

Broadband Outdoor Radiometer Calibration Shortwave

BORCAL-SW 2020-02

Generated by



Radiometer Calibration and Characterization

Calibration Facility

Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Calibration date

06/05/2020

Report Date

June 10, 2020



NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction.....3

Control Instrument history plots.....4

Results summary.....6

Appendix 1 Instrument Details.....A1-1

Appendix 2 BORCAL Notes.....A2-1

Appendix 3 Session Configuration Audit Report.....A3-1

Appendix 4 Operator Logs.....A4-1

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.

BORCAL Notes or Comments

Invalidated PSP 30942F3 and 31628F3 due to large change in Rs since last BORCAL
Invalidated PSP 32039F3 due to large AM/PM responsivity possibly due to bad level

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

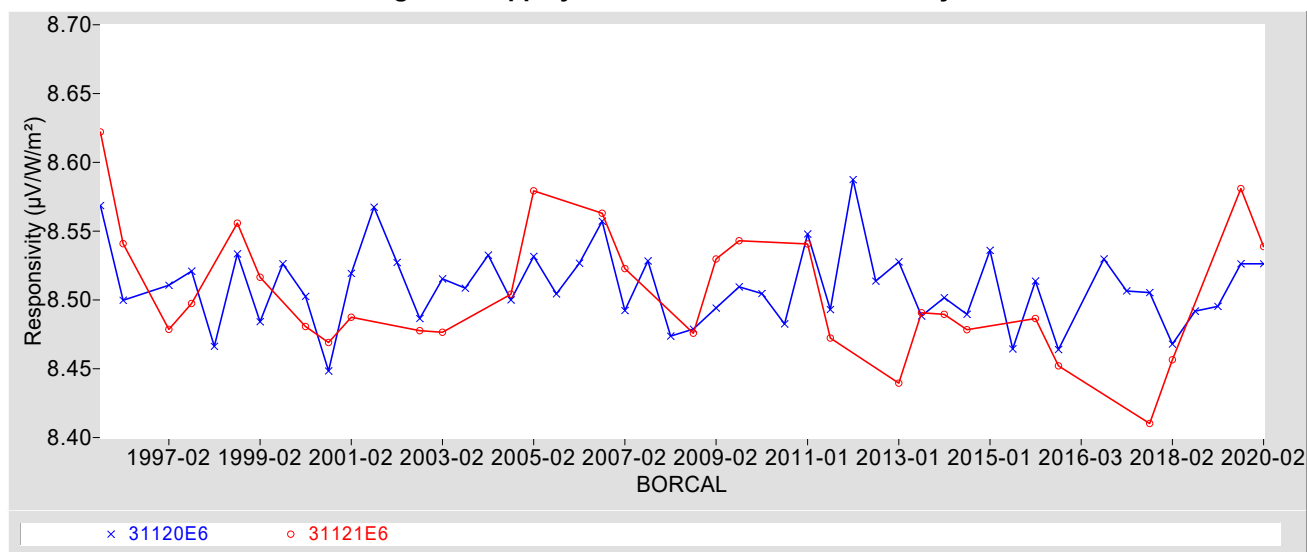


Figure 2. Eppley PSP Control Instrument History

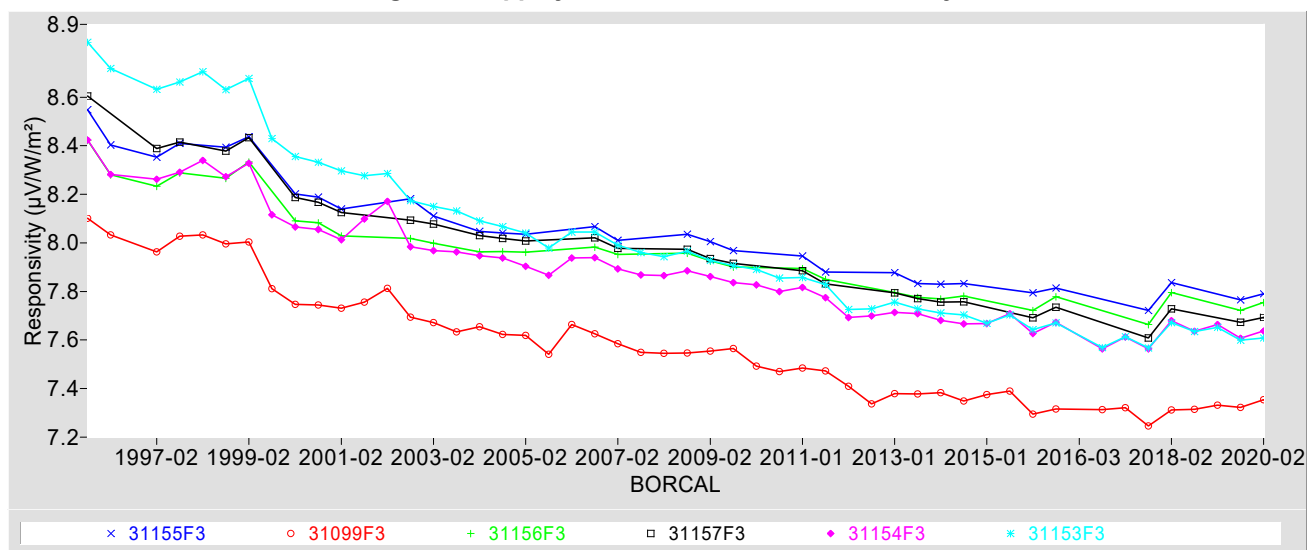
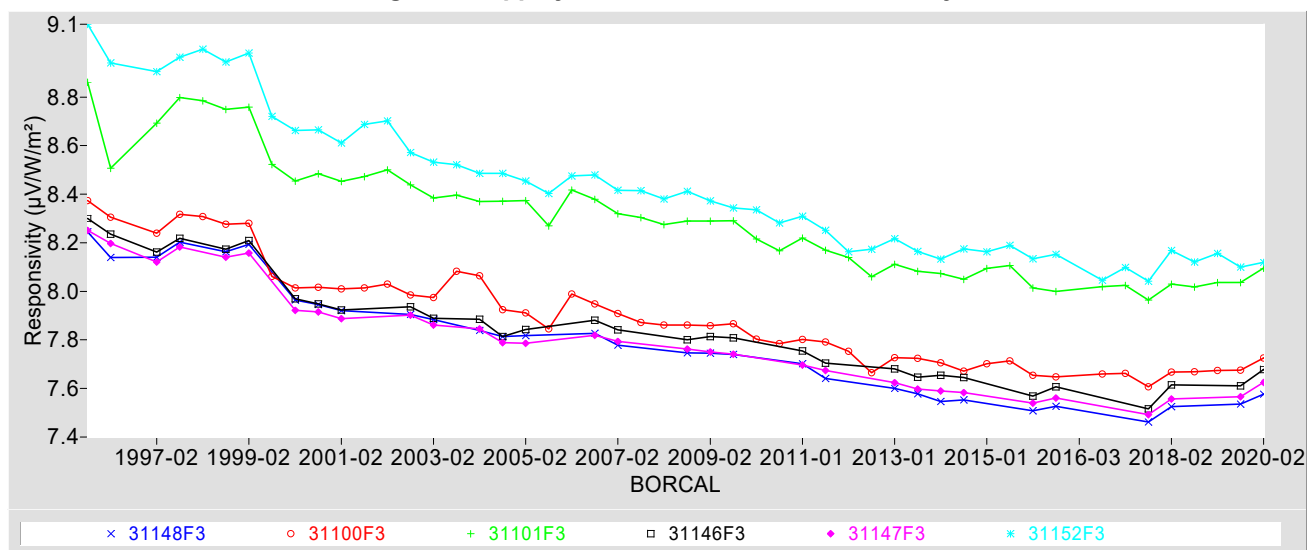
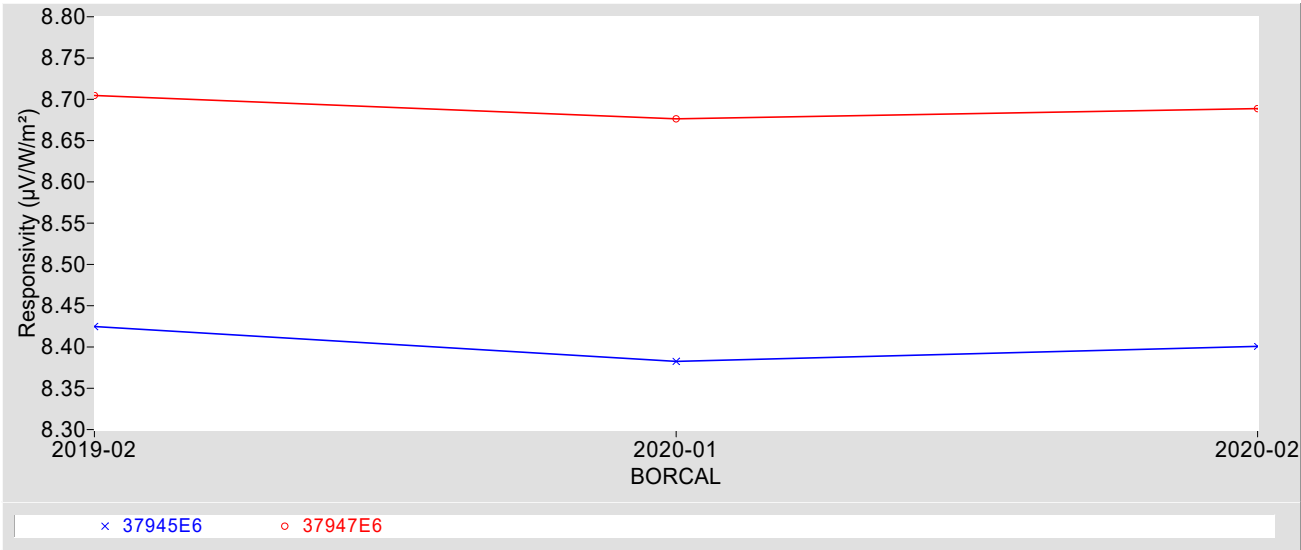


Figure 3. Eppley PSP Control Instrument History



Control Instrument History

Figure 4. Eppley sNIP Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	Customer	R@45 ¹ ($\mu\text{V}/\text{W}/\text{m}^2$)	U ² (%)	Rnet ³ ($\mu\text{V}/\text{W}/\text{m}^2$)	Page
13011F3	TWP	8.7911	+1.4 / -3.0	0.60000	A1-2
17494	TWP	12.135	+1.3 / -1.8	0	A1-5
17607E6	TWP	7.3367	+2.5 / -1.5	0	A1-8
18070E6	TWP	8.7583	+2.0 / -1.4	0	A1-11
18637E6	TWP	8.0126	+2.1 / -1.6	0	A1-14
18648E6	TWP	9.1611	+2.2 / -1.5	0	A1-17
27974F3	TWP	8.5802	+2.4 / -3.4	0.60000	A1-20
28019E6	TWP	8.5774	+3.0 / -1.9	0	A1-23
29008E6	SGP	8.1143	+2.5 / -1.8	0	A1-26
29010E6	SGP	8.7315	+1.7 / -1.4	0	A1-29
29011E6	SGP	8.4032	+2.6 / -1.6	0	A1-32
29541E6	SGP	7.9463	+2.4 / -1.6	0	A1-35
29609F3	SGP	8.1690	+2.3 / -3.5	0.63600	A1-38
29741E6	SGP	8.3462	+2.1 / -1.4	0	A1-41
29850E6	SGP	8.1339	+2.2 / -1.5	0	A1-44
29911F3	SGP	7.6103	+2.3 / -3.2	0.59755	A1-47
29935E6	SGP	8.0370	+2.3 / -1.7	0	A1-50
29936E6	SGP	8.2379	+1.8 / -1.3	0	A1-53
29938E6	SGP	8.3441	+1.7 / -1.4	0	A1-56
30569E6	TWP	8.0215	+2.4 / -1.5	0	A1-59
30584E6	SGP	8.5244	+2.3 / -1.6	0	A1-62
30621F3	SGP	8.7540	+1.8 / -2.8	0.66027	A1-65
30654F3	SGP	7.9429	+2.2 / -4.0	0.67104	A1-68
30662F3	SGP	8.0166	+2.0 / -3.1	0.64629	A1-71
30671F3	SGP	8.4504	+2.3 / -3.3	0.58700	A1-74
30708F3	SGP	8.5460	+2.5 / -4.1	0.58600	A1-77
30718E6	SGP	8.3874	+2.3 / -1.7	0	A1-80
30778F3	SGP	8.3959	+2.6 / -3.8	0.64306	A1-83
30802F3	SGP	9.0973	+1.7 / -2.8	0.68705	A1-86
30894F3	SGP	8.0499	+1.7 / -2.3	0.64666	A1-89
30900F3	SGP	8.1393	+2.0 / -3.3	0.63379	A1-92
30903F3	SGP	7.7277	+1.8 / -2.4	0.58651	A1-95
30934F3	SGP	7.2614	+2.0 / -3.3	0.53000	A1-98
30940F3	SGP	7.3425	+2.0 / -2.8	0.61870	A1-101
30944F3	SGP	7.2152	+1.9 / -2.6	0.56695	A1-104
30955F3	SGP	8.8164	+2.1 / -3.5	0.61498	A1-107
30956F3	SGP	8.6671	+2.0 / -3.3	0.57387	A1-110
31099F3	Calibration System	7.3546	+2.8 / -2.7	0.57866	A1-113
31100F3	Calibration System	7.7260	+1.9 / -2.5	0.64729	A1-116
31101F3	Calibration System	8.0962	+2.2 / -3.1	0.64834	A1-119
31120E6	Calibration System	8.5263	+2.4 / -1.4	0	A1-122
31121E6	Calibration System	8.5389	+2.1 / -1.8	0	A1-125
31146F3	Calibration System	7.6774	+1.7 / -2.6	0.54900	A1-128
31147F3	Calibration System	7.6253	+1.8 / -3.3	0.55100	A1-131
31148F3	Calibration System	7.5769	+2.1 / -2.7	0.53300	A1-134
31152F3	Calibration System	8.1191	+2.4 / -3.7	0.63390	A1-137
31153F3	Calibration System	7.6090	+3.9 / -5.9	0.64286	A1-140
31154F3	Calibration System	7.6370	+2.4 / -3.5	0.56158	A1-143
31155F3	Calibration System	7.7902	+2.0 / -3.2	0.52400	A1-146

¹ CF = 1000 / R

² See certificate for valid zenith angle range

³ Instrument's Effective Net IR Response

Results Summary

Table 1. Results Summary

Instrument	Customer	R@45 ¹ ($\mu\text{V/W/m}^2$)	U ² (%)	Rnet ³ ($\mu\text{V/W/m}^2$)	Page
31156F3	Calibration System	7.7544	+2.3 / -3.5	0.53200	A1-149
31157F3	Calibration System	7.6927	+2.3 / -3.5	0.49000	A1-152
31275F3	TWP	7.6910	+2.3 / -3.3	0.59150	A1-155
31276F3	TWP	7.7221	+1.6 / -2.3	0.56944	A1-158
31280F3	TWP	6.9471	+2.4 / -4.0	0.49700	A1-161
31295F3	TWP	8.2030	+1.8 / -2.9	0.54645	A1-164
31627F3	SGP	8.0718	+1.7 / -3.1	0.61800	A1-167
31632F3	SGP	7.7981	+2.4 / -2.8	0.60000	A1-170
31635F3	SGP	8.6307	+1.9 / -3.3	0.61365	A1-173
31746E6	SGP	8.4258	+2.0 / -1.3	0	A1-176
31762E6	NSA	8.5248	+2.4 / -1.6	0	A1-179
32015F3	NSA	8.9580	+1.8 / -3.0	0.42210	A1-182
32023F3	NSA	10.239	+1.7 / -2.6	0.70600	A1-185
32039F3	NSA	8.7564	+2.1 / -2.2	0.65771	A1-188
32330	SGP	8.8600	+2.8 / -1.9	0	A1-191
32815F3	TWP	8.6757	+1.7 / -2.9	0.60000	A1-194
32872	Calibration System	9.7666	+2.2 / -1.8	0	A1-197
32991F3	TWP	8.1492	+1.7 / -2.9	0.60000	A1-200
33237	SGP	8.3870	+2.6 / -1.8	0	A1-203
33243	TWP	9.3002	+3.6 / -2.2	0	A1-206
33267	SGP	9.0032	+1.9 / -1.8	0	A1-209
33269	SGP	8.5835	+1.6 / -1.4	0	A1-212
33273	SGP	9.6646	+3.7 / -2.0	0	A1-215
33275	SGP	8.3993	+5.7 / -2.0	0	A1-218
33278	SGP	8.7896	+3.1 / -1.8	0	A1-221
33283	SGP	9.3723	+3.2 / -1.9	0	A1-224
33288	SGP	8.8241	+2.3 / -1.7	0	A1-227
33289	SGP	9.1289	+4.9 / -2.7	0	A1-230
33363	SGP	8.5659	+3.1 / -2.1	0	A1-233
33377	TWP	8.6295	+1.9 / -1.7	0	A1-236
33383	TWP	9.1130	+1.4 / -1.7	0	A1-239
33575	TWP	9.3330	+2.4 / -1.9	0	A1-242
33703F3	TWP	7.7774	+2.1 / -2.7	0.60000	A1-245
34293F3	AMF	8.8323	+1.8 / -2.6	0.54700	A1-248
35831F3	AMF#2	8.0652	+1.9 / -2.8	0.54390	A1-251
36313E6	SGP	8.4082	+1.3 / -1.4	0	A1-254
36314E6	SGP	8.0758	+1.5 / -1.2	0	A1-257
37167	AMF	9.2610	+3.6 / -2.0	0	A1-260
37288E6	NSA	8.6279	+1.4 / -1.2	0	A1-263
37301F3	AMF	8.5472	+1.6 / -2.6	0.60000	A1-266
37315F3	NSA	8.7876	+1.3 / -2.0	0.60000	A1-269
37319F3	AMF	8.3126	+1.9 / -3.5	0.60000	A1-272
37362E6	AMF	8.1720	+1.3 / -1.2	0	A1-275
37394	AMF	9.1773	+0.90 / -1.6	0	A1-278
37945E6	SGP	8.4007	+1.00 / -1.1	0	A1-281
37947E6	SGP	8.6888	+1.1 / -1.0	0	A1-284
PY22693	Calibration System	9.1677	+3.7 / -1.9	0	A1-287

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 A1-290.

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.

