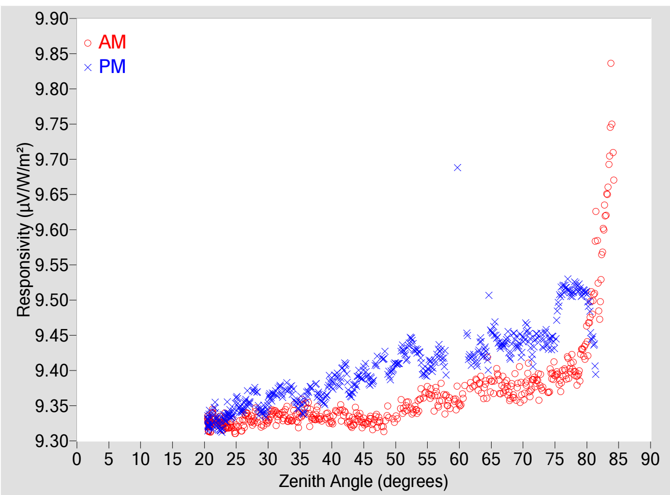


Figure 2. Responsivity vs Local Standard Time

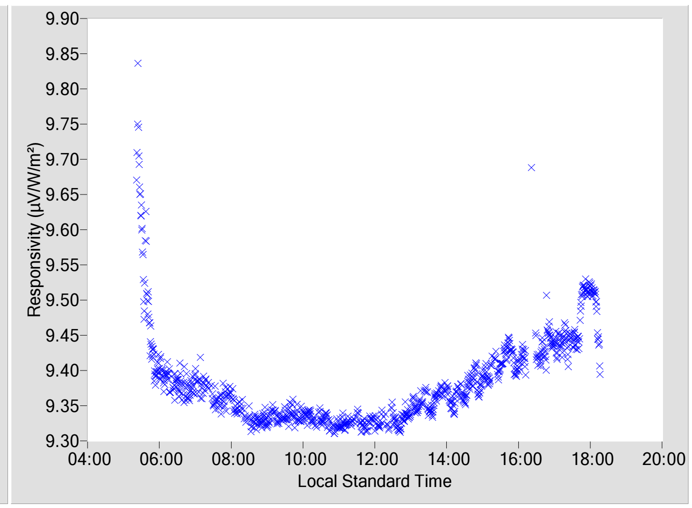


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.3299	0.29	102.01	9.3847	0.29	258.06
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.3177	0.29	99.96	9.4191	0.29	260.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3310	0.29	97.98	9.4097	0.30	262.06
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3513	0.30	96.30	9.4340	0.30	263.97
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3643	0.30	94.45	9.4102	0.30	265.80
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3608	0.30	92.45	9.4073	0.31	267.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3537	0.30	90.93	9.4107	0.32	269.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3514	0.31	89.18	9.6880	N/A	270.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3799	0.31	87.63	9.4168	0.33	272.17
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.3724	0.32	85.94	9.4261	0.34	273.85
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.3943	0.33	84.37	9.4443	0.35	275.38
22	9.3275	0.28	156.58	9.3288	0.28	203.60	68	9.3691	0.34	82.82	9.4244	0.37	277.00
24	9.3219	0.28	144.65	9.3364	0.28	215.38	70	9.3638	0.35	81.20	9.4411	N/A	278.60
26	9.3214	0.28	136.61	9.3452	0.28	223.34	72	9.3843	0.37	79.65	9.4476	N/A	280.20
28	9.3345	0.28	130.89	9.3713	0.28	229.31	74	9.3775	0.40	78.03	9.4380	N/A	281.71
30	9.3278	0.28	125.84	9.3574	0.28	234.39	76	9.3860	0.43	76.50	9.5119	N/A	283.30
32	9.3359	0.28	121.44	9.3714	0.29	238.60	78	9.4007	N/A	74.91	9.5164	N/A	284.94
34	9.3379	0.28	118.04	9.3633	0.29	242.23	80	9.4411	N/A	73.27	9.5037	N/A	286.59
36	9.3487	0.29	114.59	9.3636	0.29	245.49	82	9.5017	N/A	71.62	N/A	N/A	N/A
38	9.3354	0.29	111.72	9.3645	0.29	248.41	84	9.7416	N/A	69.90	N/A	N/A	N/A
40	9.3281	0.29	108.97	9.3813	0.29	251.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3395	0.29	106.55	9.4069	0.29	253.63	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3360	0.29	104.20	9.3891	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

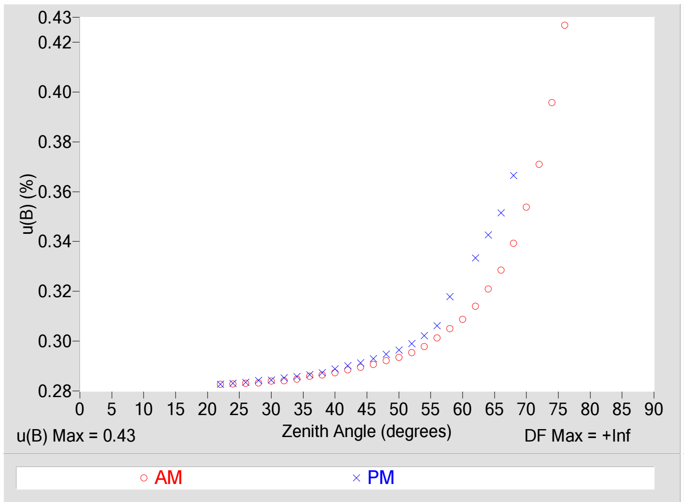


Figure 4. Residuals from Spline Interpolation

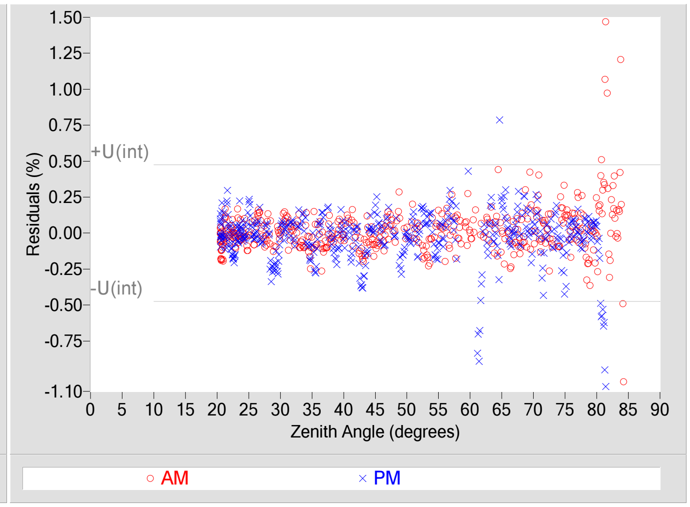


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	14662
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.96
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

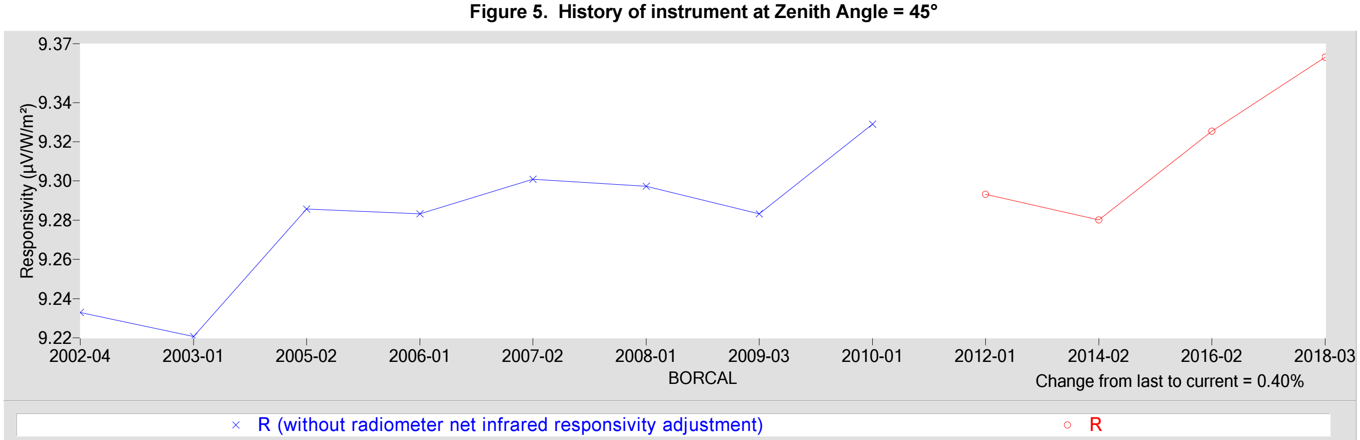
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.3631	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+3.5 / -0.49
Expanded Uncertainty, U (%)	+4.1 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM3	**Serial Number:**	014261
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

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Ibrahim Reda, Technical Manager   Date

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

Calibration Results

014261 Kipp & Zonen CM3

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

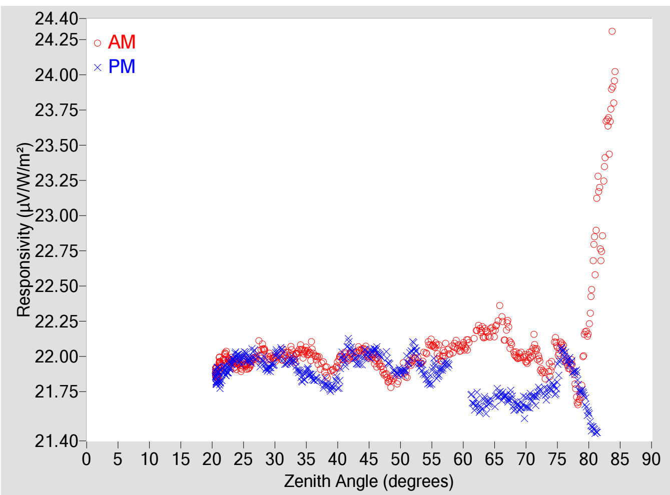


Figure 2. Responsivity vs Local Standard Time

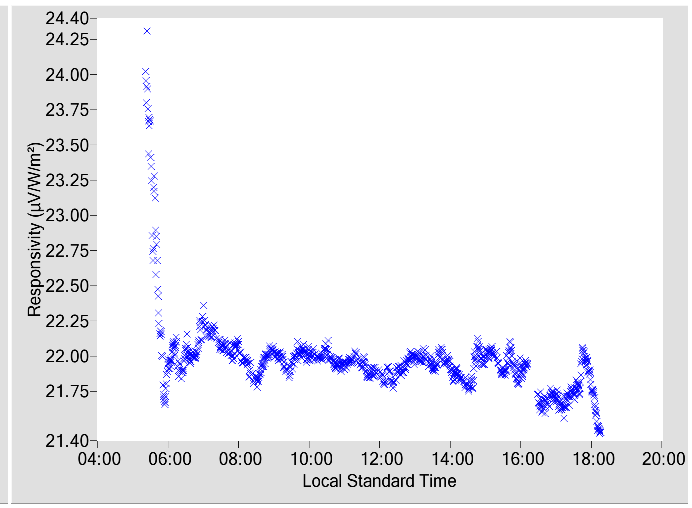


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	21.970	0.29	102.04	22.053	0.29	258.06
2	N/A	N/A	N/A	N/A	N/A	N/A	48	21.840	0.29	99.98	21.974	0.30	260.13
4	N/A	N/A	N/A	N/A	N/A	N/A	50	21.877	0.30	98.15	21.900	0.30	262.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	21.978	0.30	96.16	22.066	0.30	263.91
8	N/A	N/A	N/A	N/A	N/A	N/A	54	22.025	0.30	94.36	21.858	0.30	265.81
10	N/A	N/A	N/A	N/A	N/A	N/A	56	22.033	0.30	92.61	21.870	0.31	267.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	22.037	0.31	90.91	21.938	0.32	268.97
14	N/A	N/A	N/A	N/A	N/A	N/A	60	22.073	0.31	89.23	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	22.165	0.32	87.60	21.674	0.34	272.25
18	N/A	N/A	N/A	N/A	N/A	N/A	64	22.151	0.32	85.96	21.668	0.35	273.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	22.297	0.33	84.34	21.725	0.36	275.43
22	21.997	0.28	156.25	21.903	0.28	203.68	68	22.032	0.34	82.77	21.656	0.37	277.04
24	21.947	0.28	144.36	21.999	0.28	215.54	70	21.978	0.36	81.28	21.638	N/A	278.55
26	21.937	0.28	136.74	21.975	0.28	223.34	72	21.998	0.38	79.69	21.754	N/A	280.15
28	22.041	0.28	130.68	21.976	0.29	229.36	74	21.919	0.40	78.12	21.781	N/A	281.76
30	21.985	0.29	125.78	21.992	0.29	234.30	76	22.047	0.43	76.54	22.026	N/A	283.35
32	22.000	0.29	121.49	21.953	0.29	238.35	78	21.748	N/A	74.91	21.877	N/A	284.94
34	22.052	0.29	117.95	21.870	0.29	242.23	80	22.211	N/A	73.27	21.572	N/A	286.58
36	22.038	0.29	114.80	21.849	0.29	245.49	82	22.850	N/A	71.67	N/A	N/A	N/A
38	21.913	0.29	111.67	21.805	0.29	248.37	84	24.000	N/A	69.95	N/A	N/A	N/A
40	21.942	0.29	109.05	21.807	0.29	251.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	22.011	0.29	106.52	22.062	0.29	253.63	88	N/A	N/A	N/A	N/A	N/A	N/A
44	22.047	0.29	104.21	21.992	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

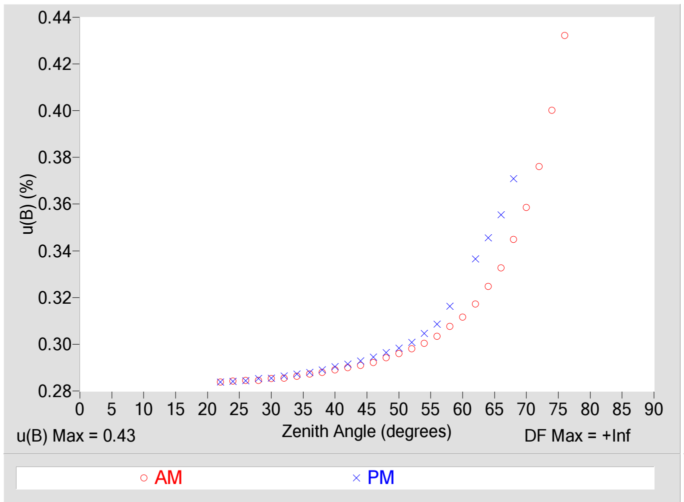


Figure 4. Residuals from Spline Interpolation

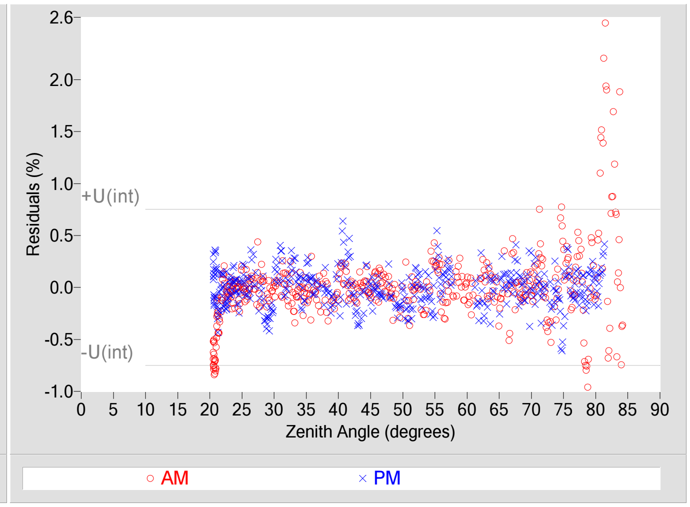


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.38
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	4418
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

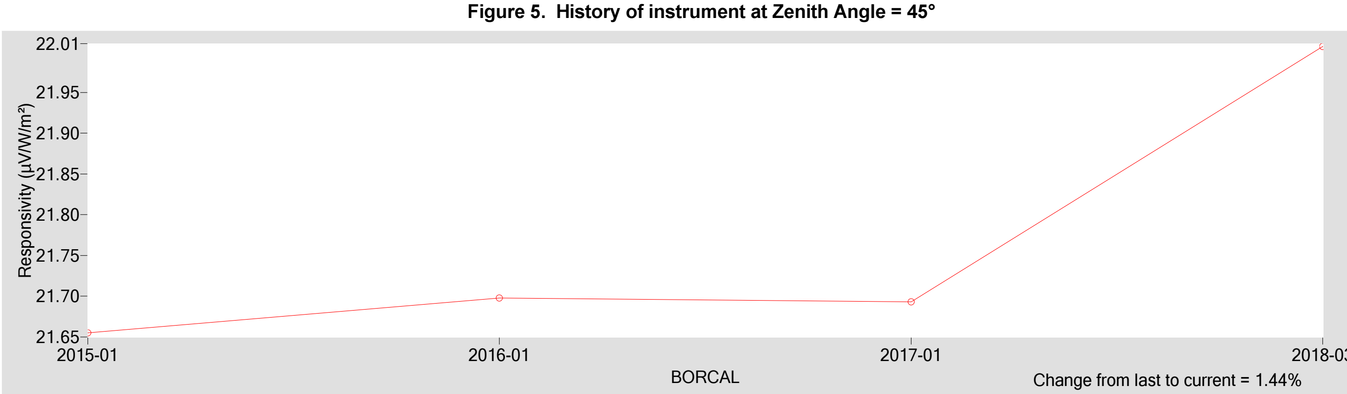
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
22.006	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.30 / -0.92
Expanded Uncertainty, U (%)	+0.92 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument: Pyranometer

Manufacturer: Kipp & Zonen

Model: CM6B

Serial Number: 015189

Calibration Date: 5/16/2018

Due Date: 5/16/2019

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/15-16

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

015189 Kipp & Zonen CM6B

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

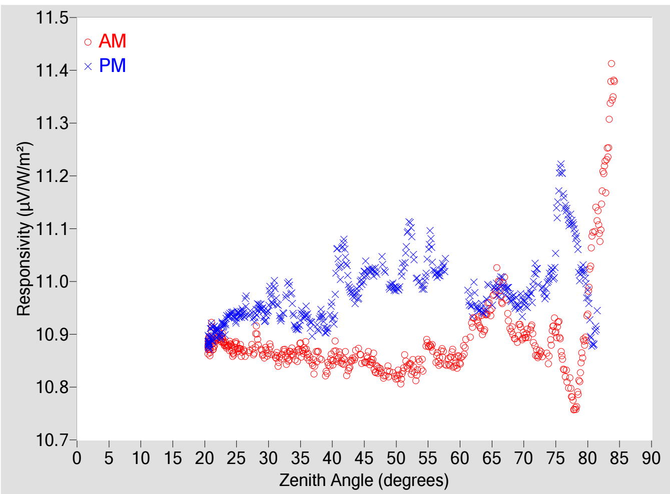


Figure 2. Responsivity vs Local Standard Time

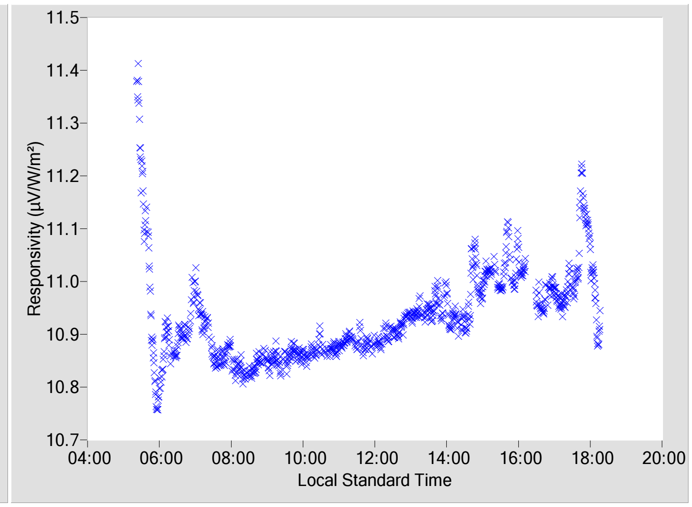


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.847	0.30	102.05	11.021	0.30	258.07
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.819	0.30	99.93	11.029	0.30	260.13
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.818	0.30	98.01	10.987	0.30	262.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.842	0.31	96.10	11.103	0.31	263.89
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.841	0.31	94.37	10.990	0.31	265.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.857	0.31	92.61	11.018	0.32	267.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.846	0.32	90.81	11.044	0.32	268.98
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.851	0.32	89.23	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.924	0.33	87.59	10.966	0.34	272.25
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.925	0.34	85.99	10.953	0.35	273.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.002	0.35	84.35	10.985	0.37	275.43
22	10.895	0.29	155.93	10.904	0.29	203.56	68	10.907	0.36	82.75	10.968	0.38	277.04
24	10.878	0.29	144.37	10.938	0.29	215.50	70	10.896	0.37	81.28	10.956	N/A	278.55
26	10.866	0.29	136.89	10.939	0.29	223.35	72	10.865	0.39	79.70	11.018	N/A	280.15
28	10.891	0.29	130.60	10.939	0.29	229.37	74	10.864	0.42	78.09	11.011	N/A	281.76
30	10.869	0.29	125.74	10.960	0.29	234.28	76	10.856	0.46	76.50	11.192	N/A	283.35
32	10.857	0.29	121.64	10.932	0.29	238.44	78	10.762	N/A	74.91	11.093	N/A	284.94
34	10.860	0.29	117.95	10.924	0.29	242.23	80	10.946	N/A	73.27	10.967	N/A	286.59
36	10.868	0.29	114.67	10.939	0.29	245.40	82	11.115	N/A	71.62	N/A	N/A	N/A
38	10.858	0.29	111.65	10.927	0.29	248.42	84	11.373	N/A	69.96	N/A	N/A	N/A
40	10.854	0.29	108.98	10.938	0.29	251.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.846	0.29	106.52	11.050	0.30	253.63	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.873	0.30	104.08	10.978	0.30	255.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

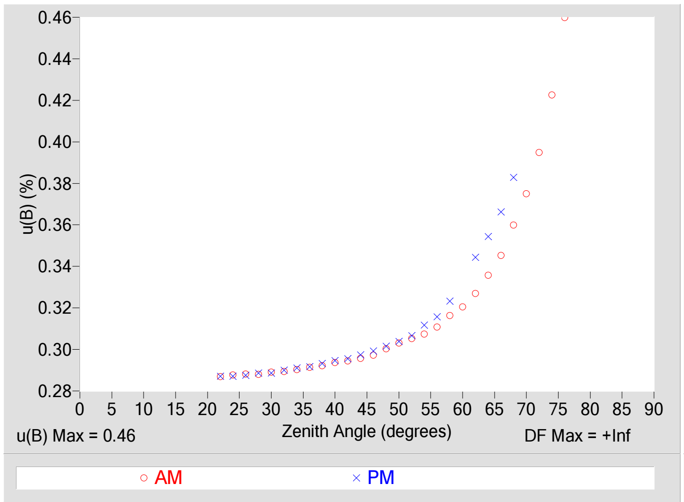


Figure 4. Residuals from Spline Interpolation

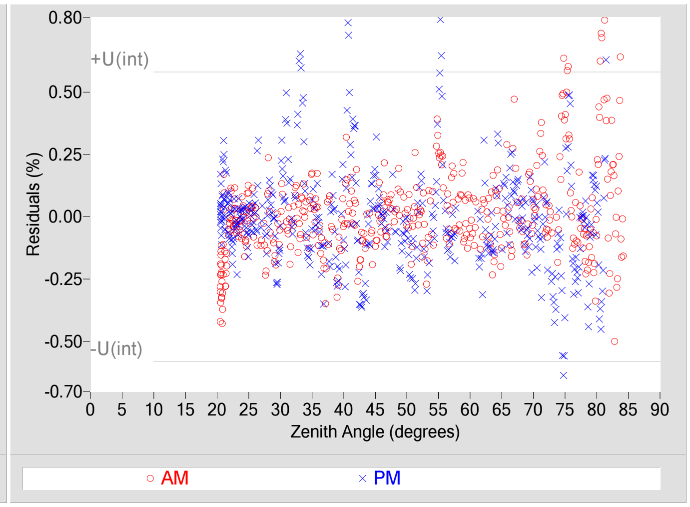


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	9863
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

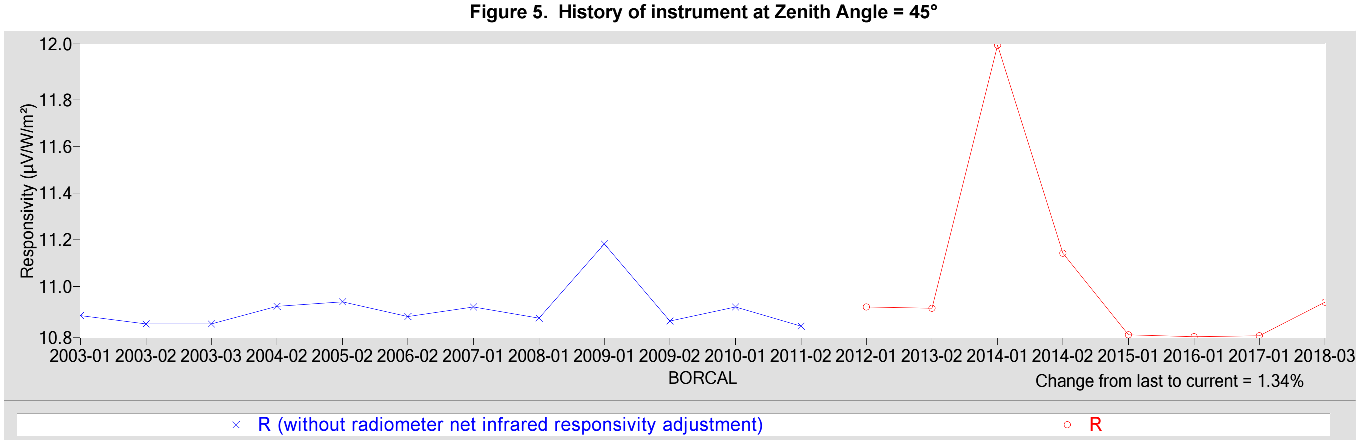
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.932	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+1.6 / -1.0
Expanded Uncertainty, U (%)	+2.2 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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

Calibration CERT #1239.02

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Yankee
Model:	TSP-700	**Serial Number:**	0212-2
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ____________

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

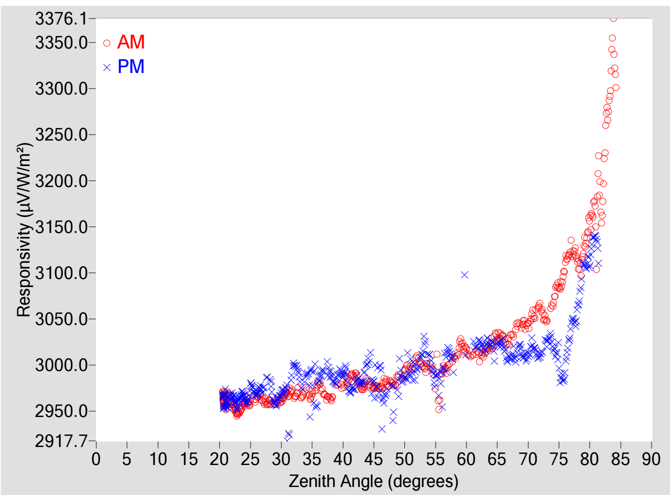


Figure 2. Responsivity vs Local Standard Time

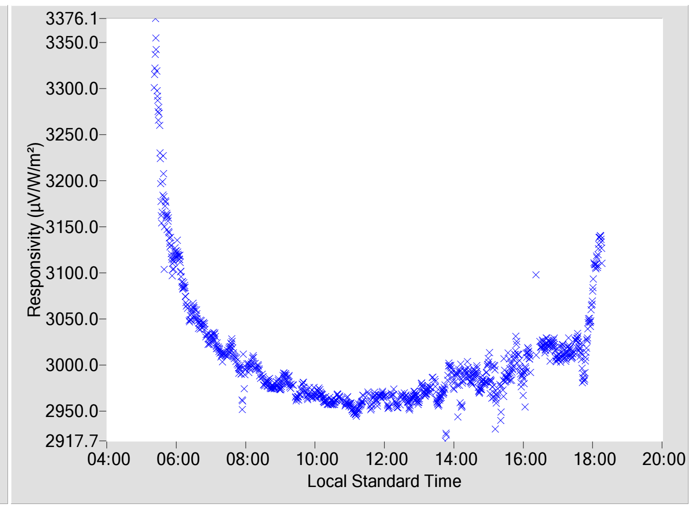


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	2975.4	0.29	102.04	2976.5	0.29	258.06
2	N/A	N/A	N/A	N/A	N/A	N/A	48	2980.1	0.29	100.04	2964.6	0.29	260.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	2994.4	0.29	98.01	2985.5	0.29	262.06
6	N/A	N/A	N/A	N/A	N/A	N/A	52	3008.6	0.29	96.14	2995.7	0.30	263.94
8	N/A	N/A	N/A	N/A	N/A	N/A	54	2999.5	0.30	94.18	3006.4	0.30	265.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	2993.5	0.30	92.50	2983.5	0.30	267.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	3007.1	0.30	90.90	3000.9	0.31	269.07
14	N/A	N/A	N/A	N/A	N/A	N/A	60	3015.9	0.31	89.25	3054.3	N/A	270.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	3010.3	0.31	87.62	3023.5	0.33	272.20
18	N/A	N/A	N/A	N/A	N/A	N/A	64	3020.1	0.32	85.94	3023.3	0.34	273.85
20	N/A	N/A	N/A	N/A	N/A	N/A	66	3030.8	0.32	84.44	3022.0	0.35	275.38
22	2960.4	0.28	156.32	2966.0	0.28	203.65	68	3041.8	0.33	82.72	3008.2	0.36	276.99
24	2957.6	0.28	144.76	2965.5	0.28	215.37	70	3043.3	0.35	81.27	3010.6	N/A	278.60
26	2964.1	0.28	136.54	2969.3	0.28	223.33	72	3062.1	0.36	79.65	3012.5	N/A	280.20
28	2959.6	0.28	130.67	2984.4	0.28	229.52	74	3067.8	0.39	78.05	3022.0	N/A	281.71
30	2961.1	0.28	125.73	2970.3	0.28	234.38	76	3109.6	0.41	76.49	2997.6	N/A	283.35
32	2967.1	0.28	121.39	2999.6	0.28	238.69	78	3112.8	N/A	74.91	3058.4	N/A	284.94
34	2973.2	0.28	118.04	2988.1	0.28	242.28	80	3155.8	N/A	73.27	3115.4	N/A	286.58
36	2979.4	0.28	114.71	2977.8	0.28	245.48	82	3171.3	N/A	71.62	N/A	N/A	N/A
38	2963.5	0.28	111.64	2990.0	0.29	248.41	84	3330.4	N/A	69.90	N/A	N/A	N/A
40	2976.4	0.29	108.92	2990.0	0.29	251.15	86	N/A	N/A	N/A	N/A	N/A	N/A
42	2989.2	0.29	106.55	2979.9	0.29	253.56	88	N/A	N/A	N/A	N/A	N/A	N/A
44	2980.4	0.29	104.19	3002.1	0.29	255.83	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

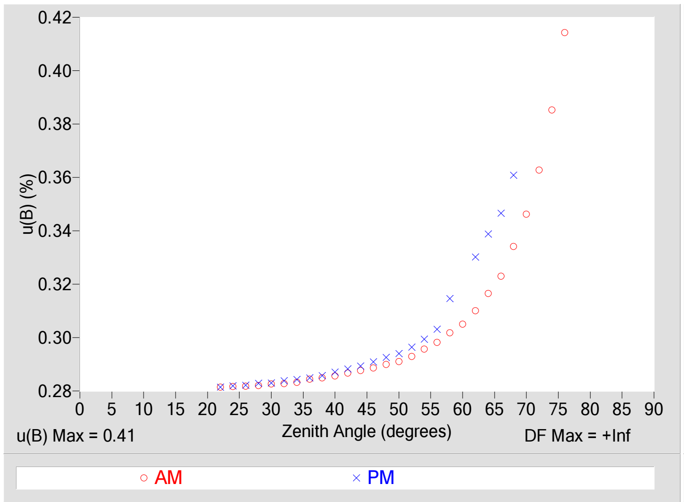


Figure 4. Residuals from Spline Interpolation

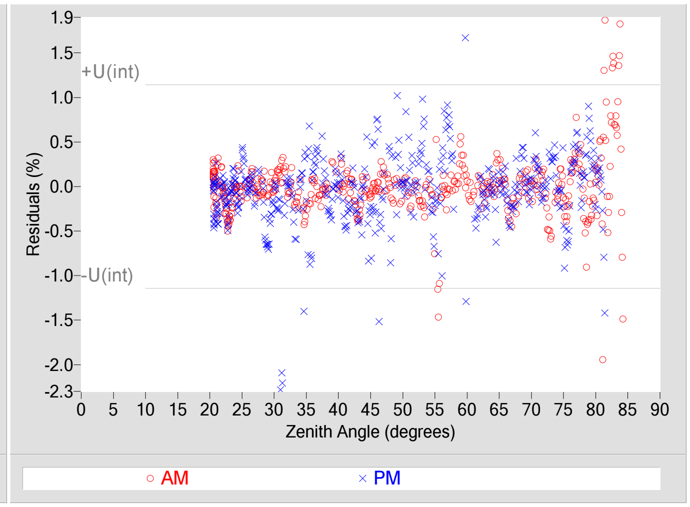


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.57
Combined Standard Uncertainty, u(c) (%)	±0.71
Effective degrees of freedom, DF(c)	1907
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

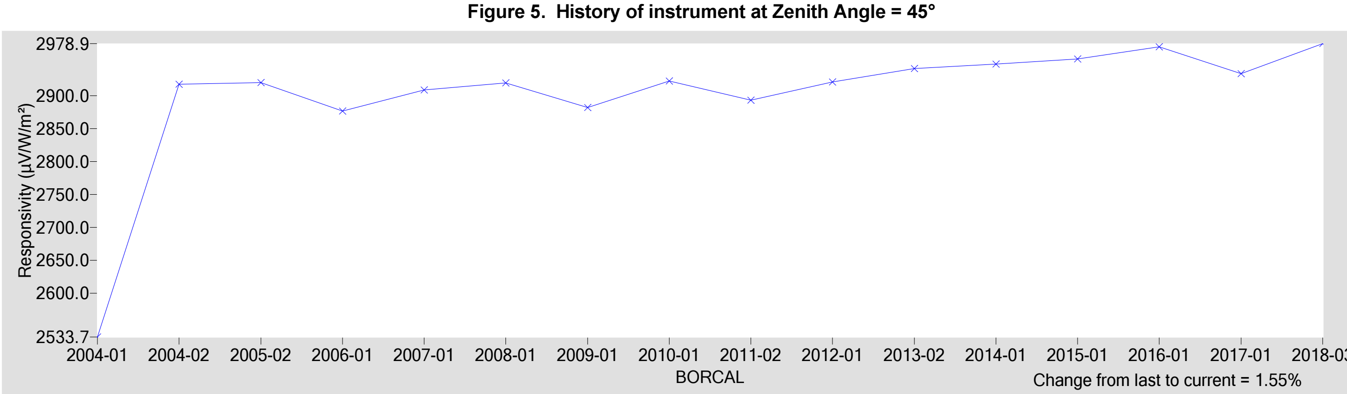
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
2978.9	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+2.5 / -0.60
Expanded Uncertainty, U (%)	+3.2 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	080009
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