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: TWP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 13011F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

13011F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

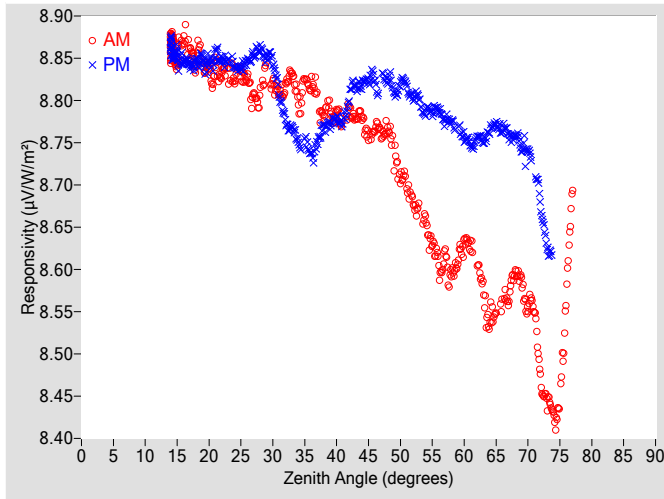


Figure 2. Responsivity vs Local Standard Time

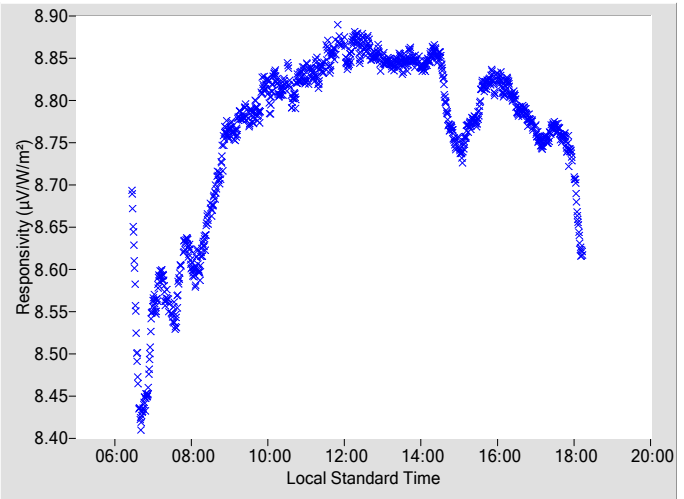


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7667	0.36	92.88	8.8211	0.35	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7663	0.35	91.34	8.8240	0.37	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7087	0.40	89.79	8.8216	0.36	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6791	0.38	88.37	8.8031	0.37	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6553	0.39	86.92	8.7879	0.38	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6047	0.42	85.54	8.7885	0.39	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5964	0.42	84.17	8.7749	0.41	275.87
14	8.8677	0.33	173.30	8.8630	0.33	187.03	60	8.6287	0.41	82.84	8.7549	0.42	277.25
16	8.8691	0.32	148.42	8.8448	0.32	211.78	62	8.6048	0.48	81.38	8.7563	0.44	278.58
18	8.8453	0.32	137.34	8.8478	0.32	222.74	64	8.5394	0.46	80.10	8.7645	N/A	279.90
20	8.8394	0.33	129.71	8.8474	0.31	230.33	66	8.5598	0.46	78.84	8.7656	N/A	281.30
22	8.8313	0.32	124.01	8.8485	0.33	236.08	68	8.5937	0.51	77.45	8.7578	N/A	282.60
24	8.8242	0.32	119.34	8.8405	0.34	240.75	70	8.5566	N/A	76.07	8.7399	N/A	283.98
26	8.8254	0.33	115.39	8.8471	0.31	244.63	72	8.4729	N/A	74.77	8.6722	N/A	285.32
28	8.8011	0.33	112.24	8.8604	0.33	247.97	74	8.4287	N/A	73.38	N/A	N/A	N/A
30	8.8201	0.34	109.13	8.8451	0.33	250.89	76	8.5634	N/A	72.00	N/A	N/A	N/A
32	8.8163	0.35	106.51	8.7770	0.32	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7996	0.33	104.08	8.7501	0.32	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8164	0.34	101.95	8.7364	0.34	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7834	0.34	99.86	8.7680	0.34	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7853	0.33	97.99	8.7789	0.33	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7902	0.37	96.18	8.8033	0.34	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7808	0.35	94.51	8.8202	0.36	265.56	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

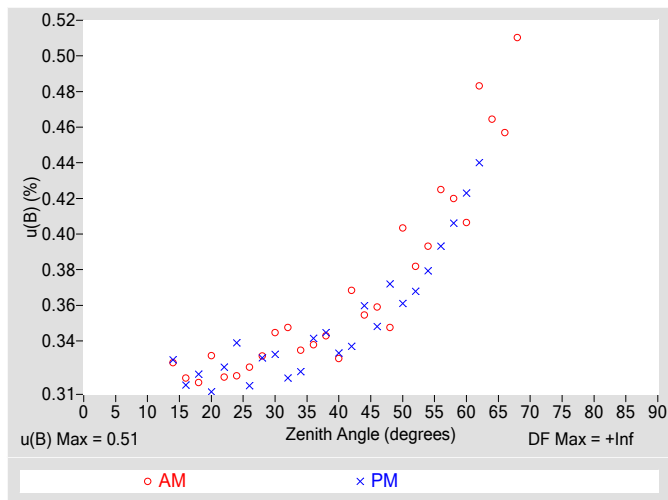


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	76870
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

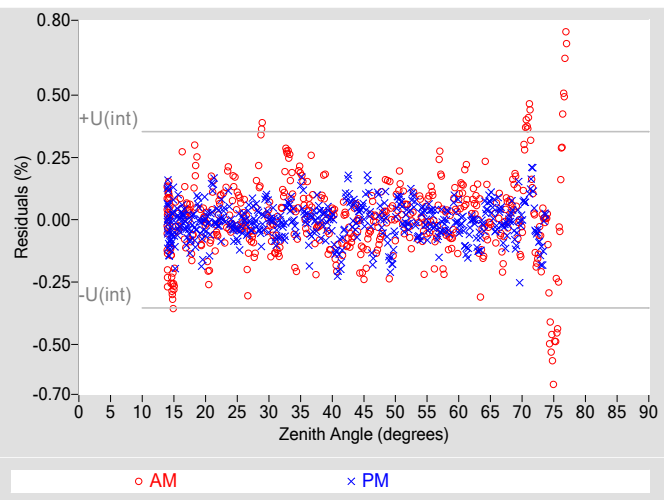


Table 4. Calibration Label Values

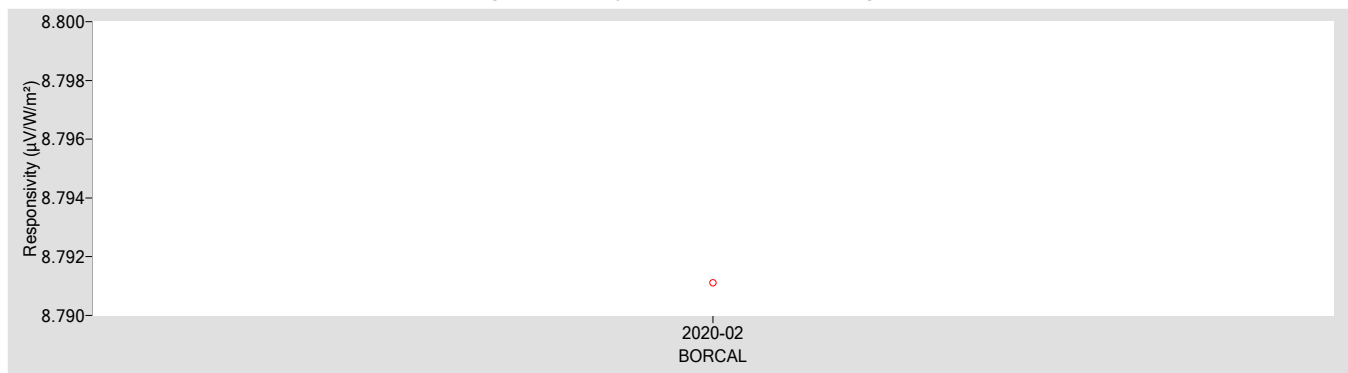
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.7911	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.83
Offset Uncertainty, $U(off)$ (%)	+0.61 / -2.2
Expanded Uncertainty, U (%)	+1.4 / -3.0
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 17494
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

17494 Eppley 8-48

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

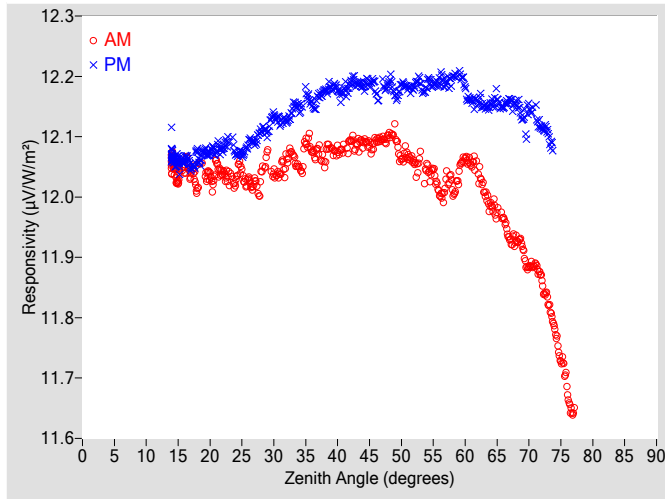


Figure 2. Responsivity vs Local Standard Time

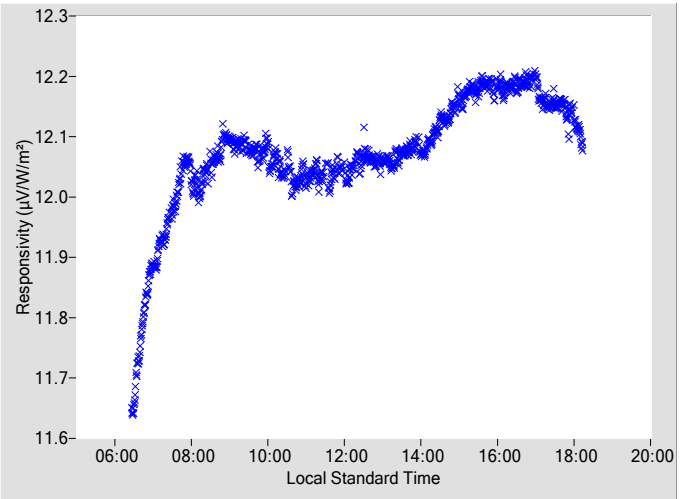


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	12.094	0.31	92.91	12.174	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.101	0.31	91.37	12.188	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.063	0.36	89.87	12.185	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.057	0.32	88.40	12.182	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.048	0.35	86.95	12.186	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.006	0.33	85.57	12.195	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.017	0.39	84.20	12.197	0.38	275.89
14	12.060	0.31	173.58	12.067	0.30	187.30	60	12.063	0.40	82.78	12.178	0.36	277.23
16	12.050	0.32	148.50	12.060	0.30	211.69	62	12.043	0.39	81.43	12.158	0.37	278.61
18	12.020	0.31	137.26	12.072	0.32	222.80	64	11.984	0.43	80.12	12.156	N/A	279.93
20	12.035	0.30	129.66	12.074	0.33	230.42	66	11.963	0.38	78.78	12.150	N/A	281.24
22	12.041	0.32	123.83	12.080	0.30	236.16	68	11.927	0.43	77.47	12.153	N/A	282.62
24	12.024	0.32	119.30	12.072	0.32	240.82	70	11.884	N/A	76.09	12.147	N/A	283.92
26	12.027	0.33	115.35	12.088	0.31	244.59	72	11.859	N/A	74.72	12.113	N/A	285.35
28	12.033	0.34	112.03	12.110	0.31	248.03	74	11.781	N/A	73.37	12.077	N/A	286.50
30	12.037	0.33	109.10	12.135	0.30	250.94	76	11.682	N/A	71.98	N/A	N/A	N/A
32	12.056	0.29	106.48	12.126	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	12.050	0.32	104.16	12.148	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	12.076	0.33	101.86	12.153	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	12.061	0.30	99.84	12.177	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	12.075	0.32	97.97	12.178	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.093	0.34	96.21	12.187	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.091	0.32	94.54	12.185	0.31	265.49	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

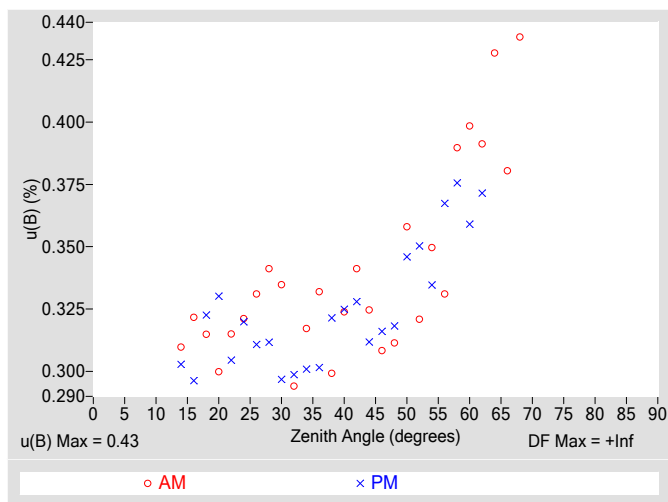


Figure 4. Residuals from Spline Interpolation

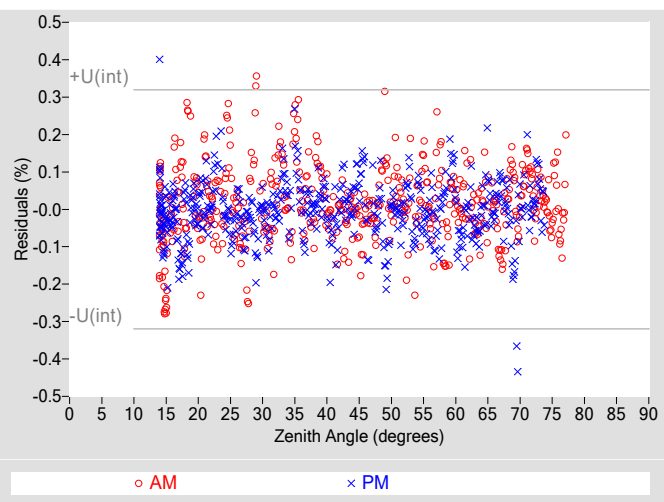


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.16
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	62928
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.91
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

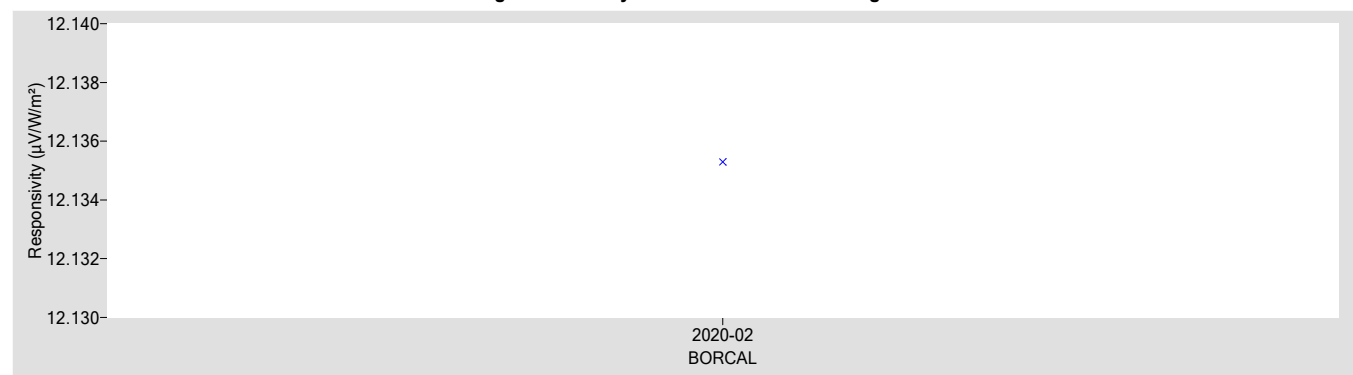
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
12.135	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+0.51 / -1.1
Expanded Uncertainty, U (%)	+1.3 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: TWP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 17607E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

17607E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

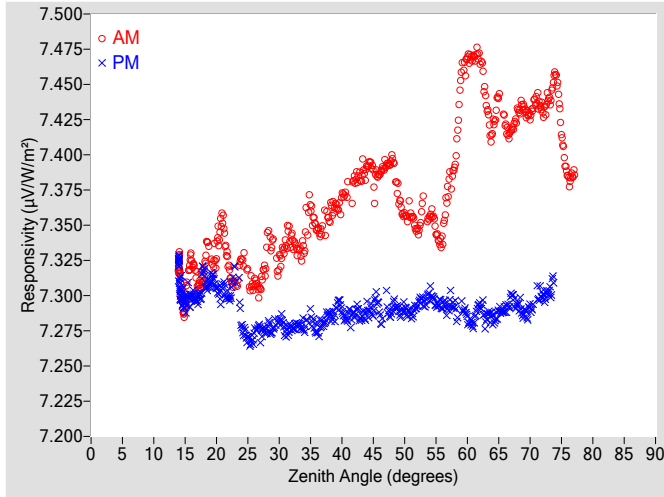


Figure 2. Responsivity vs Local Standard Time

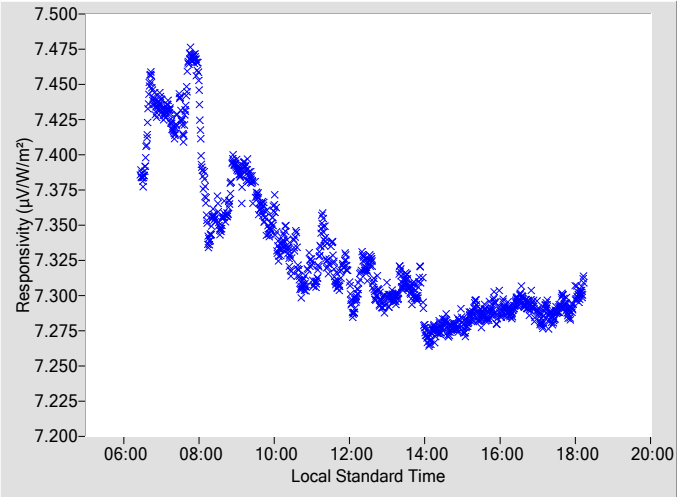


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.3861	0.29	92.93	7.2857	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3960	0.32	91.38	7.2897	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3574	0.31	89.88	7.2910	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3463	0.31	88.41	7.2926	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3558	0.29	86.96	7.3011	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3410	0.32	85.58	7.2931	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3923	0.35	84.21	7.2903	0.30	275.91
14	7.3202	0.31	173.84	7.3138	0.30	187.06	60	7.4683	0.34	82.79	7.2840	0.30	277.20
16	7.3243	0.30	148.36	7.2981	0.31	211.88	62	7.4677	0.32	81.48	7.2928	0.30	278.62
18	7.3154	0.29	137.24	7.3155	0.31	222.85	64	7.4169	0.30	80.13	7.2839	N/A	279.94
20	7.3338	0.31	129.70	7.3055	0.31	230.31	66	7.4229	0.30	78.79	7.2900	N/A	281.25
22	7.3188	0.29	123.87	7.2983	0.31	236.19	68	7.4286	0.30	77.48	7.2929	N/A	282.64
24	7.3245	0.30	119.25	7.2800	0.29	240.74	70	7.4286	N/A	76.10	7.2914	N/A	283.93
26	7.3083	0.31	115.38	7.2711	0.30	244.52	72	7.4319	N/A	74.73	7.2995	N/A	285.32
28	7.3280	0.29	112.14	7.2774	0.29	248.05	74	7.4549	N/A	73.38	7.3090	N/A	286.51
30	7.3220	0.31	109.04	7.2816	0.29	250.96	76	7.3840	N/A	71.95	N/A	N/A	N/A
32	7.3387	0.30	106.43	7.2769	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.3363	0.30	104.14	7.2789	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3480	0.30	101.88	7.2750	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3564	0.29	99.91	7.2862	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3681	0.29	97.99	7.2892	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3819	0.33	96.23	7.2873	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3895	0.32	94.55	7.2882	0.33	265.50	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

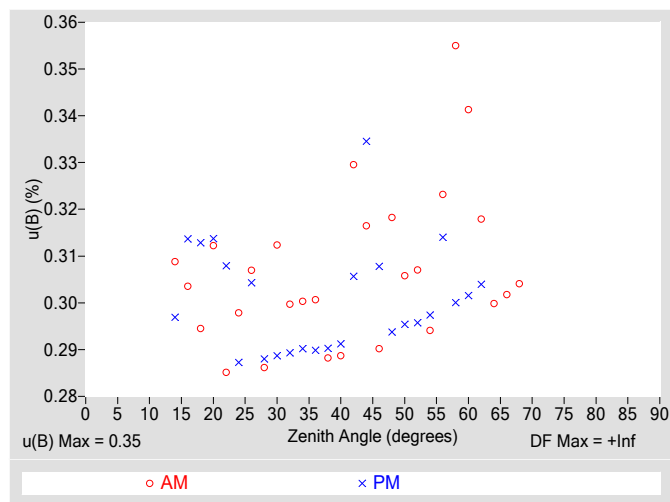


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.41
Effective degrees of freedom, $DF(c)$	13480
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 0.81
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

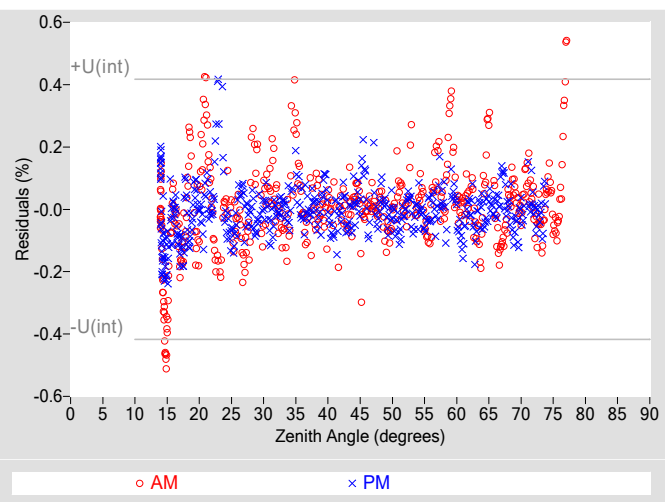


Table 4. Calibration Label Values

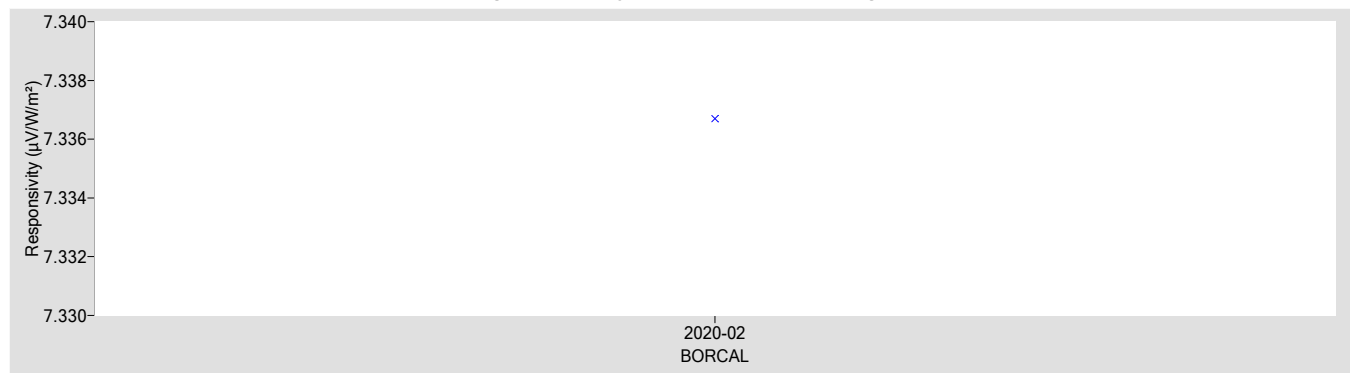
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.3367	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.8 / -0.84
Expanded Uncertainty, U (%)	+2.5 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: TWP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 18070E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

18070E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

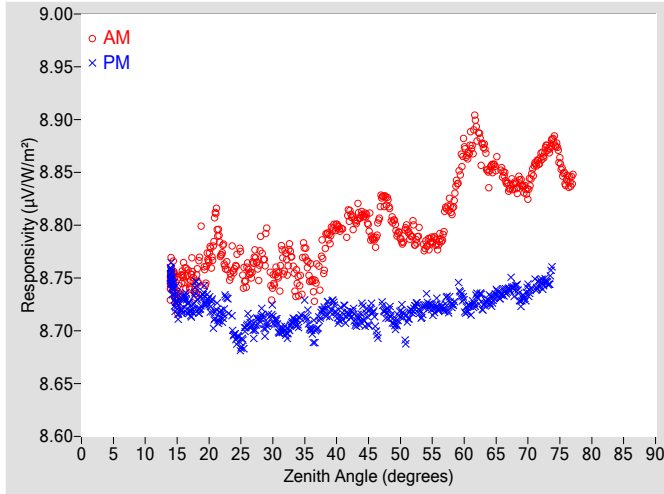


Figure 2. Responsivity vs Local Standard Time

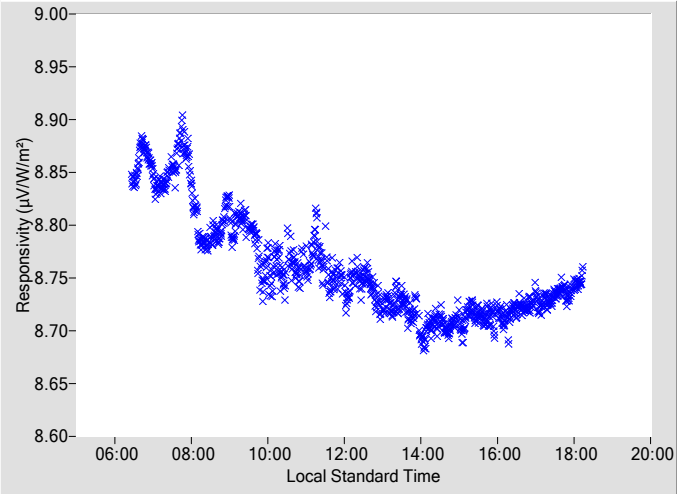


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7857	0.29	92.93	8.7064	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8227	0.32	91.38	8.7162	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7891	0.31	89.88	8.7181	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7928	0.31	88.41	8.7201	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7798	0.29	86.96	8.7264	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7833	0.32	85.58	8.7226	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8165	0.35	84.21	8.7248	0.30	275.91
14	8.7497	0.31	174.14	8.7493	0.30	187.06	60	8.8716	0.34	82.79	8.7248	0.30	277.20
16	8.7547	0.30	148.36	8.7285	0.31	211.88	62	8.8900	0.32	81.48	8.7316	0.30	278.62
18	8.7430	0.29	137.24	8.7374	0.31	222.85	64	8.8497	0.30	80.13	8.7289	N/A	279.94
20	8.7720	0.31	129.70	8.7274	0.31	230.31	66	8.8499	0.30	78.79	8.7353	N/A	281.25
22	8.7752	0.29	123.87	8.7139	0.31	236.19	68	8.8377	0.30	77.48	8.7401	N/A	282.64
24	8.7586	0.30	119.25	8.6952	0.29	240.74	70	8.8334	N/A	76.10	8.7381	N/A	283.93
26	8.7542	0.31	115.38	8.7077	0.30	244.52	72	8.8642	N/A	74.73	8.7444	N/A	285.32
28	8.7686	0.29	112.14	8.7137	0.29	248.05	74	8.8803	N/A	73.38	8.7607	N/A	286.51
30	8.7420	0.31	109.04	8.7132	0.29	250.96	76	8.8416	N/A	71.95	N/A	N/A	N/A
32	8.7654	0.30	106.43	8.6980	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7460	0.30	104.14	8.7088	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7506	0.30	101.88	8.7005	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7688	0.29	99.91	8.7195	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7989	0.29	97.99	8.7141	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8103	0.33	96.23	8.7156	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8093	0.32	94.55	8.7169	0.33	265.50	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

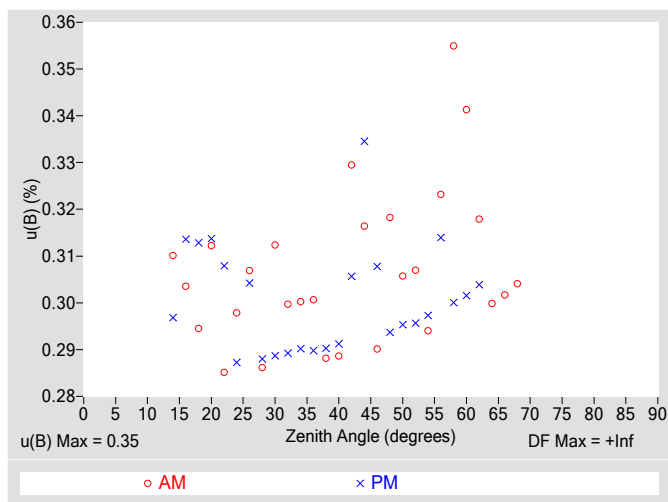


Figure 4. Residuals from Spline Interpolation

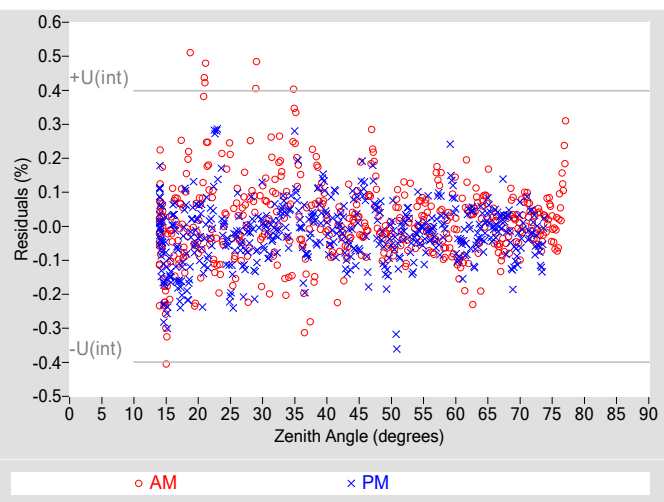


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.41
Effective degrees of freedom, $DF(c)$	15376
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.80
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

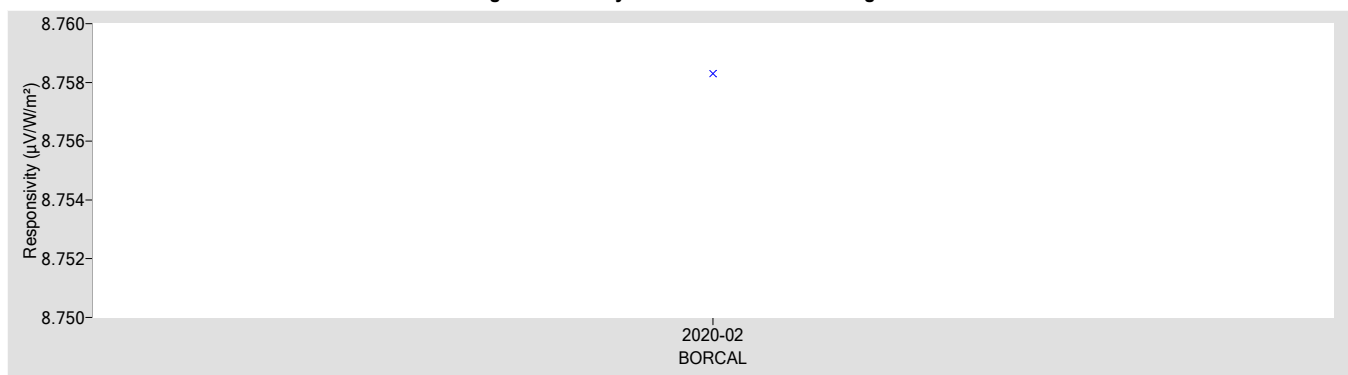
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.7583	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.3 / -0.69
Expanded Uncertainty, U (%)	+2.0 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 18637E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: TWP
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

18637E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

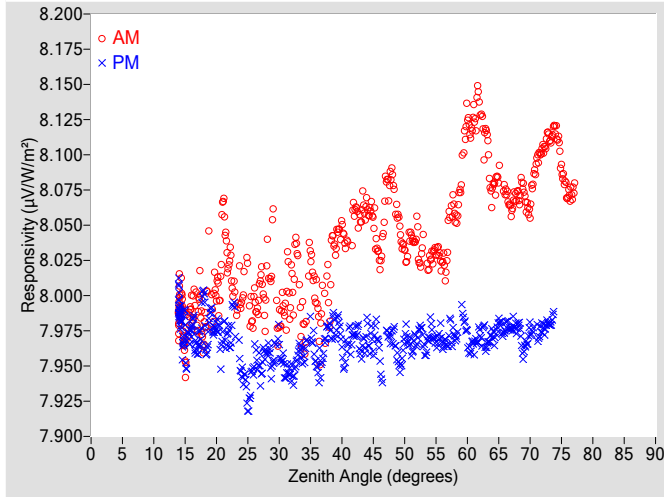


Figure 2. Responsivity vs Local Standard Time

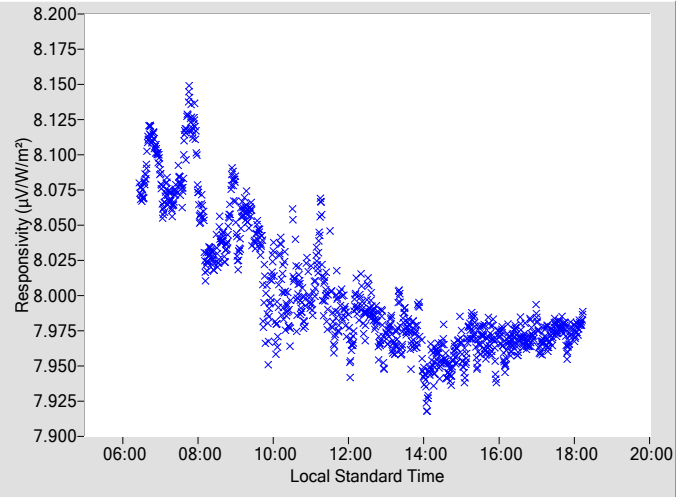


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0263	0.29	92.93	7.9537	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0851	0.32	91.38	7.9708	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0323	0.31	89.88	7.9698	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0418	0.31	88.41	7.9696	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0231	0.29	86.96	7.9747	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0240	0.32	85.58	7.9657	0.32	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0608	0.35	84.21	7.9706	0.30	275.91
14	7.9897	0.31	174.14	7.9907	0.30	187.06	60	8.1258	0.34	82.79	7.9696	0.30	277.20
16	7.9914	0.30	148.36	7.9762	0.31	211.88	62	8.1349	0.32	81.48	7.9719	0.30	278.62
18	7.9723	0.29	137.24	7.9918	0.31	222.85	64	8.0743	0.30	80.13	7.9714	N/A	279.94
20	8.0070	0.31	129.70	7.9777	0.31	230.31	66	8.0744	0.30	78.79	7.9763	N/A	281.25
22	8.0241	0.29	123.87	7.9701	0.31	236.19	68	8.0712	0.30	77.48	7.9780	N/A	282.64
24	7.9957	0.30	119.25	7.9454	0.29	240.74	70	8.0634	N/A	76.10	7.9749	N/A	283.93
26	7.9912	0.31	115.38	7.9518	0.30	244.52	72	8.1039	N/A	74.73	7.9762	N/A	285.32
28	8.0081	0.29	112.14	7.9611	0.29	248.05	74	8.1180	N/A	73.38	7.9887	N/A	286.51
30	7.9776	0.31	109.04	7.9644	0.29	250.96	76	8.0710	N/A	71.95	N/A	N/A	N/A
32	8.0035	0.30	106.43	7.9428	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9761	0.30	104.14	7.9606	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9953	0.30	101.88	7.9501	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9968	0.29	99.91	7.9762	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0470	0.29	97.99	7.9618	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0615	0.33	96.23	7.9731	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0608	0.32	94.55	7.9726	0.33	265.50	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

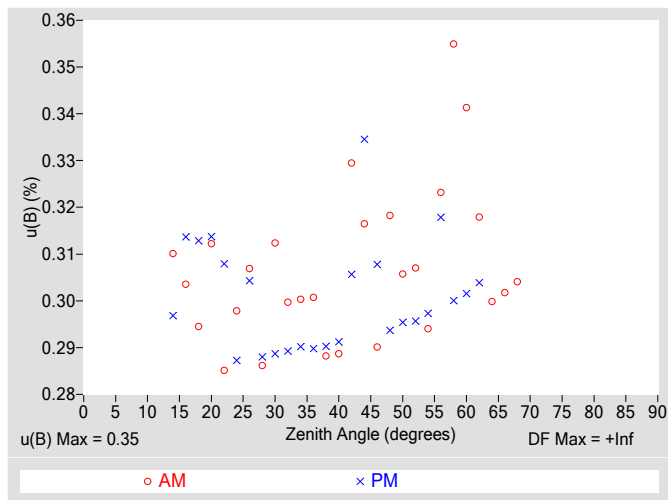


Figure 4. Residuals from Spline Interpolation

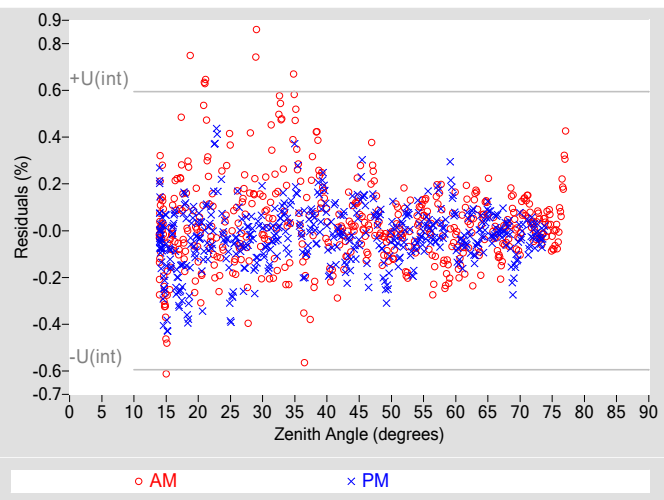


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.30
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	5203
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 0.91
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

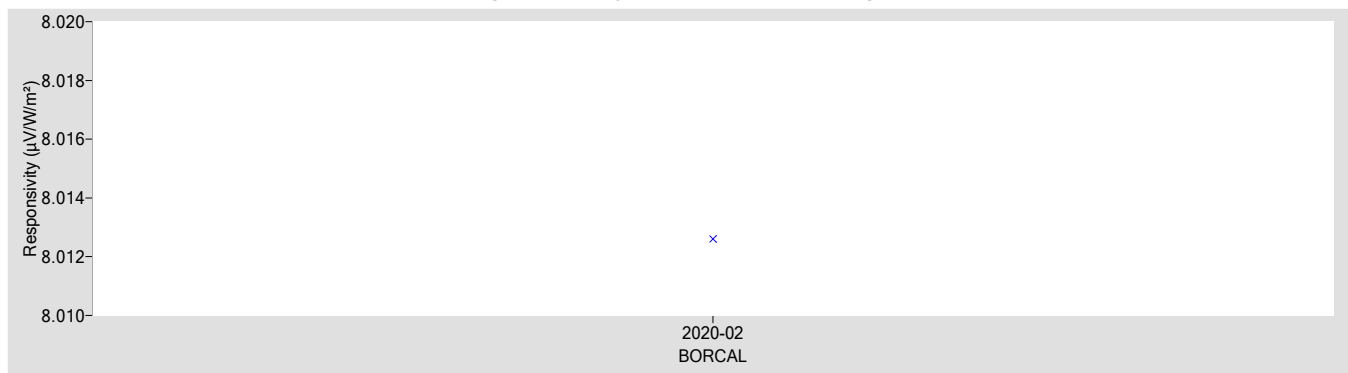
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0126	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.4 / -0.87
Expanded Uncertainty, U (%)	+2.1 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 18648E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: TWP
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

18648E6 Eppley NIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

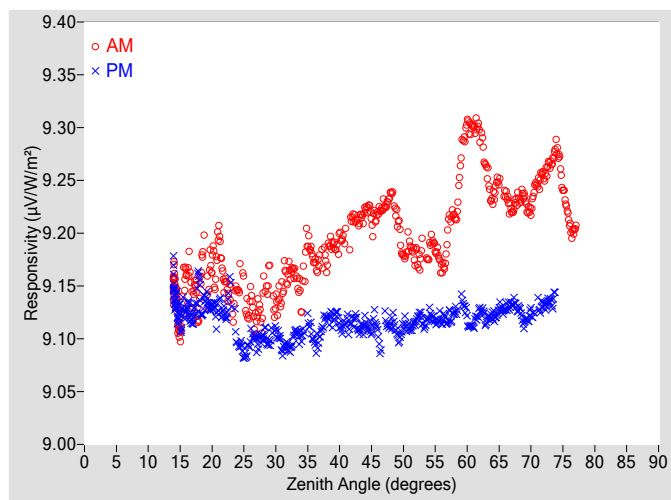


Figure 2. Responsivity vs Local Standard Time

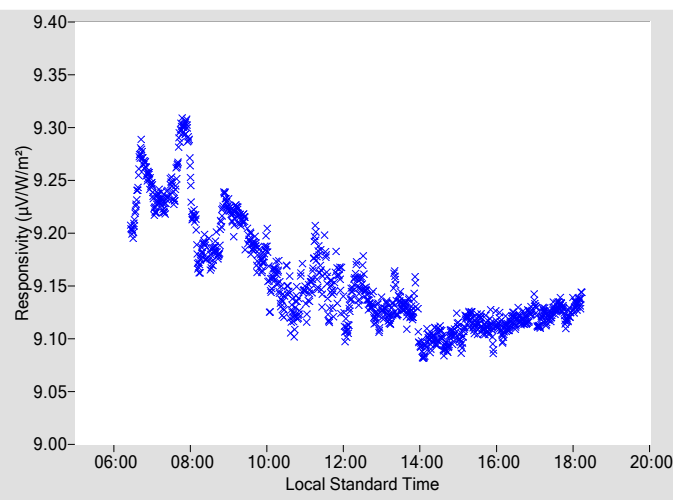


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2185	0.29	92.93	9.1005	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2359	0.32	91.38	9.1129	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1791	0.31	89.88	9.1132	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1770	0.31	88.41	9.1173	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1810	0.29	86.96	9.1222	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1684	0.32	85.58	9.1181	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2170	0.35	84.21	9.1253	0.30	275.91
14	9.1526	0.31	173.84	9.1436	0.30	187.06	60	9.3021	0.34	82.79	9.1198	0.30	277.20
16	9.1588	0.30	148.36	9.1278	0.31	211.88	62	9.2957	0.32	81.48	9.1265	0.30	278.62
18	9.1318	0.29	137.24	9.1503	0.31	222.85	64	9.2323	0.30	80.13	9.1221	N/A	279.94
20	9.1756	0.31	129.70	9.1306	0.31	230.31	66	9.2363	0.30	78.79	9.1286	N/A	281.25
22	9.1532	0.29	123.87	9.1235	0.31	236.19	68	9.2319	0.30	77.48	9.1281	N/A	282.64
24	9.1465	0.30	119.25	9.0953	0.29	240.66	70	9.2235	N/A	76.10	9.1239	N/A	283.93
26	9.1337	0.31	115.38	9.0981	0.30	244.52	72	9.2546	N/A	74.73	9.1314	N/A	285.32
28	9.1319	0.29	112.14	9.1038	0.29	248.05	74	9.2788	N/A	73.38	9.1439	N/A	286.51
30	9.1297	0.31	109.04	9.1060	0.29	250.96	76	9.2097	N/A	71.95	N/A	N/A	N/A
32	9.1613	0.30	106.43	9.0916	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.1417	0.30	104.14	9.1042	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1739	0.30	101.88	9.0979	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1752	0.29	99.91	9.1203	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1933	0.29	97.99	9.1129	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2142	0.33	96.23	9.1159	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2200	0.32	94.55	9.1133	0.33	265.50	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