________________________________ ______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

080009 Kipp & Zonen CHP1

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

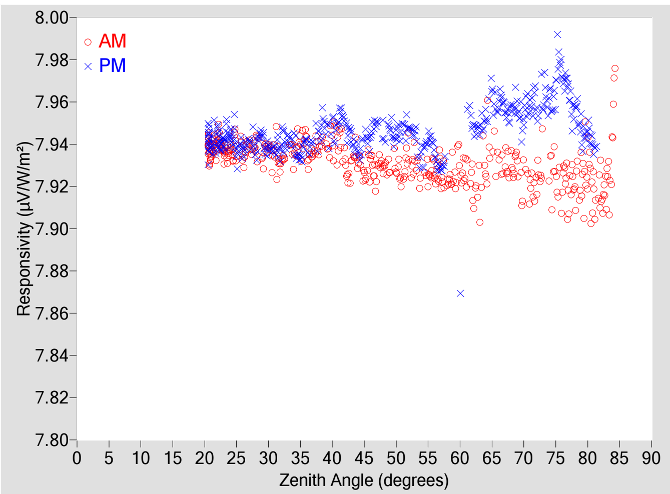


Figure 2. Responsivity vs Local Standard Time

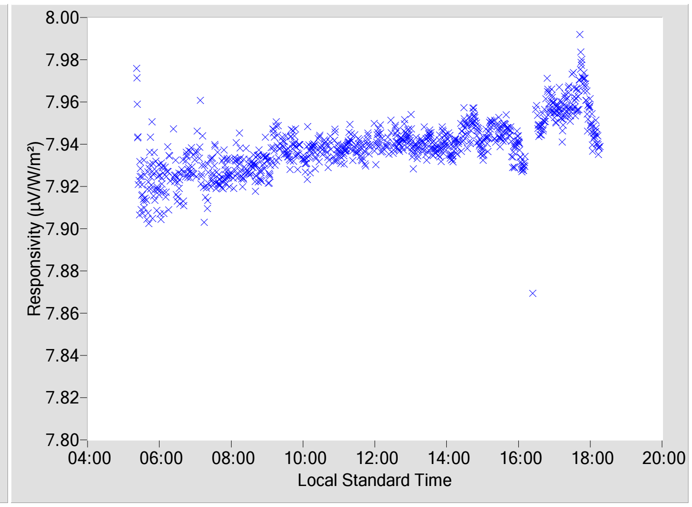


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9319	0.29	102.08	7.9442	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9294	0.29	100.02	7.9444	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9299	0.29	98.13	7.9446	0.29	262.04
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9362	0.29	96.28	7.9476	0.29	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9240	0.29	94.53	7.9335	0.30	265.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9273	0.29	92.59	7.9354	0.30	267.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9217	0.29	90.81	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9292	0.30	89.21	7.8695	N/A	270.93
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9200	0.30	87.62	7.9486	0.30	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9254	0.30	85.97	7.9522	0.31	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9345	0.30	84.40	7.9587	0.31	275.46
22	7.9424	0.29	155.80	7.9422	0.29	203.74	68	7.9313	0.30	82.71	7.9555	0.31	276.93
24	7.9368	0.29	144.71	7.9436	0.29	215.49	70	7.9246	0.30	81.25	7.9524	N/A	278.58
26	7.9352	0.29	136.72	7.9377	0.29	223.29	72	7.9223	0.31	79.65	7.9571	N/A	280.18
28	7.9388	0.29	130.76	7.9376	0.29	229.27	74	7.9305	0.31	78.00	7.9601	N/A	281.74
30	7.9387	0.29	125.76	7.9383	0.29	234.28	76	7.9202	0.31	76.43	7.9734	N/A	283.33
32	7.9307	0.29	121.56	7.9405	0.29	238.56	78	7.9186	N/A	74.89	7.9567	N/A	284.97
34	7.9335	0.29	117.96	7.9411	0.29	242.25	80	7.9275	N/A	73.30	7.9469	N/A	286.57
36	7.9389	0.29	114.64	7.9408	0.29	245.37	82	7.9189	N/A	71.60	N/A	N/A	N/A
38	7.9391	0.29	111.73	7.9438	0.29	248.39	84	7.9523	N/A	69.94	N/A	N/A	N/A
40	7.9430	0.29	108.98	7.9479	0.29	251.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9316	0.29	106.46	7.9505	0.29	253.53	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9320	0.29	104.22	7.9363	0.29	255.89	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

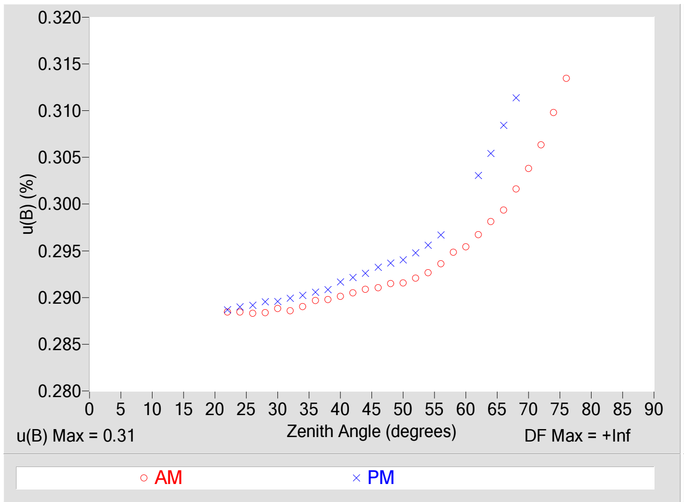


Figure 4. Residuals from Spline Interpolation

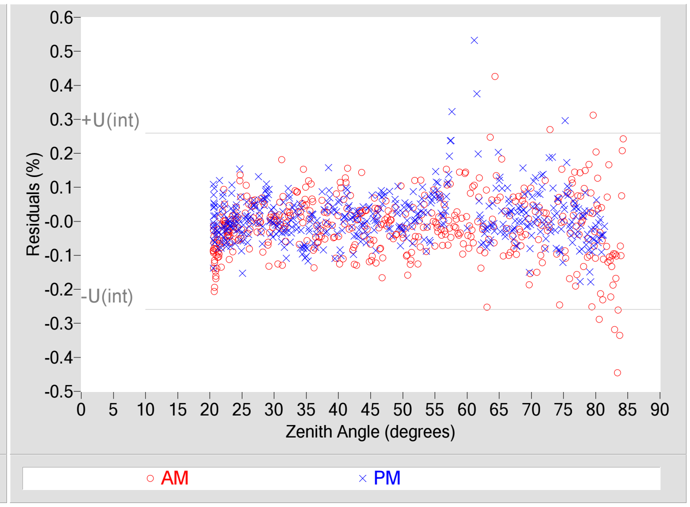


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.34
Effective degrees of freedom, DF(c)	36402
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.66
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

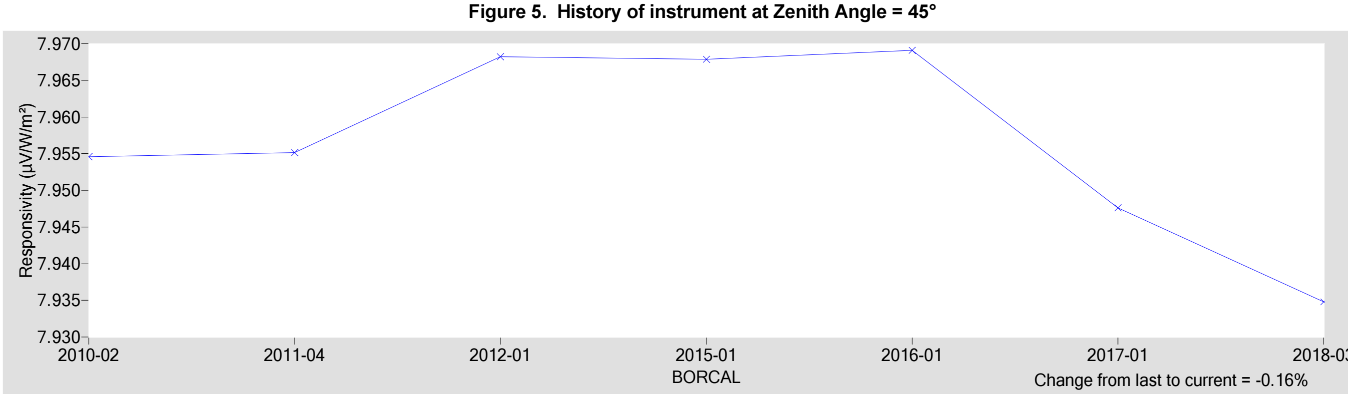
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9348	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.20 / -0.82
Expanded Uncertainty, U (%)	+0.78 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	080017
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model 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: 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, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

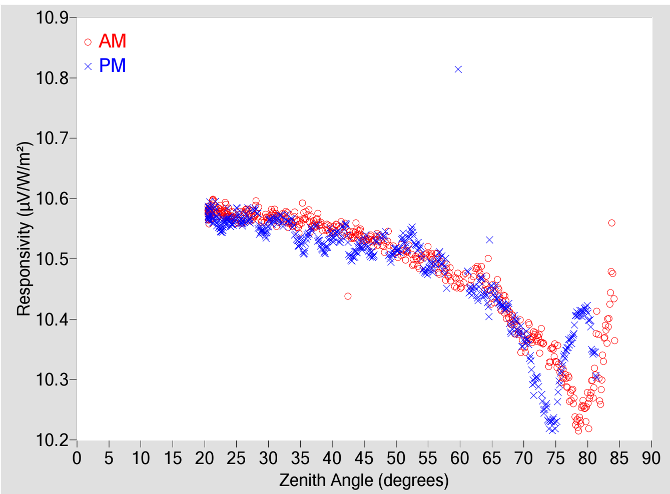


Figure 2. Responsivity vs Local Standard Time

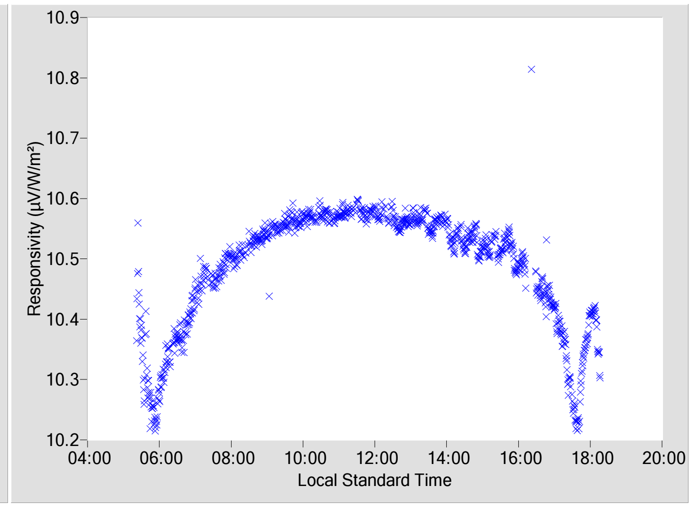


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.534	0.29	102.01	10.508	0.29	258.06
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.518	0.29	99.96	10.539	0.29	260.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.508	0.29	97.98	10.516	0.30	262.06
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.516	0.29	96.30	10.535	0.30	263.97
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.501	0.30	94.45	10.499	0.30	265.80
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.495	0.30	92.45	10.485	0.31	267.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.477	0.30	90.93	10.476	0.32	269.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.458	0.31	89.18	10.814	N/A	270.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.468	0.31	87.63	10.448	0.33	272.17
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.457	0.32	85.94	10.439	0.34	273.85
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.451	0.33	84.37	10.431	0.35	275.38
22	10.579	0.28	156.58	10.564	0.28	203.60	68	10.402	0.34	82.82	10.385	0.37	277.00
24	10.573	0.28	144.65	10.562	0.28	215.38	70	10.354	0.35	81.20	10.365	N/A	278.60
26	10.566	0.28	136.61	10.561	0.28	223.34	72	10.370	0.37	79.65	10.300	N/A	280.20
28	10.579	0.28	130.89	10.579	0.28	229.31	74	10.333	0.39	78.03	10.229	N/A	281.71
30	10.566	0.28	125.84	10.558	0.28	234.39	76	10.307	0.42	76.50	10.323	N/A	283.30
32	10.569	0.28	121.44	10.565	0.28	238.60	78	10.245	N/A	74.91	10.394	N/A	284.94
34	10.564	0.28	118.04	10.547	0.29	242.23	80	10.252	N/A	73.27	10.409	N/A	286.59
36	10.575	0.29	114.59	10.536	0.29	245.49	82	10.282	N/A	71.62	N/A	N/A	N/A
38	10.561	0.29	111.72	10.528	0.29	248.41	84	10.458	N/A	69.90	N/A	N/A	N/A
40	10.548	0.29	108.97	10.536	0.29	251.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.552	0.29	106.55	10.555	0.29	253.63	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.547	0.29	104.20	10.520	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

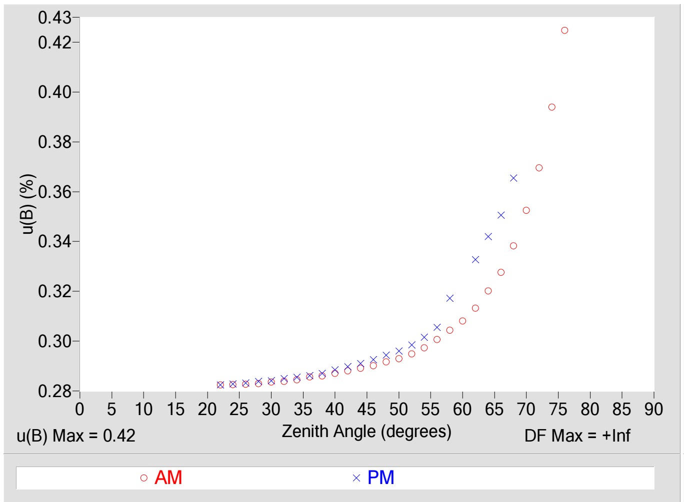


Figure 4. Residuals from Spline Interpolation

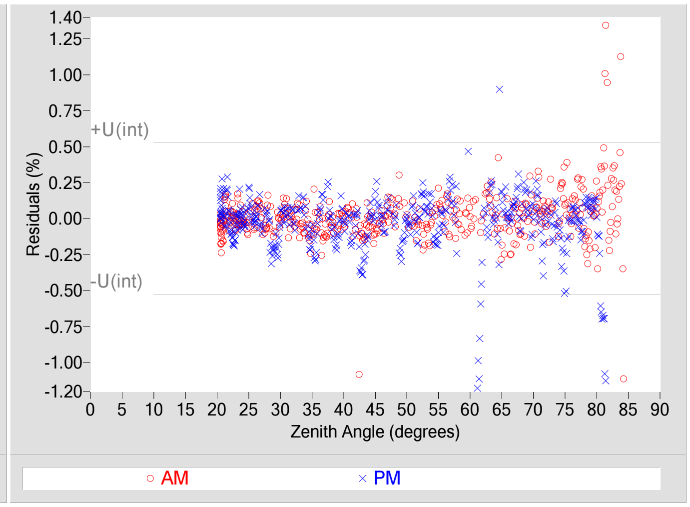


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	10568
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

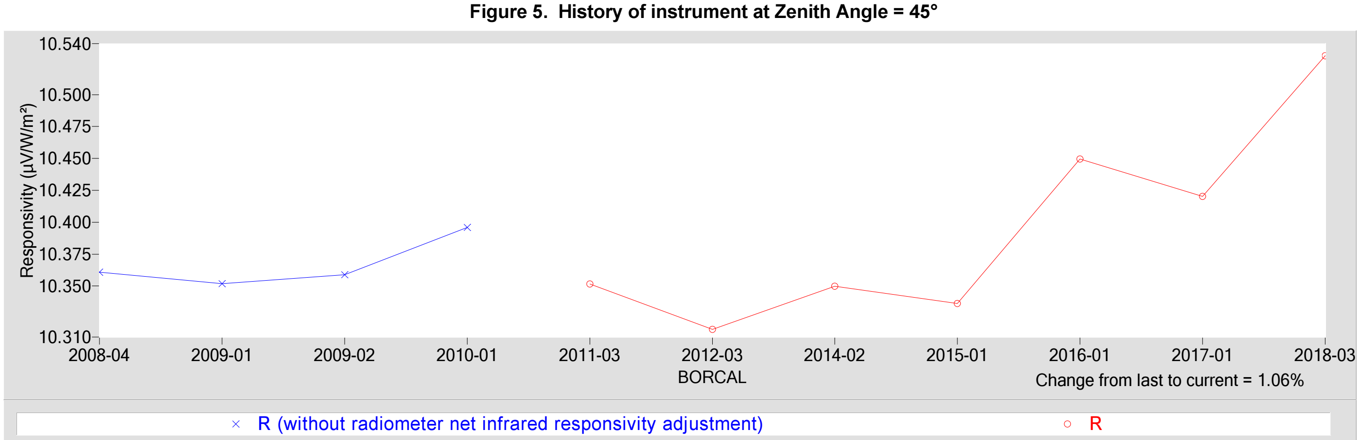
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.530	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+2.7 / -0.69
Expanded Uncertainty, U (%)	+3.3 / -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).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	100174
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

100174 Kipp & Zonen CMP22

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

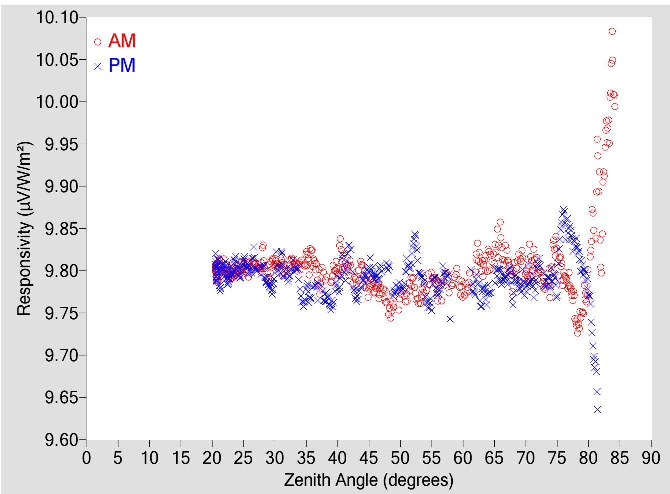


Figure 2. Responsivity vs Local Standard Time

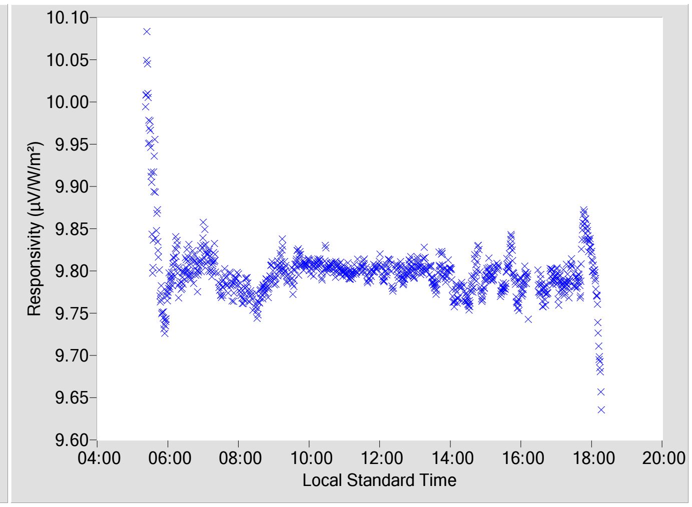


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.7771	0.29	102.04	9.7920	0.29	258.06
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7557	0.29	99.94	9.8051	0.29	260.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7641	0.29	98.11	9.7801	0.30	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7860	0.30	96.15	9.8284	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7788	0.30	94.43	9.7697	0.30	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7782	0.30	92.66	9.7746	0.31	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7798	0.30	90.84	9.7429	0.32	269.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7759	0.31	89.23	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8102	0.31	87.53	9.7829	0.33	272.25
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.8121	0.32	85.94	9.7726	0.34	273.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.8343	0.33	84.32	9.7914	0.35	275.43
22	9.8025	0.28	155.95	9.8006	0.28	203.93	68	9.7952	0.34	82.88	9.7765	0.37	277.04
24	9.7998	0.28	144.67	9.8035	0.28	215.53	70	9.7949	0.35	81.23	9.7790	N/A	278.55
26	9.8003	0.28	136.66	9.8005	0.28	223.33	72	9.8012	0.37	79.74	9.8077	N/A	280.15
28	9.8117	0.28	130.67	9.8031	0.28	229.48	74	9.7911	0.39	78.12	9.7879	N/A	281.76
30	9.8089	0.28	125.77	9.7988	0.28	234.21	76	9.7945	0.42	76.54	9.8637	N/A	283.35
32	9.8036	0.28	121.62	9.7941	0.29	238.59	78	9.7431	N/A	74.90	9.8315	N/A	284.94
34	9.8079	0.28	117.99	9.7751	0.29	242.26	80	9.7959	N/A	73.30	9.7736	N/A	286.58
36	9.8159	0.29	114.58	9.7769	0.29	245.28	82	9.8506	N/A	71.62	N/A	N/A	N/A
38	9.7934	0.29	111.69	9.7671	0.29	248.41	84	10.029	N/A	69.95	N/A	N/A	N/A
40	9.8017	0.29	109.04	9.7825	0.29	251.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8043	0.29	106.62	9.8278	0.29	253.49	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8005	0.29	104.20	9.7885	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

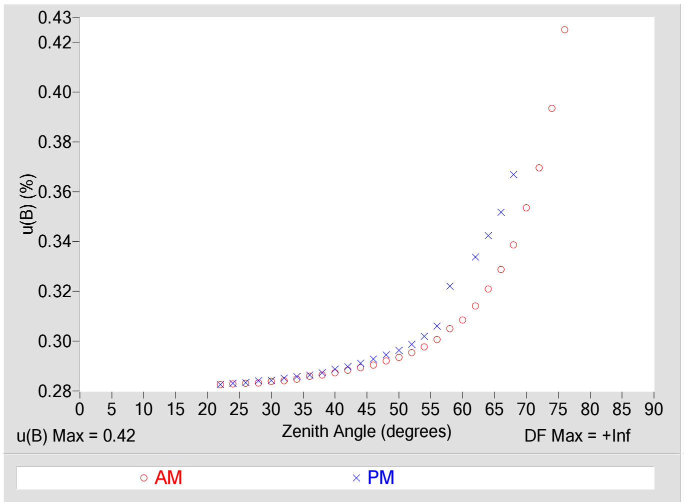


Figure 4. Residuals from Spline Interpolation

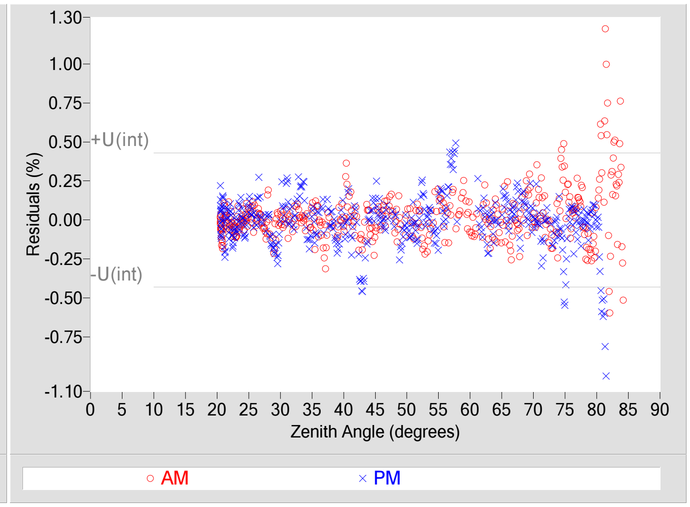


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	19202
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

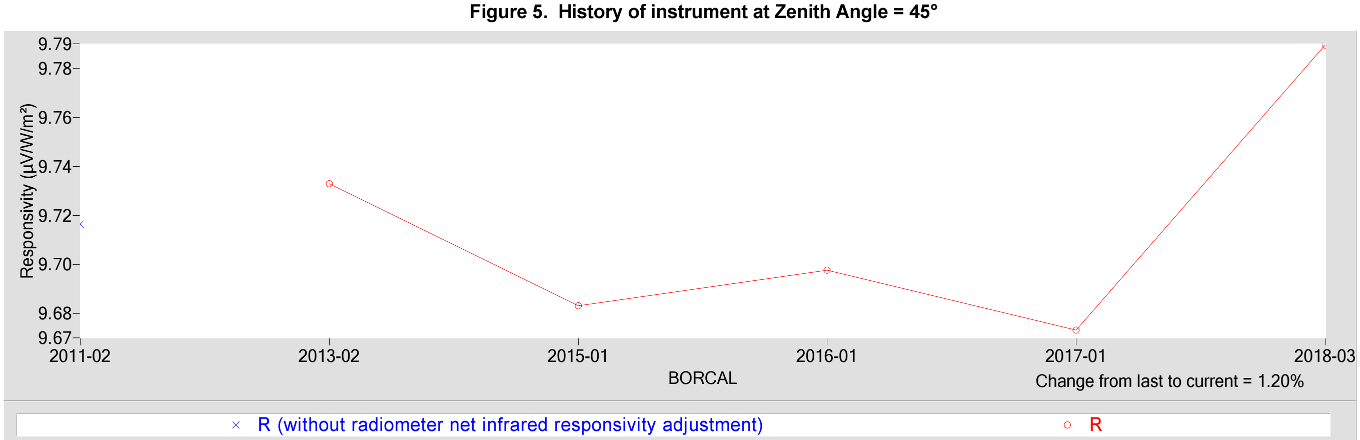
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.7895	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.40 / -0.48
Expanded Uncertainty, U (%)	+1.0 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Thermopile Pyranometer	**Manufacturer:**	Apogee
Model:	SP-510	**Serial Number:**	1171
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ____________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

1171 Apogee SP-510

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

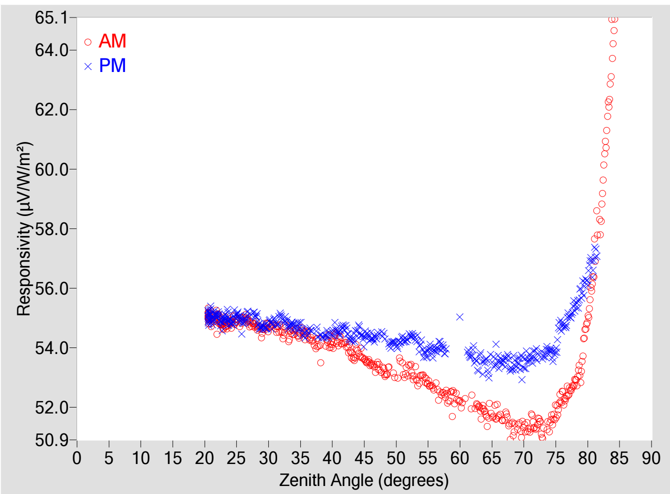


Figure 2. Responsivity vs Local Standard Time

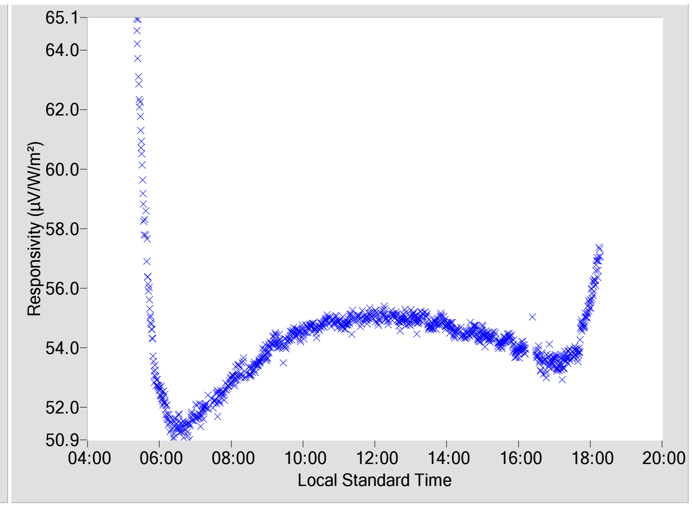


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	53.443	0.32	102.00	54.341	0.32	258.02
2	N/A	N/A	N/A	N/A	N/A	N/A	48	53.190	0.32	99.88	54.423	0.32	260.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	52.985	0.33	97.99	54.081	0.33	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	53.326	0.34	96.09	54.387	0.33	264.01
8	N/A	N/A	N/A	N/A	N/A	N/A	54	53.072	0.34	94.36	53.990	0.34	265.82
10	N/A	N/A	N/A	N/A	N/A	N/A	56	52.678	0.34	92.61	53.891	0.34	267.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	52.341	0.35	90.94	53.950	0.35	269.04
14	N/A	N/A	N/A	N/A	N/A	N/A	60	52.154	0.36	89.27	55.035	N/A	270.86
16	N/A	N/A	N/A	N/A	N/A	N/A	62	52.176	0.37	87.74	53.788	0.37	272.21
18	N/A	N/A	N/A	N/A	N/A	N/A	64	51.696	0.38	85.96	53.506	0.39	273.86
20	N/A	N/A	N/A	N/A	N/A	N/A	66	51.769	0.39	84.48	53.512	0.40	275.40
22	55.059	0.30	156.11	55.081	0.30	204.09	68	51.320	0.42	82.83	53.276	0.42	277.01
24	54.834	0.30	144.69	54.869	0.30	215.43	70	51.356	0.44	81.22	53.449	N/A	278.61
26	54.963	0.30	137.20	54.827	0.30	223.24	72	51.400	0.47	79.62	53.774	N/A	280.12
28	54.721	0.30	130.64	55.061	0.30	229.44	74	51.438	0.50	78.07	53.893	N/A	281.73
30	54.706	0.30	125.71	54.831	0.30	234.36	76	52.295	0.55	76.51	54.752	N/A	283.32
32	54.533	0.30	121.47	55.033	0.30	238.53	78	52.841	N/A	74.92	55.415	N/A	284.95
34	54.516	0.30	117.93	54.691	0.31	242.25	80	54.941	N/A	73.29	56.398	N/A	286.60
36	54.441	0.31	114.70	54.497	0.31	245.48	82	58.295	N/A	71.59	N/A	N/A	N/A
38	53.985	0.31	111.74	54.412	0.31	248.50	84	64.537	N/A	69.92	N/A	N/A	N/A
40	54.096	0.31	109.00	54.485	0.31	251.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	54.125	0.31	106.50	54.681	0.31	253.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	53.848	0.31	104.16	54.601	0.31	255.86	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

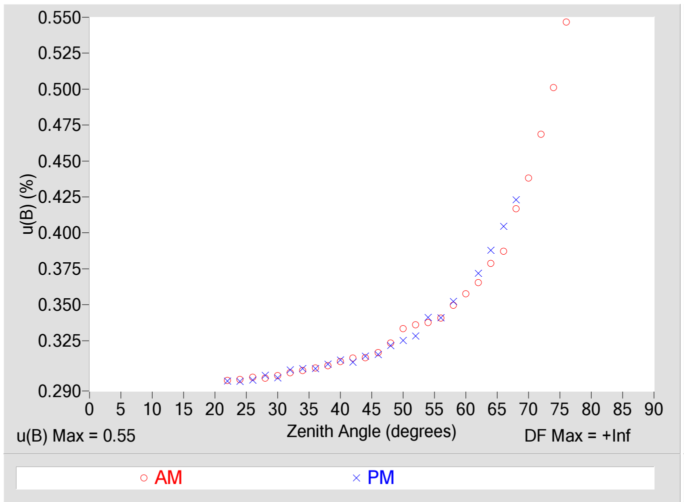


Figure 4. Residuals from Spline Interpolation

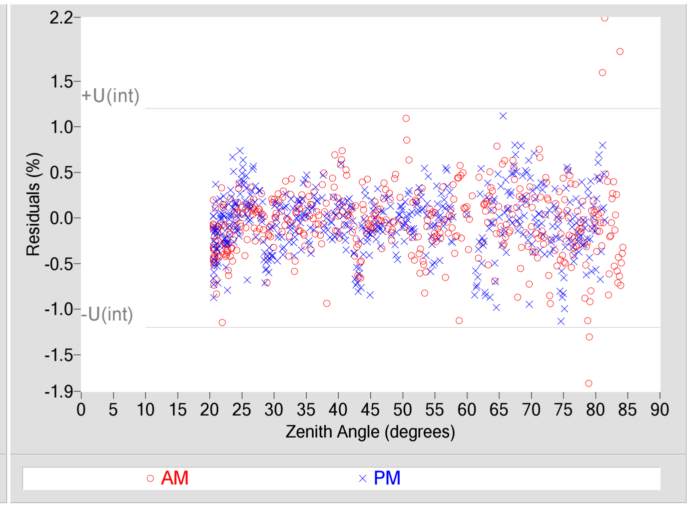


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.55
Type-A Interpolating Function, u(int) (%)	±0.60
Combined Standard Uncertainty, u(c) (%)	±0.81
Effective degrees of freedom, DF(c)	2714
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

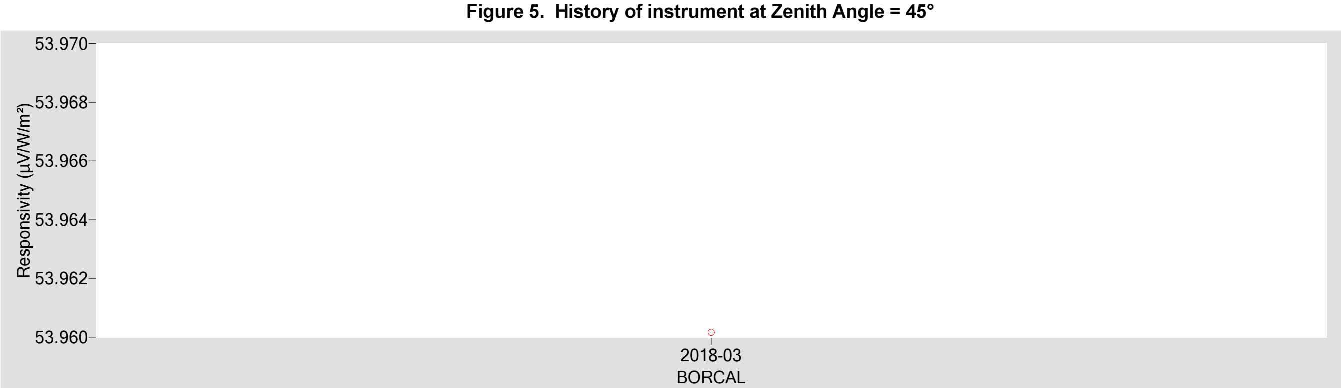
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
53.960	2.5000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.70
Offset Uncertainty, U(off) (%)	+2.0 / -3.3
Expanded Uncertainty, U (%)	+2.7 / -4.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	140043
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

_______________________________   _______________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

140043 Kipp & Zonen CMP22

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

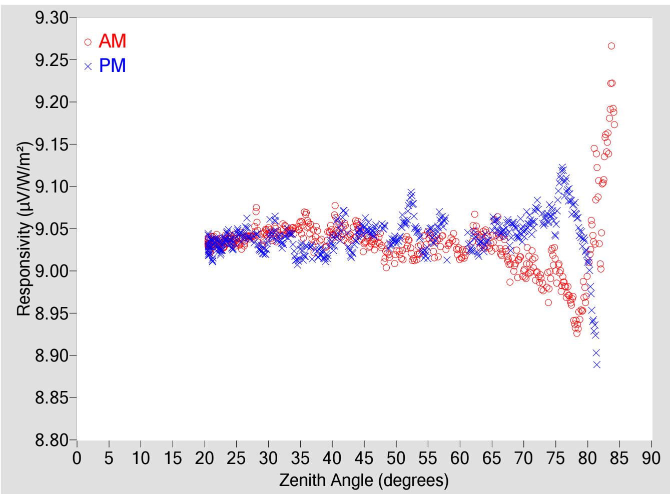


Figure 2. Responsivity vs Local Standard Time

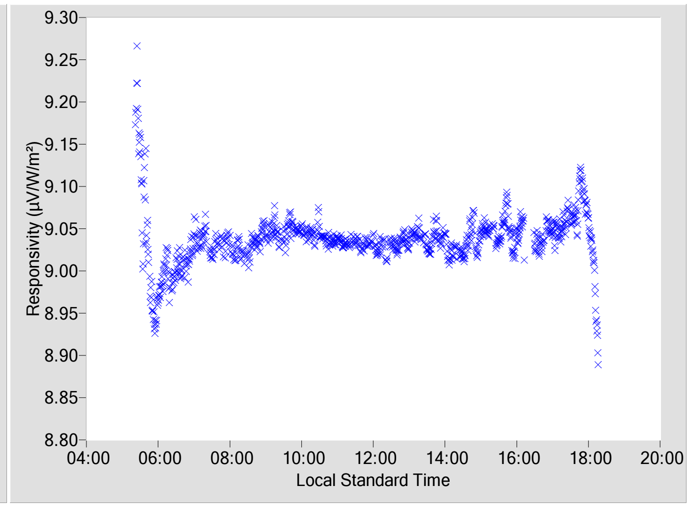


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0310	0.29	102.04	9.0462	0.29	258.06
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0186	0.29	99.94	9.0525	0.29	260.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0173	0.29	98.11	9.0363	0.30	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0325	0.30	96.15	9.0782	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0247	0.30	94.43	9.0271	0.30	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0279	0.30	92.66	9.0377	0.31	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0292	0.31	90.84	9.0128	0.32	269.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0194	0.31	89.23	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0453	0.31	87.53	9.0352	0.33	272.25
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0374	0.32	85.94	9.0334	0.34	273.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0436	0.33	84.32	9.0499	0.35	275.43
22	9.0334	0.28	155.95	9.0323	0.28	203.93	68	9.0045	0.34	82.88	9.0410	0.37	277.04
24	9.0376	0.28	144.67	9.0358	0.28	215.53	70	8.9971	0.35	81.23	9.0442	N/A	278.55
26	9.0315	0.28	136.66	9.0400	0.28	223.33	72	9.0005	0.37	79.74	9.0752	N/A	280.15
28	9.0556	0.28	130.67	9.0409	0.28	229.48	74	8.9860	0.40	78.12	9.0648	N/A	281.76
30	9.0461	0.28	125.77	9.0424	0.28	234.21	76	8.9878	0.43	76.54	9.1151	N/A	283.35
32	9.0466	0.28	121.62	9.0343	0.29	238.59	78	8.9414	N/A	74.90	9.0730	N/A	284.94
34	9.0492	0.28	117.99	9.0211	0.29	242.26	80	8.9913	N/A	73.30	9.0127	N/A	286.58
36	9.0607	0.29	114.58	9.0253	0.29	245.28	82	9.0496	N/A	71.62	N/A	N/A	N/A
38	9.0402	0.29	111.69	9.0207	0.29	248.41	84	9.2084	N/A	69.95	N/A	N/A	N/A
40	9.0455	0.29	109.04	9.0325	0.29	251.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0490	0.29	106.62	9.0700	0.29	253.49	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0527	0.29	104.20	9.0426	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

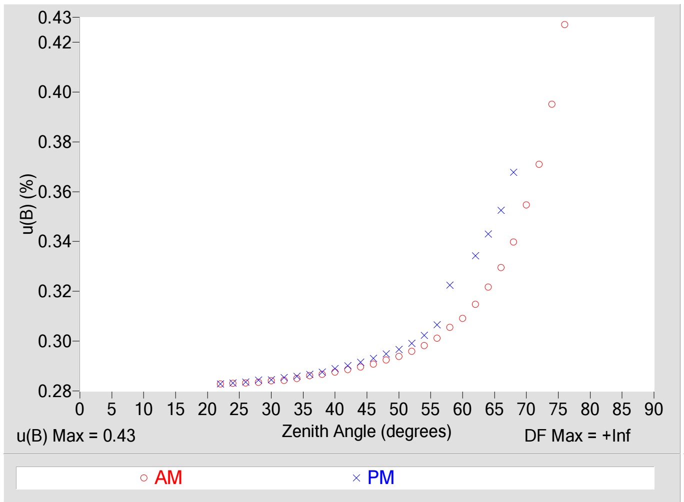


Figure 4. Residuals from Spline Interpolation

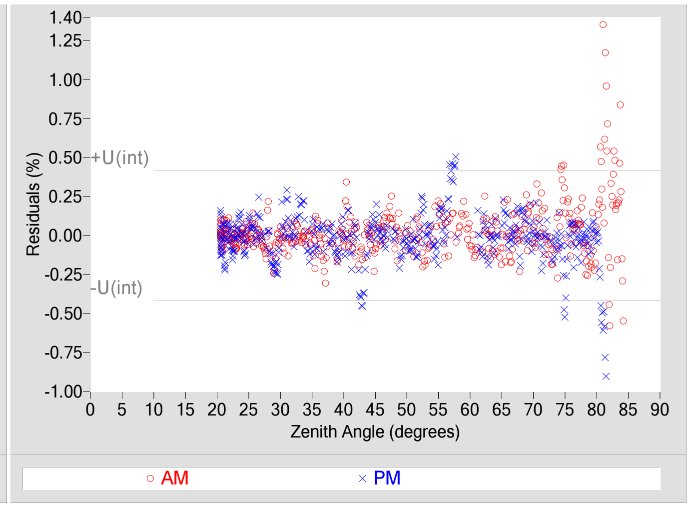


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	21690
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

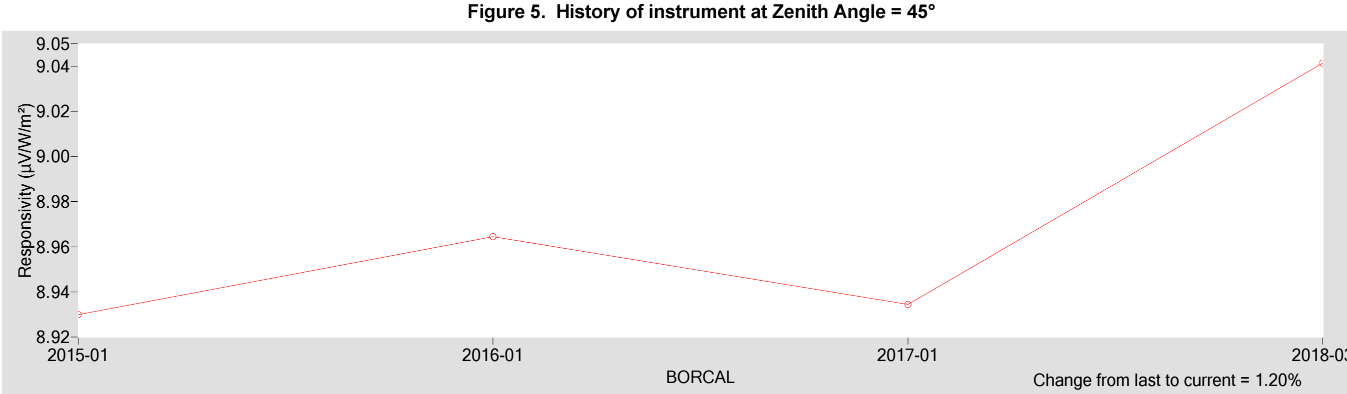
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.0413	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.41 / -0.32
Expanded Uncertainty, U (%)	+1.0 / -0.95
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	140108
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ _______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

140108 Kipp & Zonen CHP1

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

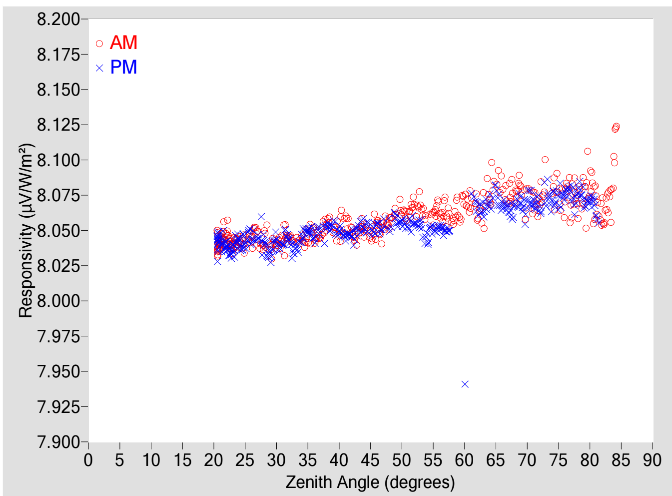


Figure 2. Responsivity vs Local Standard Time

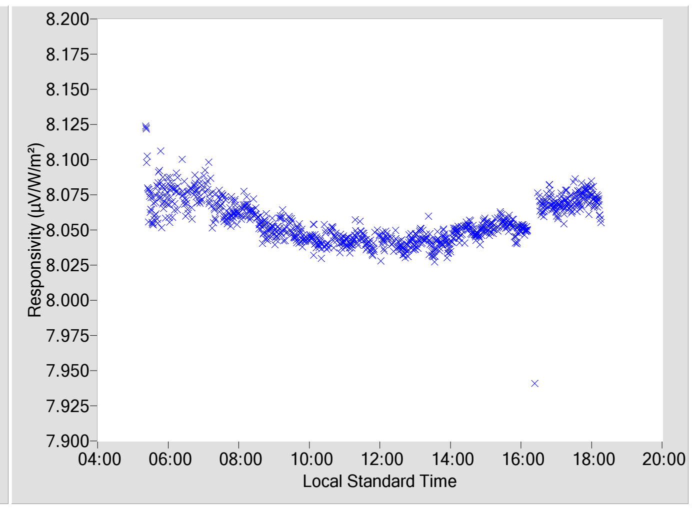


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0534	0.29	102.08	8.0533	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0554	0.29	100.02	8.0529	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0650	0.29	98.13	8.0558	0.29	262.04
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0694	0.29	96.28	8.0546	0.29	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0605	0.29	94.53	8.0441	0.30	265.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0644	0.29	92.59	8.0523	0.30	267.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0563	0.29	90.81	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0715	0.30	89.21	7.9409	N/A	270.93
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0651	0.30	87.62	8.0664	0.30	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0715	0.30	85.97	8.0697	0.31	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0839	0.30	84.40	8.0677	0.31	275.46
22	8.0462	0.29	156.04	8.0388	0.29	203.74	68	8.0752	0.30	82.71	8.0659	0.31	276.93
24	8.0419	0.29	144.71	8.0418	0.29	215.49	70	8.0749	0.30	81.25	8.0697	N/A	278.58
26	8.0432	0.29	136.72	8.0456	0.29	223.29	72	8.0710	0.31	79.65	8.0661	N/A	280.18
28	8.0417	0.29	130.76	8.0407	0.29	229.27	74	8.0814	0.31	78.00	8.0710	N/A	281.74
30	8.0399	0.29	125.76	8.0437	0.29	234.28	76	8.0731	0.31	76.43	8.0757	N/A	283.33
32	8.0451	0.29	121.56	8.0435	0.29	238.56	78	8.0712	N/A	74.89	8.0762	N/A	284.97
34	8.0440	0.29	117.96	8.0452	0.29	242.25	80	8.0780	N/A	73.30	8.0722	N/A	286.57
36	8.0478	0.29	114.64	8.0436	0.29	245.37	82	8.0610	N/A	71.60	N/A	N/A	N/A
38	8.0552	0.29	111.73	8.0530	0.29	248.39	84	8.1081	N/A	69.94	N/A	N/A	N/A
40	8.0519	0.29	108.98	8.0499	0.29	251.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0496	0.29	106.46	8.0472	0.29	253.53	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0503	0.29	104.22	8.0521	0.29	255.89	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

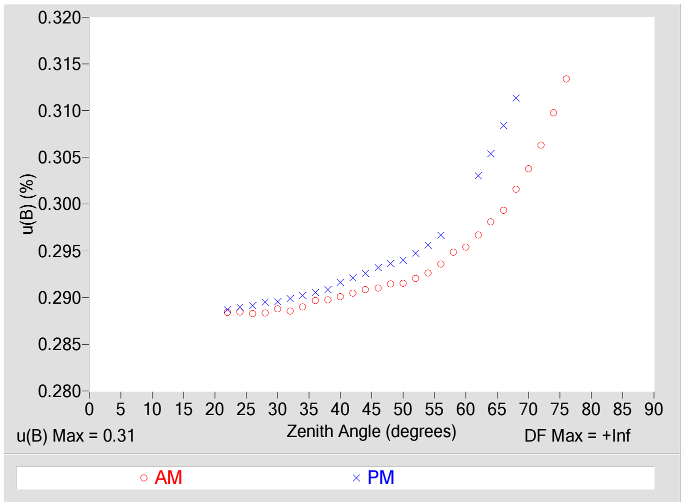


Figure 4. Residuals from Spline Interpolation

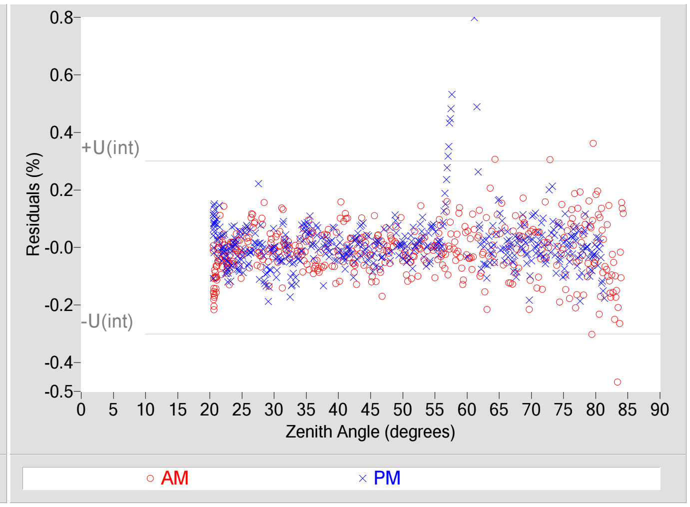


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	22232
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.68
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

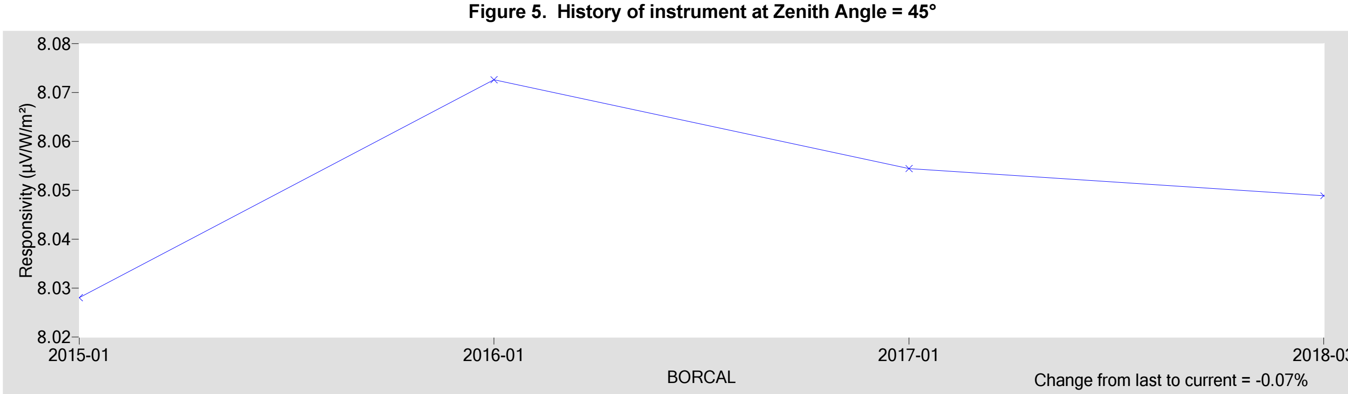
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0489	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.28 / -1.3
Expanded Uncertainty, U (%)	+0.86 / -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

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP11	**Serial Number:**	140712
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

140712 Kipp & Zonen CMP11

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

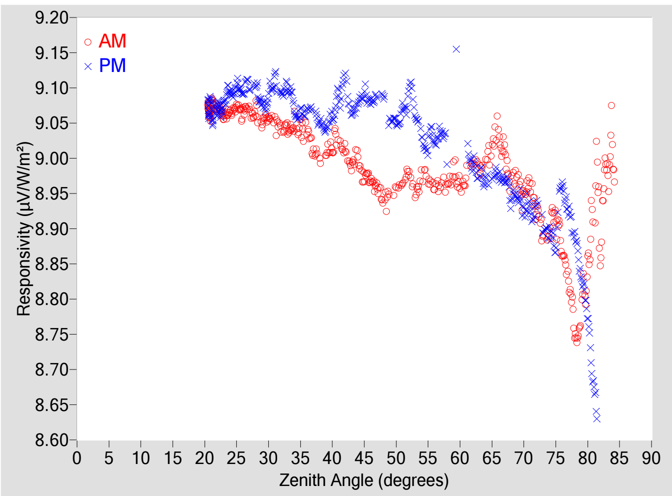


Figure 2. Responsivity vs Local Standard Time

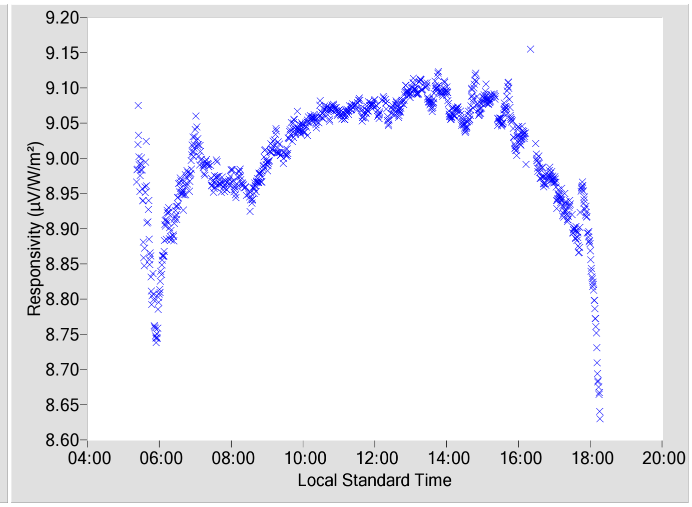


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9674	0.30	102.03	9.0804	0.30	258.05
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9394	0.30	100.01	9.0883	0.30	260.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9588	0.30	98.08	9.0512	0.30	262.11
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9777	0.30	96.15	9.1004	0.30	264.01
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9727	0.30	94.38	9.0305	0.31	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9602	0.31	92.63	9.0217	0.31	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9636	0.31	90.85	8.9916	0.33	269.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9628	0.32	89.29	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9911	0.32	87.65	8.9915	0.34	272.24
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9983	0.33	85.89	8.9666	0.35	273.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0377	0.34	84.34	8.9751	0.36	275.42
22	9.0723	0.29	156.03	9.0723	0.29	203.80	68	8.9654	0.35	82.92	8.9403	0.38	277.03
24	9.0652	0.29	144.76	9.0931	0.29	215.52	70	8.9466	0.37	81.27	8.9243	N/A	278.59
26	9.0632	0.29	136.72	9.0918	0.29	223.18	72	8.9246	0.39	79.69	8.9347	N/A	280.12
28	9.0656	0.29	130.54	9.1032	0.29	229.53	74	8.8934	0.41	78.12	8.8912	N/A	281.75
30	9.0559	0.29	125.83	9.0885	0.29	234.19	76	8.8671	0.45	76.54	8.9595	N/A	283.34
32	9.0447	0.29	121.88	9.0932	0.29	238.58	78	8.7538	N/A	74.90	8.8885	N/A	284.93
34	9.0479	0.29	118.02	9.0697	0.29	242.21	80	8.8438	N/A	73.26	8.7737	N/A	286.58
36	9.0409	0.29	114.53	9.0676	0.29	245.48	82	8.8931	N/A	71.61	N/A	N/A	N/A
38	8.9963	0.29	111.55	9.0505	0.29	248.38	84	9.0058	N/A	69.95	N/A	N/A	N/A
40	9.0125	0.29	109.03	9.0576	0.29	251.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0118	0.29	106.54	9.1162	0.29	253.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9969	0.29	104.13	9.0790	0.30	255.92	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

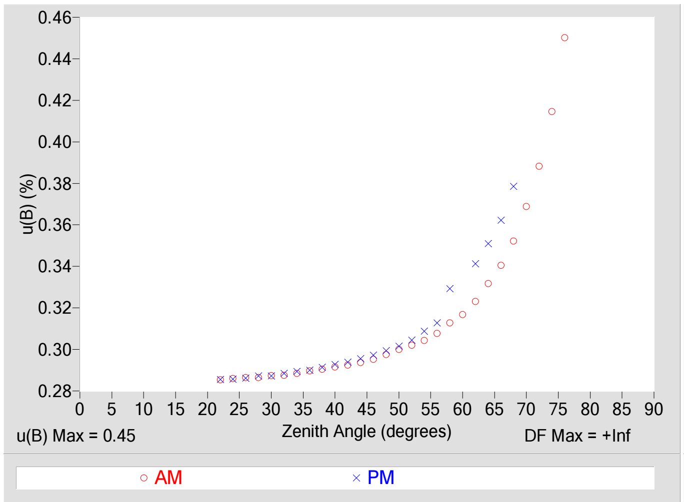


Figure 4. Residuals from Spline Interpolation

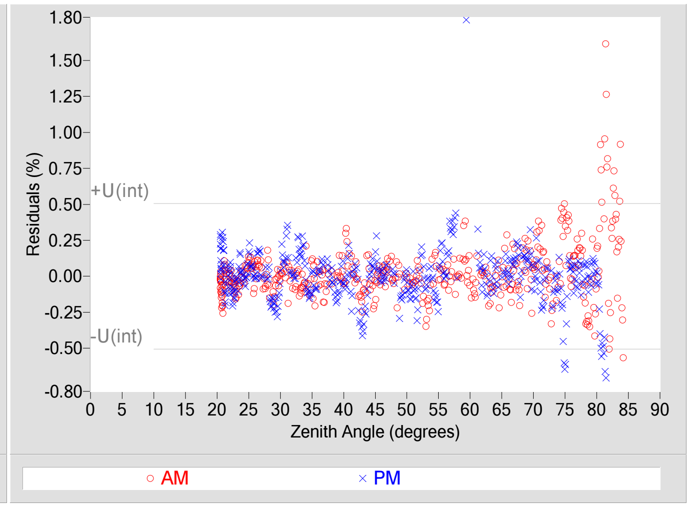


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	13817
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

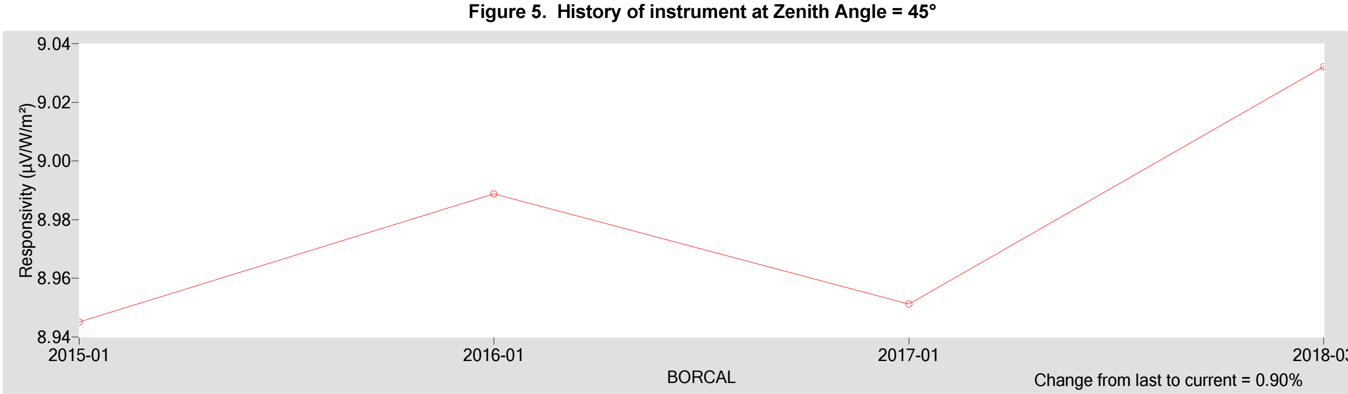
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0321	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+0.93 / -1.0
Expanded Uncertainty, U (%)	+1.6 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	151027
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

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Ibrahim Reda, Technical Manager Date

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

Calibration Results

151027 Kipp & Zonen SP-LITE2

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

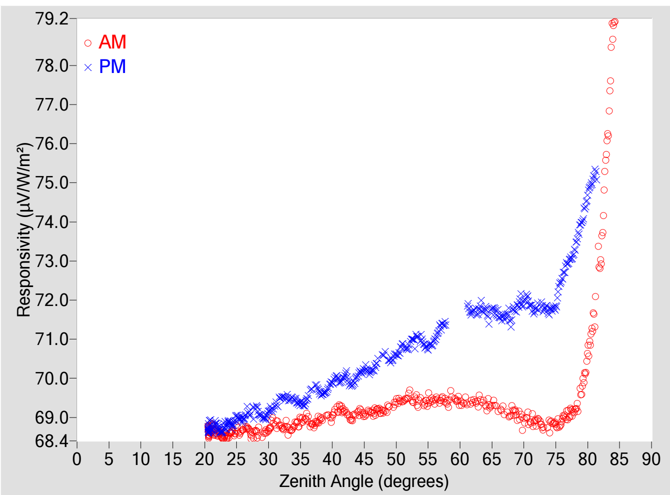


Figure 2. Responsivity vs Local Standard Time

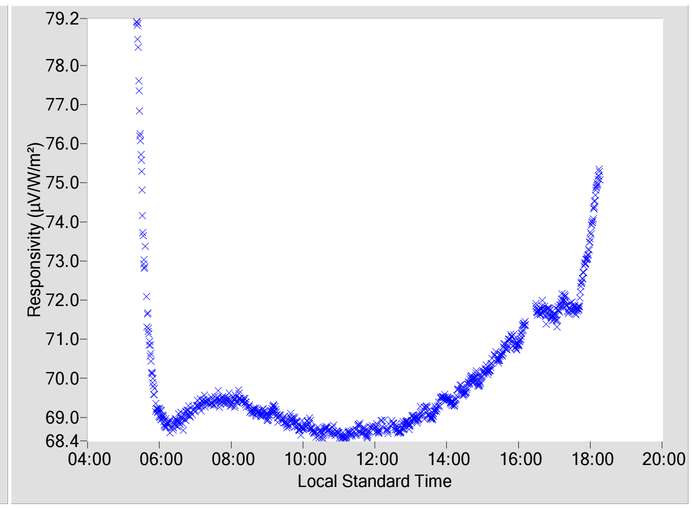


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	69.134	0.29	102.06	70.167	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	69.164	0.29	100.08	70.620	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	69.388	0.29	98.05	70.609	0.29	262.04
6	N/A	N/A	N/A	N/A	N/A	N/A	52	69.574	0.29	96.23	70.826	0.30	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	69.450	0.30	94.32	70.973	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	69.436	0.30	92.58	70.971	0.30	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	69.354	0.30	90.86	71.364	0.31	269.01
14	N/A	N/A	N/A	N/A	N/A	N/A	60	69.394	0.31	89.21	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	69.424	0.31	87.60	71.702	0.33	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	69.304	0.32	86.00	71.740	0.34	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	69.156	0.32	84.40	71.602	0.35	275.46
22	68.601	0.28	156.09	68.758	0.28	203.88	68	69.142	0.33	82.78	71.504	0.36	276.98
24	68.593	0.28	144.36	68.847	0.28	215.33	70	68.833	0.35	81.25	71.932	N/A	278.59
26	68.683	0.28	136.84	68.965	0.28	223.30	72	68.913	0.36	79.63	71.809	N/A	280.18
28	68.618	0.28	130.57	69.270	0.28	229.51	74	68.832	0.39	78.01	71.729	N/A	281.75
30	68.695	0.28	125.59	69.152	0.28	234.35	76	68.944	0.41	76.48	72.568	N/A	283.33
32	68.763	0.28	121.51	69.511	0.28	238.47	78	69.184	N/A	74.89	73.345	N/A	284.97
34	68.776	0.28	117.96	69.474	0.28	242.25	80	70.527	N/A	73.30	74.687	N/A	286.57
36	68.993	0.28	114.64	69.461	0.28	245.46	82	73.049	N/A	71.60	N/A	N/A	N/A
38	68.957	0.28	111.70	69.636	0.29	248.39	84	78.909	N/A	69.94	N/A	N/A	N/A
40	69.019	0.29	109.03	69.909	0.29	251.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	69.152	0.29	106.57	70.087	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	69.118	0.29	104.12	70.092	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

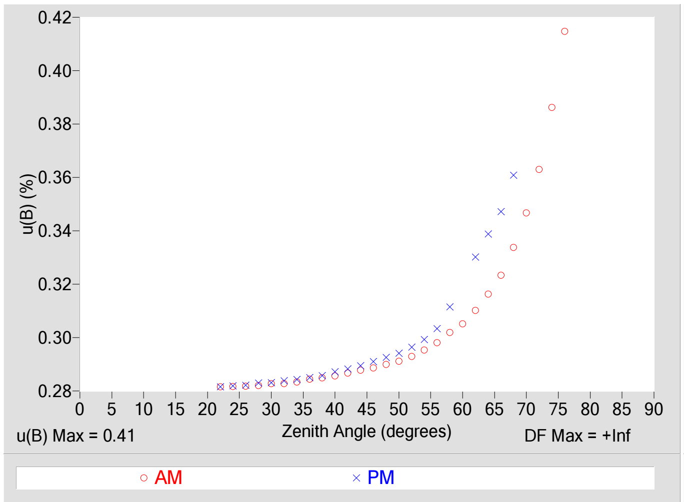


Figure 4. Residuals from Spline Interpolation

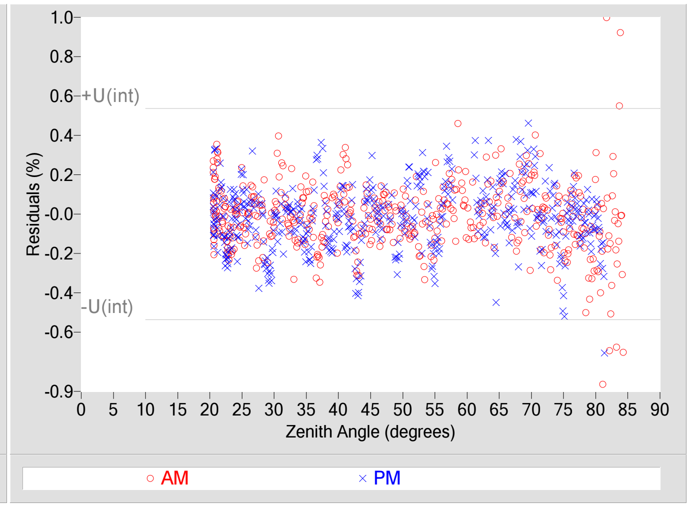


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	9129
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

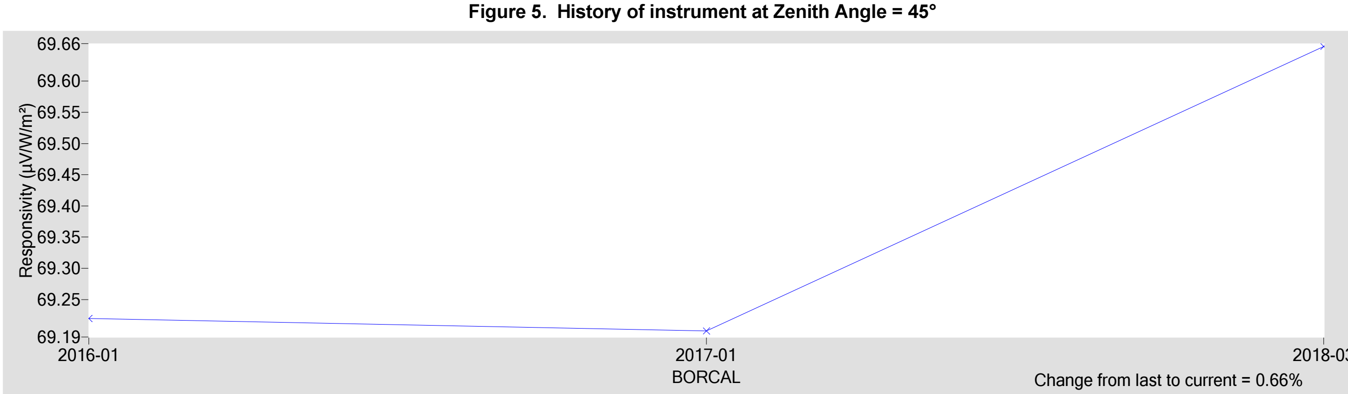
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
69.655	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.61
Offset Uncertainty, U(off) (%)	+2.5 / -1.4
Expanded Uncertainty, U (%)	+3.1 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	170515
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ____________
Ibrahim Reda, Technical Manager   Date

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

Calibration Results

170515 Kipp & Zonen CMP22

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

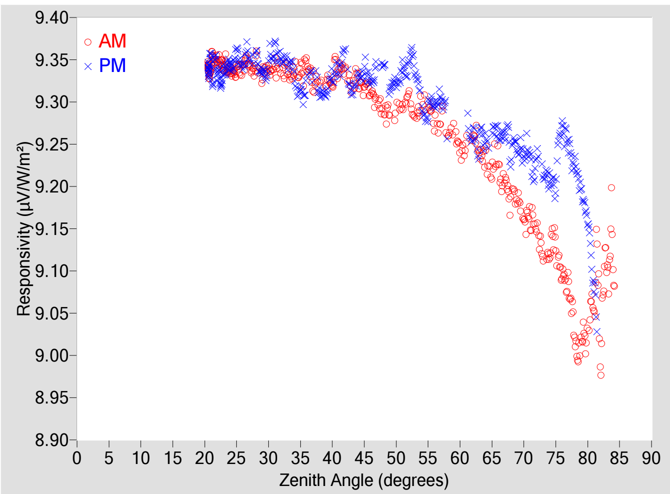


Figure 2. Responsivity vs Local Standard Time

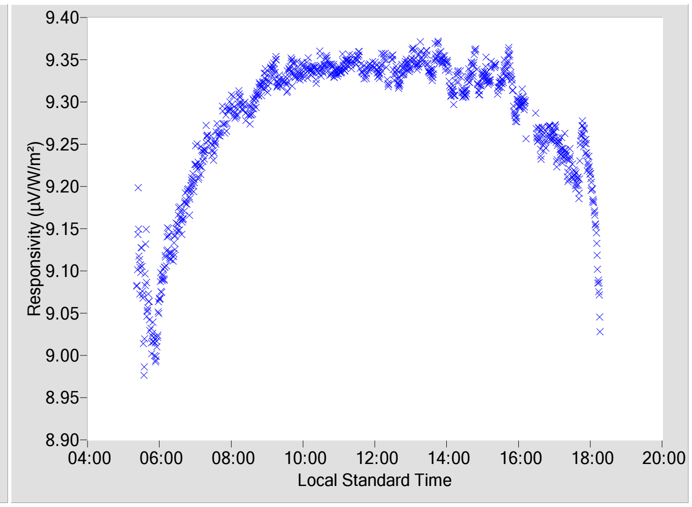


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.3097	0.29	102.04	9.3248	0.29	258.06
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2874	0.29	99.94	9.3435	0.29	260.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2882	0.29	98.11	9.3224	0.30	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3068	0.30	96.15	9.3478	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2978	0.30	94.43	9.2965	0.30	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2797	0.30	92.66	9.2955	0.31	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2612	0.31	90.84	9.2565	0.32	269.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2434	0.31	89.23	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2584	0.31	87.53	9.2601	0.33	272.25
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2319	0.32	85.94	9.2531	0.34	273.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2262	0.33	84.32	9.2612	0.35	275.43
22	9.3484	0.28	155.95	9.3366	0.28	203.93	68	9.1840	0.34	82.88	9.2369	0.37	277.04
24	9.3364	0.28	144.67	9.3427	0.28	215.53	70	9.1604	0.35	81.23	9.2346	N/A	278.55
26	9.3392	0.28	136.66	9.3429	0.28	223.33	72	9.1520	0.37	79.74	9.2332	N/A	280.15
28	9.3428	0.28	130.67	9.3557	0.28	229.48	74	9.1185	0.39	78.12	9.2038	N/A	281.76
30	9.3370	0.28	125.77	9.3474	0.28	234.21	76	9.0960	0.43	76.54	9.2687	N/A	283.35
32	9.3379	0.28	121.62	9.3510	0.29	238.59	78	9.0206	N/A	74.90	9.2250	N/A	284.94
34	9.3393	0.28	117.99	9.3296	0.29	242.26	80	9.0255	N/A	73.30	9.1574	N/A	286.58
36	9.3435	0.29	114.58	9.3217	0.29	245.28	82	9.0269	N/A	71.62	N/A	N/A	N/A
38	9.3248	0.29	111.69	9.3107	0.29	248.41	84	9.1216	N/A	69.95	N/A	N/A	N/A
40	9.3205	0.29	109.04	9.3284	0.29	251.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3379	0.29	106.62	9.3616	0.29	253.49	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3255	0.29	104.20	9.3296	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

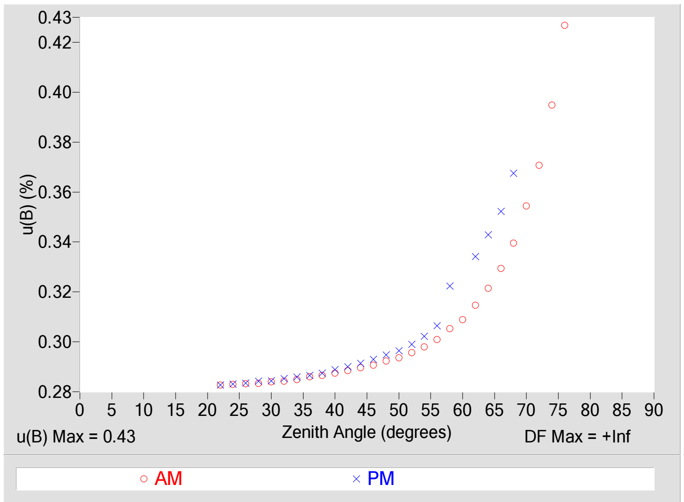


Figure 4. Residuals from Spline Interpolation

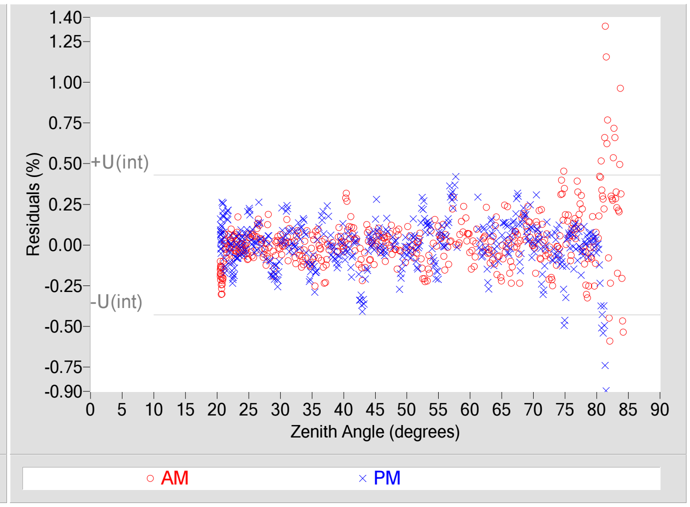


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	19580
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.94
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

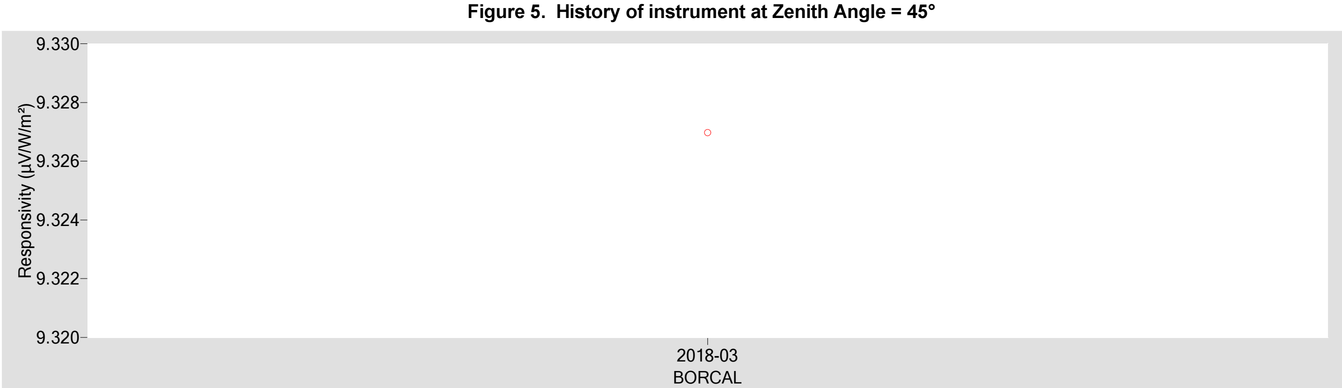
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.3270	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.37 / -0.90
Expanded Uncertainty, U (%)	+1.0 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Black and White Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	21096
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ____________