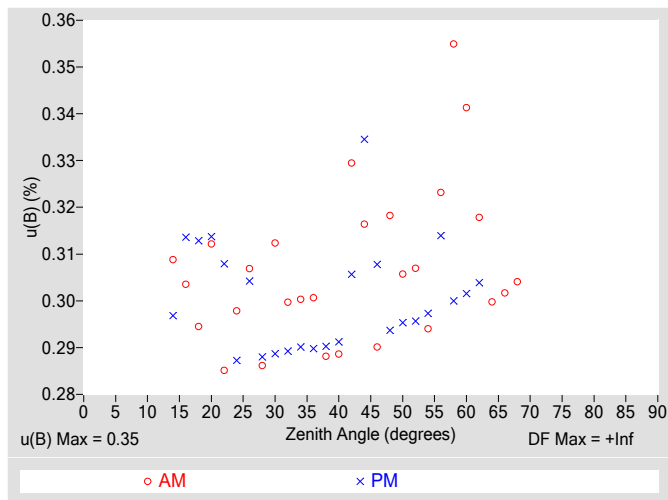


Figure 4. Residuals from Spline Interpolation

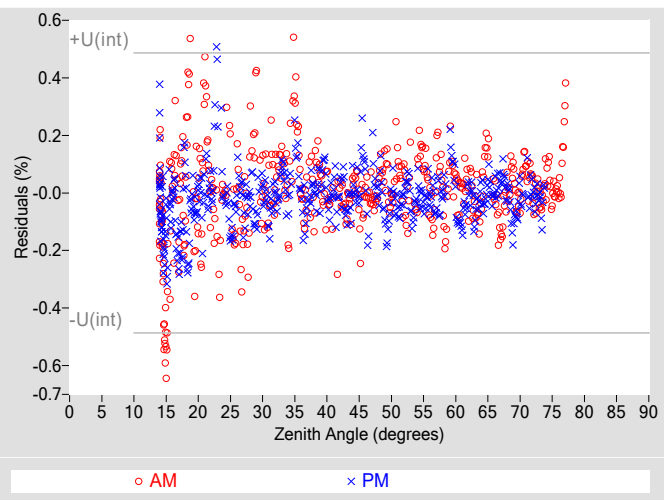


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.24
Combined Standard Uncertainty, $u(c)$ (%)	± 0.43
Effective degrees of freedom, $DF(c)$	8694
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.84
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

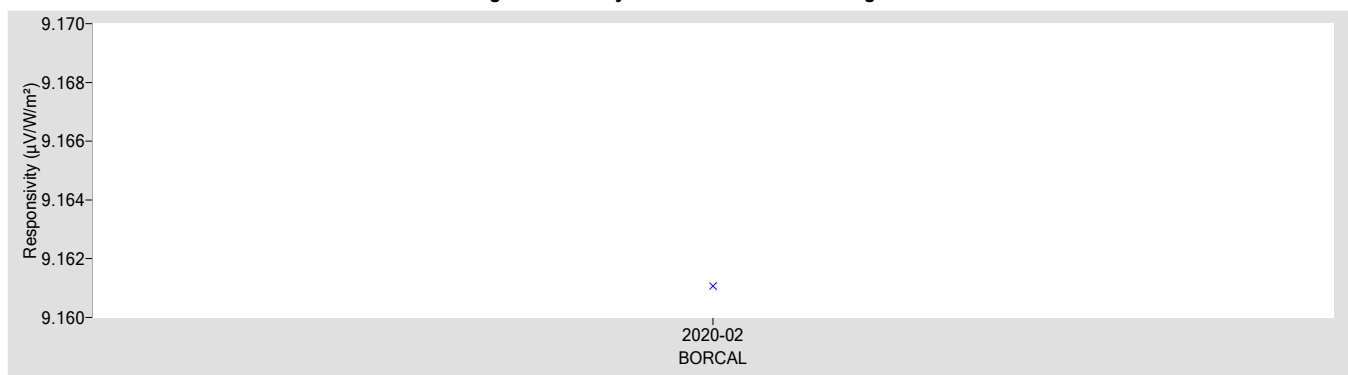
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.1611	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.5 / -0.76
Expanded Uncertainty, U (%)	+2.2 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: TWP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 27974F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

27974F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

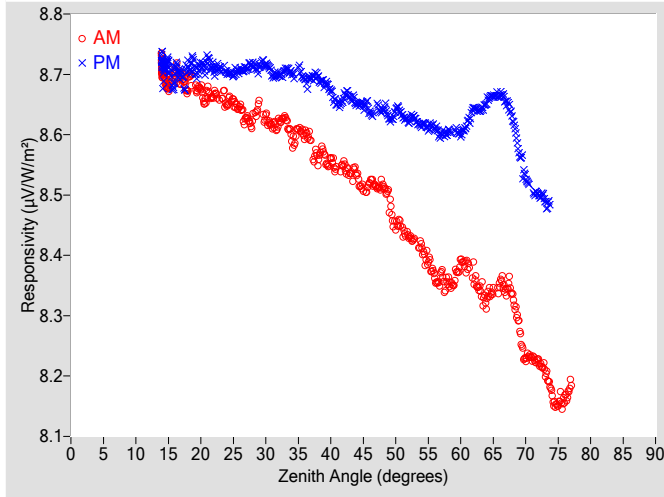


Figure 2. Responsivity vs Local Standard Time

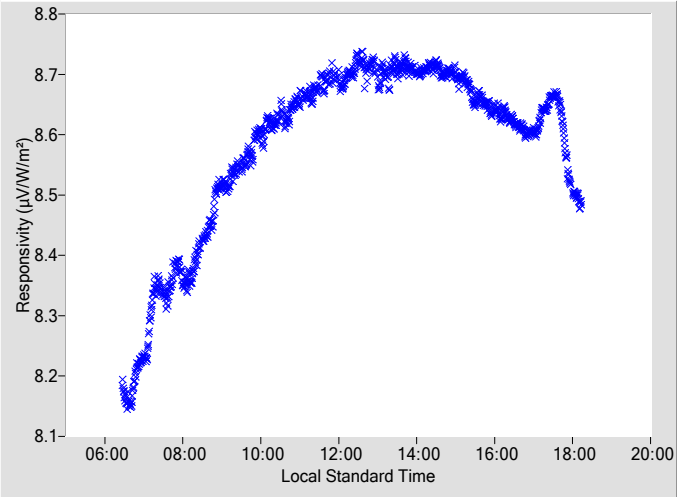


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5217	0.36	92.88	8.6371	0.35	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5158	0.35	91.34	8.6409	0.37	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4510	0.41	89.79	8.6423	0.36	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4330	0.38	88.37	8.6231	0.37	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4127	0.40	86.92	8.6166	0.38	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3632	0.43	85.54	8.6118	0.40	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3567	0.42	84.17	8.6040	0.41	275.87
14	8.7091	0.33	173.30	8.7206	0.33	186.84	60	8.3857	0.41	82.84	8.6023	0.43	277.25
16	8.6953	0.32	148.42	8.6978	0.32	211.78	62	8.3658	0.49	81.46	8.6434	0.44	278.58
18	8.6796	0.32	137.34	8.7120	0.32	222.74	64	8.3266	0.47	80.10	8.6543	N/A	279.90
20	8.6763	0.33	129.71	8.7148	0.31	230.33	66	8.3504	0.46	78.80	8.6658	N/A	281.30
22	8.6657	0.32	124.01	8.7086	0.33	236.08	68	8.3305	0.51	77.45	8.6258	N/A	282.60
24	8.6491	0.32	119.34	8.7031	0.34	240.75	70	8.2302	N/A	76.07	8.5280	N/A	283.98
26	8.6451	0.33	115.39	8.7064	0.32	244.63	72	8.2239	N/A	74.77	8.4995	N/A	285.32
28	8.6201	0.33	112.24	8.7145	0.33	247.97	74	8.1722	N/A	73.38	N/A	N/A	N/A
30	8.6274	0.35	109.13	8.7155	0.33	250.89	76	8.1624	N/A	72.00	N/A	N/A	N/A
32	8.6185	0.35	106.51	8.6996	0.32	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5948	0.34	104.08	8.7025	0.32	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6002	0.34	101.95	8.6911	0.34	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5617	0.34	99.86	8.6951	0.35	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5568	0.33	97.99	8.6734	0.33	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5494	0.37	96.18	8.6612	0.34	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5352	0.36	94.51	8.6512	0.36	265.56	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

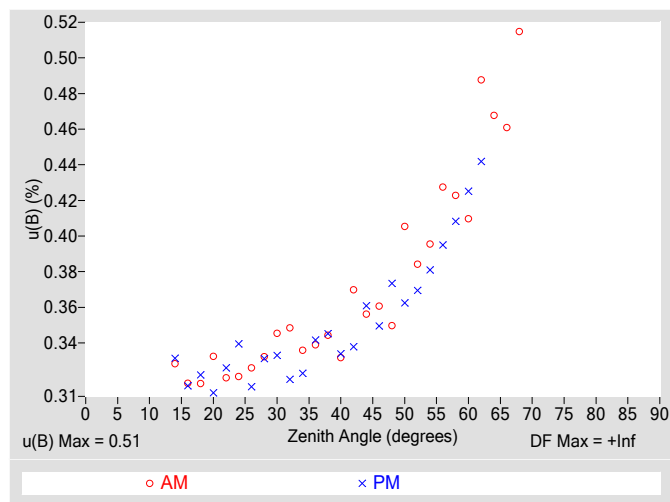


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	52886
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

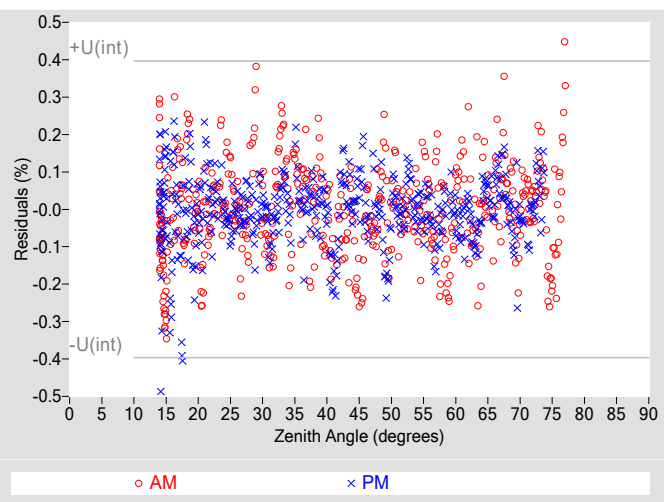


Table 4. Calibration Label Values

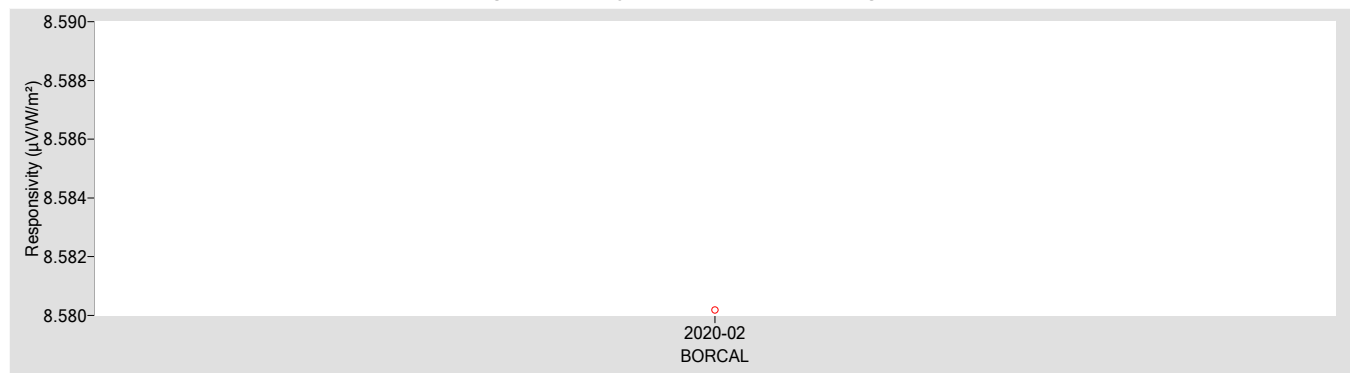
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5802	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.84
Offset Uncertainty, $U(off)$ (%)	+1.6 / -2.6
Expanded Uncertainty, U (%)	+2.4 / -3.4
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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: TWP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 28019E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

28019E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

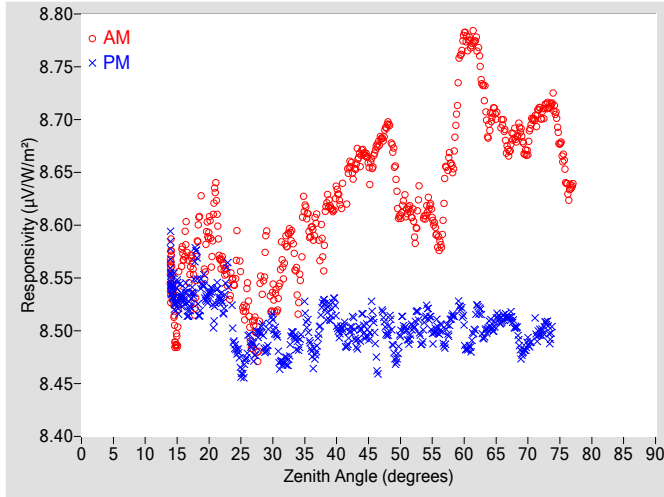


Figure 2. Responsivity vs Local Standard Time

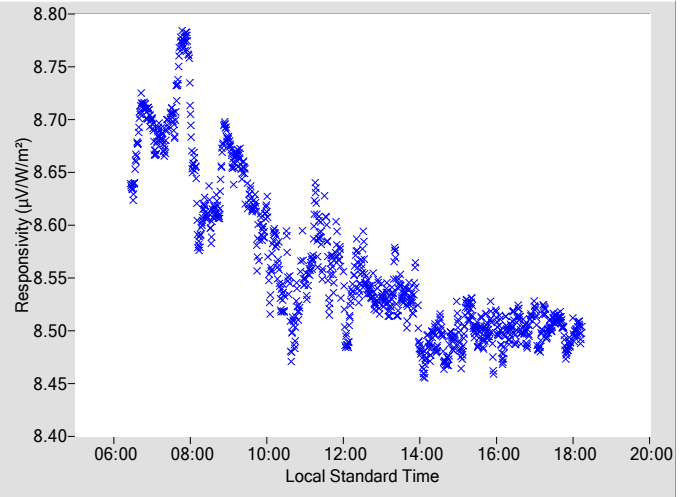


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6671	0.29	92.93	8.4864	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6947	0.32	91.38	8.4982	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6085	0.31	89.88	8.4980	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6045	0.31	88.41	8.5035	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6108	0.29	86.96	8.5158	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5842	0.32	85.58	8.5018	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6585	0.35	84.21	8.5133	0.30	275.91
14	8.5556	0.31	173.84	8.5478	0.30	187.26	60	8.7786	0.34	82.79	8.5001	0.30	277.20
16	8.5755	0.30	148.36	8.5300	0.31	211.88	62	8.7714	0.32	81.48	8.5206	0.30	278.62
18	8.5506	0.29	137.24	8.5629	0.31	222.85	64	8.6945	0.30	80.13	8.5060	N/A	279.94
20	8.5960	0.31	129.70	8.5343	0.31	230.31	66	8.6951	0.30	78.79	8.5101	N/A	281.25
22	8.5649	0.29	123.87	8.5259	0.31	236.19	68	8.6842	0.30	77.48	8.5032	N/A	282.64
24	8.5504	0.30	119.25	8.4862	0.29	240.74	70	8.6745	N/A	76.10	8.4877	N/A	283.93
26	8.5281	0.31	115.38	8.4806	0.30	244.52	72	8.7063	N/A	74.73	8.4983	N/A	285.32
28	8.5215	0.29	112.14	8.4996	0.29	248.05	74	8.7137	N/A	73.38	8.5039	N/A	286.51
30	8.5294	0.31	109.04	8.5073	0.29	250.96	76	8.6403	N/A	71.95	N/A	N/A	N/A
32	8.5791	0.30	106.43	8.4711	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5380	0.30	104.14	8.4883	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5939	0.30	101.88	8.4837	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5817	0.29	99.91	8.5265	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6314	0.29	97.99	8.5089	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6547	0.33	96.23	8.4965	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6665	0.32	94.55	8.5059	0.33	265.50	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

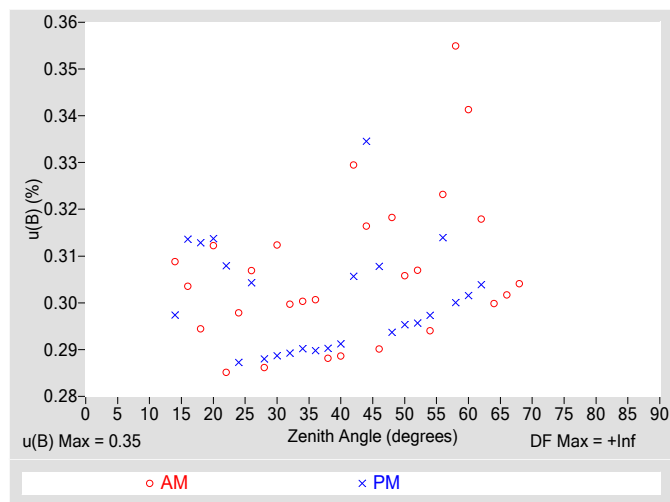


Figure 4. Residuals from Spline Interpolation

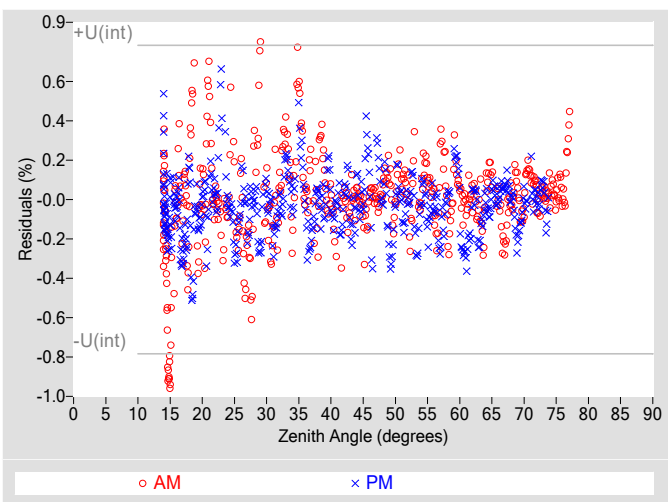


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.39
Combined Standard Uncertainty, $u(c)$ (%)	± 0.53
Effective degrees of freedom, $DF(c)$	2940
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.0
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

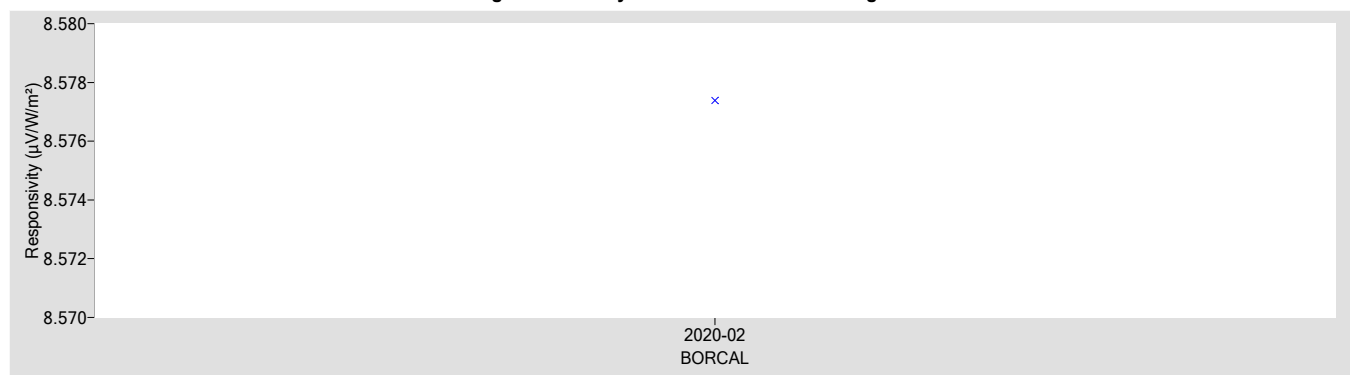
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5774	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+2.3 / -1.2
Expanded Uncertainty, U (%)	+3.0 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 29008E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29008E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

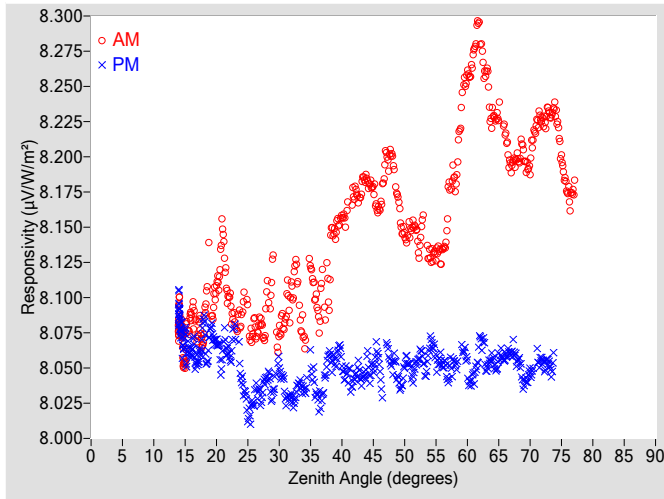


Figure 2. Responsivity vs Local Standard Time

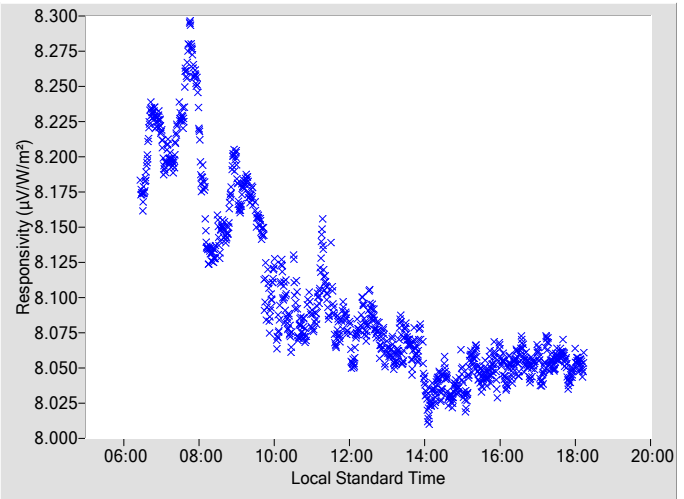


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1637	0.29	92.93	8.0468	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2004	0.32	91.38	8.0518	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1451	0.31	89.88	8.0511	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1436	0.31	88.41	8.0547	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1286	0.29	86.96	8.0657	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1303	0.32	85.58	8.0538	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1842	0.35	84.21	8.0527	0.30	275.91
14	8.0836	0.31	174.14	8.0865	0.30	187.06	60	8.2574	0.34	82.79	8.0498	0.30	277.20
16	8.0893	0.30	148.36	8.0619	0.31	211.88	62	8.2876	0.32	81.48	8.0686	0.30	278.62
18	8.0777	0.29	137.24	8.0784	0.31	222.85	64	8.2281	0.30	80.13	8.0556	N/A	279.94
20	8.1078	0.31	129.70	8.0679	0.31	230.31	66	8.2173	0.30	78.79	8.0568	N/A	281.25
22	8.0991	0.29	123.87	8.0589	0.31	236.19	68	8.1988	0.30	77.48	8.0549	N/A	282.64
24	8.0865	0.30	119.25	8.0420	0.29	240.74	70	8.1967	N/A	76.10	8.0464	N/A	283.93
26	8.0778	0.31	115.38	8.0266	0.30	244.52	72	8.2261	N/A	74.73	8.0538	N/A	285.32
28	8.0953	0.29	112.14	8.0433	0.29	248.05	74	8.2321	N/A	73.38	8.0610	N/A	286.51
30	8.0723	0.31	109.04	8.0503	0.29	250.96	76	8.1742	N/A	71.95	N/A	N/A	N/A
32	8.1036	0.30	106.43	8.0277	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0730	0.30	104.14	8.0347	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0943	0.30	101.88	8.0304	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1117	0.29	99.91	8.0587	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1571	0.29	97.99	8.0536	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1751	0.33	96.23	8.0434	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1829	0.32	94.55	8.0525	0.33	265.50	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

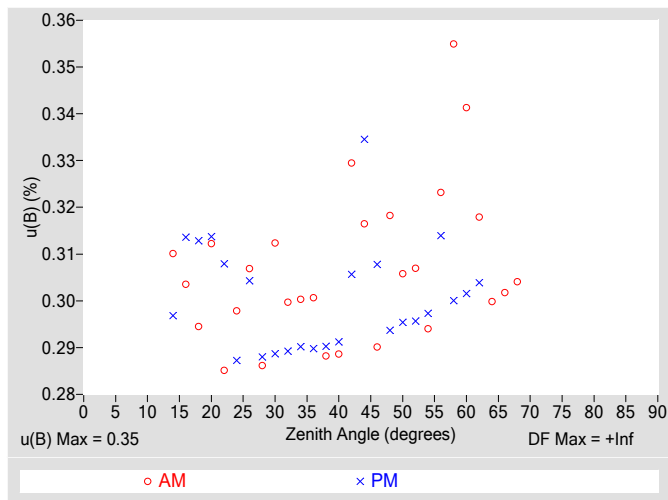


Figure 4. Residuals from Spline Interpolation

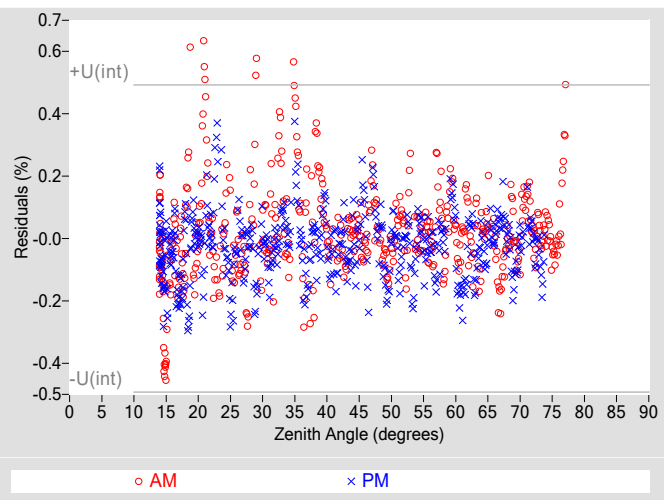


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.25
Combined Standard Uncertainty, $u(c)$ (%)	± 0.43
Effective degrees of freedom, $DF(c)$	8348
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.85
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

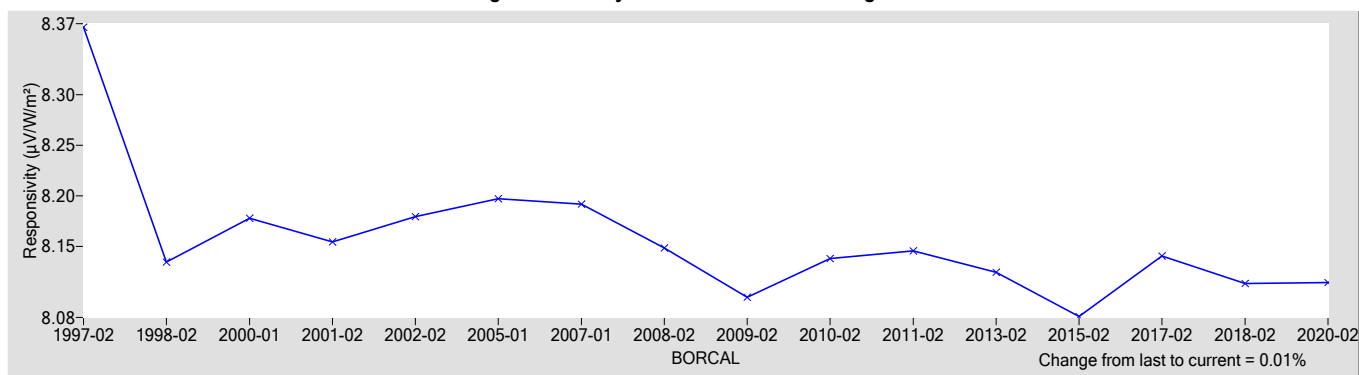
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.1143	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.8 / -1.1
Expanded Uncertainty, U (%)	+2.5 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 29010E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29010E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

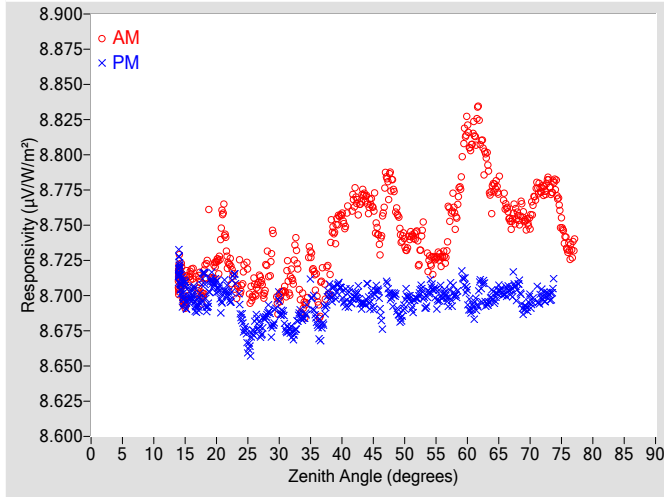


Figure 2. Responsivity vs Local Standard Time

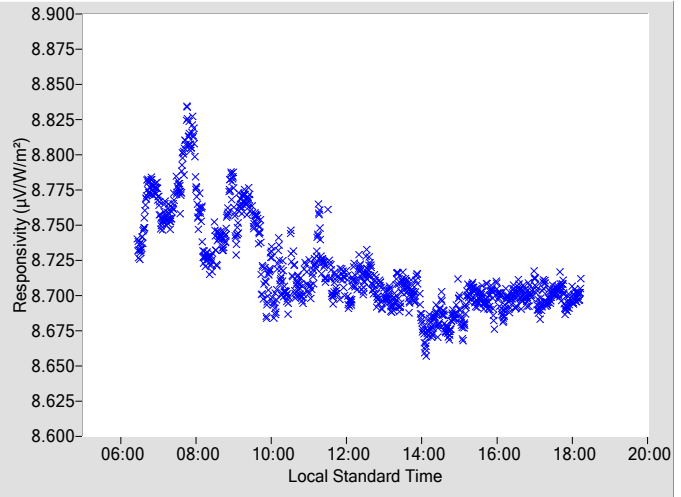


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7385	0.29	92.93	8.6920	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7805	0.32	91.38	8.6979	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7388	0.31	89.88	8.6953	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7382	0.31	88.41	8.6985	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7227	0.29	86.96	8.7049	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7269	0.32	85.58	8.7011	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7595	0.35	84.21	8.7004	0.30	275.91
14	8.7133	0.31	174.14	8.7156	0.30	187.06	60	8.8166	0.34	82.79	8.6991	0.30	277.20
16	8.7153	0.30	148.36	8.6993	0.31	211.88	62	8.8191	0.32	81.48	8.7050	0.30	278.62
18	8.7077	0.29	137.24	8.7117	0.31	222.85	64	8.7726	0.30	80.13	8.6996	N/A	279.94
20	8.7240	0.31	129.70	8.7072	0.31	230.31	66	8.7659	0.30	78.79	8.7017	N/A	281.25
22	8.7225	0.29	123.87	8.6984	0.31	236.19	68	8.7571	0.30	77.48	8.7056	N/A	282.64
24	8.7075	0.30	119.25	8.6842	0.29	240.74	70	8.7551	N/A	76.10	8.6961	N/A	283.93
26	8.7033	0.31	115.38	8.6761	0.30	244.52	72	8.7754	N/A	74.73	8.6998	N/A	285.32
28	8.7197	0.29	112.14	8.6875	0.29	248.05	74	8.7787	N/A	73.38	8.7120	N/A	286.51
30	8.6963	0.31	109.04	8.6938	0.29	250.96	76	8.7332	N/A	71.95	N/A	N/A	N/A
32	8.7126	0.30	106.43	8.6730	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.6931	0.30	104.14	8.6852	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7016	0.30	101.88	8.6815	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7152	0.29	99.91	8.7021	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7565	0.29	97.99	8.7015	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7699	0.33	96.23	8.6999	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7664	0.32	94.55	8.7014	0.33	265.50	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

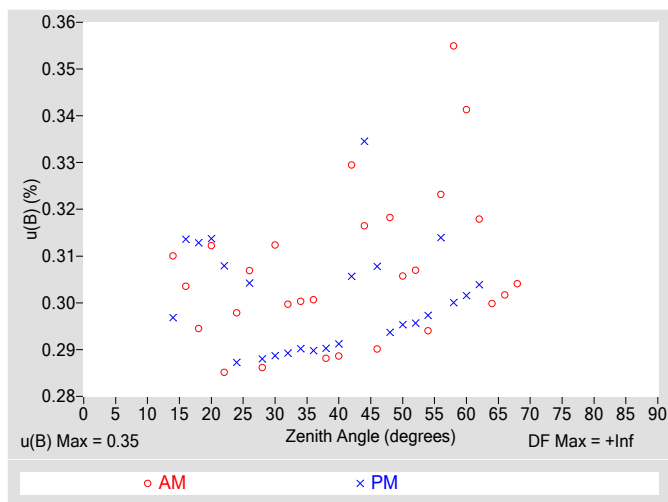


Figure 4. Residuals from Spline Interpolation

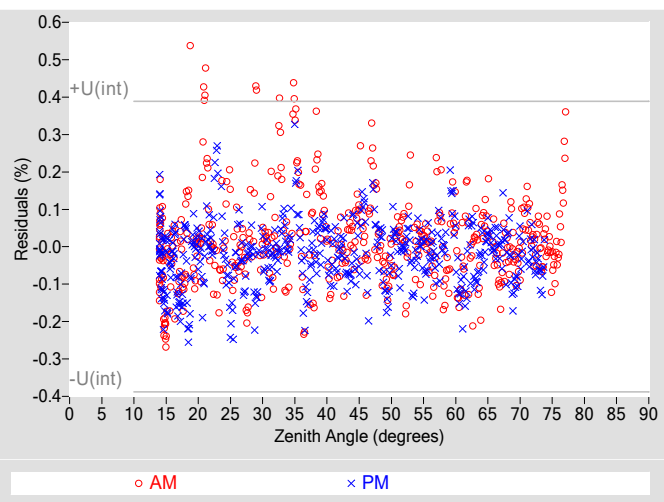


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.40
Effective degrees of freedom, $DF(c)$	16646
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.79
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

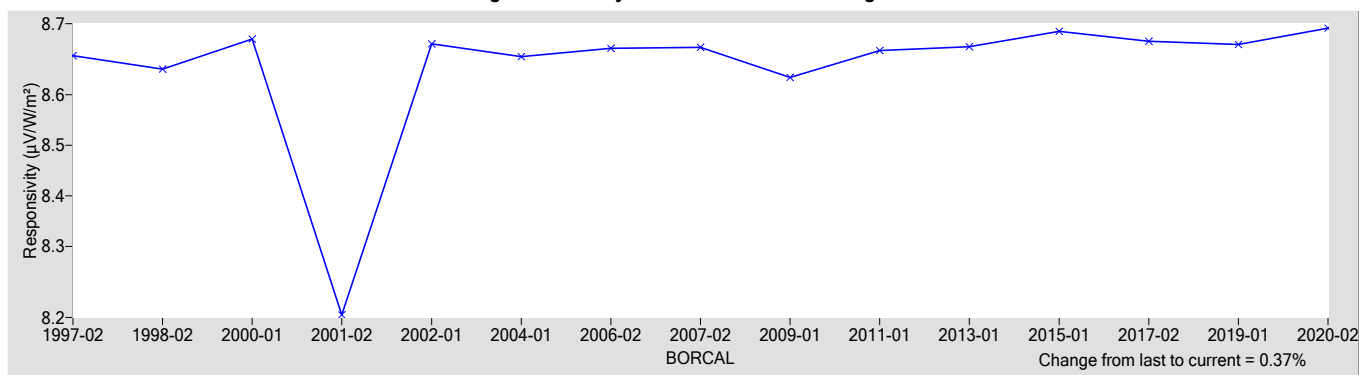
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.7315	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+0.98 / -0.67
Expanded Uncertainty, U (%)	+1.7 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 29011E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29011E6 Eppley NIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

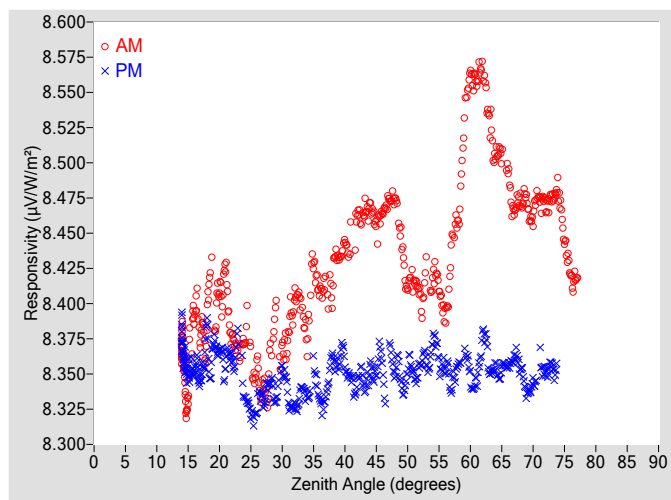


Figure 2. Responsivity vs Local Standard Time

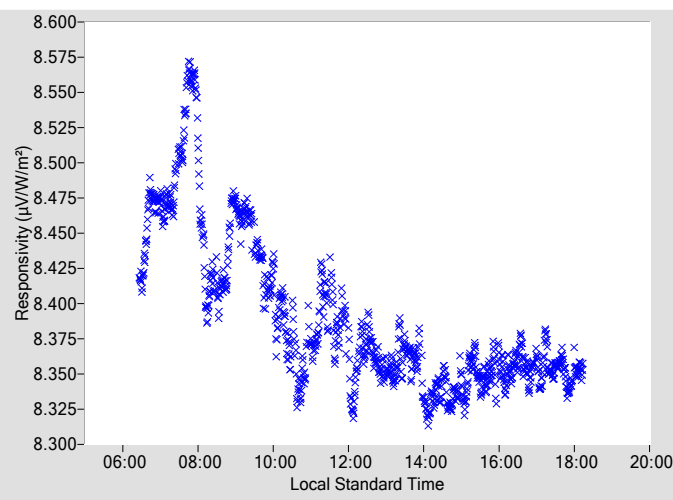


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V/W/m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V/W/m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V/W/m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V/W/m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4646	0.29	92.93	8.3487	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4736	0.32	91.38	8.3507	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4119	0.31	89.88	8.3524	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4058	0.31	88.41	8.3563	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4147	0.29	86.96	8.3726	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3932	0.32	85.58	8.3543	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4582	0.35	84.21	8.3569	0.30	275.91
14	8.3702	0.31	173.84	8.3713	0.30	187.06	60	8.5611	0.34	82.79	8.3477	0.30	277.20
16	8.3943	0.30	148.36	8.3523	0.31	211.88	62	8.5645	0.32	81.48	8.3774	0.30	278.62
18	8.3827	0.29	137.24	8.3792	0.31	222.85	64	8.5051	0.30	80.13	8.3539	N/A	279.94
20	8.4098	0.31	129.70	8.3661	0.31	230.31	66	8.4932	0.30	78.79	8.3554	N/A	281.25
22	8.3760	0.29	123.87	8.3584	0.31	236.19	68	8.4722	0.30	77.48	8.3531	N/A	282.64
24	8.3748	0.30	119.25	8.3337	0.29	240.66	70	8.4626	N/A	76.10	8.3429	N/A	283.93
26	8.3530	0.31	115.38	8.3257	0.30	244.52	72	8.4704	N/A	74.73	8.3514	N/A	285.32
28	8.3552	0.29	112.14	8.3437	0.29	248.05	74	8.4780	N/A	73.38	8.3574	N/A	286.51
30	8.3640	0.31	109.04	8.3521	0.29	250.96	76	8.4186	N/A	71.95	N/A	N/A	N/A
32	8.4028	0.30	106.43	8.3271	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3785	0.30	104.14	8.3346	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4098	0.30	101.88	8.3324	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4120	0.29	99.91	8.3620	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4434	0.29	97.99	8.3579	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4627	0.33	96.23	8.3443	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4666	0.32	94.55	8.3523	0.33	265.50	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