Ibrahim Reda, Technical Manager — Date

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

Calibration Results

21096 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

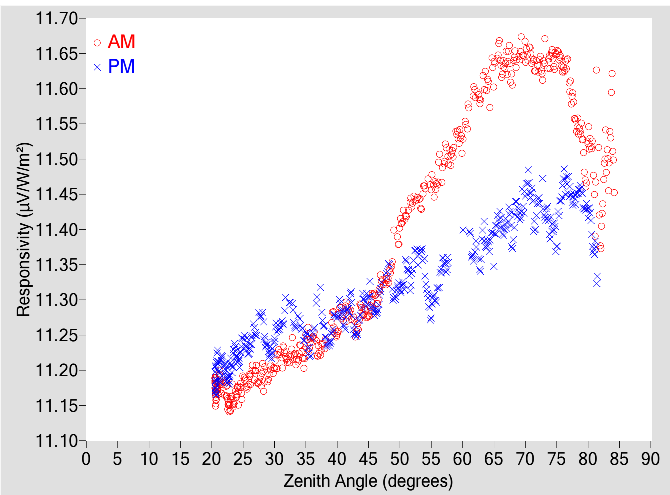


Figure 2. Responsivity vs Local Standard Time

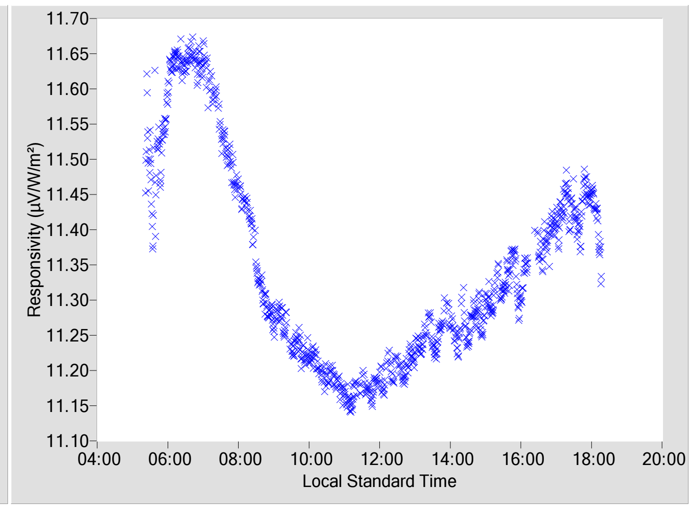


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	11.301	0.29	102.13	11.282	0.29	258.09
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.327	0.29	100.01	11.342	0.29	260.15
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.397	0.29	98.06	11.316	0.30	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.440	0.29	96.18	11.339	0.30	263.91
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.460	0.30	94.42	11.332	0.30	265.83
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.470	0.30	92.63	11.312	0.30	267.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.502	0.30	90.90	11.353	0.31	269.00
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.523	0.31	89.30	11.399	N/A	270.92
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.596	0.31	87.58	11.370	0.33	272.20
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.607	0.32	86.01	11.377	0.34	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.644	0.33	84.39	11.411	0.35	275.45
22	11.179	0.28	155.67	11.207	0.28	203.52	68	11.628	0.34	82.79	11.388	0.36	276.97
24	11.167	0.28	144.43	11.220	0.28	215.46	70	11.652	0.35	81.16	11.448	N/A	278.57
26	11.186	0.28	136.71	11.229	0.28	223.40	72	11.634	0.37	79.64	11.436	N/A	280.17
28	11.190	0.28	130.62	11.276	0.28	229.35	74	11.645	0.39	78.10	11.401	N/A	281.78
30	11.203	0.28	125.74	11.246	0.28	234.33	76	11.628	0.42	76.51	11.468	N/A	283.37
32	11.216	0.28	121.64	11.303	0.28	238.04	78	11.551	N/A	74.88	11.446	N/A	284.96
34	11.224	0.28	117.99	11.268	0.28	242.27	80	11.515	N/A	73.29	11.429	N/A	286.56
36	11.245	0.29	114.58	11.245	0.29	245.44	82	11.399	N/A	71.59	N/A	N/A	N/A
38	11.237	0.29	111.60	11.256	0.29	248.37	84	11.535	N/A	69.98	N/A	N/A	N/A
40	11.257	0.29	109.01	11.276	0.29	251.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.281	0.29	106.48	11.298	0.29	253.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.284	0.29	104.24	11.296	0.29	255.93	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

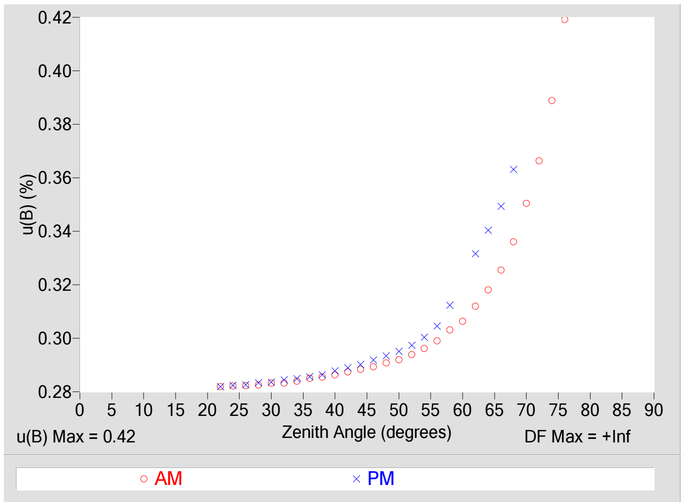


Figure 4. Residuals from Spline Interpolation

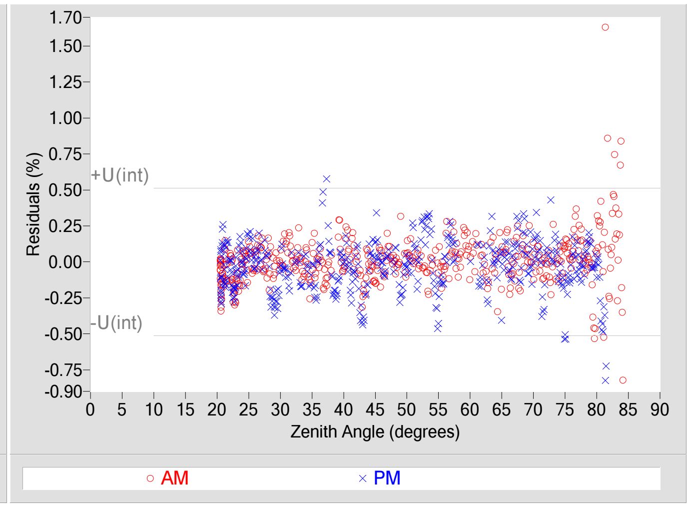


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	10990
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.96
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

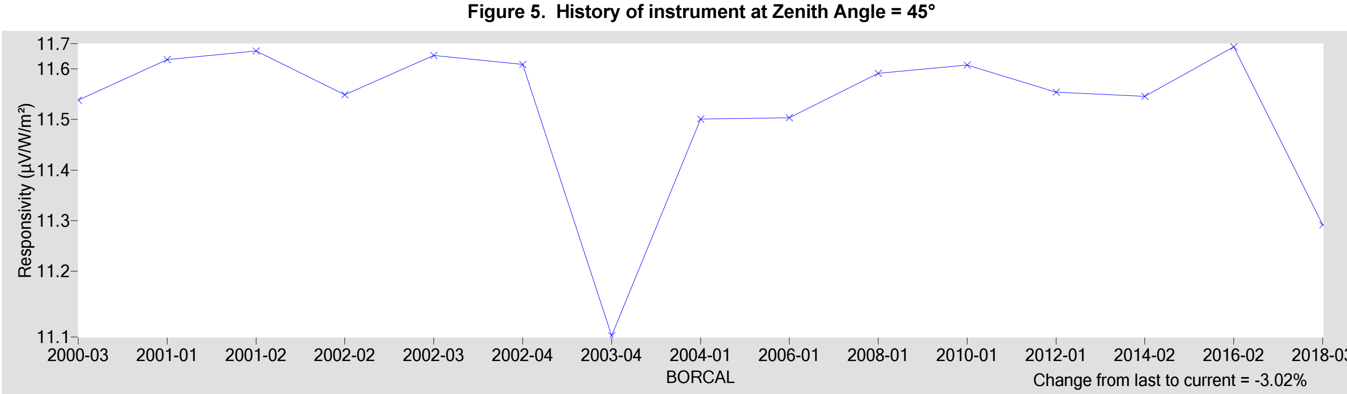
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.292	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.61
Offset Uncertainty, U(off) (%)	+2.1 / -0.78
Expanded Uncertainty, U (%)	+2.7 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2530
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

2530 Hukseflux SR25

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

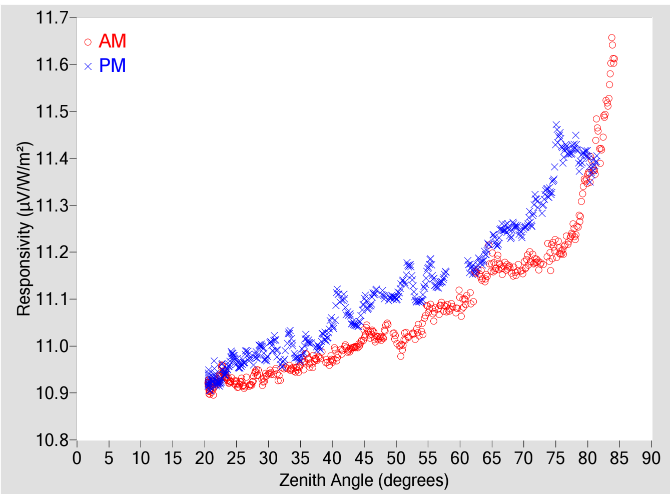


Figure 2. Responsivity vs Local Standard Time

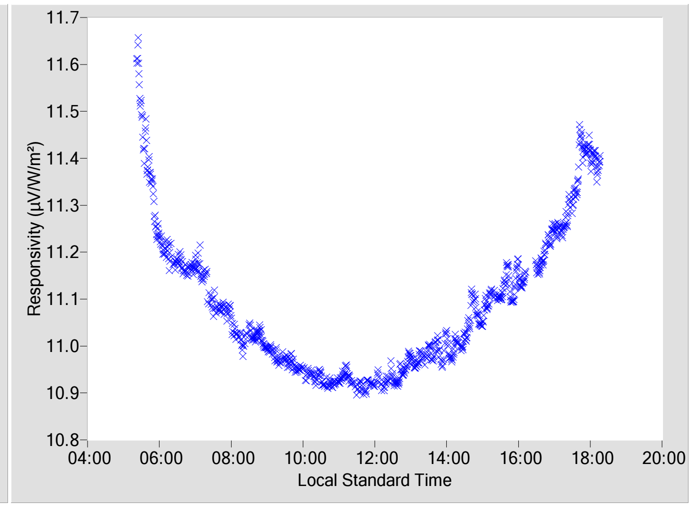


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	11.026	0.29	102.02	11.091	0.29	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.024	0.29	99.96	11.108	0.29	260.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.014	0.29	98.09	11.104	0.30	262.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.019	0.29	96.28	11.171	0.30	264.01
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.035	0.30	94.27	11.099	0.30	265.74
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.069	0.30	92.64	11.134	0.30	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.079	0.30	90.86	11.157	0.31	269.06
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.095	0.31	89.23	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.092	0.31	87.66	11.163	0.33	272.23
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.145	0.32	85.93	11.196	0.34	273.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.178	0.33	84.35	11.225	0.35	275.41
22	10.926	0.28	156.00	10.923	0.28	203.66	68	11.164	0.34	82.91	11.241	0.36	277.03
24	10.925	0.28	144.63	10.972	0.28	215.49	70	11.165	0.35	81.26	11.248	N/A	278.61
26	10.919	0.28	136.98	10.964	0.28	223.39	72	11.182	0.37	79.68	11.310	N/A	280.14
28	10.944	0.28	130.64	10.979	0.28	229.57	74	11.190	0.39	78.08	11.325	N/A	281.75
30	10.944	0.28	125.55	10.984	0.28	234.13	76	11.199	0.42	76.53	11.416	N/A	283.33
32	10.940	0.28	121.57	10.961	0.28	238.57	78	11.244	N/A	74.89	11.430	N/A	284.92
34	10.949	0.28	117.85	10.985	0.29	242.24	80	11.361	N/A	73.26	11.404	N/A	286.57
36	10.976	0.29	114.66	11.014	0.29	245.46	82	11.412	N/A	71.60	N/A	N/A	N/A
38	10.976	0.29	111.72	11.000	0.29	248.39	84	11.625	N/A	69.94	N/A	N/A	N/A
40	10.971	0.29	109.02	11.046	0.29	251.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.999	0.29	106.46	11.090	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.000	0.29	104.15	11.045	0.29	255.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

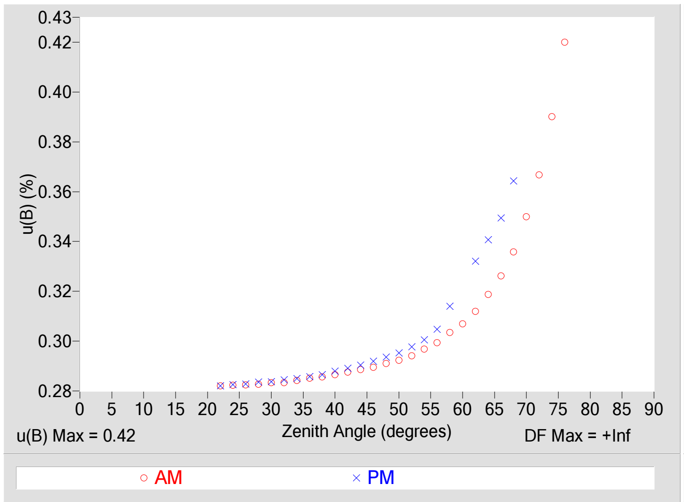


Figure 4. Residuals from Spline Interpolation

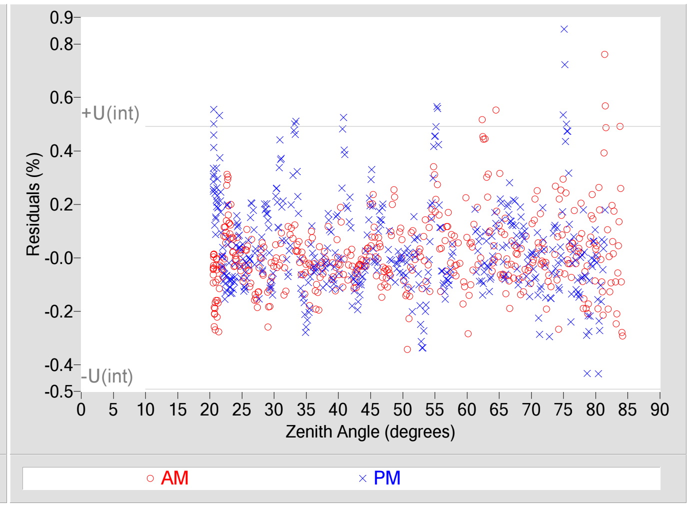


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	12022
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.95
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

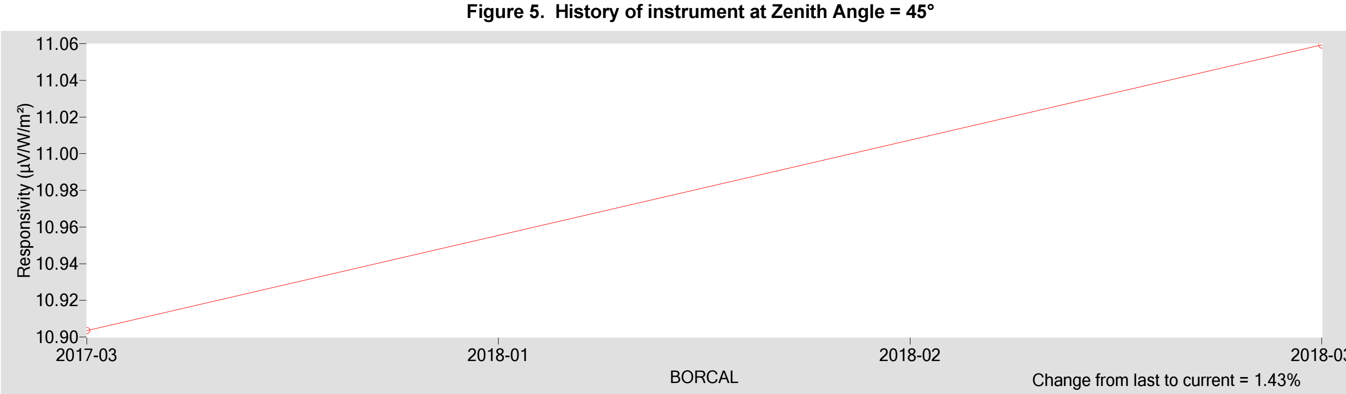
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.059	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+1.0 / -1.1
Expanded Uncertainty, U (%)	+1.6 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2543
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ____________
Ibrahim Reda, Technical Manager Date

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

Calibration Results

2543 Hukseflux SR25

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

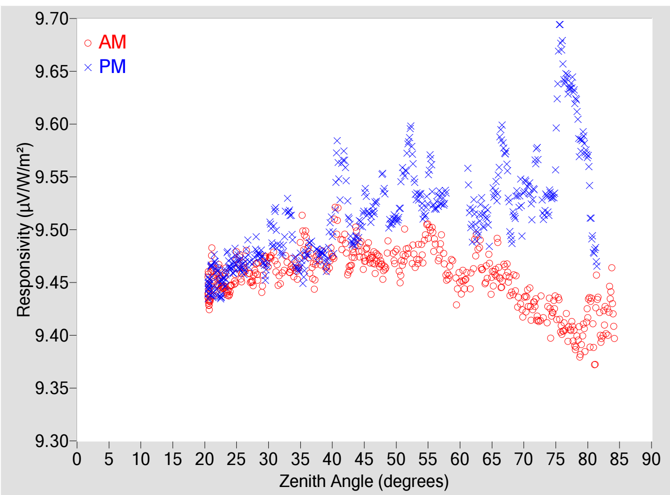


Figure 2. Responsivity vs Local Standard Time

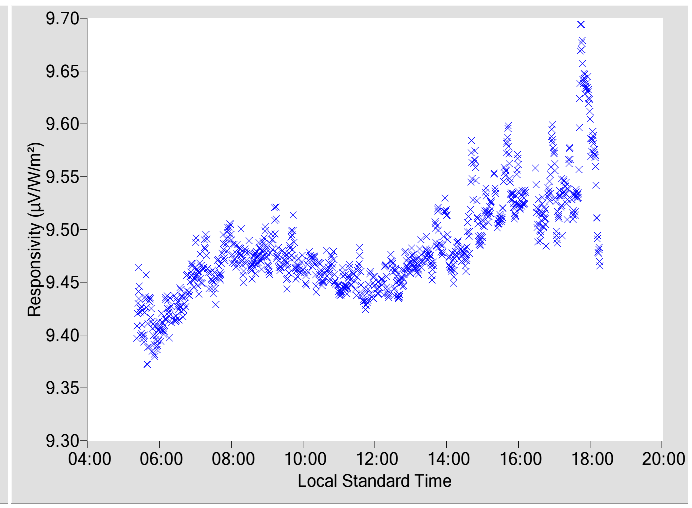


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.4727	0.29	102.02	9.5130	0.29	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4620	0.29	99.96	9.5431	0.29	260.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.4763	0.29	98.09	9.5099	0.30	262.10
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.4798	0.29	96.28	9.5892	0.30	264.01
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4769	0.30	94.27	9.5245	0.30	265.74
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4886	0.30	92.64	9.5212	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4556	0.30	90.86	9.5349	0.31	269.06
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.4496	0.31	89.23	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.4611	0.31	87.66	9.5112	0.33	272.23
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.4546	0.32	85.93	9.5120	0.34	273.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.4705	0.33	84.35	9.5520	0.35	275.41
22	9.4562	0.28	156.00	9.4536	0.28	203.66	68	9.4446	0.34	82.91	9.4974	0.37	277.03
24	9.4431	0.28	144.63	9.4664	0.28	215.49	70	9.4287	0.35	81.26	9.5409	N/A	278.68
26	9.4596	0.28	136.98	9.4623	0.28	223.39	72	9.4217	0.37	79.68	9.5698	N/A	280.14
28	9.4628	0.28	130.64	9.4803	0.28	229.57	74	9.4213	0.39	78.08	9.5271	N/A	281.75
30	9.4709	0.28	125.55	9.4808	0.28	234.13	76	9.4042	0.42	76.53	9.6650	N/A	283.33
32	9.4539	0.28	121.57	9.4795	0.28	238.57	78	9.3940	N/A	74.89	9.6258	N/A	284.92
34	9.4619	0.28	117.85	9.4760	0.29	242.24	80	9.4248	N/A	73.26	9.5644	N/A	286.57
36	9.4869	0.29	114.66	9.4773	0.29	245.46	82	9.4031	N/A	71.60	N/A	N/A	N/A
38	9.4716	0.29	111.72	9.4764	0.29	248.39	84	9.4239	N/A	69.94	N/A	N/A	N/A
40	9.4763	0.29	109.02	9.4952	0.29	251.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.4870	0.29	106.46	9.5613	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.4861	0.29	104.15	9.4956	0.29	255.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

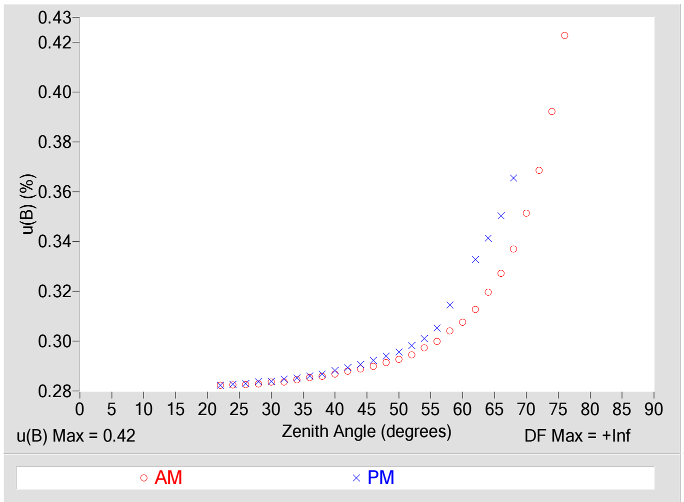


Figure 4. Residuals from Spline Interpolation

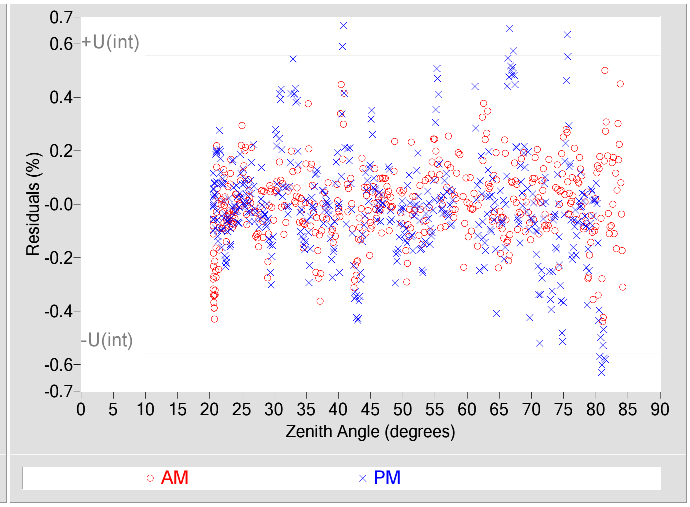


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	8569
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

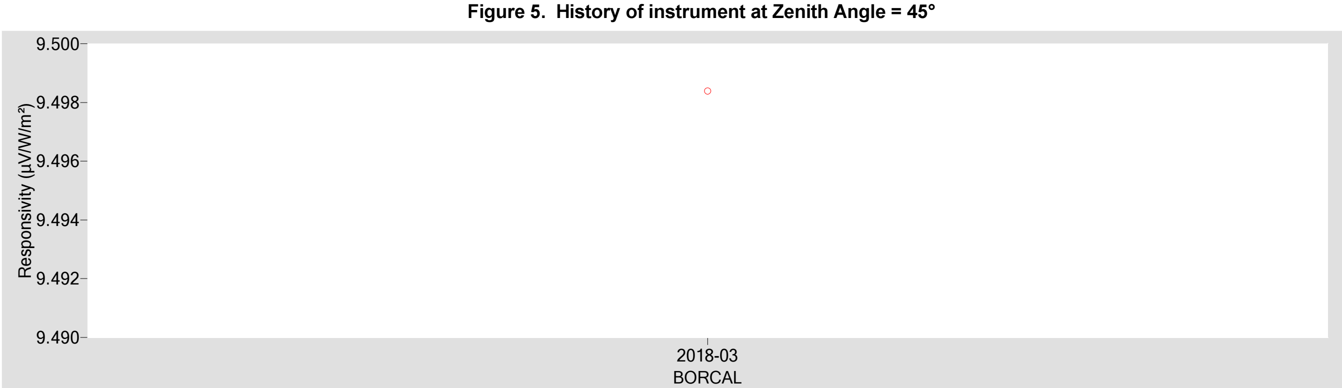
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.4984	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.96 / -0.51
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

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	28402F3
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	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: 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, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

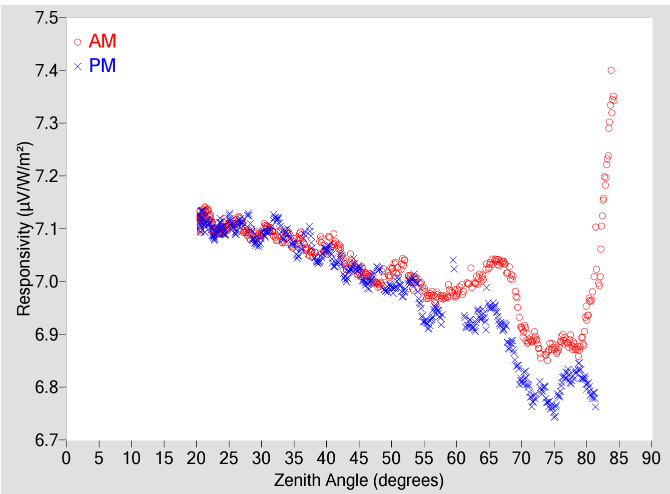


Figure 2. Responsivity vs Local Standard Time

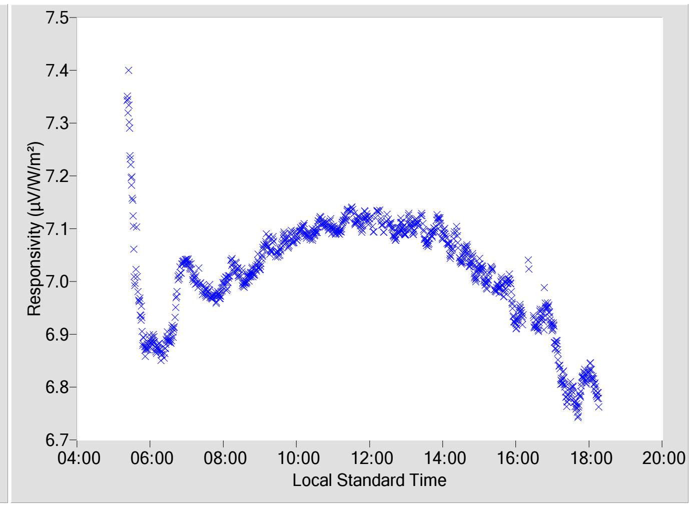


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.0129	0.31	102.00	6.9962	0.32	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.9936	0.32	99.94	7.0245	0.32	260.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.0209	0.32	97.99	6.9882	0.32	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.0386	0.32	96.25	6.9801	0.33	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.0037	0.33	94.32	6.9800	0.33	265.82
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.9766	0.33	92.57	6.9227	0.34	267.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.9696	0.34	90.89	6.9368	0.35	269.04
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9779	0.35	89.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.0055	0.36	87.63	6.9209	0.37	272.21
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.0060	0.37	86.00	6.9357	0.38	273.86
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.0402	0.39	84.38	6.9482	0.40	275.39
22	7.1250	0.29	156.57	7.1079	0.29	203.66	68	7.0199	0.40	82.89	6.8797	0.42	277.01
24	7.1001	0.30	144.72	7.0987	0.30	215.58	70	6.9076	0.43	81.19	6.8110	N/A	278.61
26	7.1099	0.30	136.92	7.0941	0.30	223.33	72	6.8943	0.46	79.66	6.7784	N/A	280.11
28	7.0900	0.30	130.71	7.1222	0.30	229.39	74	6.8632	0.50	78.09	6.7710	N/A	281.73
30	7.0874	0.30	125.83	7.0876	0.30	234.43	76	6.8855	0.55	76.48	6.7937	N/A	283.31
32	7.0853	0.30	121.52	7.1201	0.30	238.60	78	6.8786	N/A	74.92	6.8216	N/A	284.98
34	7.0902	0.30	117.92	7.0920	0.30	242.25	80	6.9317	N/A	73.28	6.8060	N/A	286.60
36	7.0865	0.30	114.69	7.0637	0.30	245.59	82	7.0149	N/A	71.58	N/A	N/A	N/A
38	7.0537	0.30	111.66	7.0510	0.31	248.49	84	7.3516	N/A	69.92	N/A	N/A	N/A
40	7.0575	0.31	109.06	7.0600	0.31	251.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0654	0.31	106.57	7.0461	0.31	253.61	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.0336	0.31	104.24	7.0307	0.31	255.85	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

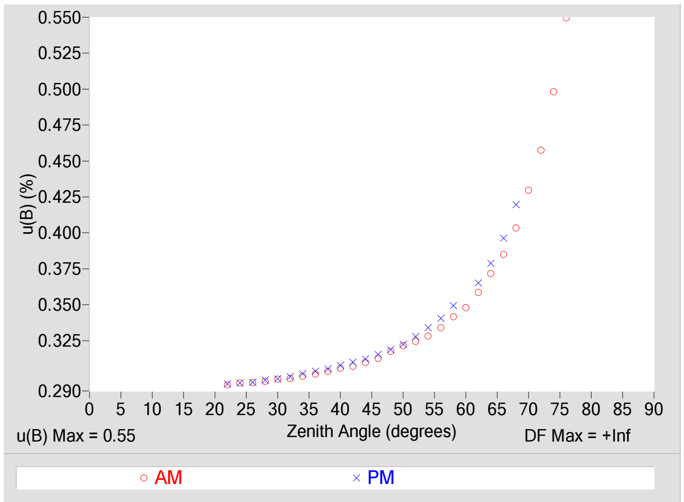


Figure 4. Residuals from Spline Interpolation

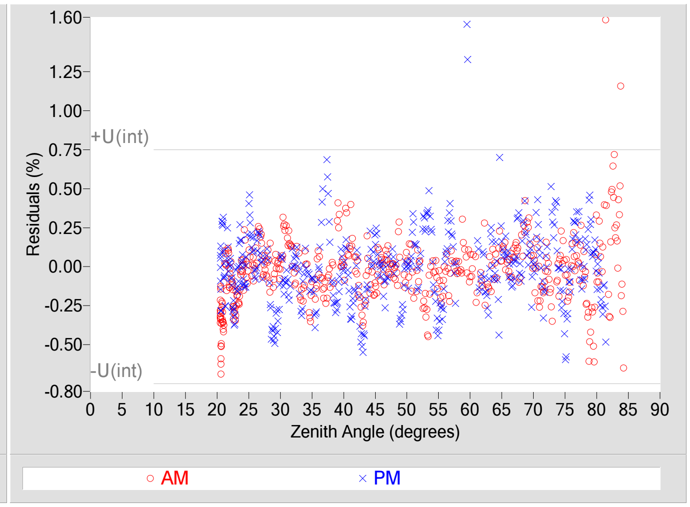


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.55
Type-A Interpolating Function, u(int) (%)	±0.38
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	8153
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

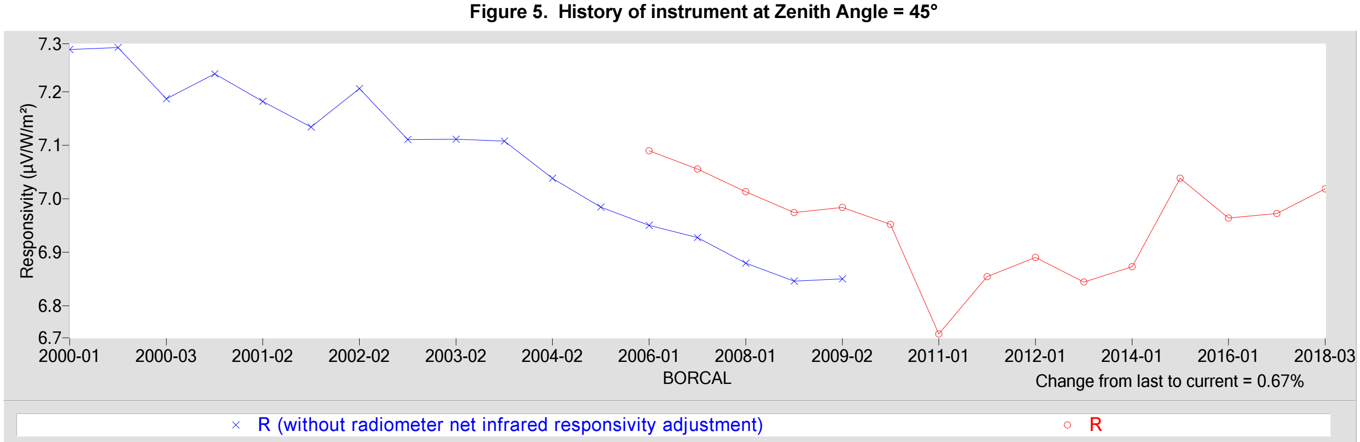
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.0189	0.64000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.68
Offset Uncertainty, U(off) (%)	+1.4 / -1.4
Expanded Uncertainty, U (%)	+2.1 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31137E6
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

31137E6 Eppley NIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

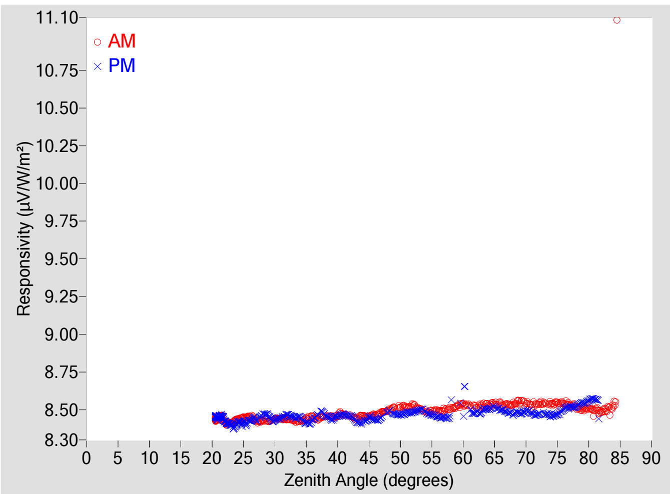


Figure 2. Responsivity vs Local Standard Time

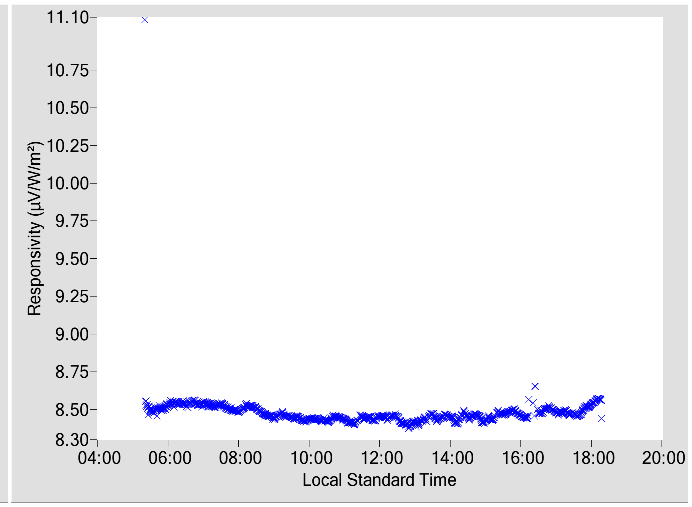


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4653	0.29	102.08	8.4338	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4937	0.29	100.07	8.4857	0.29	260.16
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5182	0.29	98.12	8.4684	0.29	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5304	0.29	96.16	8.4834	0.29	263.94
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4905	0.29	94.31	8.4850	0.30	265.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4950	0.29	92.64	8.4516	0.30	267.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5075	0.29	90.93	8.4890	0.30	269.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5341	0.30	89.21	8.5879	N/A	271.02
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5208	0.30	87.61	8.4802	0.30	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5294	0.30	86.02	8.5039	0.31	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5414	0.30	84.39	8.4983	0.31	275.45
22	8.4153	0.29	155.78	8.4288	0.29	203.67	68	8.5372	0.30	82.79	8.4700	0.31	277.02
24	8.4355	0.29	144.57	8.4117	0.29	215.47	70	8.5468	0.30	81.19	8.4887	N/A	278.58
26	8.4500	0.29	136.86	8.4279	0.29	223.27	72	8.5385	0.31	79.65	8.4709	N/A	280.18
28	8.4265	0.29	130.75	8.4643	0.29	229.20	74	8.5417	0.31	78.10	8.4606	N/A	281.74
30	8.4408	0.29	125.75	8.4320	0.29	234.34	76	8.5400	0.31	76.45	8.5060	N/A	283.38
32	8.4351	0.29	121.65	8.4681	0.29	238.45	78	8.5162	N/A	74.89	8.5239	N/A	284.96
34	8.4253	0.29	117.90	8.4510	0.29	242.18	80	8.5106	N/A	73.30	8.5617	N/A	286.57
36	8.4510	0.29	114.63	8.4322	0.29	245.45	82	8.4861	N/A	71.60	N/A	N/A	N/A
38	8.4563	0.29	111.69	8.4631	0.29	248.38	84	8.5319	N/A	69.93	N/A	N/A	N/A
40	8.4616	0.29	109.02	8.4573	0.29	251.15	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4578	0.29	106.52	8.4579	0.29	253.61	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4597	0.29	104.24	8.4211	0.29	255.94	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