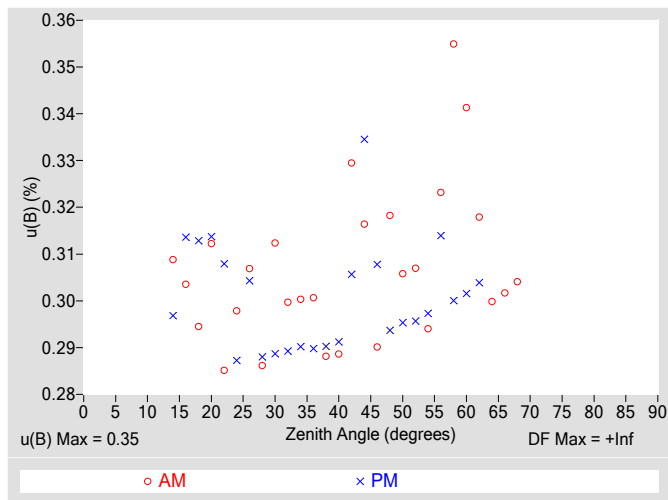


Figure 4. Residuals from Spline Interpolation

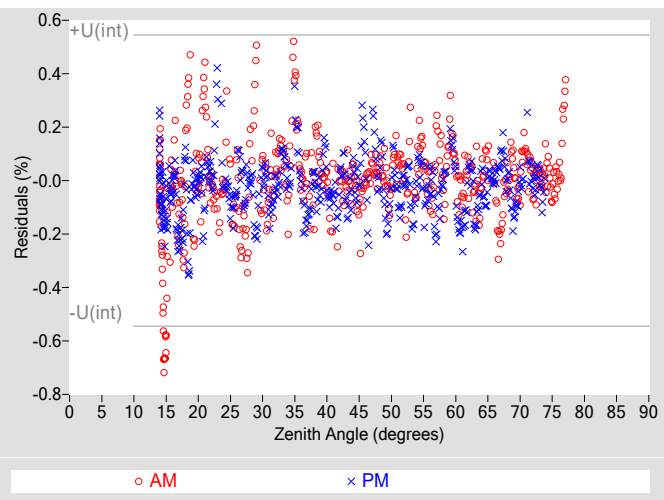


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.27
Combined Standard Uncertainty, $u(c)$ (%)	± 0.45
Effective degrees of freedom, $DF(c)$	6448
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 0.88
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

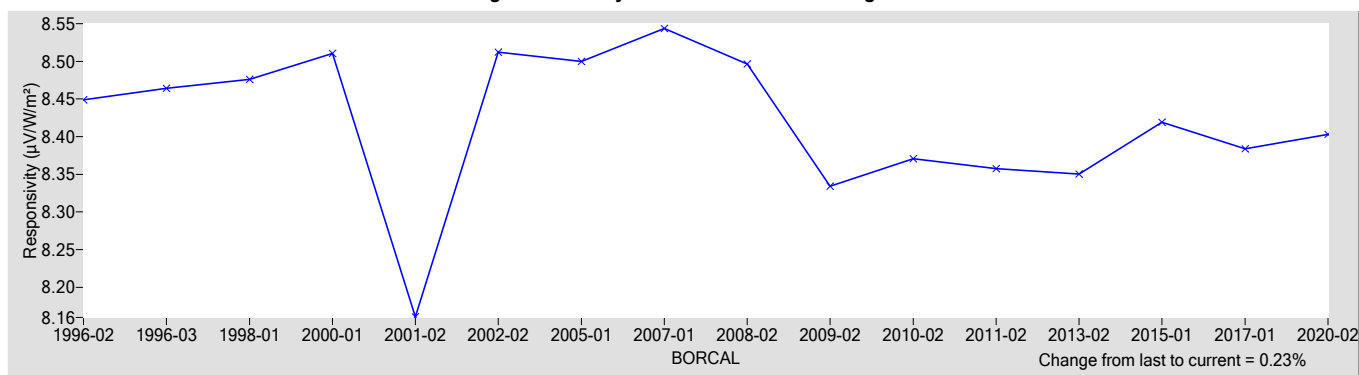
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.4032	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.9 / -0.91
Expanded Uncertainty, U (%)	+2.6 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 29541E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29541E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

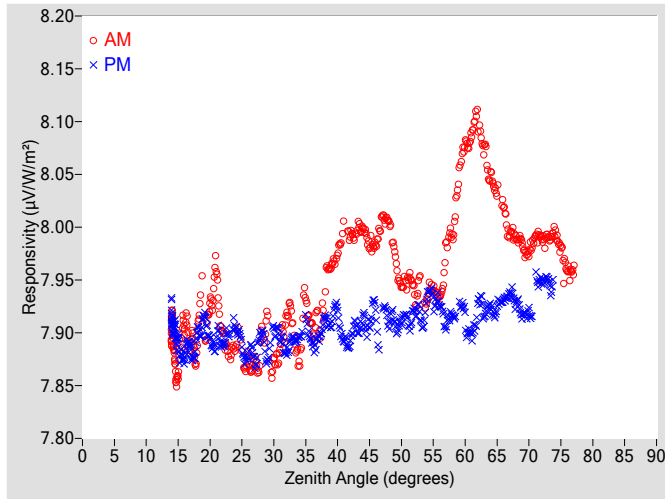


Figure 2. Responsivity vs Local Standard Time

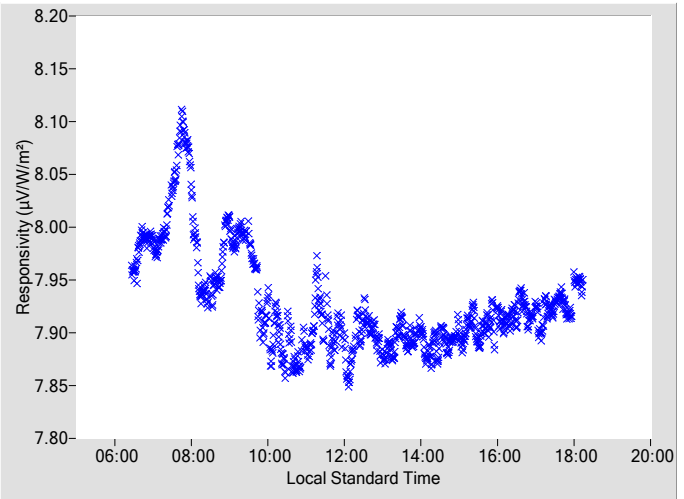


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9839	0.29	92.93	7.9103	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0057	0.32	91.38	7.9095	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9451	0.31	89.88	7.9115	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9395	0.31	88.41	7.9200	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9302	0.29	86.96	7.9312	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9335	0.32	85.58	7.9287	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9928	0.35	84.21	7.9158	0.30	275.91
14	7.9028	0.31	174.14	7.9100	0.30	187.06	60	8.0781	0.34	82.79	7.9130	0.30	277.20
16	7.9094	0.30	148.36	7.8787	0.31	211.88	62	8.1008	0.32	81.48	7.9265	0.30	278.62
18	7.8908	0.29	137.24	7.9006	0.31	222.85	64	8.0472	0.30	80.13	7.9235	N/A	279.94
20	7.9248	0.31	129.70	7.8938	0.31	230.31	66	8.0194	0.30	78.79	7.9308	N/A	281.25
22	7.8990	0.29	123.87	7.8889	0.31	236.19	68	7.9903	0.30	77.48	7.9281	N/A	282.64
24	7.8889	0.30	119.25	7.9039	0.29	240.74	70	7.9778	N/A	76.10	7.9184	N/A	283.93
26	7.8727	0.31	115.38	7.8770	0.30	244.52	72	7.9898	N/A	74.73	7.9490	N/A	285.32
28	7.8921	0.29	112.14	7.8998	0.29	248.05	74	7.9942	N/A	73.38	7.9504	N/A	286.51
30	7.8710	0.31	109.04	7.9018	0.29	250.96	76	7.9597	N/A	71.95	N/A	N/A	N/A
32	7.9149	0.30	106.43	7.8818	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.8757	0.30	104.14	7.8965	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9052	0.30	101.88	7.8912	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9299	0.29	99.91	7.9143	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9756	0.29	97.99	7.9188	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9931	0.33	96.23	7.8925	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9979	0.32	94.55	7.9133	0.33	265.50	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

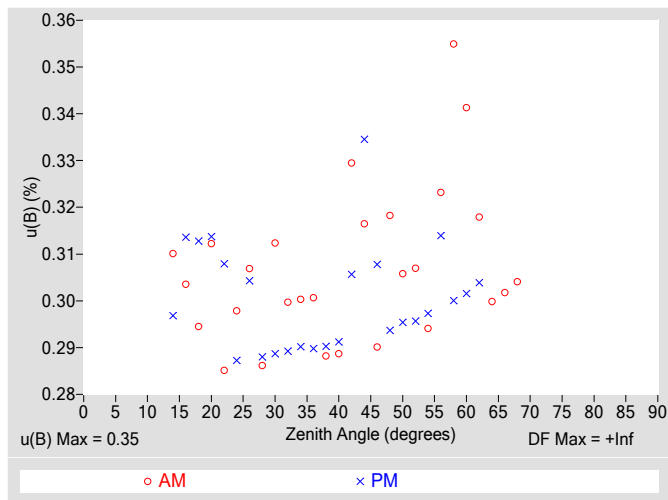


Figure 4. Residuals from Spline Interpolation

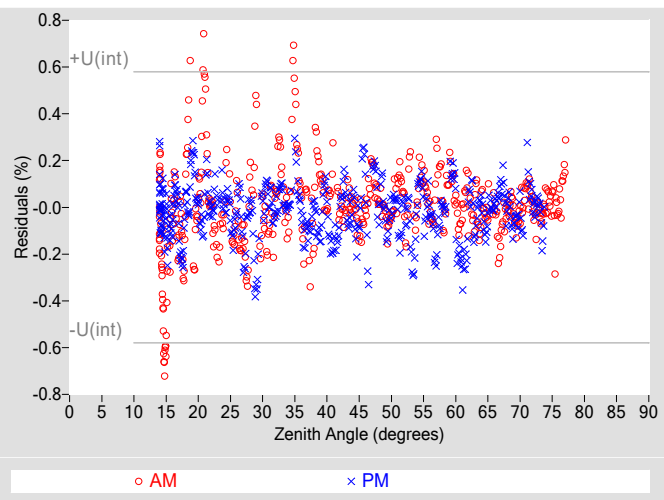


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.29
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	5530
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.90
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

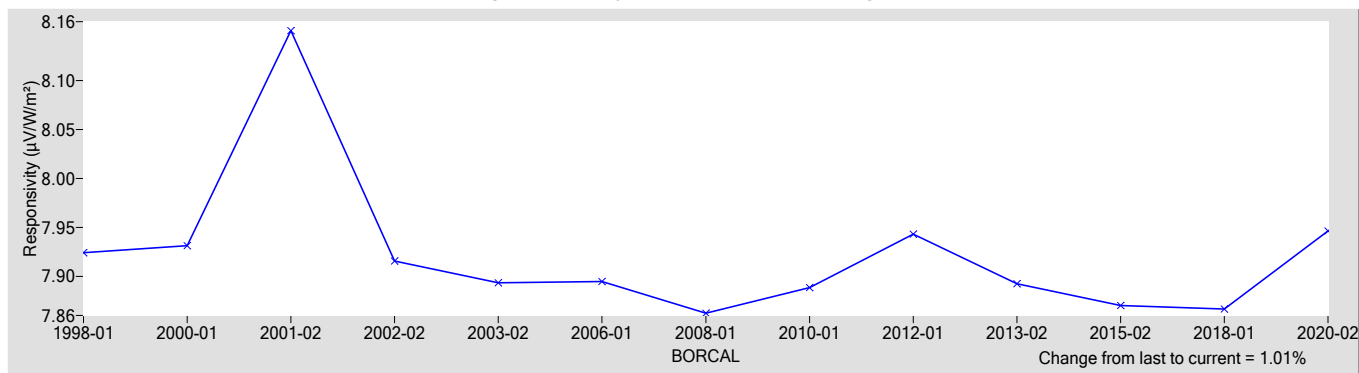
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.9463	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.7 / -0.95
Expanded Uncertainty, U (%)	+2.4 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 29609F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29609F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

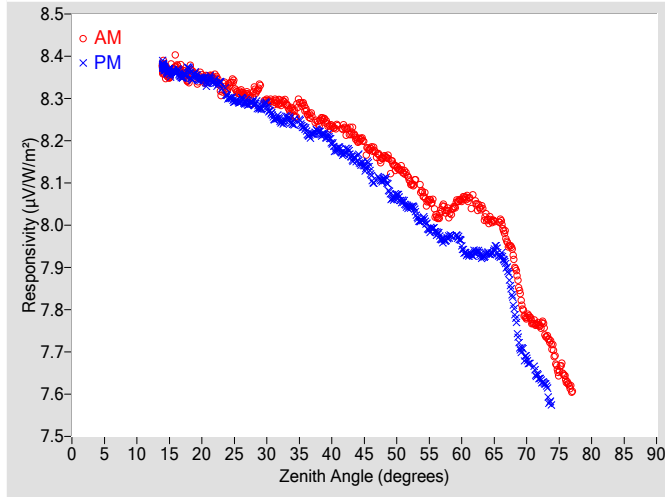


Figure 2. Responsivity vs Local Standard Time

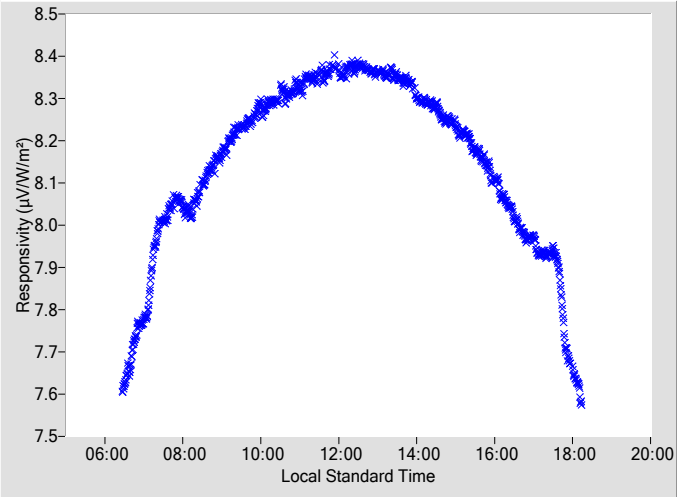


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1803	0.36	92.85	8.1223	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1611	0.34	91.31	8.1063	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1351	0.37	89.81	8.0712	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1030	0.36	88.35	8.0423	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0747	0.38	86.98	8.0140	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0236	0.37	85.52	7.9844	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0301	0.42	84.19	7.9725	0.37	275.84
14	8.3746	0.31	173.63	8.3756	0.31	187.51	60	8.0607	0.39	82.81	7.9532	0.38	277.22
16	8.3796	0.33	148.36	8.3616	0.31	211.47	62	8.0601	0.37	81.45	7.9352	0.39	278.56
18	8.3463	0.32	137.40	8.3668	0.34	222.94	64	8.0138	0.50	80.15	7.9335	N/A	279.96
20	8.3509	0.32	129.62	8.3469	0.30	230.39	66	8.0081	0.40	78.81	7.9280	N/A	281.27
22	8.3498	0.31	123.93	8.3400	0.31	236.13	68	7.9177	0.42	77.42	7.8131	N/A	282.58
24	8.3233	0.32	119.27	8.3031	0.30	240.79	70	7.7831	N/A	76.13	7.6832	N/A	283.95
26	8.3150	0.33	115.33	8.2952	0.30	244.67	72	7.7625	N/A	74.75	7.6377	N/A	285.30
28	8.3108	0.30	112.09	8.2896	0.30	248.01	74	7.7067	N/A	73.36	7.5741	N/A	286.53
30	8.2944	0.32	109.08	8.2824	0.30	250.93	76	7.6360	N/A	71.97	N/A	N/A	N/A
32	8.2903	0.30	106.47	8.2472	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.2711	0.30	104.04	8.2400	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2726	0.34	101.91	8.2251	0.34	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2418	0.35	99.89	8.2219	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2325	0.35	97.96	8.1943	0.32	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2276	0.35	96.25	8.1725	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2020	0.34	94.53	8.1574	0.35	265.55	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

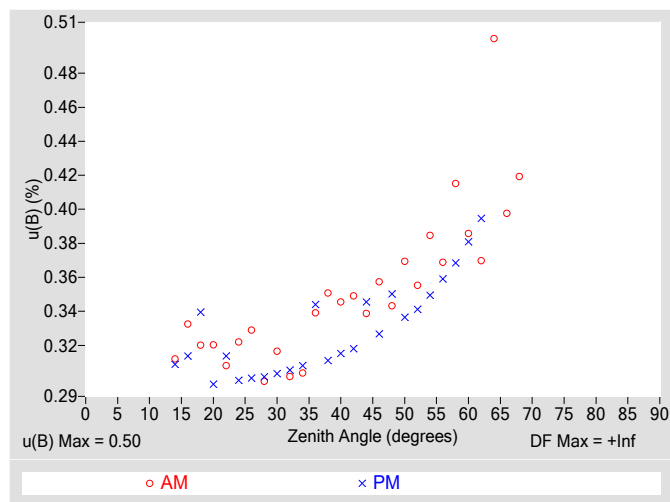


Figure 4. Residuals from Spline Interpolation

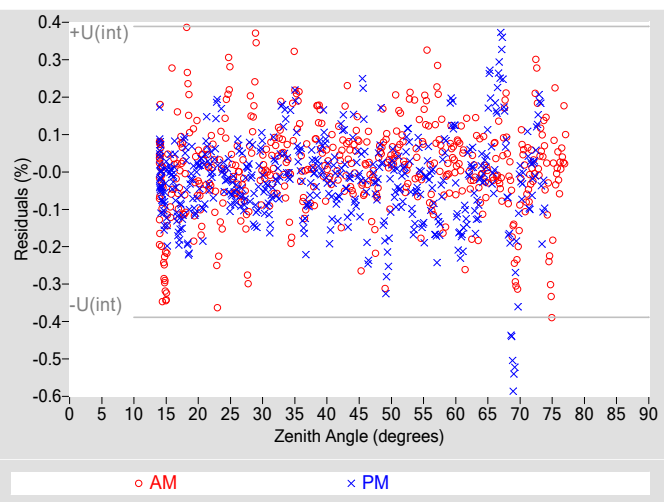


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	50570
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

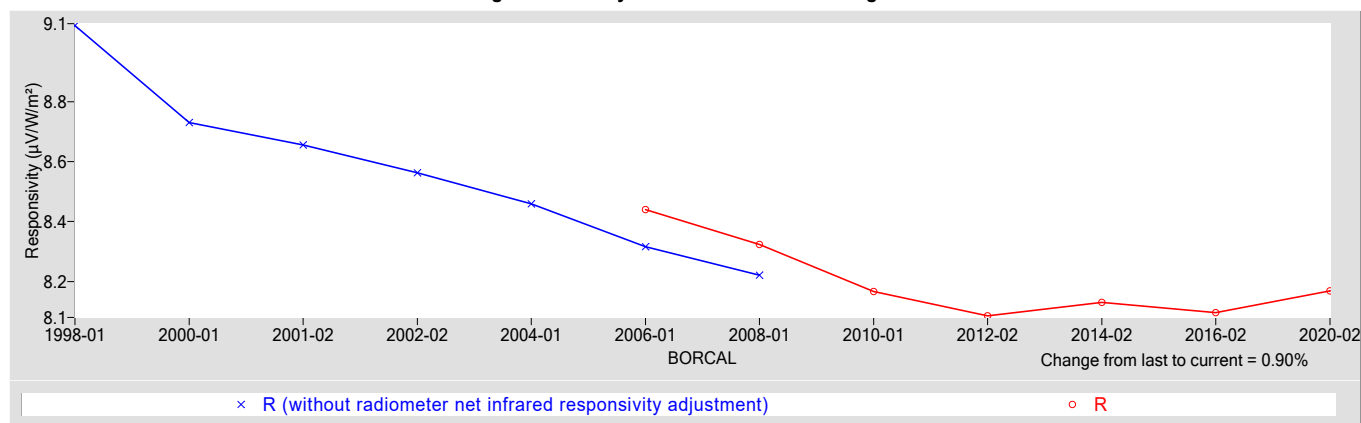
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.1690	0.63600

† R_{net} determination date: 04/20/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.5 / -2.6
Expanded Uncertainty, U (%)	+2.3 / -3.5
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 29741E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29741E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

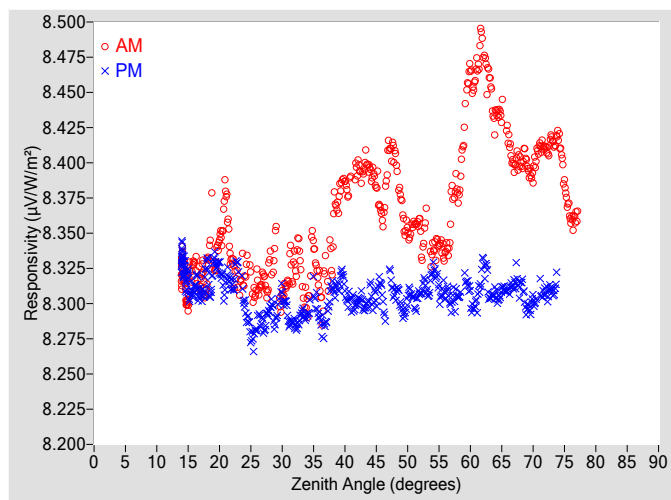


Figure 2. Responsivity vs Local Standard Time

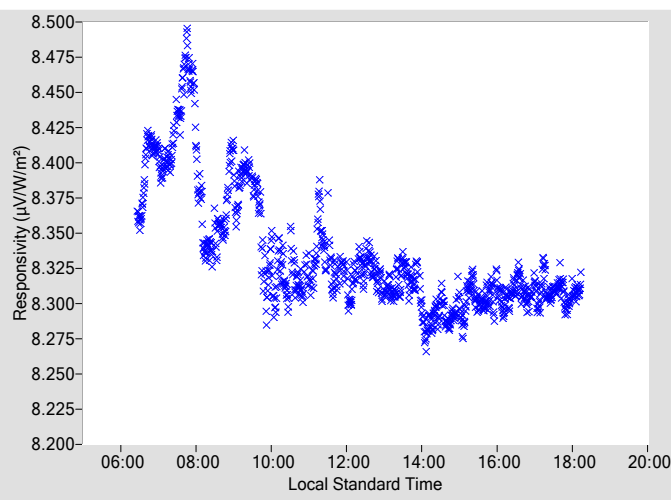


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3618	0.29	92.93	8.3013	0.31	267.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4052	0.32	91.38	8.3064	0.29	268.68
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3522	0.31	89.88	8.3032	0.30	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3520	0.31	88.41	8.3075	0.30	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3358	0.29	86.96	8.3232	0.30	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3358	0.32	85.58	8.3082	0.31	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3801	0.35	84.21	8.3049	0.30	275.91
14	8.3256	0.31	174.14	8.3295	0.30	187.06	60	8.4631	0.34	82.79	8.3041	0.30	277.20
16	8.3287	0.30	148.36	8.3110	0.31	211.88	62	8.4832	0.32	81.48	8.3268	0.30	278.62
18	8.3188	0.29	137.24	8.3259	0.31	222.85	64	8.4319	0.30	80.13	8.3062	N/A	279.94
20	8.3451	0.31	129.70	8.3250	0.31	230.31	66	8.4188	0.30	78.79	8.3089	N/A	281.25
22	8.3297	0.29	123.87	8.3119	0.31	236.19	68	8.4010	0.30	77.48	8.3126	N/A	282.64
24	8.3184	0.30	119.25	8.2991	0.29	240.74	70	8.3938	N/A	76.10	8.3018	N/A	283.93
26	8.3120	0.31	115.38	8.2839	0.30	244.52	72	8.4101	N/A	74.73	8.3076	N/A	285.32
28	8.3267	0.29	112.14	8.2976	0.29	248.05	74	8.4179	N/A	73.38	8.3223	N/A	286.51
30	8.3038	0.31	109.04	8.3062	0.29	250.96	76	8.3602	N/A	71.95	N/A	N/A	N/A
32	8.3274	0.30	106.43	8.2849	0.29	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3015	0.30	104.14	8.2921	0.29	255.99	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3109	0.30	101.88	8.2892	0.29	258.07	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3374	0.29	99.91	8.3116	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3867	0.29	97.99	8.3098	0.29	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3976	0.33	96.23	8.3018	0.31	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3942	0.32	94.55	8.3064	0.33	265.50	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

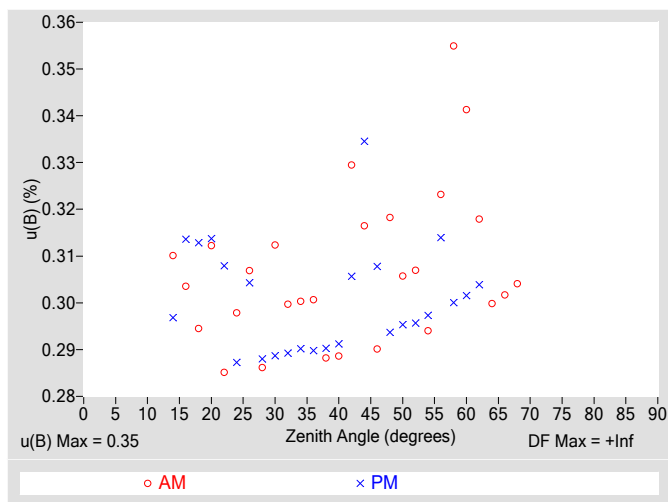


Figure 4. Residuals from Spline Interpolation

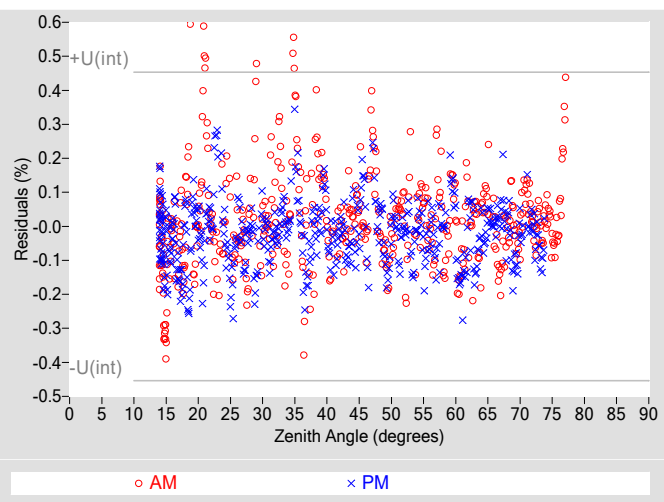


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.35
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.42
Effective degrees of freedom, $DF(c)$	10515
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.83
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

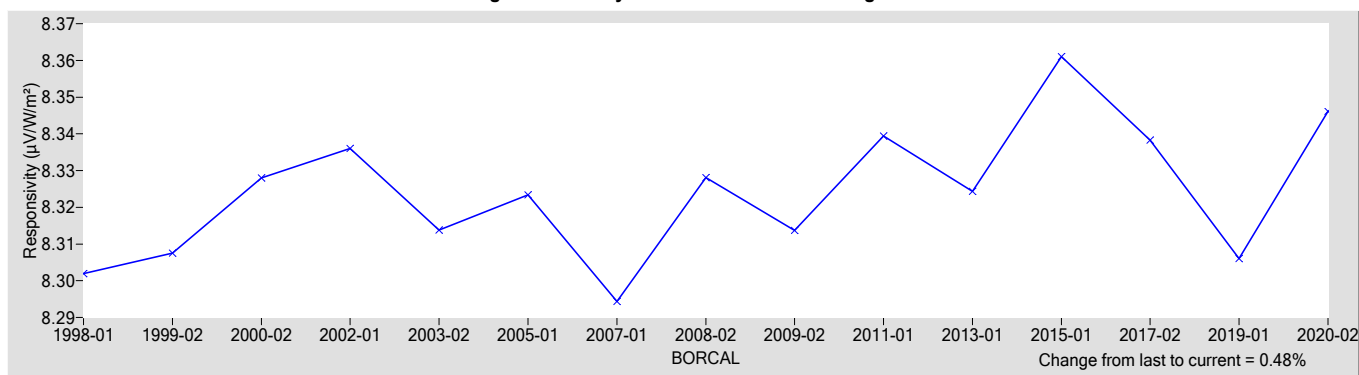
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.3462	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.70
Offset Uncertainty, $U(off)$ (%)	+1.4 / -0.73
Expanded Uncertainty, U (%)	+2.1 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 29850E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29850E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

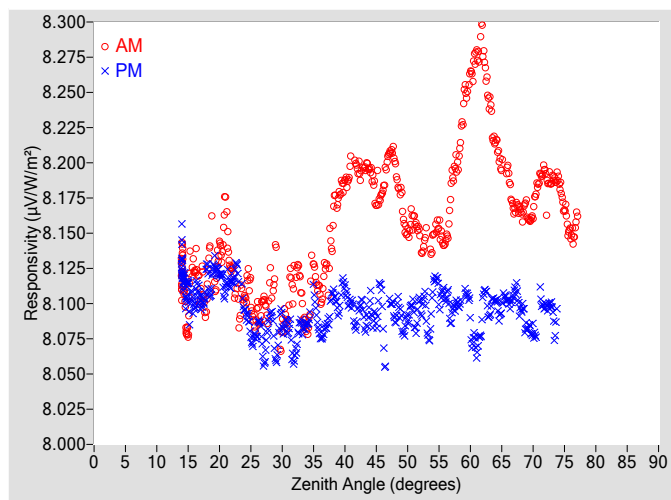


Figure 2. Responsivity vs Local Standard Time

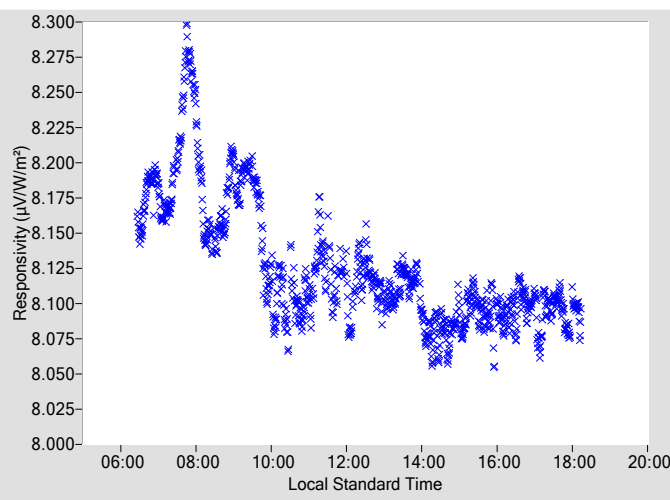


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1794	0.30	92.93	8.0943	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1984	0.31	91.34	8.0892	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1496	0.33	89.84	8.0895	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1480	0.31	88.44	8.0983	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1437	0.32	86.96	8.1075	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1438	0.29	85.58	8.1053	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1999	0.33	84.21	8.0993	0.30	275.91
14	8.1241	0.30	173.58	8.1238	0.30	186.95	60	8.2624	0.34	82.80	8.0878	0.30	277.21
16	8.1269	0.32	147.89	8.1012	0.29	211.91	62	8.2846	0.33	81.47	8.0971	0.30	278.54
18	8.1051	0.30	137.34	8.1228	0.30	223.07	64	8.2159	0.32	80.14	8.1020	N/A	279.95
20	8.1377	0.32	129.72	8.1213	0.30	230.33	66	8.1931	0.32	78.80	8.1018	N/A	281.26
22	8.1244	0.31	123.88	8.1153	0.30	236.21	68	8.1657	0.30	77.49	8.0955	N/A	282.64
24	8.1030	0.33	119.23	8.0954	0.29	240.76	70	8.1657	N/A	76.11	8.0793	N/A	283.94
26	8.0915	0.29	115.39	8.0807	0.33	244.63	72	8.1925	N/A	74.76	8.0975	N/A	285.32
28	8.1140	0.31	112.06	8.0910	0.30	248.06	74	8.1874	N/A	73.34	8.0963	N/A	286.52
30	8.0800	0.31	109.05	8.0869	0.32	250.97	76	8.1508	N/A	71.96	N/A	N/A	N/A
32	8.1187	0.33	106.49	8.0626	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0829	0.29	104.15	8.0861	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1066	0.30	101.89	8.0788	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1490	0.29	99.92	8.1065	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1876	0.31	98.00	8.1107	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1974	0.32	96.23	8.0899	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1953	0.29	94.56	8.0982	0.29	265.51	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

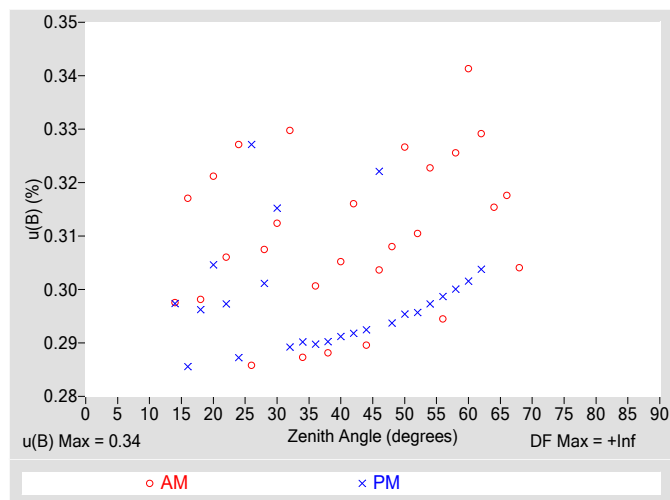


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.27
Combined Standard Uncertainty, $u(c)$ (%)	± 0.43
Effective degrees of freedom, $DF(c)$	6102
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.85
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

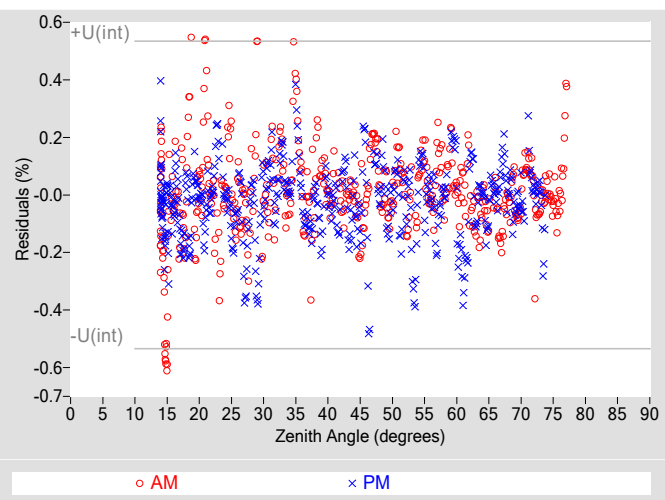


Table 4. Calibration Label Values

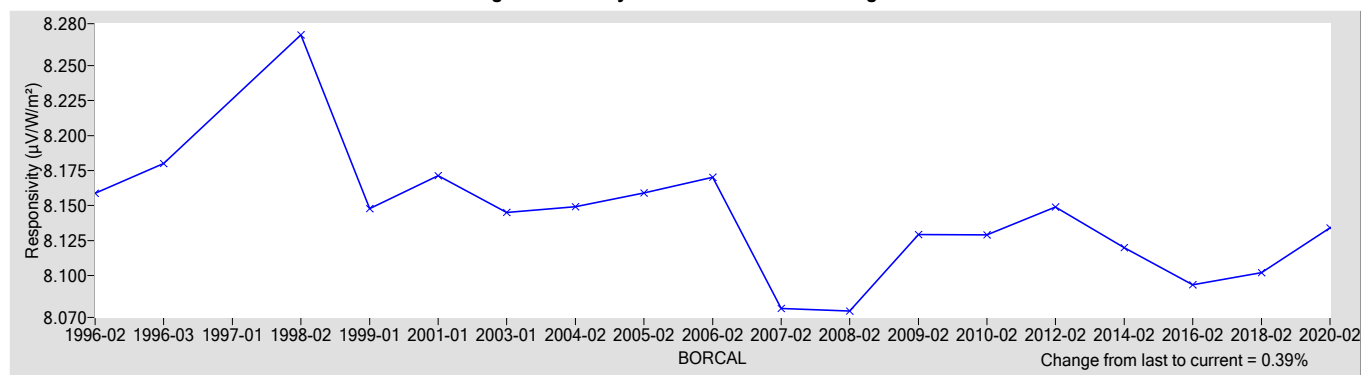
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.1339	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.6 / -0.88
Expanded Uncertainty, U (%)	+2.2 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 29911F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29911F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

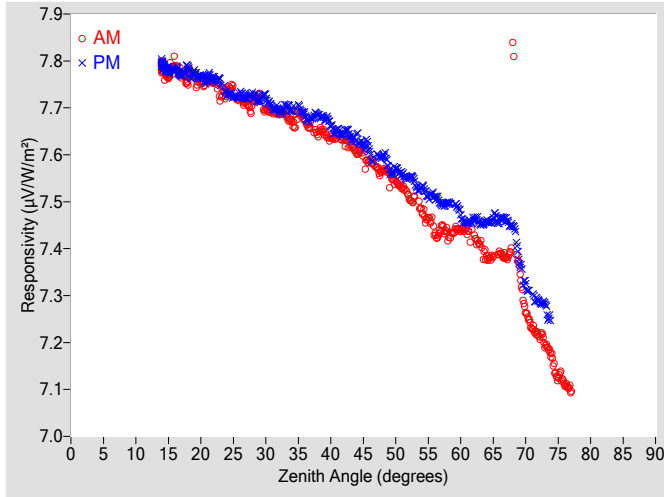


Figure 2. Responsivity vs Local Standard Time

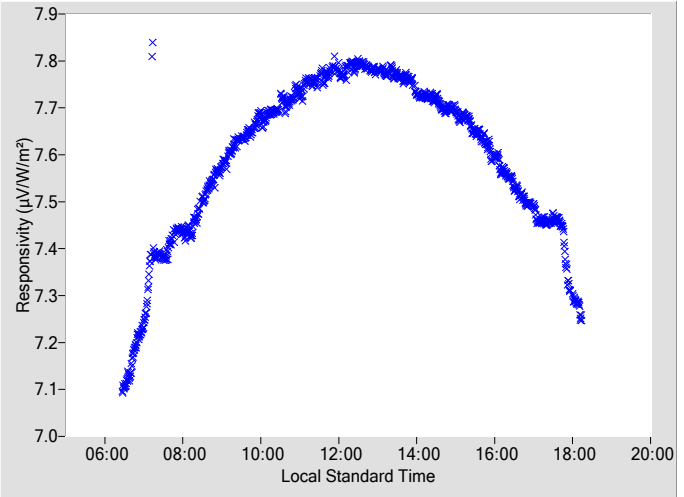


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5859	0.36	92.85	7.6058	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5665	0.34	91.31	7.5965	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5411	0.37	89.81	7.5708	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5088	0.36	88.35	7.5508	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4810	0.39	86.98	7.5309	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4318	0.37	85.52	7.5111	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4303	0.42	84.19	7.4974	0.37	275.84
14	7.7906	0.31	173.63	7.7922	0.31	187.51	60	7.4395	0.39	82.81	7.4726	0.38	277.22
16	7.7878	0.33	148.48	7.7797	0.31	211.47	62	7.4303	0.37	81.45	7.4618	0.39	278.56
18	7.7609	0.33	137.23	7.7835	0.34	222.94	64	7.3827	0.50	80.15	7.4576	N/A	279.96
20	7.7580	0.32	129.62	7.7666	0.30	230.39	66	7.3899	0.40	78.81	7.4613	N/A	281.27
22	7.7565	0.31	123.93	7.7628	0.31	236.13	68	7.6835	0.42	77.45	7.4487	N/A	282.58
24	7.7293	0.32	119.27	7.7304	0.30	240.79	70	7.2694	N/A	76.13	7.3221	N/A	283.95
26	7.7201	0.33	115.33	7.7272	0.30	244.67	72	7.2147	N/A	74.75	7.2888	N/A	285.30
28	7.7111	0.30	112.09	7.7261	0.30	248.01	74	7.1680	N/A	73.36	7.2465	N/A	286.53
30	7.6954	0.32	109.08	7.7215	0.30	250.93	76	7.1121	N/A	71.97	N/A	N/A	N/A
32	7.6903	0.30	106.47	7.6943	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6703	0.30	104.04	7.6936	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6740	0.34	101.91	7.6853	0.34	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6447	0.35	99.89	7.6855	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6354	0.35	97.96	7.6626	0.32	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6305	0.35	96.25	7.6465	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6062	0.34	94.53	7.6362	0.35	265.55	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