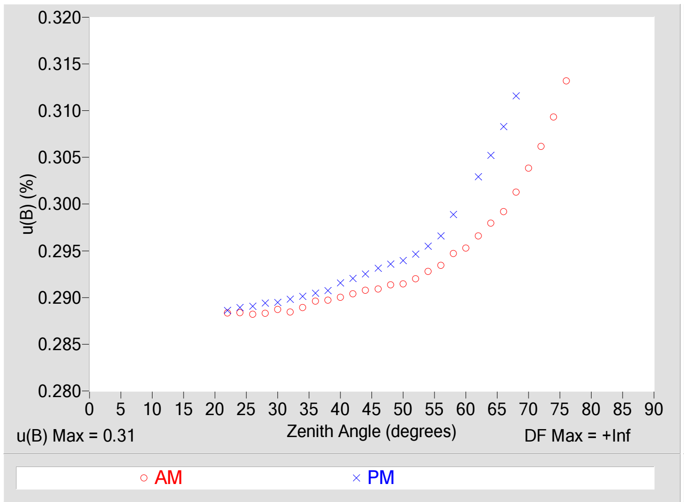


Figure 4. Residuals from Spline Interpolation

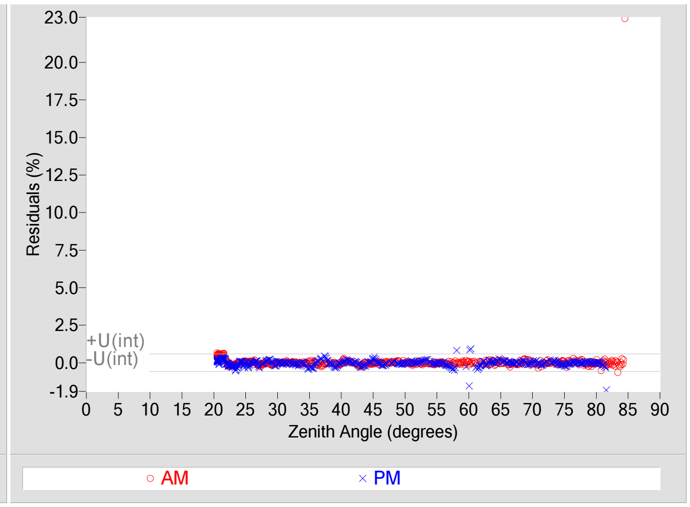


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.43
Effective degrees of freedom, DF(c)	4239
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.84
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

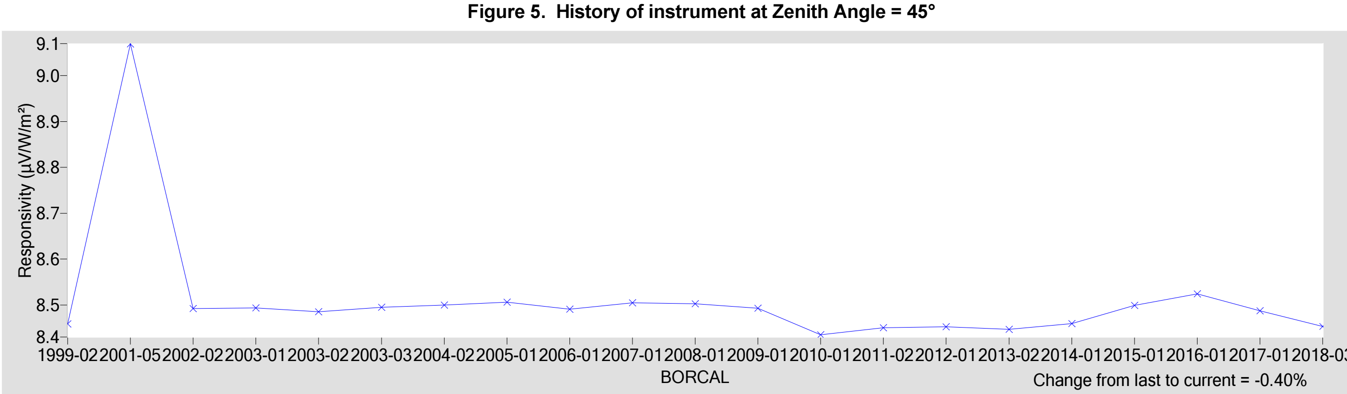
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4532	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+1.6 / -0.38
Expanded Uncertainty, U (%)	+2.2 / -0.97
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	GPP Pyranometer	**Manufacturer:**	Eppley
Model:	GPP	**Serial Number:**	37831F3
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

________________________________ ________________
Ibrahim Reda, Technical Manager Date

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

Calibration Results

37831F3 Eppley GPP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

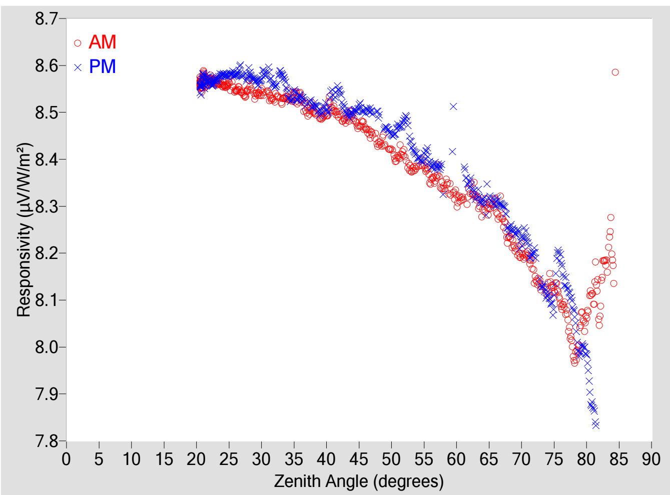


Figure 2. Responsivity vs Local Standard Time

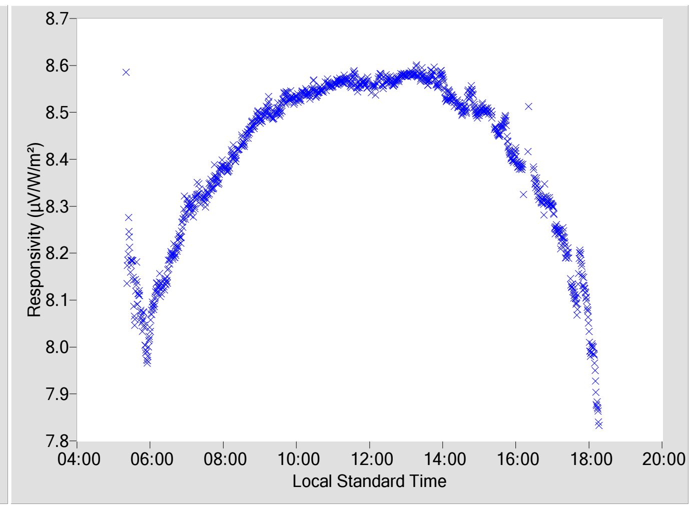


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4650	0.29	102.02	8.5038	0.30	258.07
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4328	0.30	99.96	8.4970	0.30	260.04
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4211	0.30	98.09	8.4525	0.30	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4077	0.30	96.13	8.4874	0.30	264.00
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3835	0.30	94.44	8.4061	0.31	265.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3565	0.31	92.59	8.3888	0.31	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3408	0.31	90.86	8.3252	0.33	269.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3157	0.31	89.26	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3326	0.32	87.61	8.3490	0.34	272.23
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2955	0.33	85.92	8.3102	0.35	273.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2997	0.34	84.41	8.3067	0.36	275.41
22	8.5698	0.28	156.07	8.5674	0.28	203.49	68	8.2318	0.35	82.85	8.2514	0.37	277.02
24	8.5572	0.28	144.34	8.5797	0.28	215.48	70	8.1994	0.36	81.26	8.2287	N/A	278.63
26	8.5456	0.28	136.55	8.5806	0.28	223.14	72	8.1555	0.38	79.68	8.2009	N/A	280.13
28	8.5554	0.29	130.76	8.5808	0.29	229.44	74	8.1202	0.41	78.10	8.1091	N/A	281.74
30	8.5425	0.29	125.87	8.5761	0.29	234.35	76	8.0937	0.44	76.52	8.1866	N/A	283.33
32	8.5294	0.29	121.66	8.5575	0.29	238.46	78	7.9863	N/A	74.94	8.0806	N/A	284.92
34	8.5334	0.29	117.91	8.5410	0.29	242.19	80	8.0663	N/A	73.25	7.9783	N/A	286.57
36	8.5312	0.29	114.64	8.5322	0.29	245.46	82	8.0802	N/A	71.65	N/A	N/A	N/A
38	8.5049	0.29	111.69	8.5135	0.29	248.39	84	8.1937	N/A	69.94	N/A	N/A	N/A
40	8.4969	0.29	109.02	8.5067	0.29	251.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4956	0.29	106.66	8.5439	0.29	253.60	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4917	0.29	104.18	8.4986	0.29	255.87	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

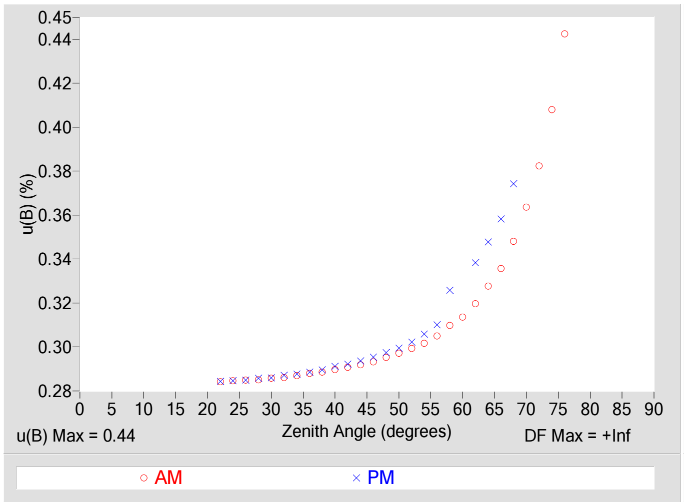


Figure 4. Residuals from Spline Interpolation

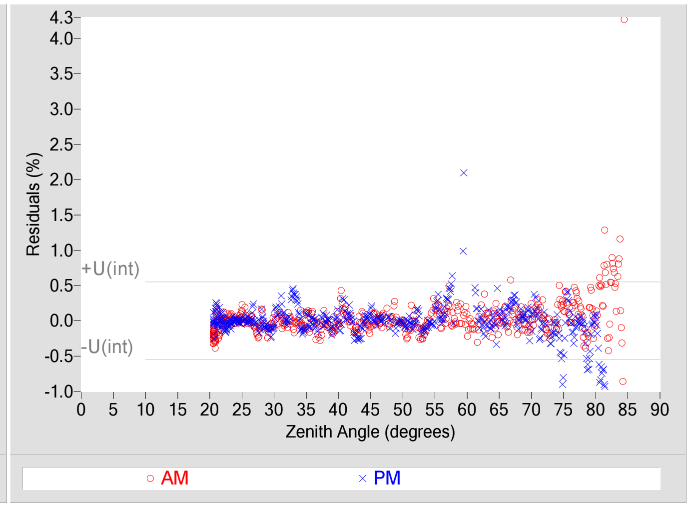


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	11561
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

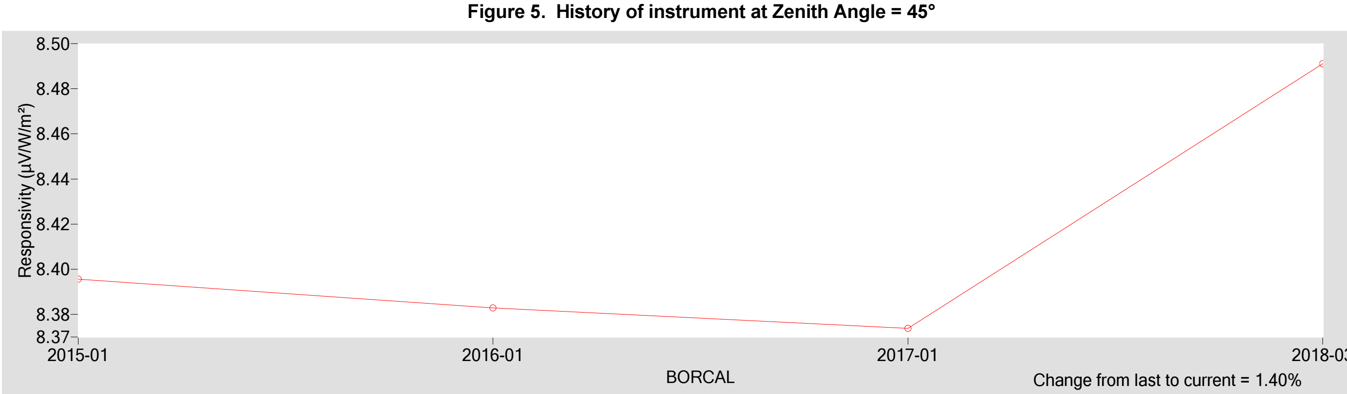
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4910	0.15000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.0 / -2.1
Expanded Uncertainty, U (%)	+1.6 / -2.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Standard Precision Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	SPP	**Serial Number:**	37839F3
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	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: 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, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

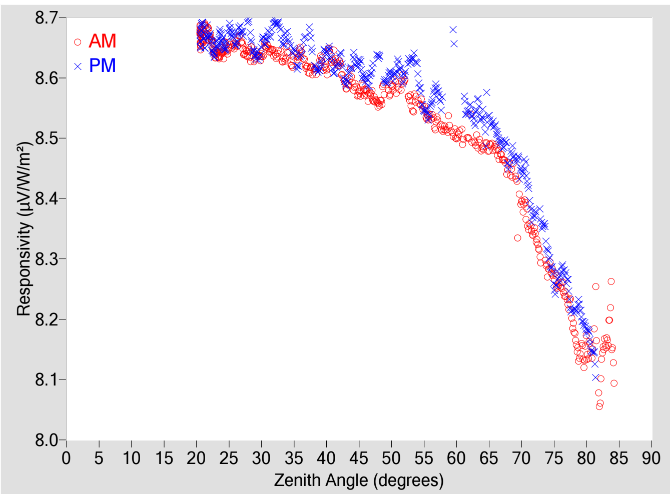


Figure 2. Responsivity vs Local Standard Time

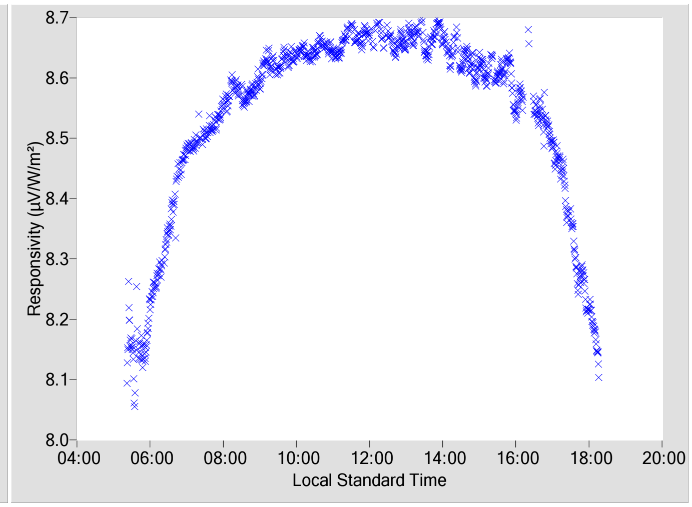


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5762	0.30	102.00	8.5967	0.30	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5569	0.31	99.94	8.6362	0.31	260.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5824	0.31	97.99	8.6041	0.31	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5967	0.31	96.25	8.6037	0.31	263.92
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5632	0.31	94.32	8.6059	0.32	265.82
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5367	0.32	92.57	8.5485	0.32	267.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5156	0.32	90.89	8.5678	0.33	269.04
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5051	0.33	89.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5135	0.34	87.63	8.5480	0.35	272.21
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4821	0.35	86.00	8.5336	0.36	273.86
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4848	0.36	84.38	8.5158	0.38	275.39
22	8.6716	0.29	156.57	8.6672	0.29	203.66	68	8.4491	0.38	82.89	8.4568	0.39	277.01
24	8.6429	0.29	144.72	8.6580	0.29	215.58	70	8.3898	0.40	81.19	8.4453	N/A	278.61
26	8.6543	0.29	136.92	8.6583	0.29	223.33	72	8.3411	0.42	79.66	8.3739	N/A	280.11
28	8.6410	0.29	130.71	8.6892	0.29	229.39	74	8.2831	0.45	78.09	8.3148	N/A	281.73
30	8.6349	0.29	125.83	8.6579	0.29	234.43	76	8.2563	0.50	76.48	8.2740	N/A	283.31
32	8.6385	0.29	121.52	8.6919	0.29	238.60	78	8.1868	N/A	74.92	8.2147	N/A	284.98
34	8.6423	0.29	117.92	8.6667	0.29	242.25	80	8.1449	N/A	73.28	8.1827	N/A	286.60
36	8.6425	0.29	114.69	8.6400	0.30	245.59	82	8.0740	N/A	71.58	N/A	N/A	N/A
38	8.6135	0.30	111.66	8.6279	0.30	248.49	84	8.1573	N/A	69.92	N/A	N/A	N/A
40	8.6136	0.30	109.06	8.6411	0.30	251.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6235	0.30	106.57	8.6355	0.30	253.61	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5947	0.30	104.24	8.6274	0.30	255.85	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

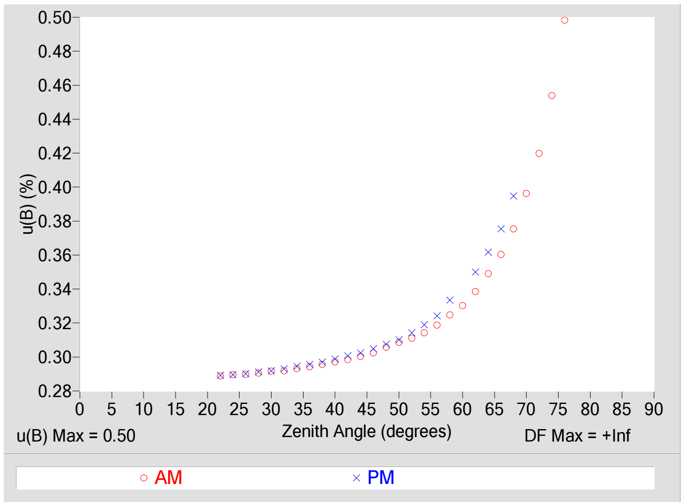


Figure 4. Residuals from Spline Interpolation

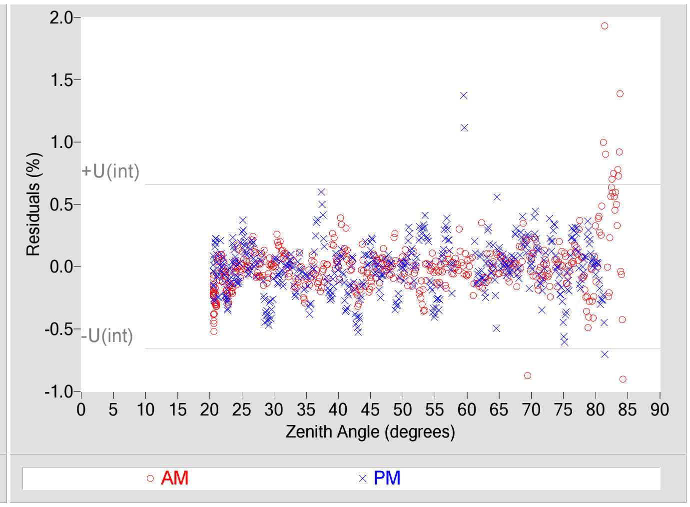


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.50
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.60
Effective degrees of freedom, DF(c)	8880
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

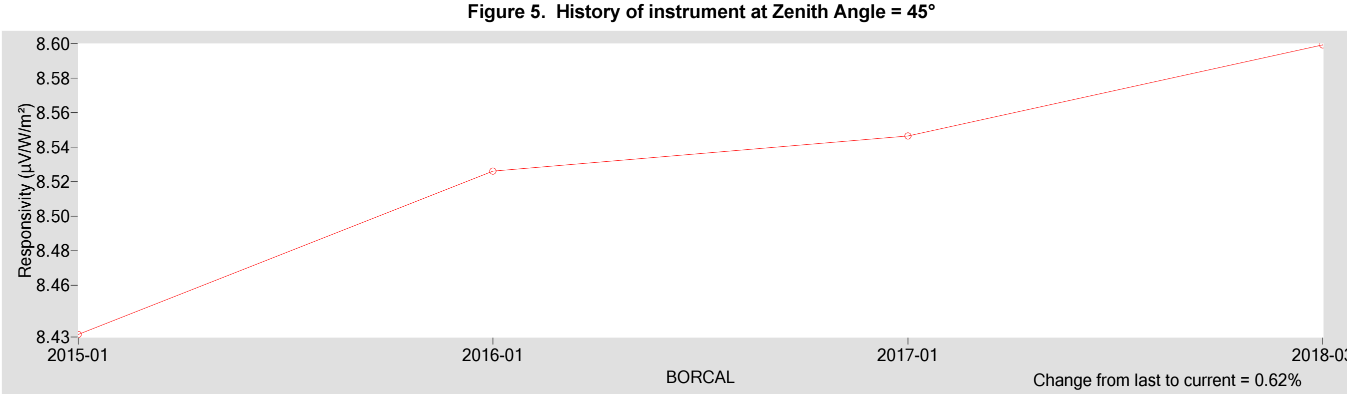
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.5992	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+1.1 / -1.1
Expanded Uncertainty, U (%)	+1.7 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Short Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37882E6
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ____________

Ibrahim Reda, Technical Manager — Date

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

Calibration Results

37882E6 Eppley sNIP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

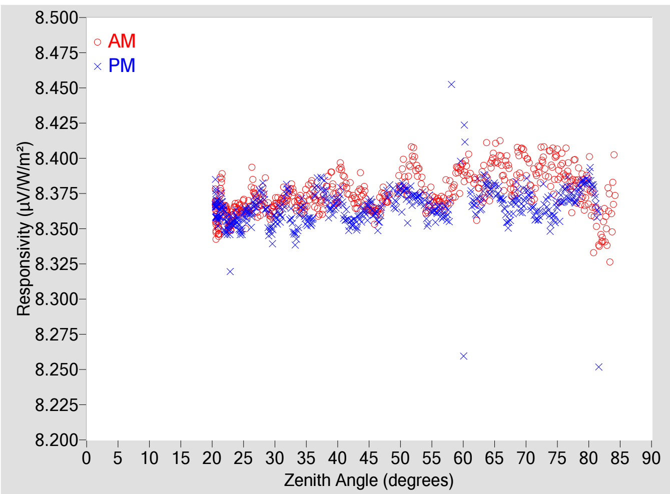


Figure 2. Responsivity vs Local Standard Time

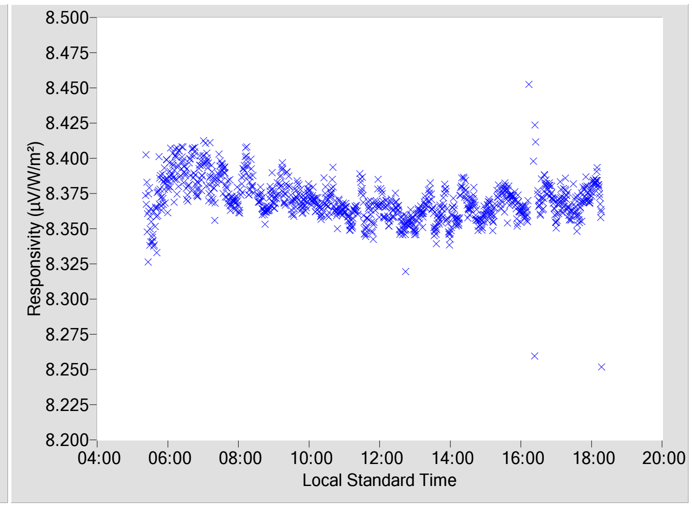


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3607	0.29	102.08	8.3600	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3700	0.29	100.07	8.3755	0.29	260.16
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3820	0.29	98.12	8.3758	0.29	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4035	0.29	96.16	8.3723	0.29	263.94
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3673	0.29	94.31	8.3620	0.30	265.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3702	0.29	92.64	8.3642	0.30	267.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3756	0.29	90.93	8.3925	0.30	269.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3908	0.30	89.21	8.3649	N/A	271.02
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3738	0.30	87.61	8.3657	0.30	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3847	0.30	86.02	8.3793	0.31	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3997	0.30	84.39	8.3705	0.31	275.45
22	8.3636	0.29	155.78	8.3570	0.29	203.67	68	8.3766	0.30	82.79	8.3677	0.31	277.02
24	8.3633	0.29	144.57	8.3566	0.29	215.47	70	8.3973	0.30	81.19	8.3766	N/A	278.58
26	8.3678	0.29	136.86	8.3605	0.29	223.27	72	8.3898	0.31	79.65	8.3593	N/A	280.18
28	8.3712	0.29	130.75	8.3760	0.29	229.20	74	8.3978	0.31	78.10	8.3588	N/A	281.74
30	8.3680	0.29	125.75	8.3571	0.29	234.34	76	8.3895	0.31	76.45	8.3749	N/A	283.38
32	8.3703	0.29	121.65	8.3779	0.29	238.45	78	8.3838	N/A	74.89	8.3722	N/A	284.96
34	8.3690	0.29	117.90	8.3621	0.29	242.18	80	8.3820	N/A	73.30	8.3870	N/A	286.57
36	8.3778	0.29	114.63	8.3589	0.29	245.45	82	8.3467	N/A	71.60	N/A	N/A	N/A
38	8.3743	0.29	111.69	8.3771	0.29	248.38	84	8.3749	N/A	69.98	N/A	N/A	N/A
40	8.3757	0.29	109.02	8.3696	0.29	251.15	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3761	0.29	106.52	8.3528	0.29	253.61	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3742	0.29	104.24	8.3599	0.29	255.94	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

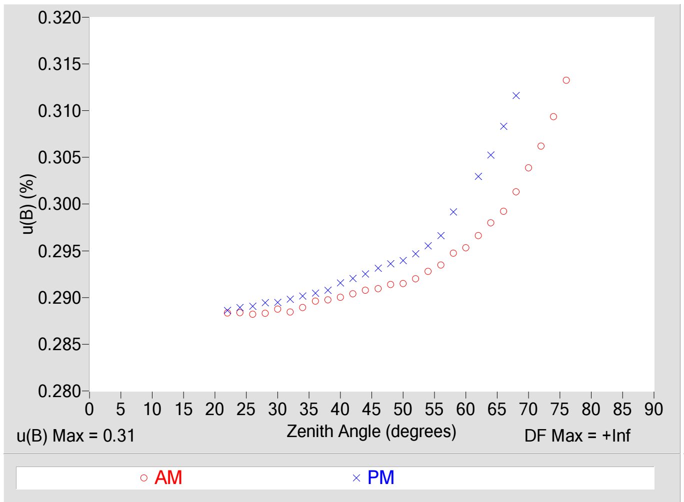


Figure 4. Residuals from Spline Interpolation

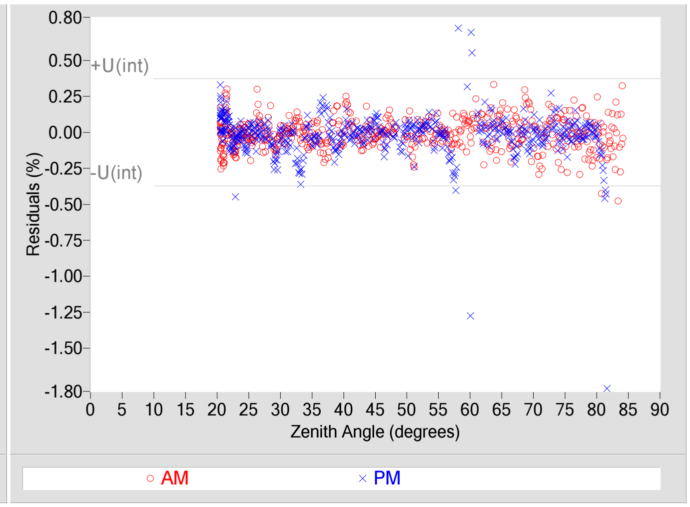


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	13300
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.71
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

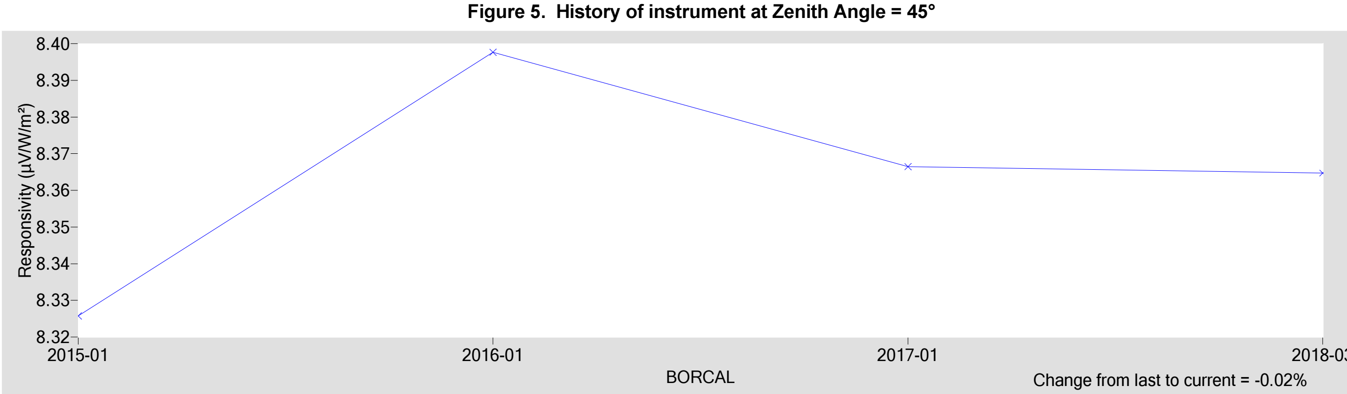
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3647	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.46 / -0.14
Expanded Uncertainty, U (%)	+1.1 / -0.73
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Si pyranometer	**Manufacturer:**	Apogee
Model:	SP-110	**Serial Number:**	40337
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

40337 Apogee SP-110

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

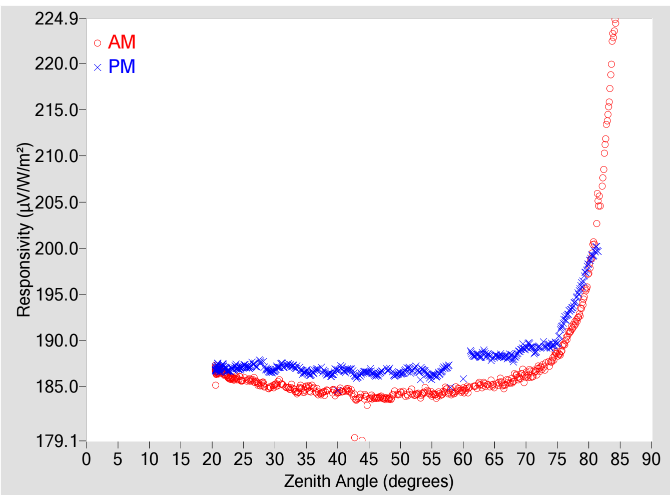


Figure 2. Responsivity vs Local Standard Time

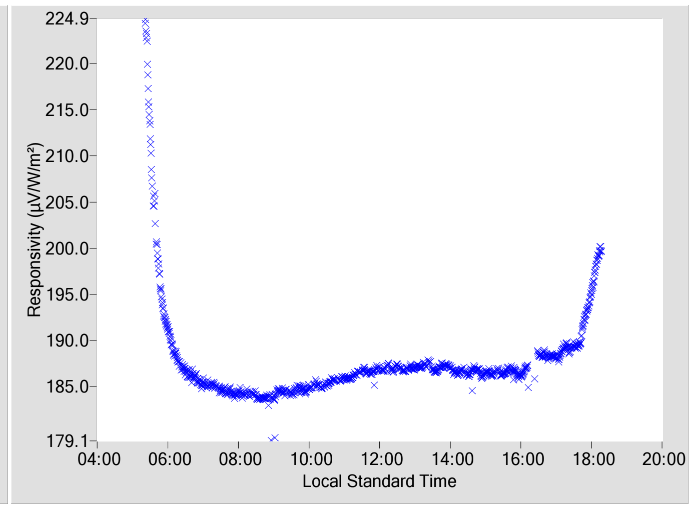


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	183.73	0.29	102.06	186.23	0.29	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	183.69	0.29	100.00	186.82	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	184.29	0.29	98.01	186.45	0.29	262.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	184.30	0.29	96.18	186.75	0.30	263.89
8	N/A	N/A	N/A	N/A	N/A	N/A	54	184.60	0.30	94.34	186.49	0.30	265.76
10	N/A	N/A	N/A	N/A	N/A	N/A	56	184.08	0.30	92.62	186.31	0.30	267.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	184.39	0.30	90.86	186.12	0.31	269.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	184.60	0.31	89.19	185.82	N/A	270.91
16	N/A	N/A	N/A	N/A	N/A	N/A	62	184.96	0.31	87.67	188.36	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	185.12	0.32	85.97	188.41	0.34	273.81
20	N/A	N/A	N/A	N/A	N/A	N/A	66	185.48	0.32	84.33	188.31	0.35	275.44
22	186.43	0.28	156.29	187.06	0.28	203.42	68	185.72	0.33	82.83	188.08	0.36	277.00
24	185.90	0.28	144.75	186.93	0.28	215.58	70	186.06	0.35	81.24	189.17	N/A	278.56
26	185.70	0.28	136.61	187.06	0.28	223.28	72	186.79	0.36	79.71	189.25	N/A	280.16
28	185.27	0.28	130.58	187.65	0.28	229.26	74	187.69	0.39	78.06	189.37	N/A	281.77
30	185.13	0.28	125.76	186.82	0.28	234.30	76	189.48	0.41	76.51	192.13	N/A	283.36
32	184.88	0.28	121.64	187.33	0.28	238.42	78	192.12	N/A	74.87	194.57	N/A	284.95
34	184.79	0.28	117.88	186.83	0.28	242.34	80	197.26	N/A	73.28	198.39	N/A	286.55
36	184.93	0.28	114.49	186.54	0.28	245.51	82	206.15	N/A	71.63	N/A	N/A	N/A
38	184.38	0.28	111.70	186.48	0.29	248.48	84	223.54	N/A	69.92	N/A	N/A	N/A
40	184.39	0.29	108.92	186.79	0.29	251.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	184.43	0.29	106.50	186.86	0.29	253.51	88	N/A	N/A	N/A	N/A	N/A	N/A
44	181.40	0.29	104.15	186.52	0.29	255.95	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

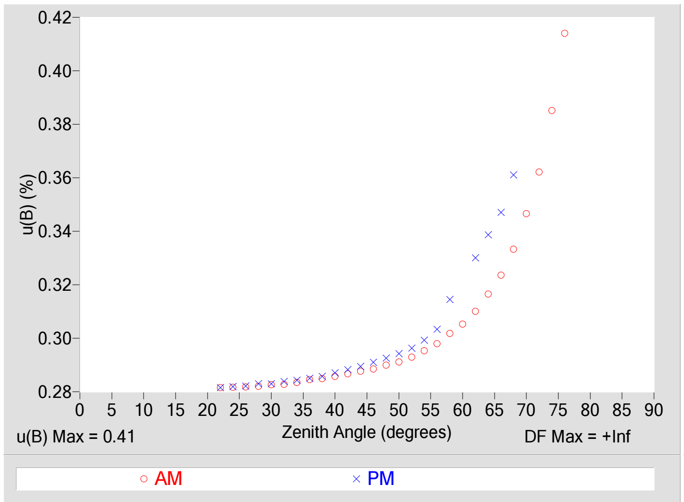


Figure 4. Residuals from Spline Interpolation

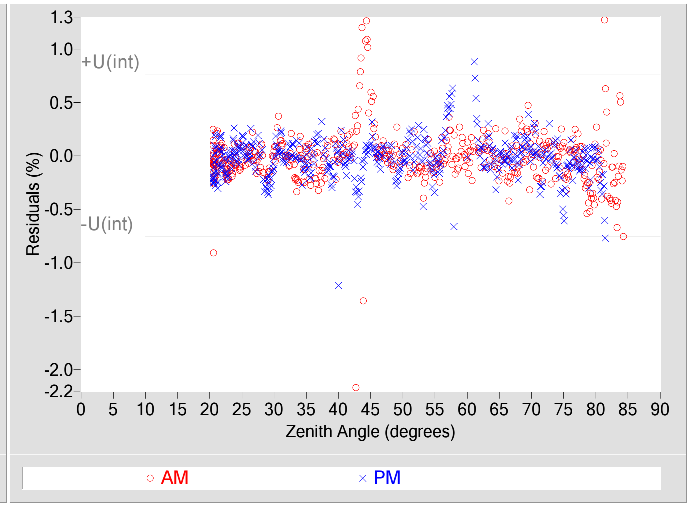


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.38
Combined Standard Uncertainty, u(c) (%)	±0.56
Effective degrees of freedom, DF(c)	3980
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

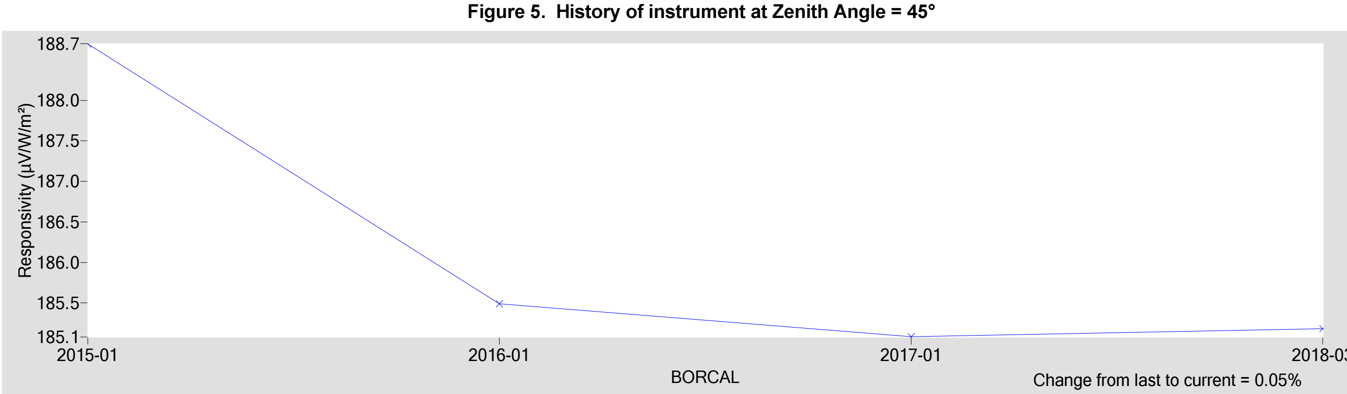
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
185.18	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+1.2 / -2.0
Expanded Uncertainty, U (%)	+1.8 / -2.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Hukseflux
Model:	DR02	**Serial Number:**	9206
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

____________________________________ ________________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

9206 Hukseflux DR02

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

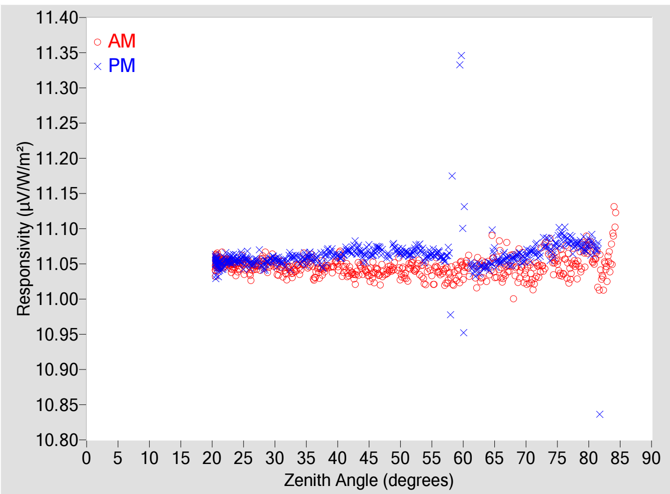


Figure 2. Responsivity vs Local Standard Time

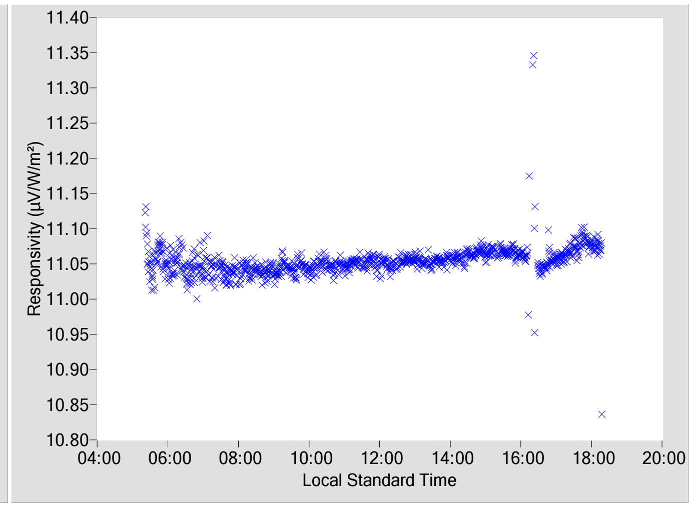


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	11.037	0.29	102.08	11.070	0.29	258.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.040	0.29	100.01	11.061	0.29	260.16
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.039	0.29	98.07	11.067	0.29	262.03
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.048	0.29	96.16	11.068	0.29	263.94
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.033	0.29	94.34	11.059	0.30	265.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.044	0.29	92.64	11.065	0.30	267.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.038	0.29	90.95	11.073	0.30	269.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.042	0.29	89.21	11.061	N/A	270.92
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.041	0.30	87.56	11.042	0.30	272.18
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.038	0.30	86.02	11.047	0.30	273.83
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.050	0.30	84.39	11.053	0.31	275.46
22	11.052	0.29	156.43	11.054	0.29	203.60	68	11.036	0.30	82.82	11.057	0.31	276.97
24	11.043	0.29	144.42	11.056	0.29	215.54	70	11.035	0.30	81.21	11.061	N/A	278.58
26	11.041	0.29	136.72	11.051	0.29	223.27	72	11.041	0.31	79.67	11.063	N/A	280.18
28	11.054	0.29	130.62	11.046	0.29	229.43	74	11.067	0.31	78.09	11.068	N/A	281.79
30	11.050	0.29	125.71	11.057	0.29	234.34	76	11.050	0.31	76.47	11.089	N/A	283.33
32	11.039	0.29	121.65	11.056	0.29	238.50	78	11.046	N/A	74.89	11.078	N/A	284.97
34	11.042	0.29	118.04	11.056	0.29	242.14	80	11.072	N/A	73.29	11.079	N/A	286.56
36	11.045	0.29	114.63	11.057	0.29	245.36	82	11.040	N/A	71.59	10.837	N/A	288.00
38	11.044	0.29	111.68	11.061	0.29	248.38	84	11.098	N/A	69.93	N/A	N/A	N/A
40	11.052	0.29	109.01	11.062	0.29	251.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.039	0.29	106.52	11.067	0.29	253.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.045	0.29	104.21	11.061	0.29	255.94	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

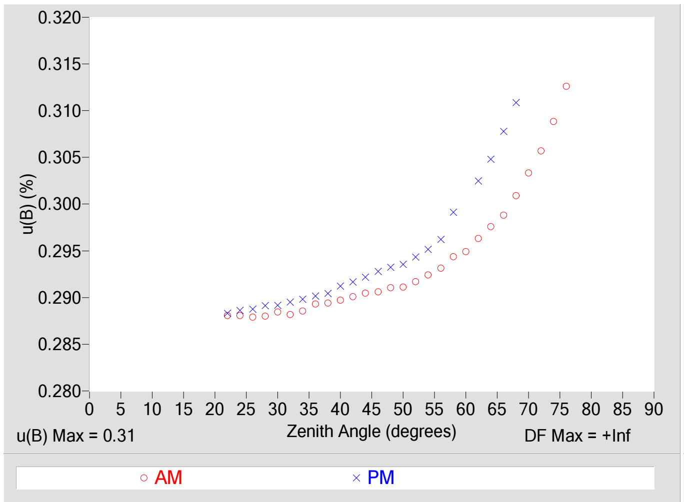


Figure 4. Residuals from Spline Interpolation

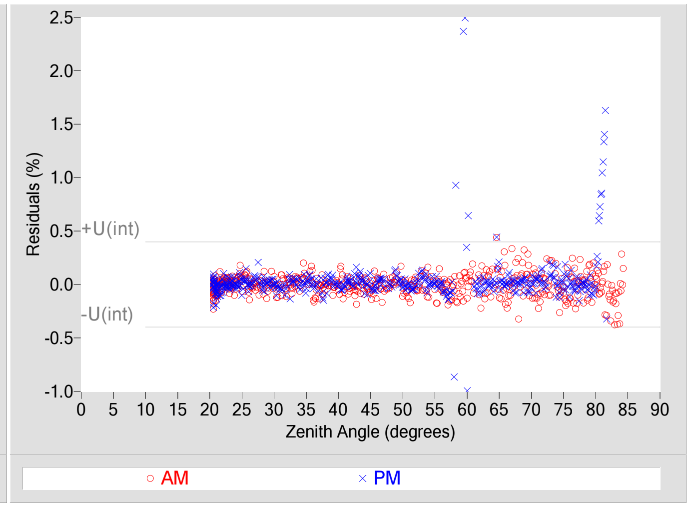


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	10734
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.73
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

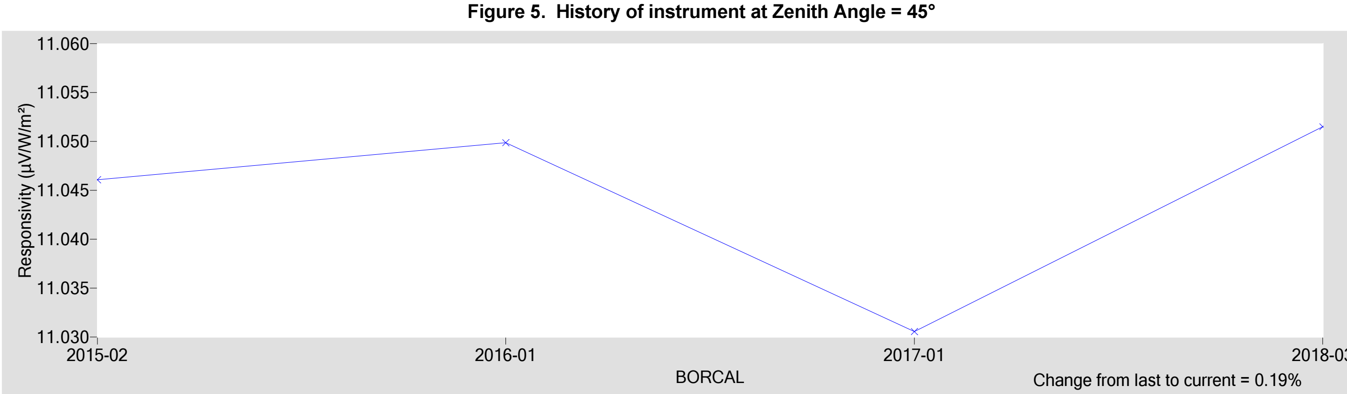
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.052	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.19 / -0.17
Expanded Uncertainty, U (%)	+0.78 / -0.75
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Sunshine Pyranometer - Global Output	**Manufacturer:**	Delta-T
Model:	SPN1	**Serial Number:**	A360
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

A360 Delta-T SPN1

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

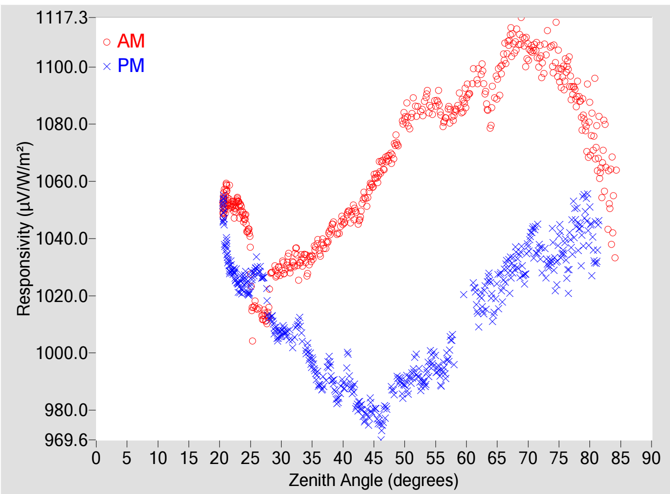


Figure 2. Responsivity vs Local Standard Time

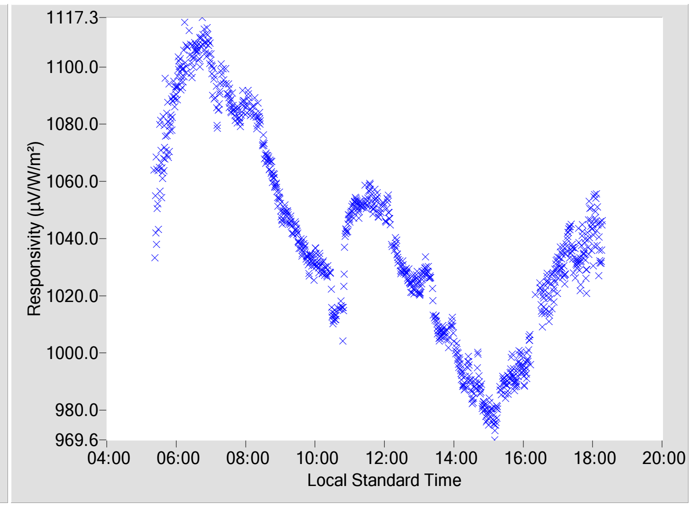


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	1064.4	0.29	102.06	974.44	0.29	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	1068.3	0.29	100.03	986.92	0.29	260.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	1081.8	0.29	98.05	989.77	0.29	262.14
6	N/A	N/A	N/A	N/A	N/A	N/A	52	1085.1	0.29	96.22	993.84	0.30	263.99
8	N/A	N/A	N/A	N/A	N/A	N/A	54	1085.4	0.30	94.27	996.32	0.30	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	1082.2	0.30	92.66	992.28	0.30	267.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	1083.5	0.30	90.84	1001.2	0.31	269.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	1090.4	0.31	89.19	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	1096.4	0.31	87.74	1014.3	0.33	272.14
18	N/A	N/A	N/A	N/A	N/A	N/A	64	1084.3	0.32	85.96	1020.2	0.34	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	1104.0	0.32	84.36	1024.1	0.35	275.44
22	1051.8	0.28	156.02	1029.3	0.28	203.92	68	1108.2	0.33	82.83	1032.4	0.36	277.01
24	1047.3	0.28	144.57	1026.1	0.28	215.50	70	1106.0	0.35	81.29	1037.1	N/A	278.57
26	1016.3	0.28	136.97	1030.2	0.28	223.27	72	1102.1	0.36	79.71	1034.5	N/A	280.16
28	1017.7	0.28	130.80	1012.3	0.28	229.43	74	1103.3	0.38	78.09	1035.3	N/A	281.77
30	1029.9	0.28	125.54	1007.4	0.28	234.31	76	1098.1	0.41	76.51	1034.3	N/A	283.36
32	1031.8	0.28	121.52	1004.0	0.28	238.36	78	1090.1	N/A	74.90	1043.9	N/A	284.95
34	1031.6	0.28	117.88	1001.4	0.28	242.35	80	1076.4	N/A	73.29	1044.3	N/A	286.55
36	1037.1	0.28	114.61	990.02	0.28	245.51	82	1066.8	N/A	71.63	N/A	N/A	N/A
38	1043.1	0.28	111.66	994.04	0.29	248.44	84	1048.5	N/A	69.94	N/A	N/A	N/A
40	1046.1	0.29	108.99	988.86	0.29	251.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	1049.0	0.29	106.57	983.87	0.29	253.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	1054.0	0.29	104.18	977.70	0.29	255.92	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

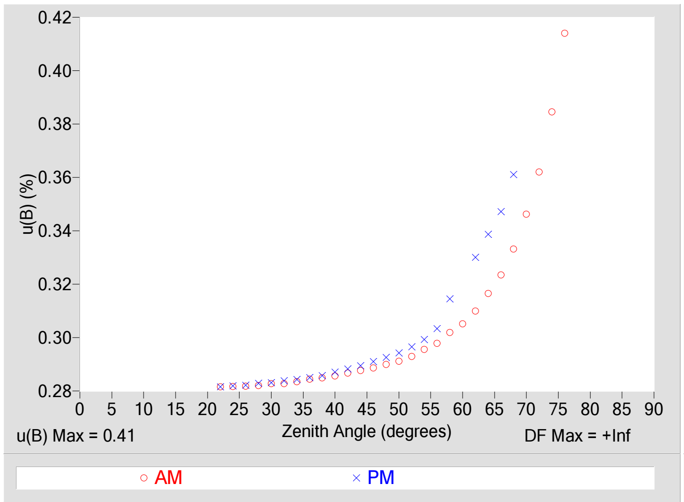


Figure 4. Residuals from Spline Interpolation

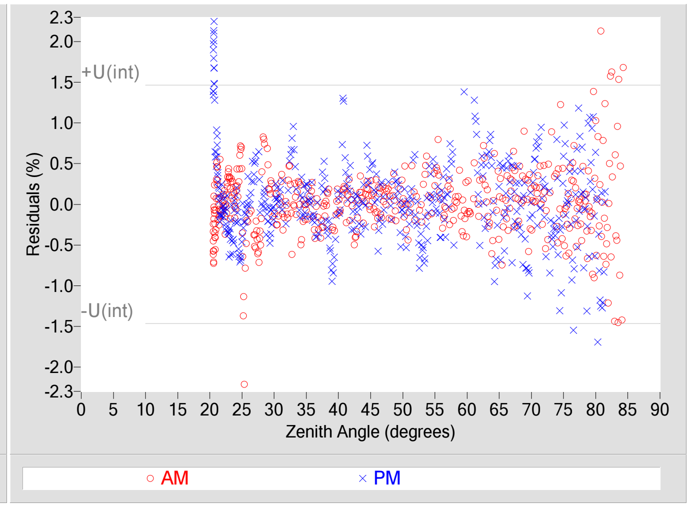


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.73
Combined Standard Uncertainty, u(c) (%)	±0.84
Effective degrees of freedom, DF(c)	1417
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.7
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

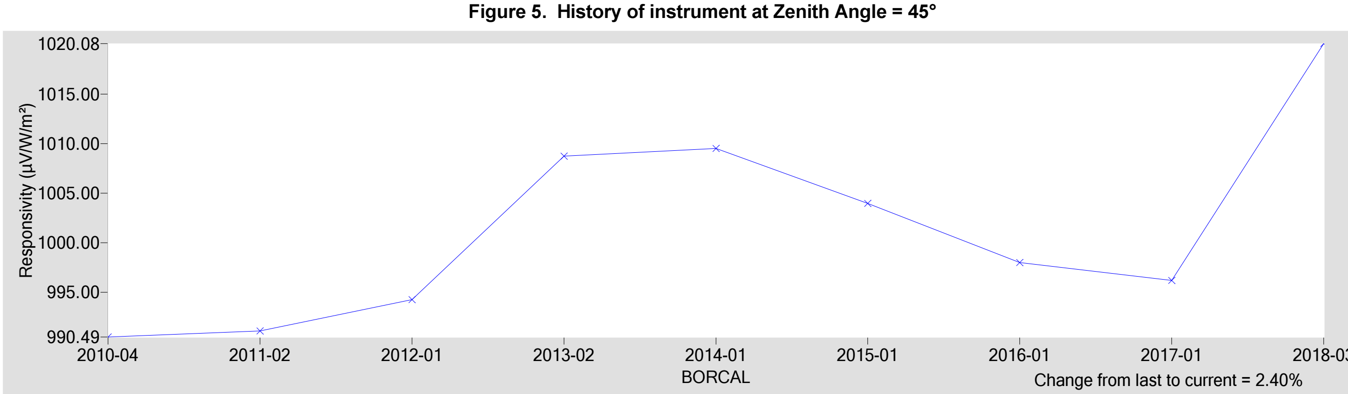
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
1020.1	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+6.9 / -4.5
Expanded Uncertainty, U (%)	+7.5 / -5.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	EKO
Model:	MS-802	**Serial Number:**	F14077R
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

________________________________ ________________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

F14077R EKO MS-802

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

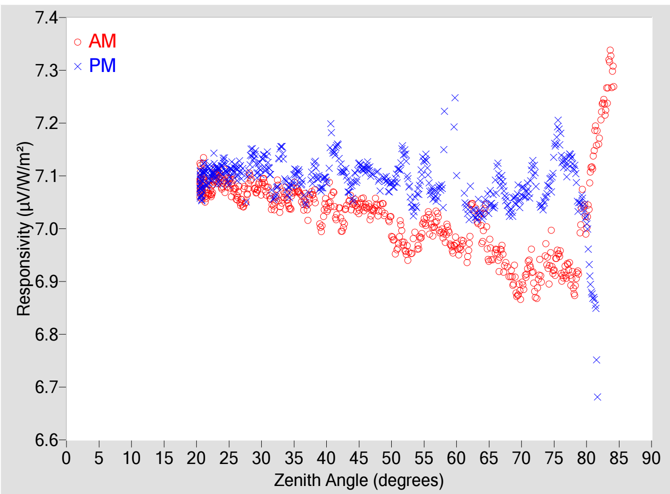


Figure 2. Responsivity vs Local Standard Time

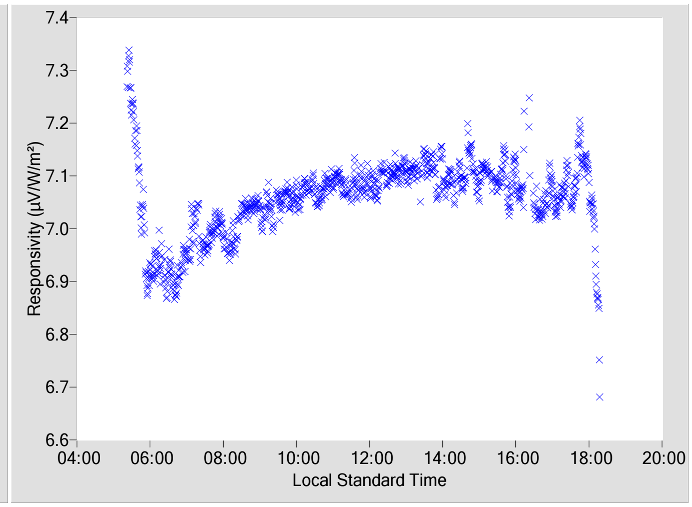


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.0398	0.30	102.02	7.1135	0.30	258.04
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.0369	0.30	99.99	7.0940	0.30	260.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.9988	0.30	98.01	7.0851	0.30	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.9622	0.30	96.11	7.1396	0.31	264.00
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.9639	0.31	94.27	7.0581	0.31	265.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.0095	0.31	92.59	7.0743	0.32	267.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.9881	0.32	90.85	7.1220	0.33	269.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9712	0.32	89.28	7.1744	N/A	270.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9816	0.33	87.62	7.0448	0.34	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9959	0.34	85.97	7.0296	0.35	273.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.9570	0.35	84.30	7.0721	0.37	275.41
22	7.0737	0.29	156.50	7.1041	0.29	203.80	68	6.9186	0.36	82.85	7.0355	0.38	277.02
24	7.0885	0.29	144.62	7.1201	0.29	215.47	70	6.8851	0.38	81.26	7.0627	N/A	278.58
26	7.0673	0.29	136.80	7.1095	0.29	223.38	72	6.8915	0.39	79.72	7.1071	N/A	280.13
28	7.0829	0.29	130.75	7.1141	0.29	229.63	74	6.9338	0.42	78.10	7.0745	N/A	281.74
30	7.0824	0.29	125.58	7.1242	0.29	234.34	76	6.9346	0.46	76.53	7.1584	N/A	283.33
32	7.0499	0.29	121.45	7.0600	0.29	238.56	78	6.8923	N/A	74.89	7.1206	N/A	284.92
34	7.0535	0.29	117.91	7.0742	0.29	242.28	80	7.0165	N/A	73.25	7.0099	N/A	286.56
36	7.0636	0.29	114.65	7.0954	0.29	245.44	82	7.1897	N/A	71.55	N/A	N/A	N/A
38	7.0629	0.29	111.68	7.1106	0.29	248.38	84	7.2940	N/A	69.93	N/A	N/A	N/A
40	7.0428	0.29	109.02	7.0928	0.29	250.97	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0237	0.29	106.39	7.1305	0.30	253.60	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.0451	0.30	104.15	7.0738	0.30	255.88	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

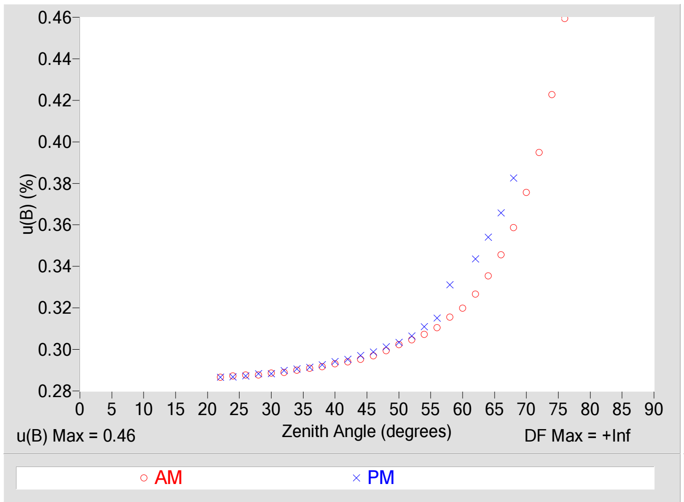


Figure 4. Residuals from Spline Interpolation

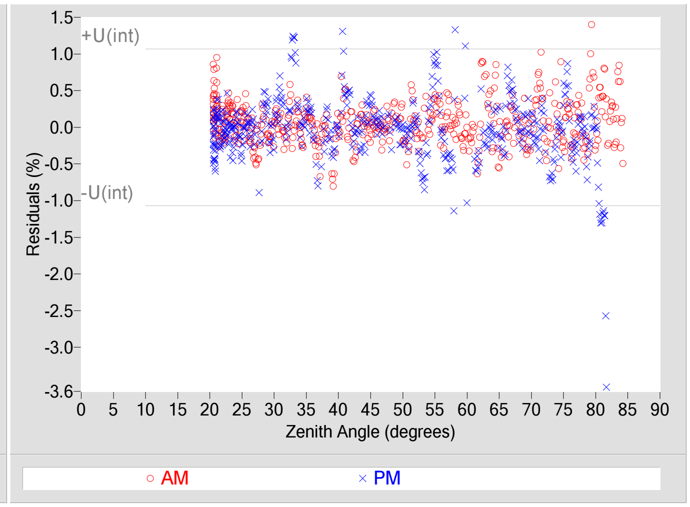


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.53
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	2736
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

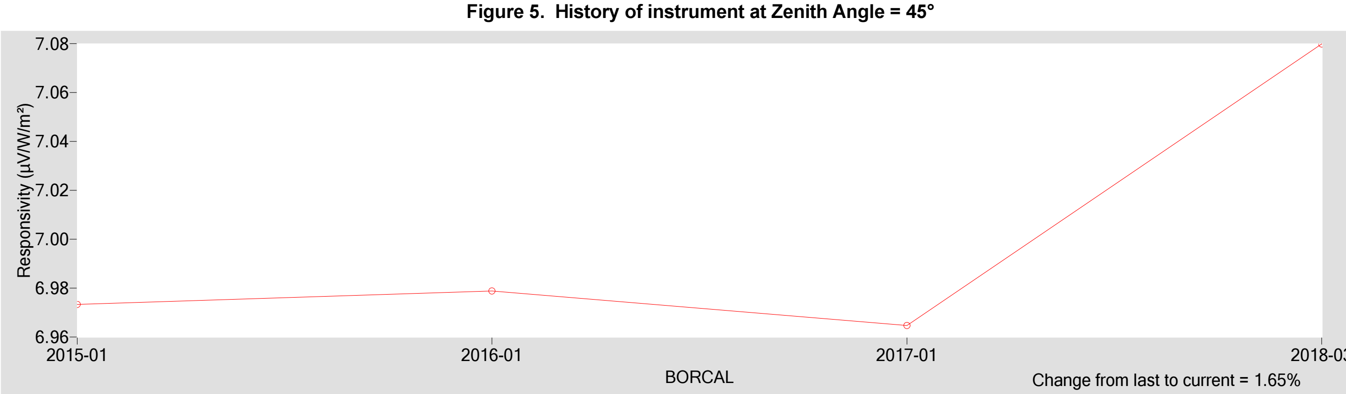
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.0798	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+1.3 / -1.7
Expanded Uncertainty, U (%)	+2.0 / -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

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	EKO
Model:	MS-56	**Serial Number:**	P12022
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

P12022 EKO MS-56

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

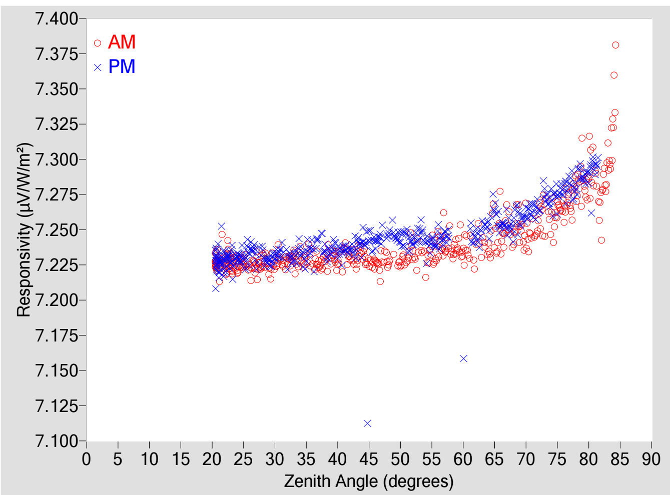


Figure 2. Responsivity vs Local Standard Time

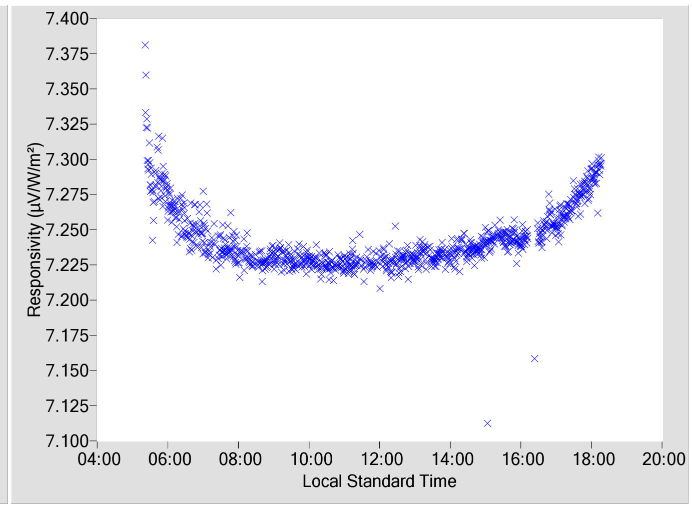


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.2266	0.29	102.07	7.2415	0.29	258.09
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2273	0.29	100.01	7.2465	0.29	260.15
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2255	0.29	98.11	7.2433	0.29	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2332	0.29	96.18	7.2421	0.29	263.94
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2257	0.29	94.31	7.2385	0.30	265.83
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2375	0.29	92.63	7.2443	0.30	267.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2392	0.29	90.85	7.2438	0.30	268.99
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2346	0.30	89.20	7.1585	N/A	270.92
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2308	0.30	87.65	7.2459	0.30	272.17
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2351	0.30	85.96	7.2512	0.31	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.2508	0.30	84.39	7.2524	0.31	275.45
22	7.2254	0.29	155.85	7.2263	0.29	203.66	68	7.2434	0.30	82.77	7.2523	0.31	276.97
24	7.2254	0.29	144.42	7.2314	0.29	215.56	70	7.2498	0.30	81.20	7.2595	N/A	278.57
26	7.2217	0.29	136.85	7.2341	0.29	223.39	72	7.2556	0.31	79.67	7.2650	N/A	280.17
28	7.2275	0.29	130.73	7.2339	0.29	229.41	74	7.2597	0.31	78.10	7.2691	N/A	281.78
30	7.2250	0.29	125.65	7.2313	0.29	234.32	76	7.2638	0.31	76.47	7.2799	N/A	283.37
32	7.2274	0.29	121.62	7.2297	0.29	238.64	78	7.2802	N/A	74.88	7.2815	N/A	284.96
34	7.2302	0.29	117.94	7.2376	0.29	242.08	80	7.2868	N/A	73.29	7.2901	N/A	286.56
36	7.2311	0.29	114.79	7.2341	0.29	245.43	82	7.2689	N/A	71.59	N/A	N/A	N/A
38	7.2304	0.29	111.59	7.2336	0.29	248.45	84	7.3373	N/A	69.92	N/A	N/A	N/A
40	7.2283	0.29	109.00	7.2341	0.29	251.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2297	0.29	106.51	7.2364	0.29	253.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2333	0.29	104.20	7.2407	0.29	255.93	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

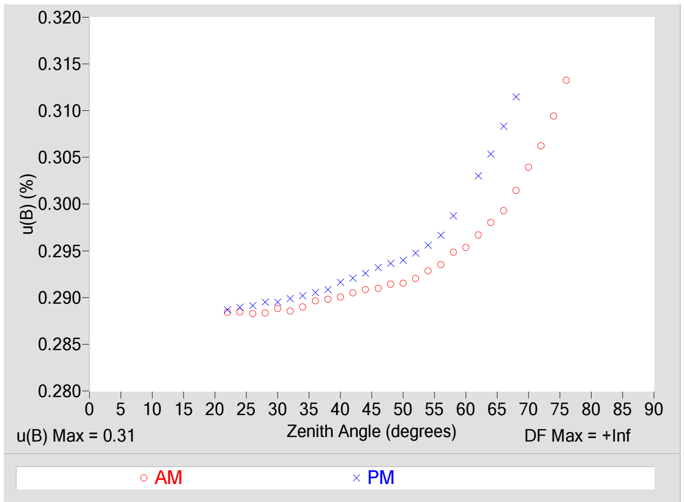


Figure 4. Residuals from Spline Interpolation

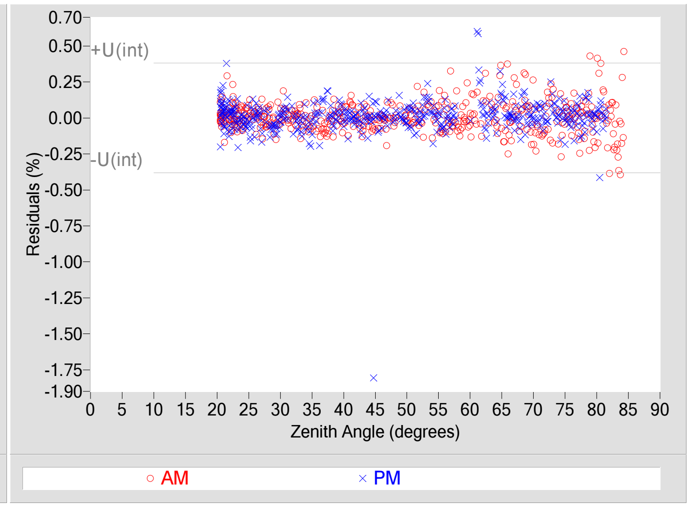


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	11248
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.72
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

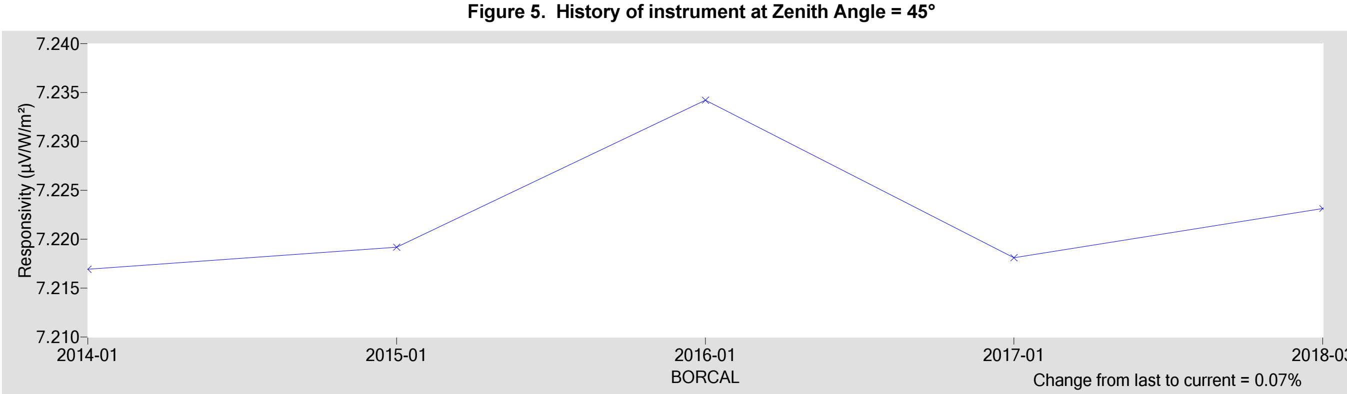
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.2231	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.32 / -0.90
Expanded Uncertainty, U (%)	+0.91 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Revised Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200R	**Serial Number:**	PY100360
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

_______________________________ ____________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

PY100360 Licor LI200R

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

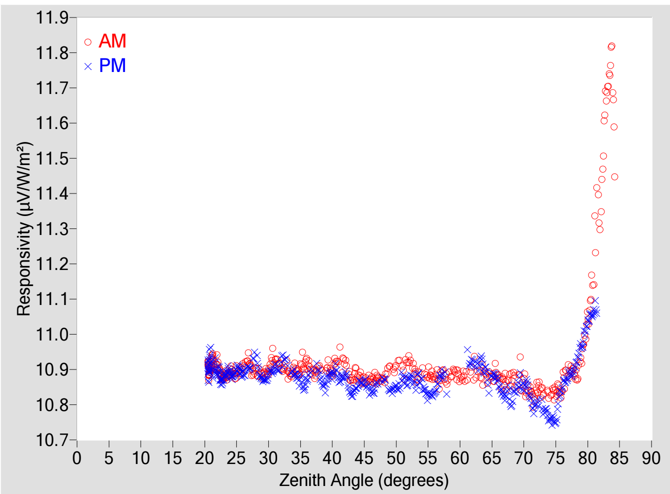


Figure 2. Responsivity vs Local Standard Time

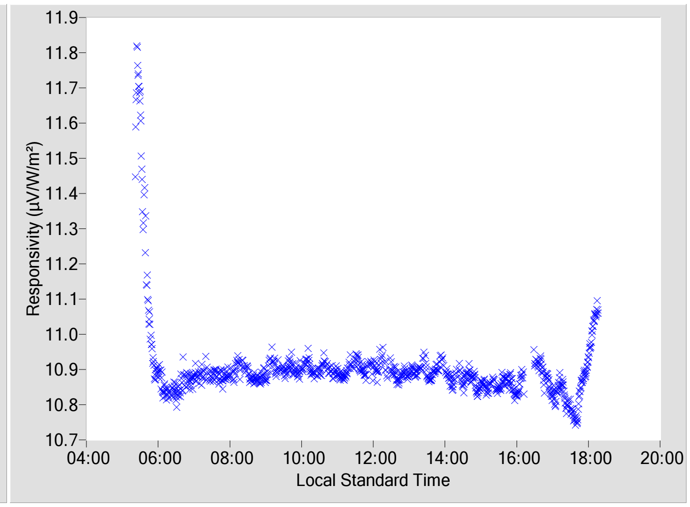


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.873	0.29	102.04	10.837	0.29	258.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.873	0.29	99.97	10.871	0.29	260.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.908	0.29	98.08	10.850	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.926	0.29	96.12	10.873	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.905	0.30	94.22	10.861	0.30	265.80
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.879	0.30	92.60	10.834	0.30	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.870	0.30	90.97	10.830	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.877	0.31	89.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.905	0.31	87.54	10.923	0.33	272.09
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.883	0.32	85.96	10.893	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.882	0.33	84.41	10.859	0.35	275.42
22	10.914	0.28	156.21	10.895	0.28	203.77	68	10.874	0.34	82.86	10.803	0.36	276.99
24	10.893	0.28	144.65	10.887	0.28	215.36	70	10.862	0.35	81.20	10.850	N/A	278.59
26	10.904	0.28	137.02	10.889	0.28	223.32	72	10.845	0.37	79.64	10.804	N/A	280.19
28	10.895	0.28	130.66	10.934	0.28	229.34	74	10.827	0.39	78.10	10.760	N/A	281.75
30	10.896	0.28	125.72	10.885	0.28	234.30	76	10.853	0.42	76.49	10.849	N/A	283.34
32	10.904	0.28	121.43	10.927	0.28	238.78	78	10.889	N/A	74.90	10.911	N/A	284.98
34	10.903	0.28	117.95	10.890	0.28	242.21	80	11.036	N/A	73.26	11.032	N/A	286.58
36	10.919	0.29	114.66	10.872	0.29	245.47	82	11.350	N/A	71.61	N/A	N/A	N/A
38	10.908	0.29	111.76	10.883	0.29	248.48	84	11.642	N/A	69.90	N/A	N/A	N/A
40	10.894	0.29	108.96	10.887	0.29	251.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.920	0.29	106.54	10.883	0.29	253.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.884	0.29	104.16	10.857	0.29	255.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

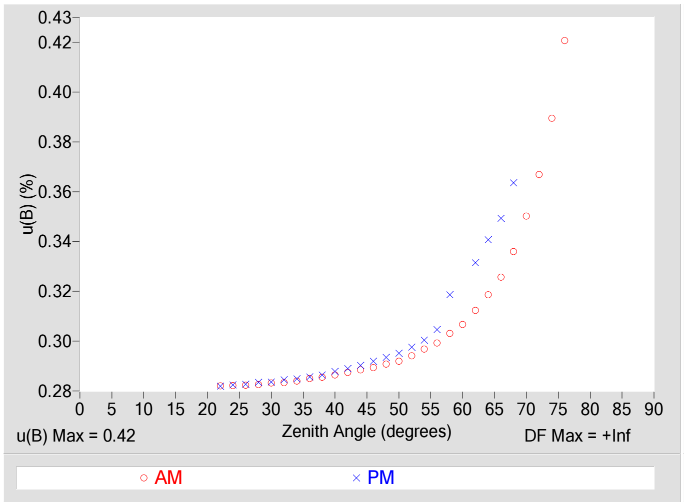


Figure 4. Residuals from Spline Interpolation

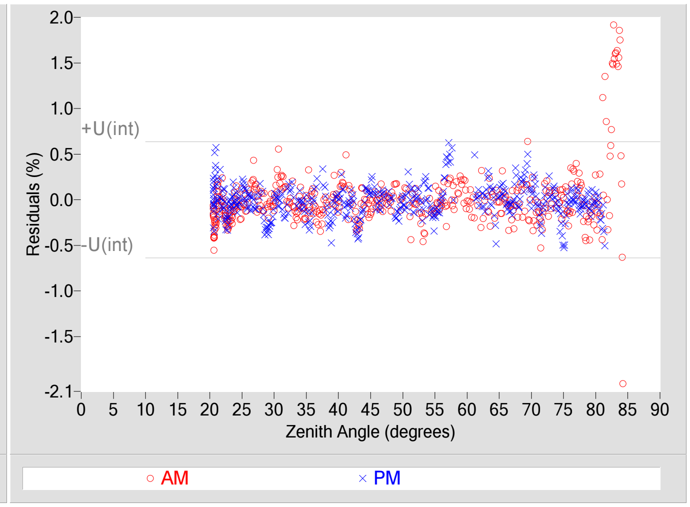


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	6178
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

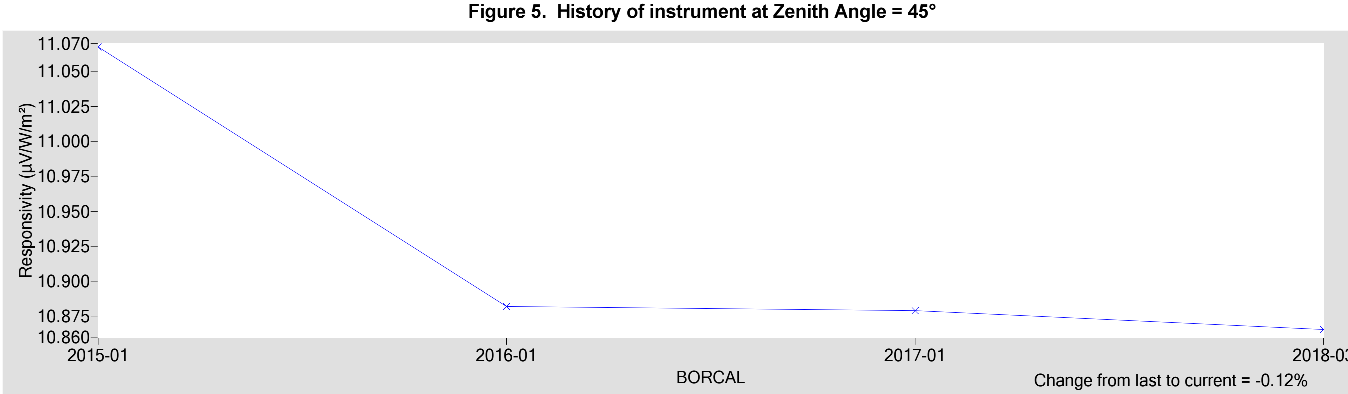
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.866	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.57 / -0.32
Expanded Uncertainty, U (%)	+1.2 / -0.95
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Revised Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200R	**Serial Number:**	PY102023
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

________________________________ _______________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

PY102023 Licor LI200R

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

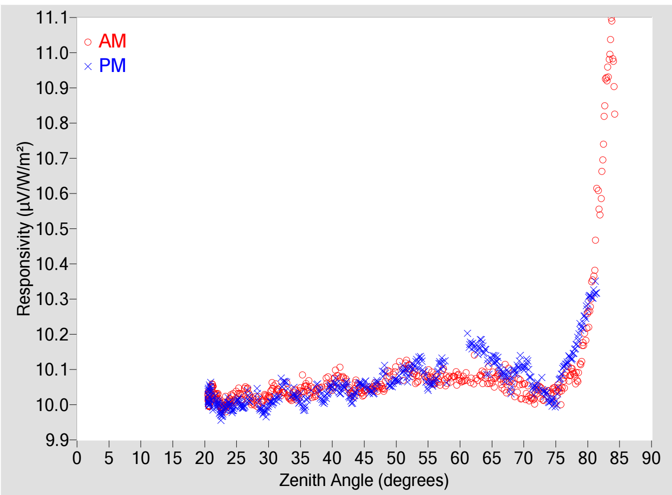


Figure 2. Responsivity vs Local Standard Time

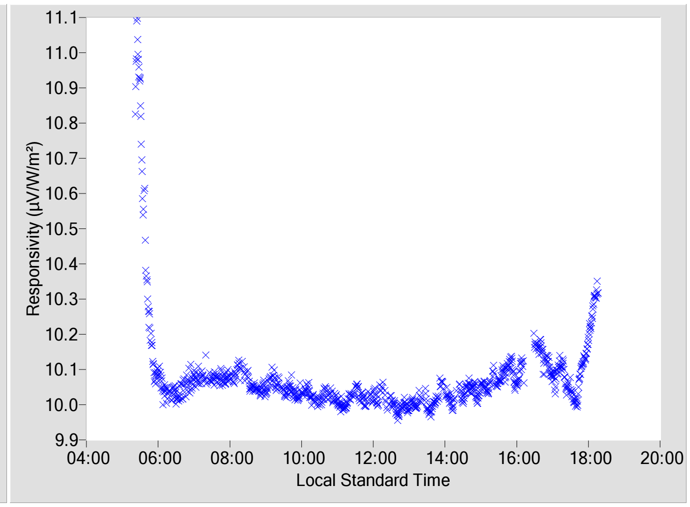


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.045	0.29	102.04	10.037	0.29	258.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.049	0.29	99.97	10.094	0.29	260.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.090	0.29	98.20	10.071	0.30	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.107	0.29	96.12	10.089	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.089	0.30	94.22	10.117	0.30	265.80
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.067	0.30	92.60	10.066	0.30	267.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.068	0.30	90.97	10.062	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.074	0.31	89.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.092	0.31	87.54	10.168	0.33	272.09
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.077	0.32	85.96	10.135	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.090	0.33	84.41	10.115	0.35	275.42
22	10.022	0.28	156.21	10.001	0.28	203.77	68	10.056	0.34	82.86	10.053	0.36	276.99
24	10.012	0.28	144.65	9.9957	0.28	215.36	70	10.048	0.35	81.20	10.105	N/A	278.59
26	10.026	0.28	137.02	9.9944	0.28	223.32	72	10.041	0.37	79.64	10.053	N/A	280.19
28	10.008	0.28	130.66	10.039	0.28	229.96	74	10.035	0.39	78.10	10.011	N/A	281.75
30	10.018	0.28	125.72	9.9949	0.28	234.30	76	10.046	0.42	76.49	10.095	N/A	283.34
32	10.032	0.28	121.43	10.061	0.28	238.78	78	10.081	N/A	74.90	10.161	N/A	284.98
34	10.033	0.28	117.95	10.031	0.29	242.21	80	10.235	N/A	73.26	10.290	N/A	286.58
36	10.051	0.29	114.66	10.011	0.29	245.39	82	10.586	N/A	71.61	N/A	N/A	N/A
38	10.046	0.29	111.76	10.032	0.29	248.48	84	10.955	N/A	69.90	N/A	N/A	N/A
40	10.055	0.29	108.96	10.050	0.29	251.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.069	0.29	106.54	10.057	0.29	253.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.054	0.29	104.16	10.052	0.29	255.91	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

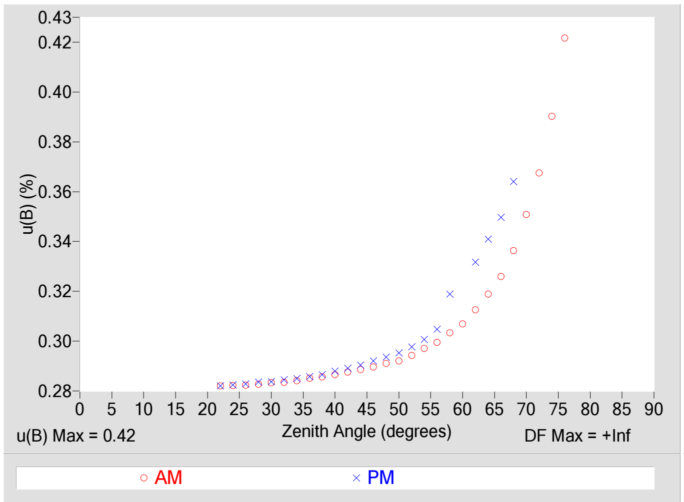


Figure 4. Residuals from Spline Interpolation

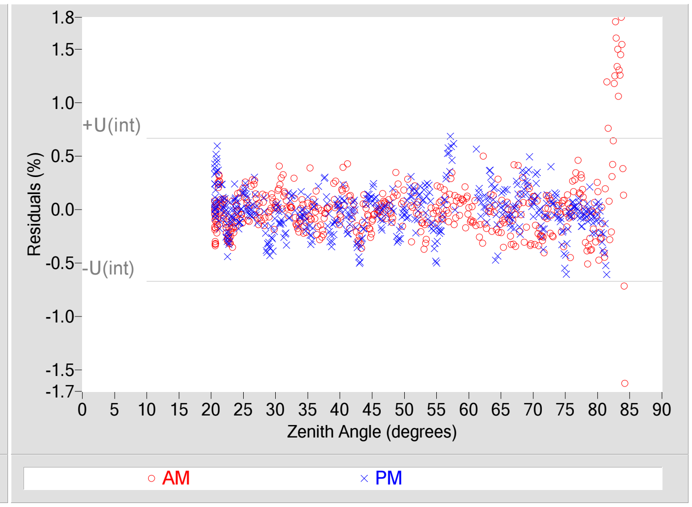


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	5470
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

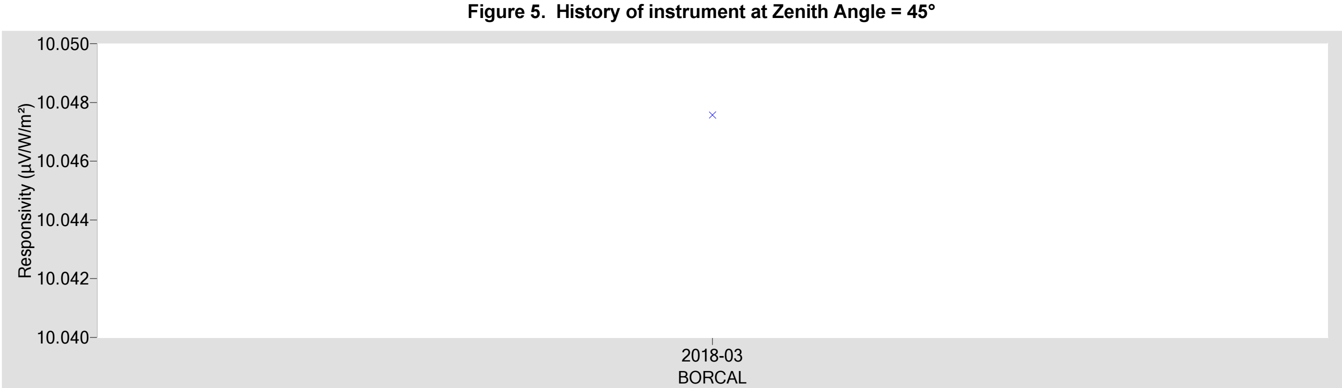
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.048	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.69 / -0.52
Expanded Uncertainty, U (%)	+1.3 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY28257
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ____________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

PY28257 Licor LI200

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

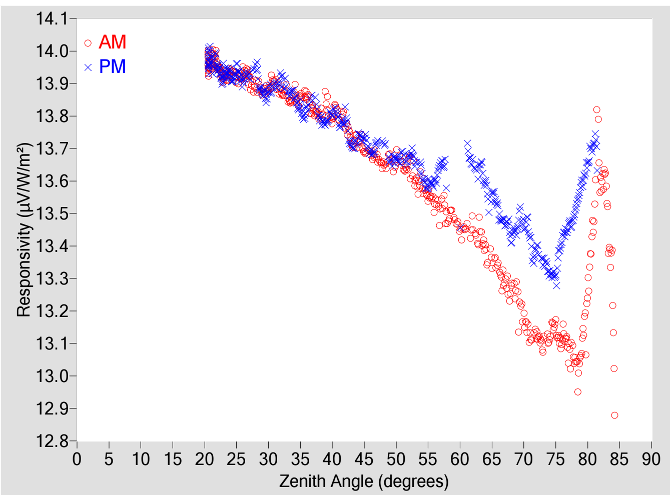


Figure 2. Responsivity vs Local Standard Time

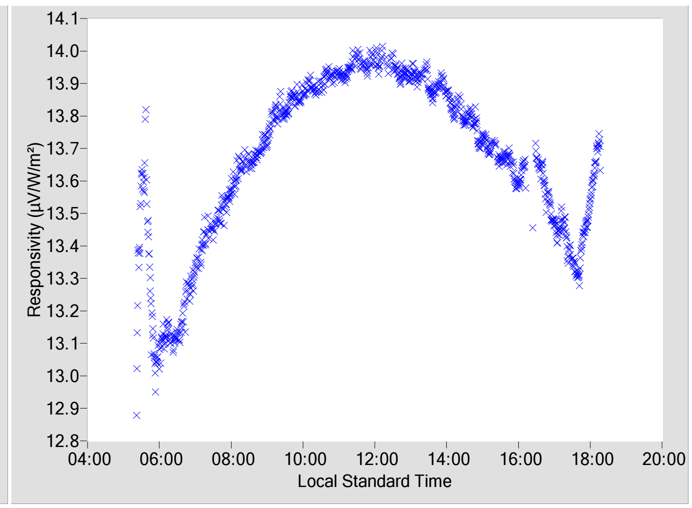


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	13.684	0.29	101.99	13.687	0.29	258.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.650	0.29	100.09	13.716	0.29	260.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.662	0.29	98.14	13.669	0.29	262.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.648	0.29	96.17	13.672	0.30	263.96
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.589	0.30	94.29	13.627	0.30	265.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	13.531	0.30	92.55	13.596	0.30	267.52
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.480	0.30	90.94	13.578	0.32	269.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.438	0.31	89.15	13.456	N/A	270.94
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.464	0.31	87.67	13.652	0.33	272.16
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.388	0.32	86.03	13.586	0.34	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	13.336	0.33	84.38	13.507	0.35	275.42
22	13.959	0.28	156.29	13.951	0.28	203.76	68	13.262	0.33	82.85	13.425	0.36	276.98
24	13.935	0.28	144.48	13.927	0.28	215.35	70	13.169	0.35	81.20	13.462	N/A	278.59
26	13.924	0.28	137.27	13.913	0.28	223.31	72	13.125	0.37	79.64	13.391	N/A	280.19
28	13.890	0.28	130.61	13.951	0.28	229.48	74	13.109	0.39	78.11	13.317	N/A	281.75
30	13.884	0.28	125.78	13.878	0.28	234.30	76	13.116	0.42	76.49	13.421	N/A	283.34
32	13.872	0.28	121.47	13.917	0.28	238.58	78	13.048	N/A	74.90	13.510	N/A	284.98
34	13.868	0.28	117.91	13.866	0.28	242.26	80	13.218	N/A	73.31	13.655	N/A	286.58
36	13.862	0.28	114.65	13.823	0.29	245.46	82	13.600	N/A	71.61	N/A	N/A	N/A
38	13.806	0.29	111.70	13.796	0.29	248.40	84	13.169	N/A	69.94	N/A	N/A	N/A
40	13.792	0.29	109.03	13.808	0.29	251.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	13.783	0.29	106.49	13.790	0.29	253.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	13.728	0.29	104.26	13.733	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

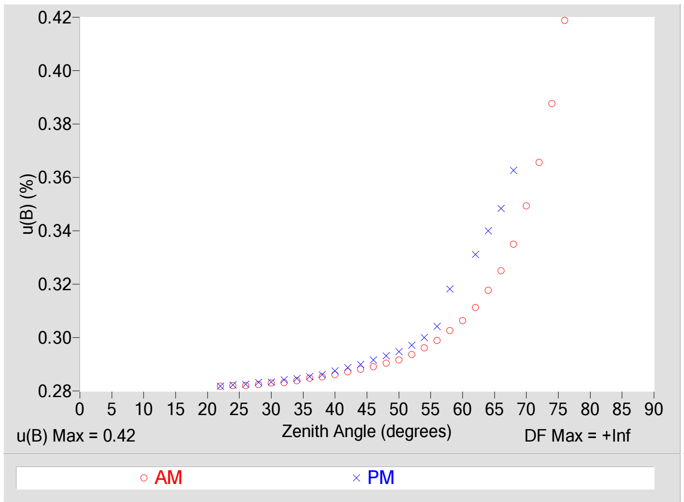


Figure 4. Residuals from Spline Interpolation

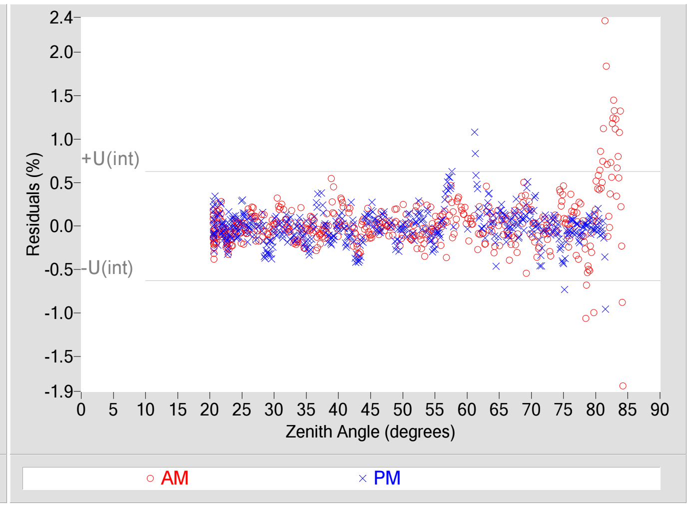


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	6285
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

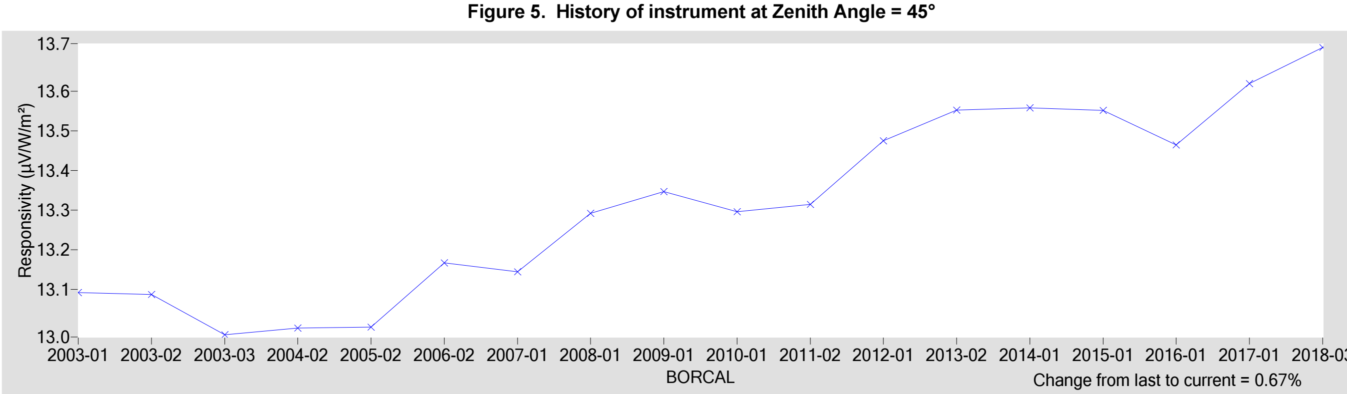
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
13.711	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+1.5 / -2.0
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 Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Semiconductor Pyrheliometer	**Manufacturer:**	Licor
Model:	LI201SB	**Serial Number:**	PYHR101
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

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Ibrahim Reda, Technical Manager — Date

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

Calibration Results

PYHR101 Licor LI201SB

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

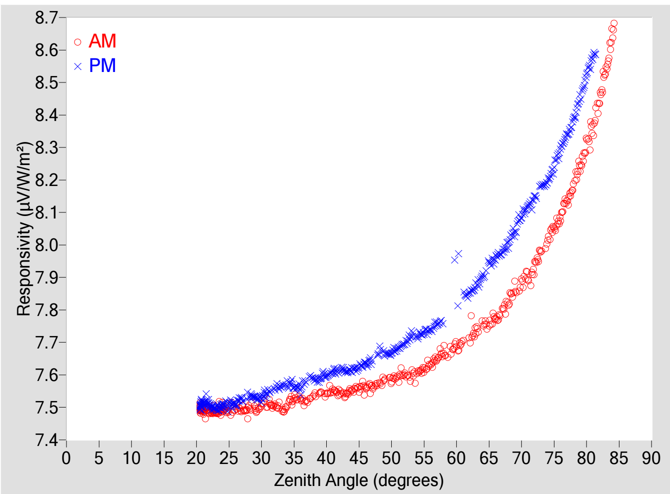


Figure 2. Responsivity vs Local Standard Time

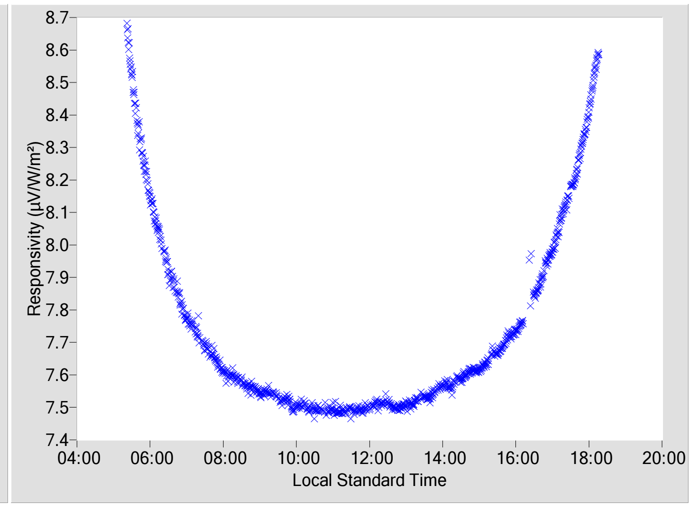


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5586	0.29	102.04	7.6344	0.29	258.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5723	0.29	99.97	7.6712	0.29	260.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5860	0.29	98.03	7.6674	0.29	262.06
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5998	0.29	96.12	7.6971	0.29	263.93
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6079	0.29	94.26	7.7201	0.30	265.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6304	0.29	92.53	7.7376	0.30	267.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6680	0.29	90.92	7.7579	0.30	269.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6898	0.30	89.25	7.8928	N/A	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7315	0.30	87.51	7.8513	0.30	272.19
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7578	0.30	85.87	7.9035	0.31	273.84
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7751	0.30	84.41	7.9566	0.31	275.38
22	7.4896	0.29	156.32	7.5079	0.29	203.63	68	7.8272	0.30	82.76	8.0070	0.31	276.99
24	7.4917	0.29	144.66	7.5050	0.29	215.37	70	7.8811	0.30	81.20	8.0892	N/A	278.60
26	7.4929	0.29	136.86	7.5103	0.29	223.33	72	7.9351	0.31	79.64	8.1469	N/A	280.19
28	7.4917	0.29	130.87	7.5342	0.29	229.34	74	8.0146	0.31	78.07	8.1953	N/A	281.71
30	7.5080	0.29	125.72	7.5291	0.29	234.38	76	8.0850	0.31	76.49	8.2948	N/A	283.34
32	7.5049	0.29	121.46	7.5587	0.29	238.75	78	8.1804	N/A	74.93	8.3893	N/A	284.98
34	7.5046	0.29	118.03	7.5701	0.29	242.27	80	8.3089	N/A	73.29	8.5250	N/A	286.58
36	7.5264	0.29	114.62	7.5570	0.29	245.47	82	8.4417	N/A	71.61	N/A	N/A	N/A
38	7.5388	0.29	111.61	7.5878	0.29	248.48	84	8.6541	N/A	69.90	N/A	N/A	N/A
40	7.5402	0.29	108.93	7.5966	0.29	251.14	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5448	0.29	106.54	7.6127	0.29	253.51	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5515	0.29	104.21	7.6167	0.29	255.90	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

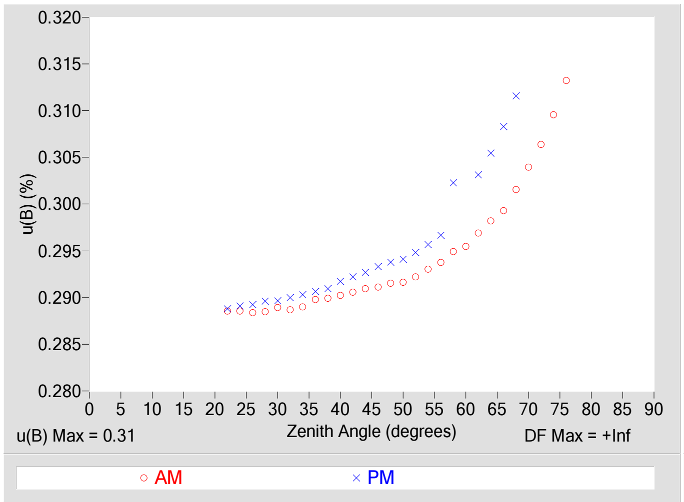


Figure 4. Residuals from Spline Interpolation

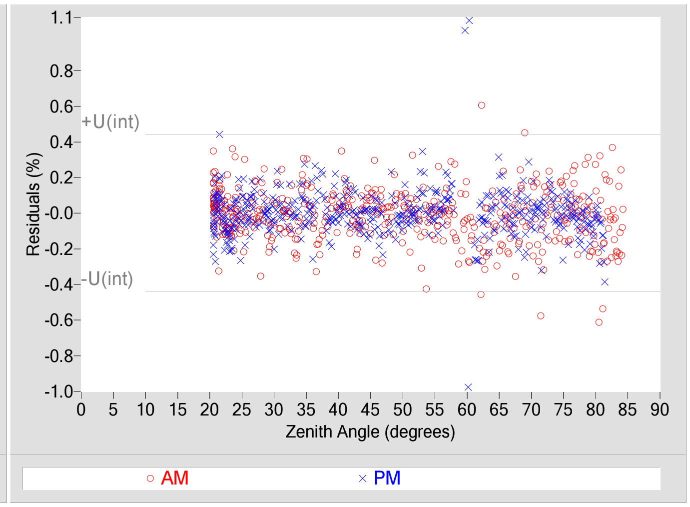


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	7537
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

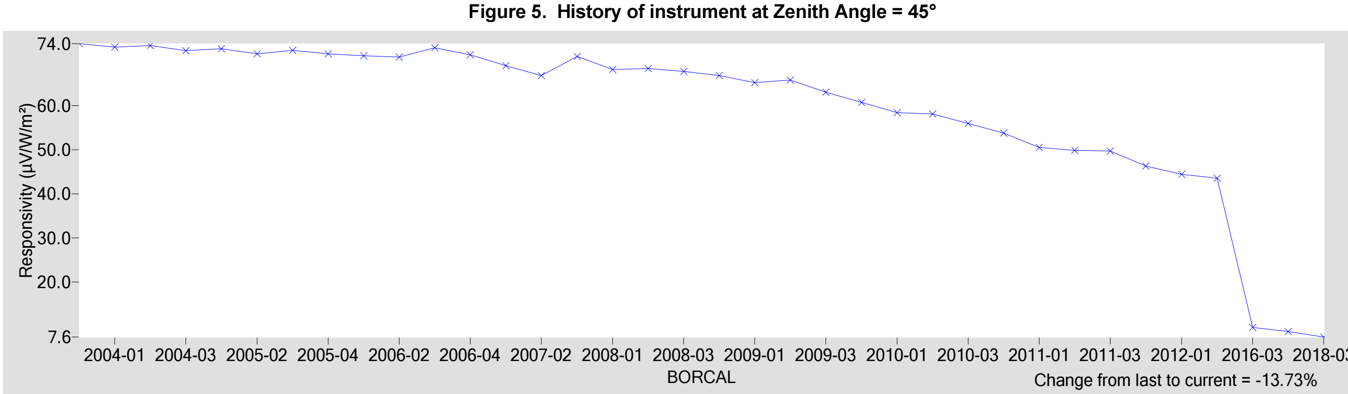
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5910	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+4.0 / -1.1
Expanded Uncertainty, U (%)	+4.6 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	EKO
Model:	MS-602	**Serial Number:**	S13071483
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

________________________________ ________________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

S13071483 EKO MS-602

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

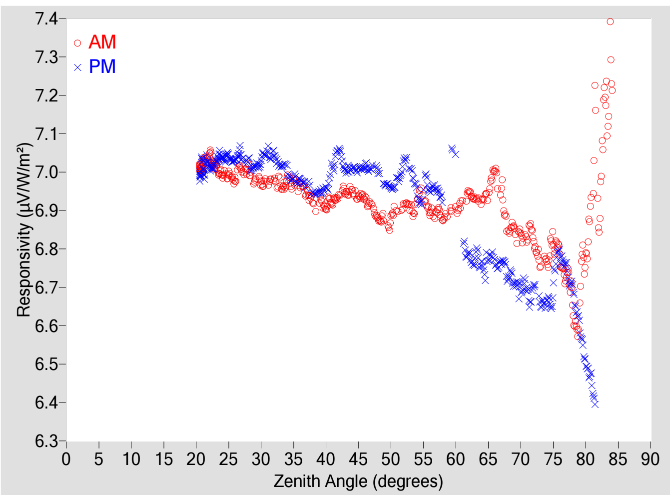


Figure 2. Responsivity vs Local Standard Time

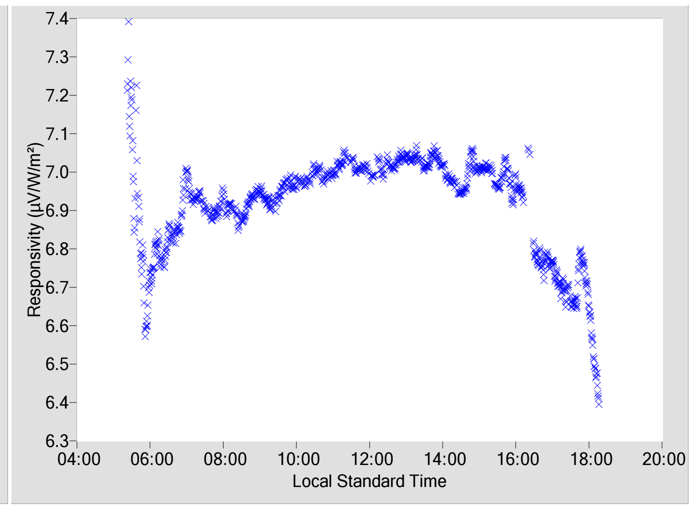


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	6.9308	0.31	102.01	7.0146	0.31	258.03
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.8791	0.31	99.95	7.0049	0.31	260.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.8774	0.32	98.00	6.9598	0.32	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.9141	0.32	96.10	7.0288	0.32	263.99
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.9224	0.32	94.42	6.9475	0.33	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.8983	0.33	92.58	6.9533	0.33	267.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.8773	0.34	90.80	6.9303	0.35	269.10
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9014	0.34	89.15	7.0457	N/A	270.87
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9483	0.35	87.61	6.7849	0.36	272.22
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9254	0.36	85.92	6.7579	0.38	273.87
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.0036	0.37	84.39	6.7665	0.39	275.42
22	7.0439	0.29	156.27	7.0175	0.29	203.52	68	6.8554	0.39	82.84	6.7235	0.41	277.02
24	6.9950	0.30	144.79	7.0375	0.29	215.61	70	6.8375	0.41	81.25	6.6959	N/A	278.62
26	6.9771	0.30	136.94	7.0310	0.29	223.26	72	6.8206	0.44	79.67	6.7008	N/A	280.12
28	7.0061	0.30	130.66	7.0285	0.30	229.46	74	6.7649	0.47	78.10	6.6617	N/A	281.73
30	6.9713	0.30	125.72	7.0322	0.30	234.33	76	6.7831	0.52	76.52	6.7859	N/A	283.32
32	6.9793	0.30	121.44	7.0454	0.30	238.44	78	6.6592	N/A	74.93	6.7002	N/A	284.91
34	6.9777	0.30	117.99	7.0013	0.30	242.32	80	6.7691	N/A	73.29	6.5005	N/A	286.61
36	6.9645	0.30	114.71	6.9793	0.30	245.43	82	6.8772	N/A	71.59	N/A	N/A	N/A
38	6.9250	0.30	111.81	6.9448	0.30	248.55	84	7.2819	N/A	69.97	N/A	N/A	N/A
40	6.9063	0.30	109.00	6.9563	0.31	251.15	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.9364	0.30	106.62	7.0573	0.31	253.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.9484	0.31	104.10	7.0080	0.31	255.87	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

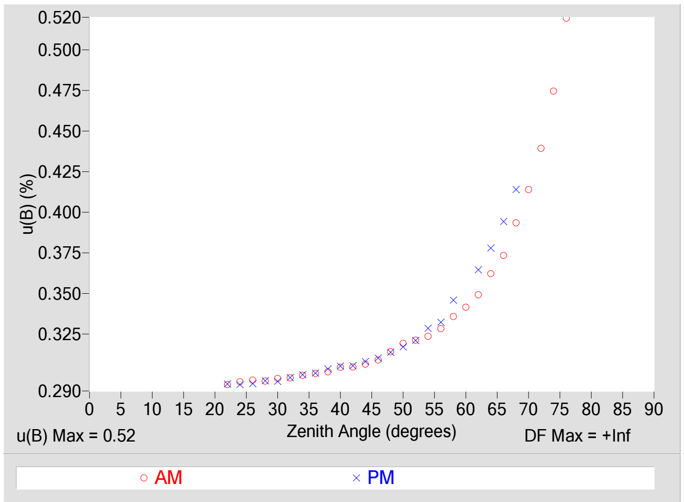


Figure 4. Residuals from Spline Interpolation

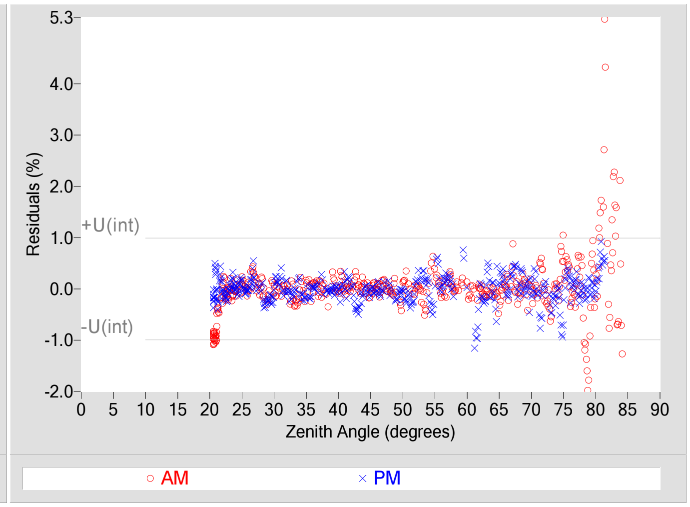


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.52
Type-A Interpolating Function, u(int) (%)	±0.50
Combined Standard Uncertainty, u(c) (%)	±0.72
Effective degrees of freedom, DF(c)	3591
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

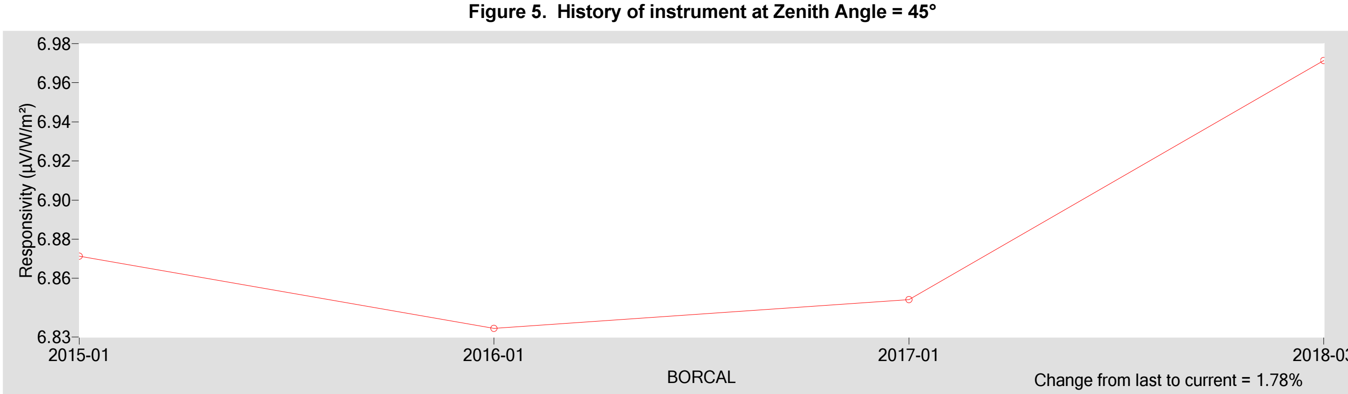
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
6.9713	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.68
Offset Uncertainty, U(off) (%)	+1.2 / -1.3
Expanded Uncertainty, U (%)	+1.9 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	EKO
Model:	ML-01	**Serial Number:**	S13135063
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: RCC

______________________________ ______________

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

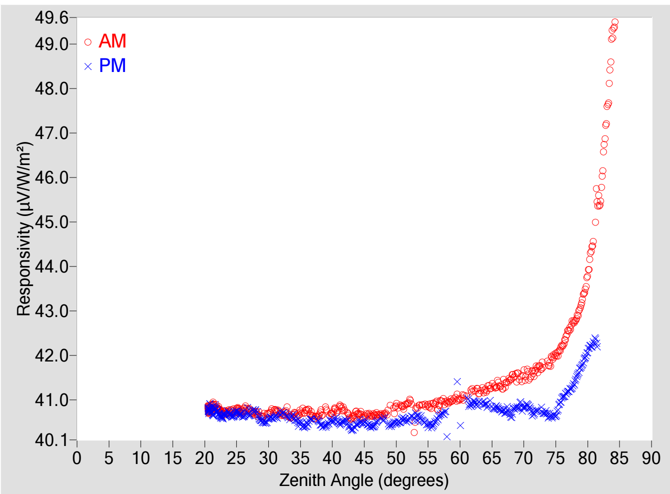


Figure 2. Responsivity vs Local Standard Time

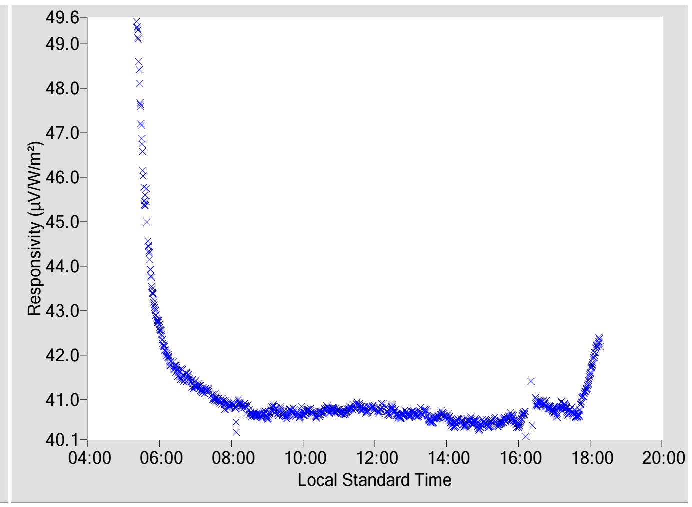


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	40.654	0.29	102.07	40.401	0.29	258.08
2	N/A	N/A	N/A	N/A	N/A	N/A	48	40.659	0.29	100.00	40.564	0.29	260.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	40.829	0.29	98.11	40.484	0.29	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	40.955	0.29	96.15	40.560	0.30	263.93
8	N/A	N/A	N/A	N/A	N/A	N/A	54	40.890	0.30	94.25	40.564	0.30	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	40.923	0.30	92.63	40.484	0.30	267.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	40.946	0.30	90.84	40.457	0.31	269.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	41.011	0.31	89.22	40.426	N/A	270.91
16	N/A	N/A	N/A	N/A	N/A	N/A	62	41.210	0.31	87.62	40.923	0.33	272.17
18	N/A	N/A	N/A	N/A	N/A	N/A	64	41.200	0.32	86.01	40.902	0.34	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	41.346	0.32	84.38	40.800	0.35	275.45
22	40.814	0.28	155.88	40.717	0.28	203.95	68	41.500	0.33	82.79	40.655	0.36	276.96
24	40.748	0.28	144.57	40.668	0.28	215.44	70	41.519	0.35	81.24	40.813	N/A	278.57
26	40.753	0.28	136.70	40.631	0.28	223.55	72	41.694	0.36	79.66	40.757	N/A	280.17
28	40.692	0.28	130.60	40.746	0.28	229.28	74	41.830	0.38	78.09	40.633	N/A	281.78
30	40.699	0.28	125.68	40.567	0.28	234.38	76	42.201	0.41	76.51	41.041	N/A	283.37
32	40.678	0.28	121.61	40.699	0.28	238.38	78	42.780	N/A	74.88	41.426	N/A	284.96
34	40.690	0.28	117.93	40.599	0.28	242.35	80	43.786	N/A	73.29	42.088	N/A	286.56
36	40.774	0.28	114.65	40.460	0.29	245.52	82	45.604	N/A	71.64	N/A	N/A	N/A
38	40.691	0.28	111.67	40.475	0.29	248.44	84	49.301	N/A	69.92	N/A	N/A	N/A
40	40.711	0.29	109.00	40.519	0.29	251.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	40.764	0.29	106.71	40.531	0.29	253.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	40.694	0.29	104.23	40.479	0.29	255.93	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

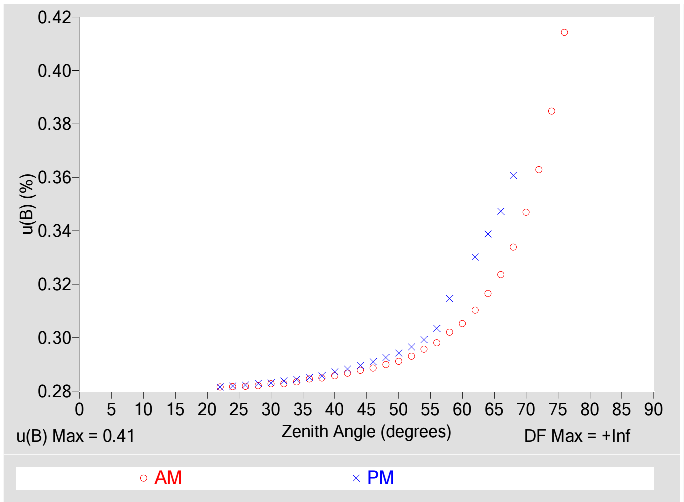


Figure 4. Residuals from Spline Interpolation

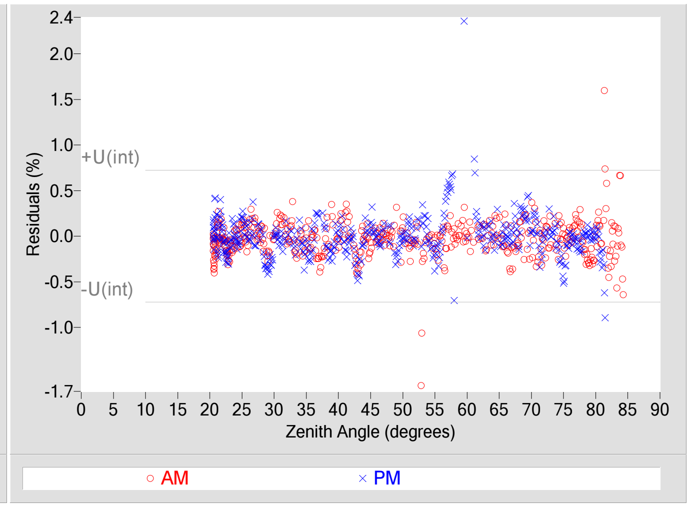


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.36
Combined Standard Uncertainty, u(c) (%)	±0.55
Effective degrees of freedom, DF(c)	4448
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

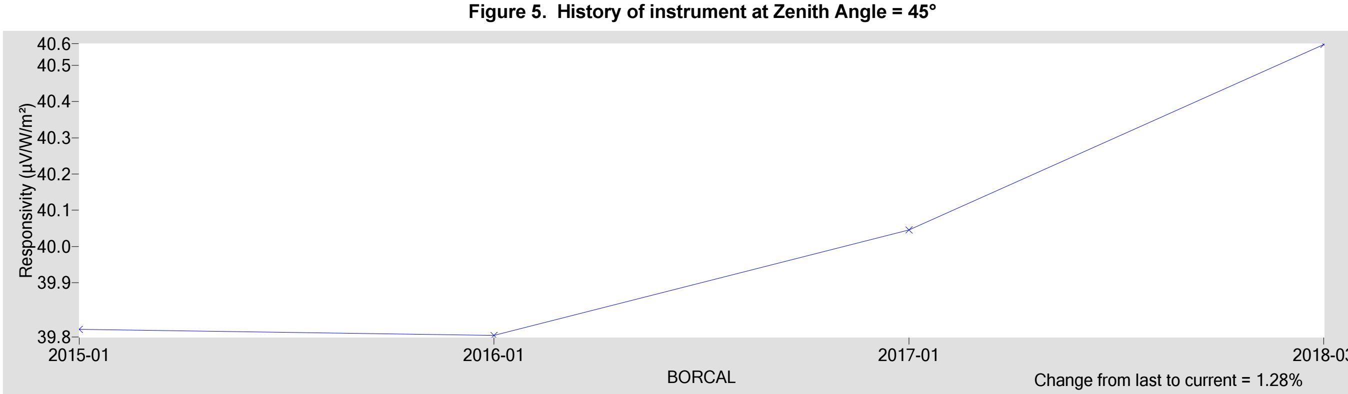
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
40.557	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+1.1 / -0.39
Expanded Uncertainty, U (%)	+1.7 / -1.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	EKO
Model:	MS-410	**Serial Number:**	S13144.085R
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

____   ________________

Ibrahim Reda, Technical Manager   Date

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

Calibration Results

S13144.085R EKO MS-410

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

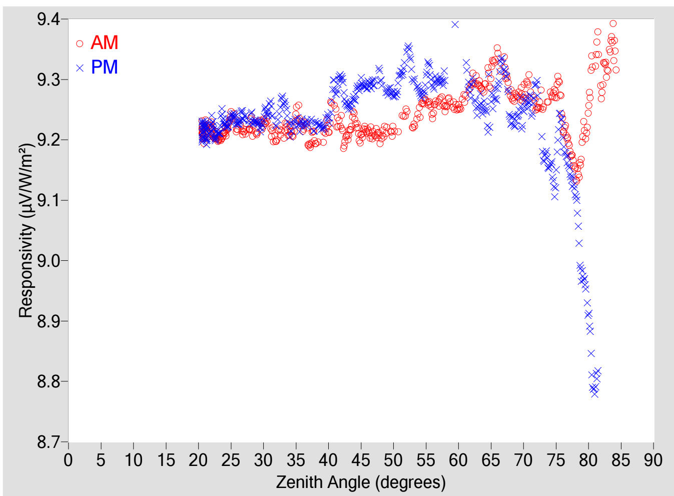


Figure 2. Responsivity vs Local Standard Time

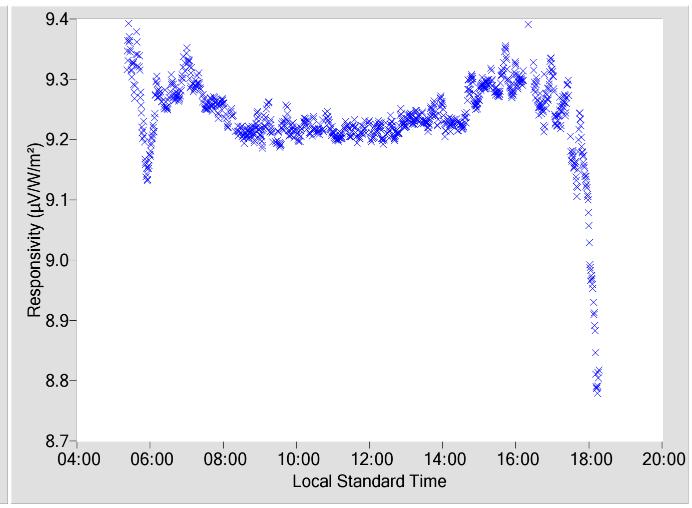


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2140	0.29	102.00	9.2900	0.30	258.02
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2026	0.30	99.94	9.3038	0.30	260.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2142	0.30	98.08	9.2751	0.30	262.08
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2456	0.30	96.21	9.3512	0.30	264.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2445	0.30	94.39	9.2790	0.31	265.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2469	0.31	92.58	9.2905	0.31	267.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2540	0.31	90.84	9.3060	0.32	269.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2527	0.32	89.25	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2957	0.32	87.58	9.2877	0.34	272.22
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2881	0.33	85.96	9.2524	0.35	273.87
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.3477	0.34	84.38	9.2815	0.36	275.40
22	9.2219	0.29	156.91	9.2209	0.29	203.70	68	9.2762	0.35	82.81	9.2344	0.38	277.01
24	9.2115	0.29	144.74	9.2264	0.29	215.60	70	9.2752	0.37	81.25	9.2477	N/A	278.62
26	9.2200	0.29	137.07	9.2276	0.29	223.25	72	9.2548	0.39	79.66	9.2890	N/A	280.12
28	9.2235	0.29	130.72	9.2357	0.29	229.45	74	9.2706	0.41	78.14	9.1566	N/A	281.73
30	9.2260	0.29	125.71	9.2378	0.29	234.35	76	9.2357	0.45	76.51	9.2165	N/A	283.32
32	9.2034	0.29	121.59	9.2268	0.29	238.60	78	9.1457	N/A	74.93	9.1065	N/A	284.96
34	9.2132	0.29	117.85	9.2180	0.29	242.31	80	9.2469	N/A	73.29	8.9052	N/A	286.60
36	9.2231	0.29	114.60	9.2274	0.29	245.43	82	9.2819	N/A	71.59	N/A	N/A	N/A
38	9.2000	0.29	111.83	9.2240	0.29	248.29	84	9.3502	N/A	69.92	N/A	N/A	N/A
40	9.2219	0.29	109.00	9.2360	0.29	251.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2164	0.29	106.44	9.3019	0.29	253.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2341	0.29	104.16	9.2691	0.29	255.86	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

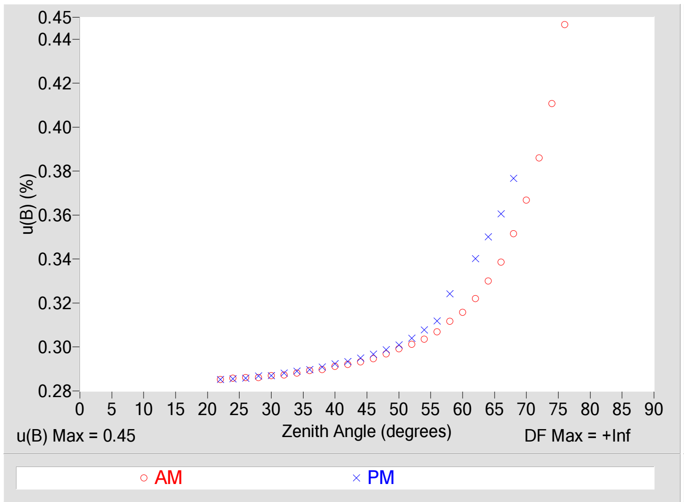


Figure 4. Residuals from Spline Interpolation

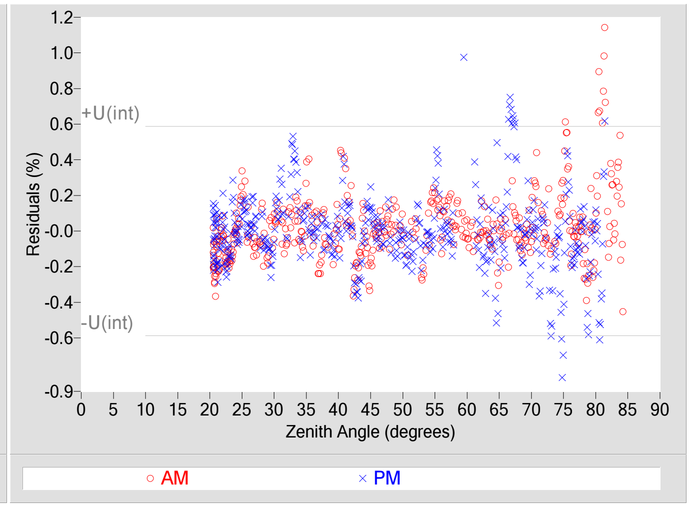


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	8699
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

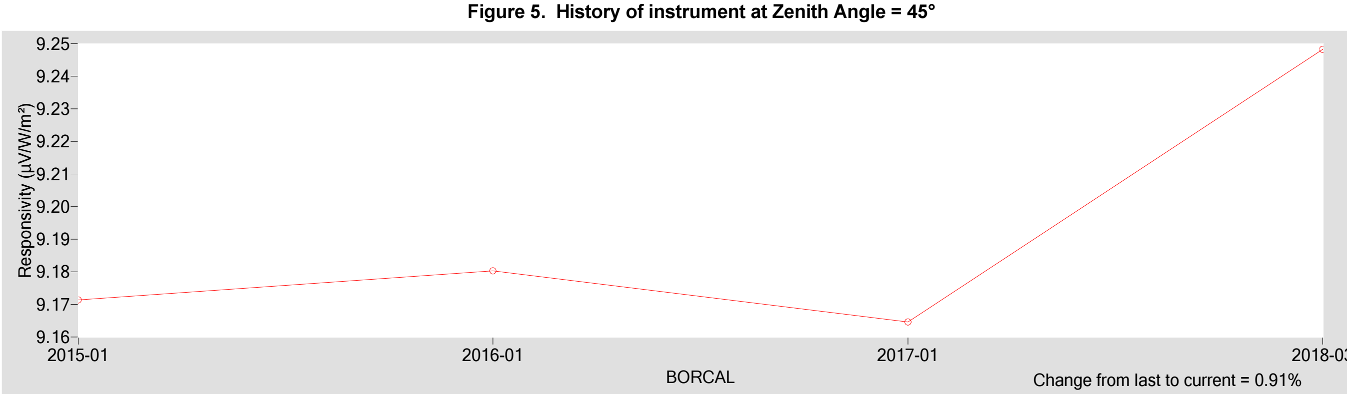
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.2482	0.20000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+1.1 / -0.52
Expanded Uncertainty, U (%)	+1.7 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	EKO
Model:	MS-80	**Serial Number:**	S17096005
Calibration Date:	5/16/2018	**Due Date:**	5/16/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/15-16		

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

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

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

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

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/11/2018	04/11/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/18/2018	04/18/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

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

Number of pages of certificate: 4

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

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

Calibrated by: RCC

________________________________ ________________

Ibrahim Reda, Technical Manager Date

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

Calibration Results

S17096005 EKO MS-80

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

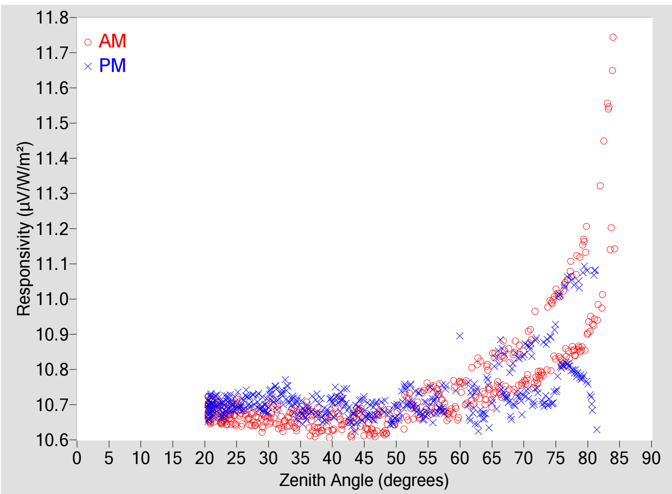


Figure 2. Responsivity vs Local Standard Time

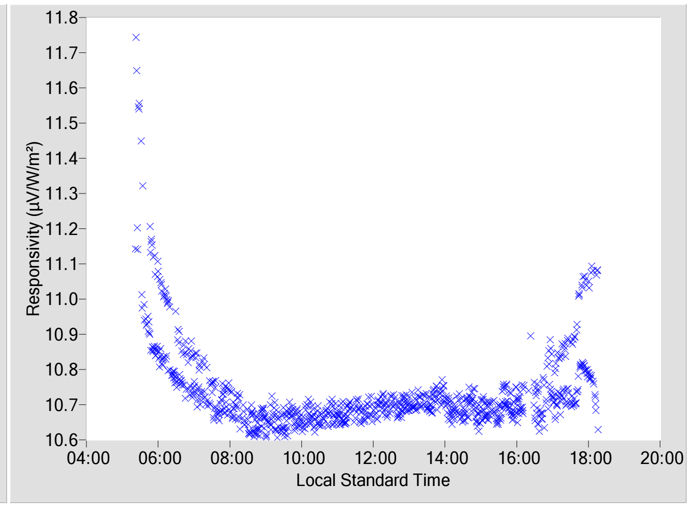


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.632	0.29	102.01	10.683	0.29	258.03
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.631	0.29	99.95	10.696	0.29	260.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.669	0.29	98.01	10.683	0.30	262.09
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.699	0.29	96.13	10.724	0.30	263.99
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.712	0.30	94.44	10.671	0.30	265.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.699	0.30	92.56	10.693	0.30	267.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.666	0.30	90.80	10.755	0.31	269.05
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.738	0.31	89.25	10.895	N/A	270.87
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.740	0.31	87.67	10.720	0.33	272.23
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.754	0.32	85.96	10.712	0.34	273.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.746	0.33	84.35	10.779	0.35	275.43
22	10.692	0.28	155.86	10.710	0.28	203.07	68	10.782	0.34	82.98	10.747	0.36	277.02
24	10.670	0.28	144.64	10.702	0.28	215.62	70	10.787	0.35	81.26	10.800	N/A	278.62
26	10.667	0.28	137.12	10.699	0.28	223.10	72	10.814	0.37	79.67	10.799	N/A	280.13
28	10.657	0.28	130.74	10.711	0.28	229.58	74	10.923	0.39	78.06	10.780	N/A	281.74
30	10.667	0.28	125.72	10.711	0.28	234.33	76	10.862	0.42	76.52	10.810	N/A	283.33
32	10.642	0.28	121.37	10.731	0.28	238.51	78	10.892	N/A	74.93	10.841	N/A	284.92
34	10.661	0.28	117.99	10.697	0.29	242.27	80	10.986	N/A	73.30	10.869	N/A	286.52
36	10.690	0.29	114.65	10.681	0.29	245.44	82	11.148	N/A	71.54	N/A	N/A	N/A
38	10.647	0.29	111.68	10.689	0.29	248.46	84	11.512	N/A	69.90	N/A	N/A	N/A
40	10.649	0.29	109.01	10.696	0.29	251.11	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.666	0.29	106.72	10.723	0.29	253.60	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.685	0.29	104.17	10.676	0.29	255.87	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

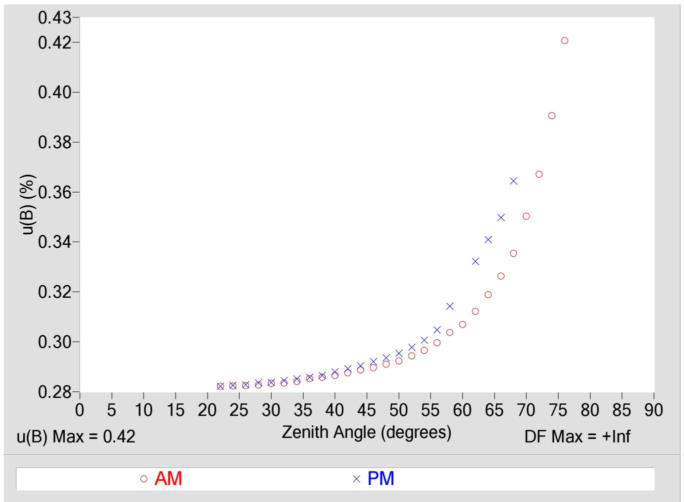


Figure 4. Residuals from Spline Interpolation

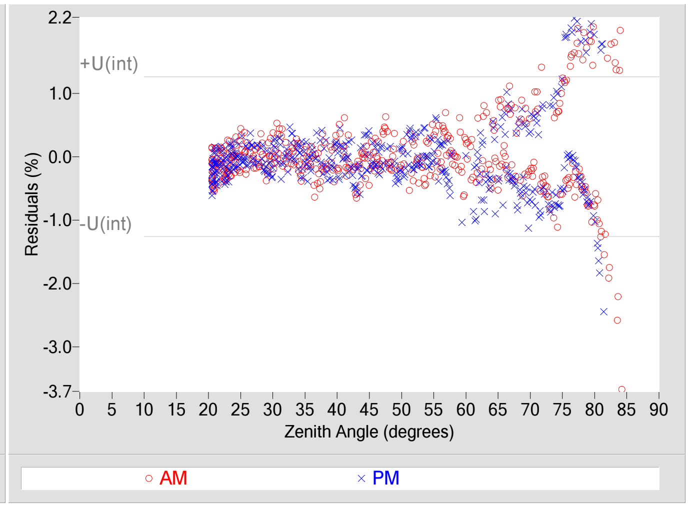


Table 3. Uncertainty using Spline Interpolation

Type-B Standard Uncertainty, u(B) (%)	±0.42
Type-A Interpolating Function, u(int) (%)	±0.63
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	1695
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 68°

Table 4. Calibration Label Values

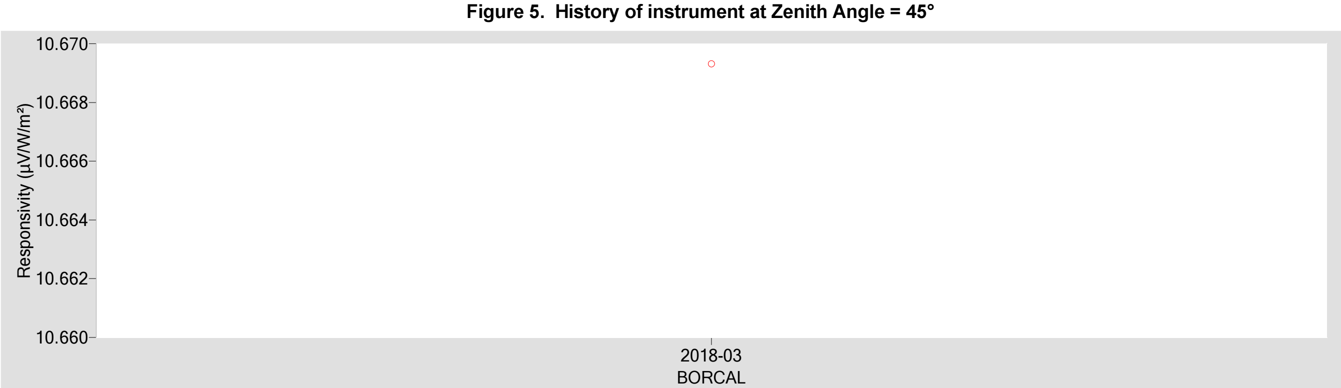
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.669	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+2.1 / -0.36
Expanded Uncertainty, U (%)	+2.7 / -0.97
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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[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Environmental and Sky Conditions for BORCAL-SW 2018-03

Calibration Facility: Solar Radiation Research Laboratory

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

Reference Irradiance:

Figure 6. Reference Irradiance

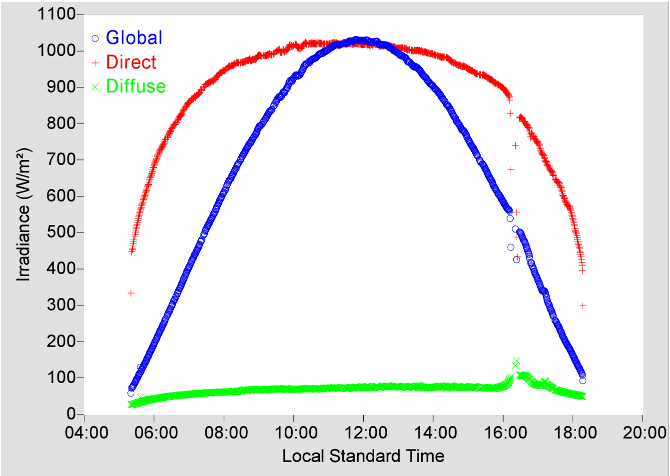
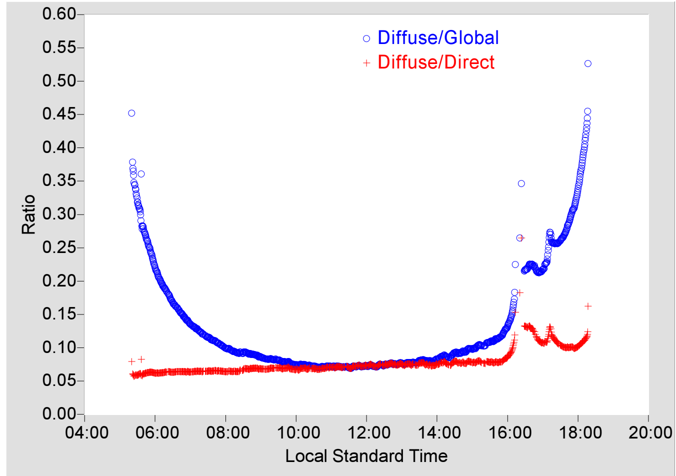


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

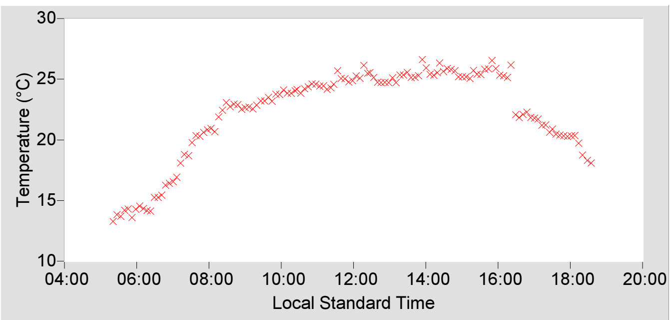


Figure 9. Humidity

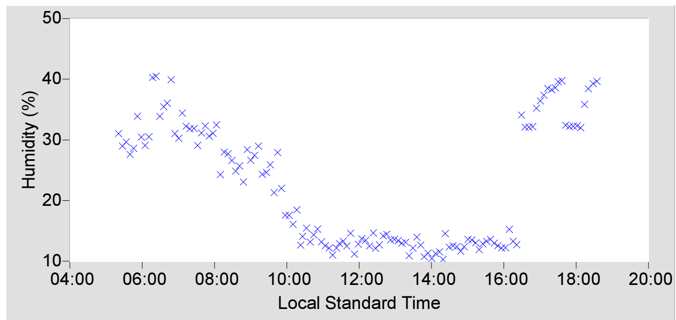


Figure 10. Pressure

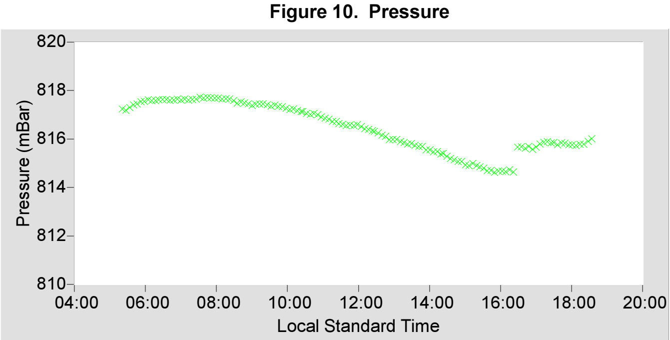


Figure 11. Effective Net Infrared

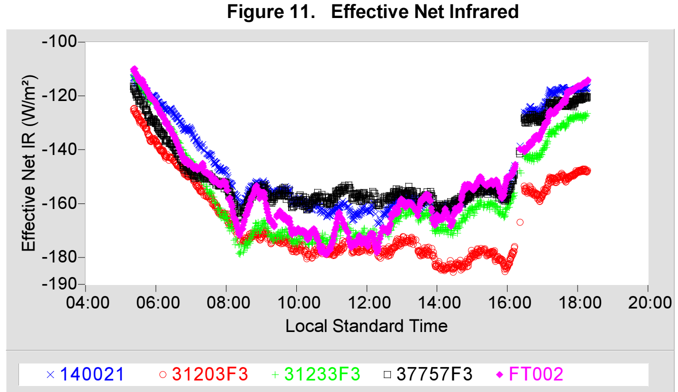


Figure 12. Estimated Broadband Aerosol Optical Depth

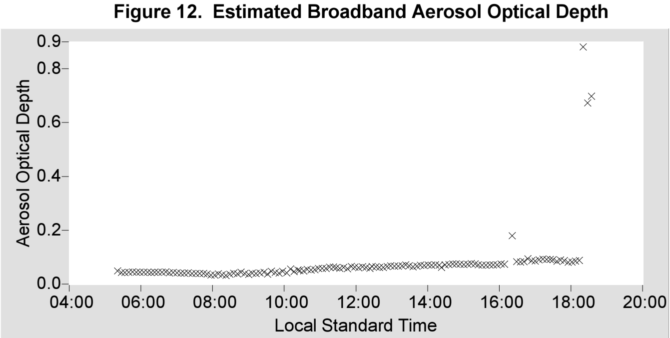


Table 6. Meteorological Observations

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

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

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

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

Session Config: 1171 Apogee SP-510; Number: 4
Comments:
30K Case Thermistor is measured from dedicated Apogee SL-510 pyrgeometer which is co-located (SL-510 thermopile is not measured).