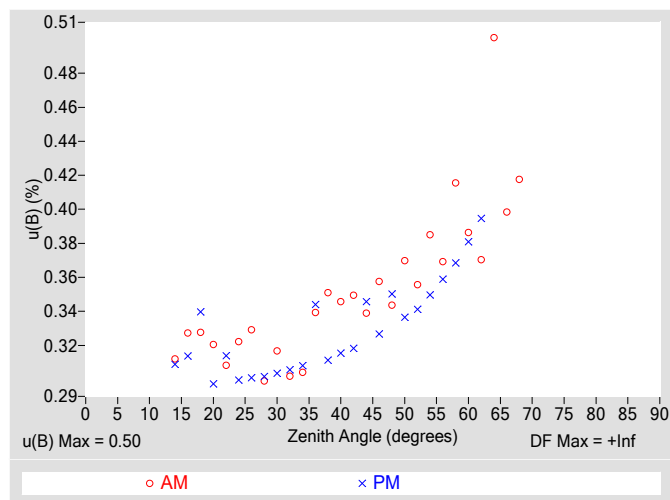


Figure 4. Residuals from Spline Interpolation

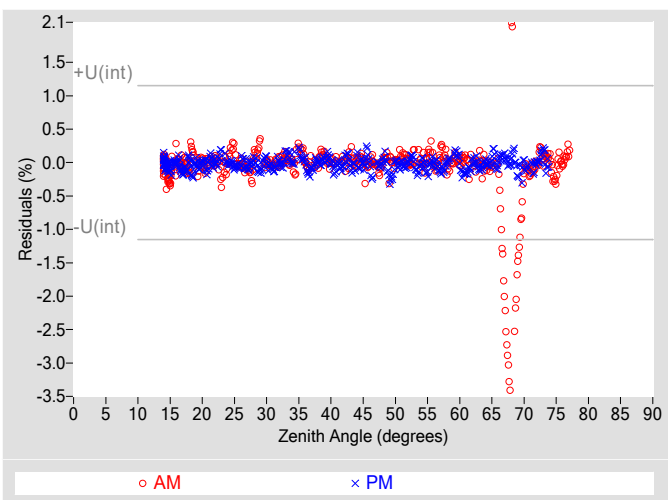


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.58
Combined Standard Uncertainty, $u(c)$ (%)	± 0.76
Effective degrees of freedom, $DF(c)$	2678
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.5
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

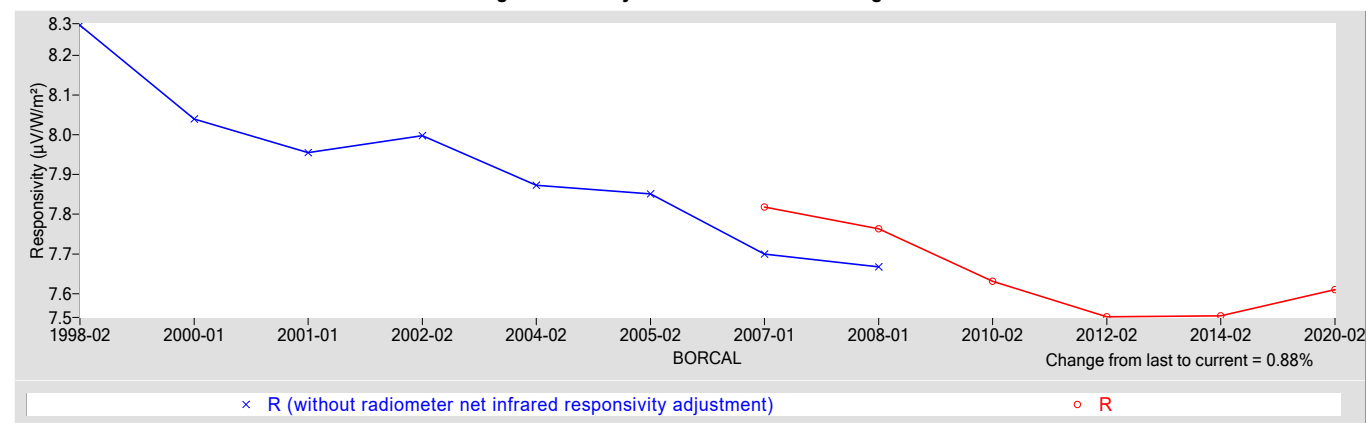
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.6103	0.59755

† R_{net} determination date: 04/24/2007

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.5 / -2.4
Expanded Uncertainty, U (%)	+2.3 / -3.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 29935E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29935E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

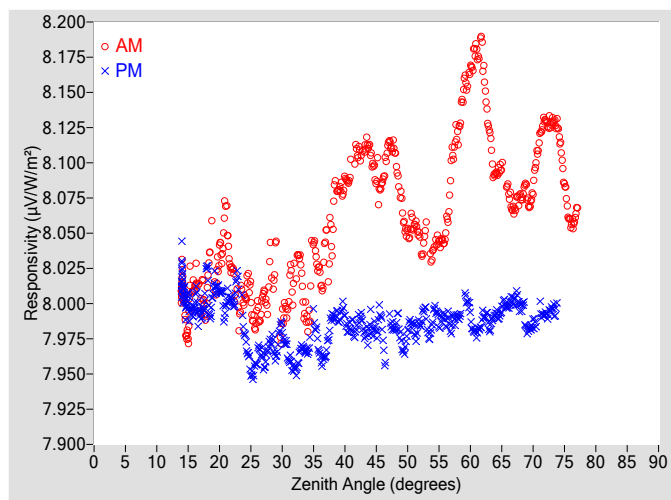


Figure 2. Responsivity vs Local Standard Time

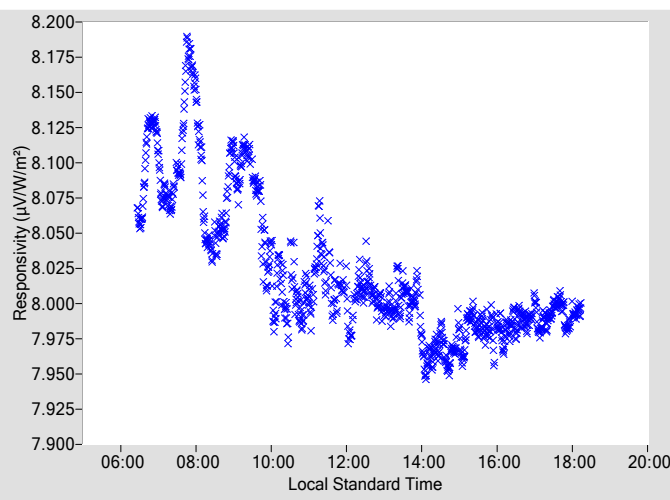


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0863	0.30	92.93	7.9806	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1053	0.31	91.34	7.9828	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0498	0.33	89.84	7.9800	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0454	0.31	88.44	7.9861	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0353	0.32	86.96	7.9891	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0486	0.29	85.58	7.9884	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1210	0.33	84.21	7.9903	0.30	275.91
14	8.0114	0.30	173.58	8.0134	0.30	186.95	60	8.1665	0.34	82.80	7.9922	0.30	277.21
16	8.0151	0.32	147.89	7.9991	0.29	211.91	62	8.1734	0.33	81.47	7.9894	0.30	278.54
18	8.0022	0.30	137.34	8.0197	0.30	223.07	64	8.0922	0.32	80.14	7.9931	N/A	279.95
20	8.0350	0.32	129.72	8.0095	0.30	230.33	66	8.0806	0.32	78.80	7.9982	N/A	281.26
22	8.0240	0.31	123.88	8.0015	0.30	236.21	68	8.0747	0.30	77.49	7.9977	N/A	282.64
24	8.0027	0.33	119.23	7.9782	0.29	240.76	70	8.0824	N/A	76.11	7.9857	N/A	283.94
26	7.9914	0.29	115.39	7.9620	0.33	244.63	72	8.1297	N/A	74.74	7.9919	N/A	285.32
28	8.0283	0.31	112.06	7.9720	0.30	248.06	74	8.1224	N/A	73.34	8.0005	N/A	286.52
30	7.9858	0.31	109.05	7.9805	0.32	250.97	76	8.0581	N/A	71.96	N/A	N/A	N/A
32	8.0201	0.33	106.49	7.9526	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9892	0.29	104.15	7.9665	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0199	0.30	101.89	7.9638	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0512	0.29	99.92	7.9903	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0869	0.31	98.00	7.9899	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1086	0.32	96.23	7.9862	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1095	0.29	94.56	7.9840	0.29	265.51	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

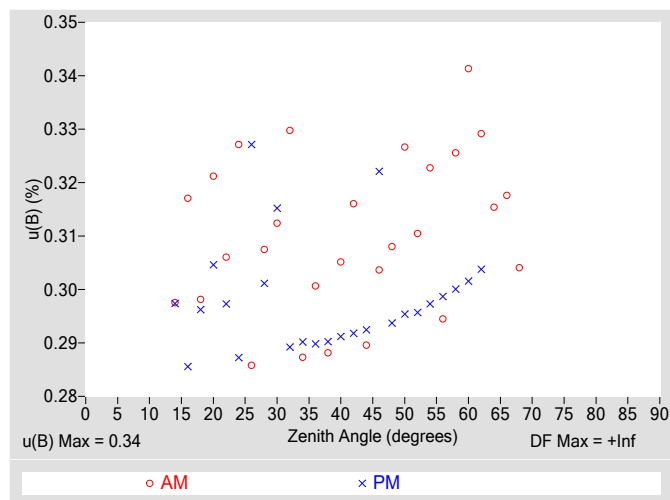


Figure 4. Residuals from Spline Interpolation

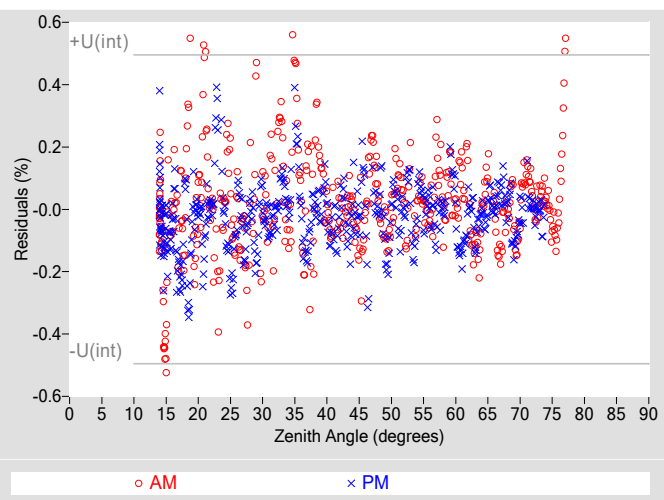


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.25
Combined Standard Uncertainty, $u(c)$ (%)	± 0.42
Effective degrees of freedom, $DF(c)$	7429
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.83
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

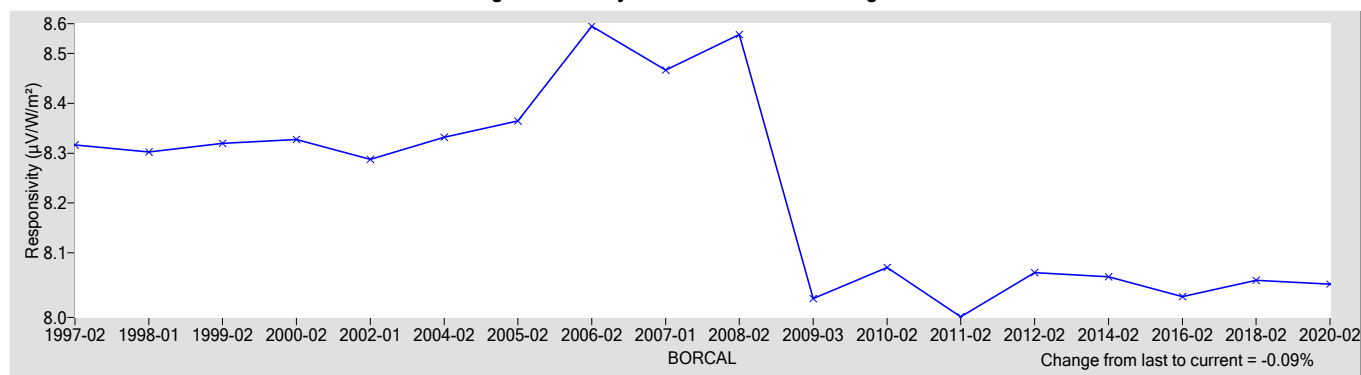
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0370	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.6 / -1.0
Expanded Uncertainty, U (%)	+2.3 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 29936E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29936E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

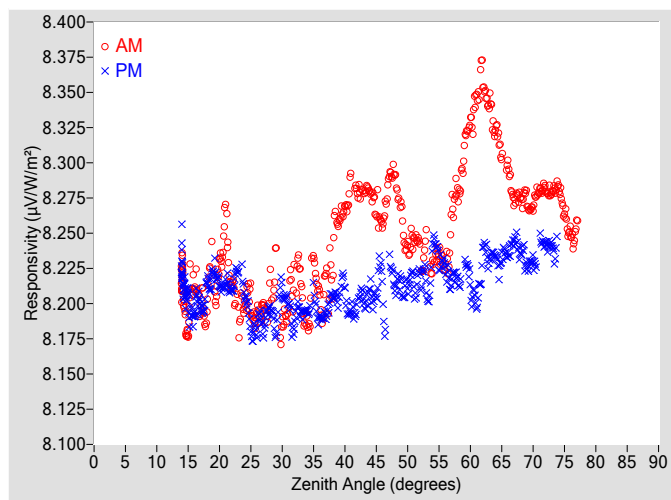


Figure 2. Responsivity vs Local Standard Time

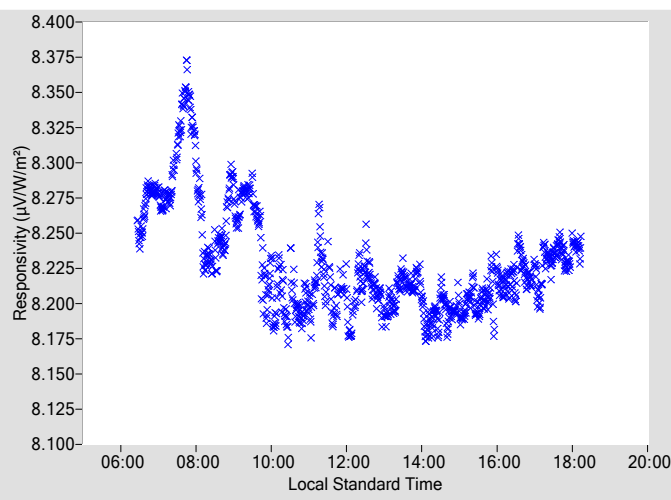


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2577	0.30	92.93	8.2109	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2891	0.31	91.34	8.2108	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2394	0.33	89.84	8.2130	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2392	0.31	88.44	8.2181	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2261	0.32	86.96	8.2400	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2280	0.29	85.58	8.2247	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2803	0.33	84.21	8.2149	0.30	275.91
14	8.2175	0.30	173.58	8.2205	0.30	186.95	60	8.3283	0.34	82.80	8.2114	0.30	277.21
16	8.2143	0.32	147.89	8.1946	0.29	211.91	62	8.3607	0.33	81.47	8.2329	0.30	278.54
18	8.1961	0.30	137.34	8.2157	0.30	223.07	64	8.3234	0.32	80.14	8.2331	N/A	279.95
20	8.2276	0.32	129.72	8.2133	0.30	230.33	66	8.2961	0.32	78.80	8.2354	N/A	281.26
22	8.2138	0.31	123.88	8.2097	0.30	236.21	68	8.2750	0.30	77.49	8.2356	N/A	282.64
24	8.1973	0.33	119.23	8.2069	0.29	240.76	70	8.2699	N/A	76.11	8.2295	N/A	283.94
26	8.1910	0.29	115.39	8.1834	0.33	244.63	72	8.2806	N/A	74.74	8.2411	N/A	285.32
28	8.2130	0.31	112.06	8.1959	0.30	248.06	74	8.2823	N/A	73.34	8.2478	N/A	286.52
30	8.1827	0.31	109.05	8.2094	0.32	250.97	76	8.2498	N/A	71.96	N/A	N/A	N/A
32	8.2150	0.33	106.49	8.1865	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1866	0.29	104.15	8.1942	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2032	0.30	101.89	8.1890	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2229	0.29	99.92	8.2046	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2684	0.31	98.00	8.2086	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2807	0.32	96.23	8.1998	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2797	0.29	94.56	8.2093	0.29	265.51	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

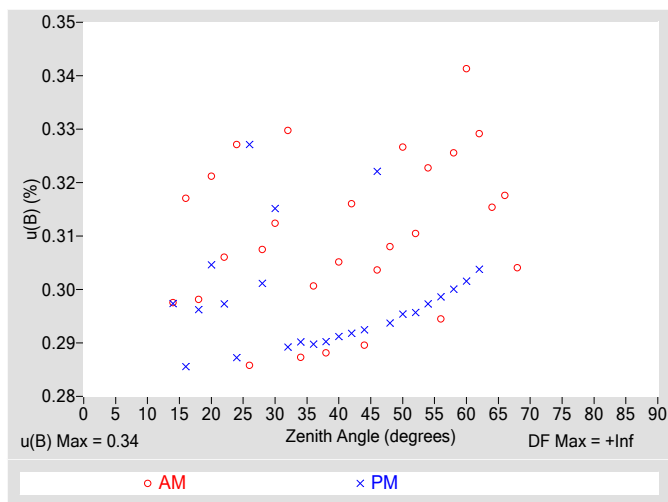


Figure 4. Residuals from Spline Interpolation

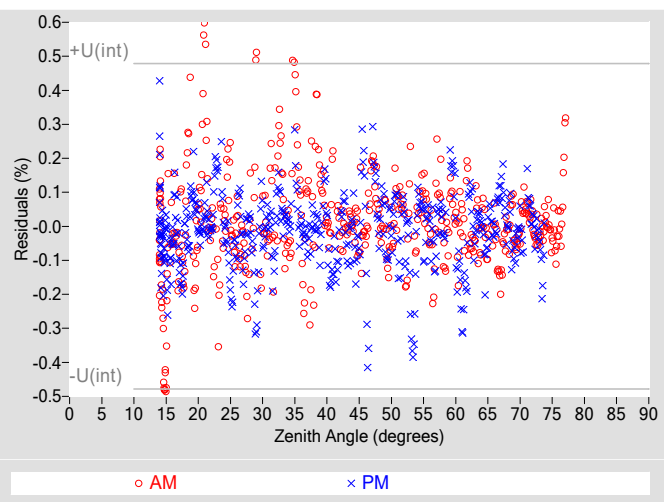


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.24
Combined Standard Uncertainty, $u(c)$ (%)	± 0.42
Effective degrees of freedom, $DF(c)$	8130
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 0.82
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

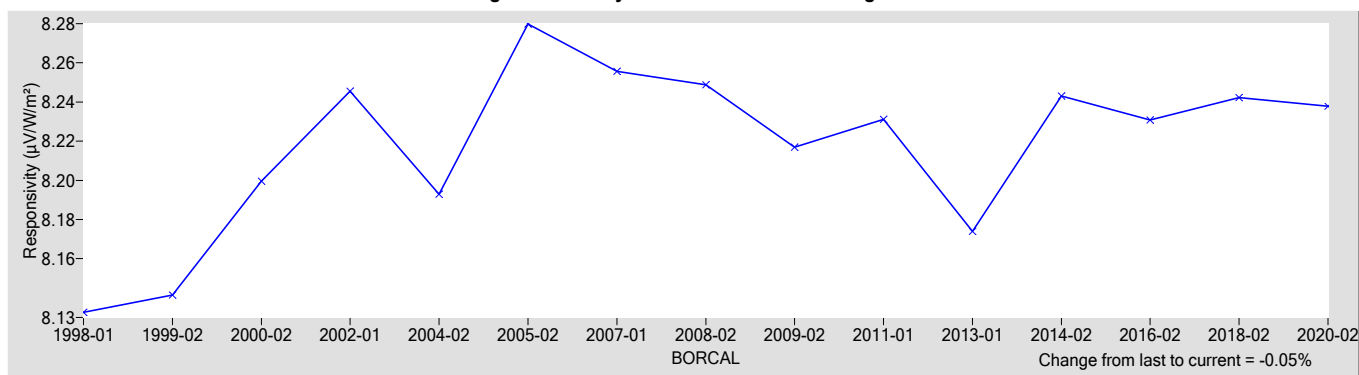
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.2379	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.1 / -0.67
Expanded Uncertainty, U (%)	+1.8 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 29938E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29938E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

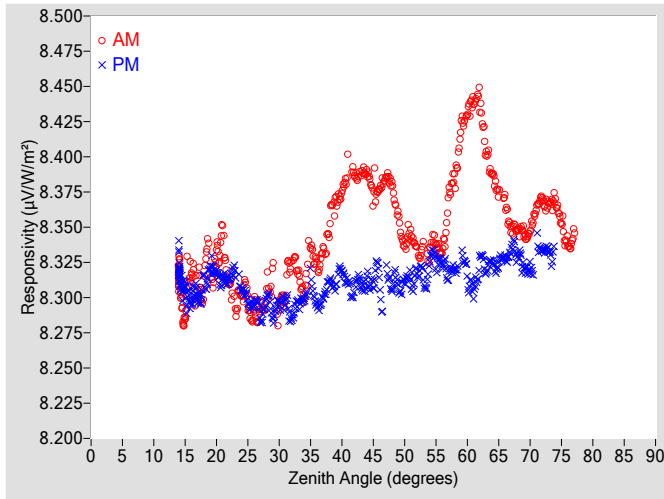


Figure 2. Responsivity vs Local Standard Time

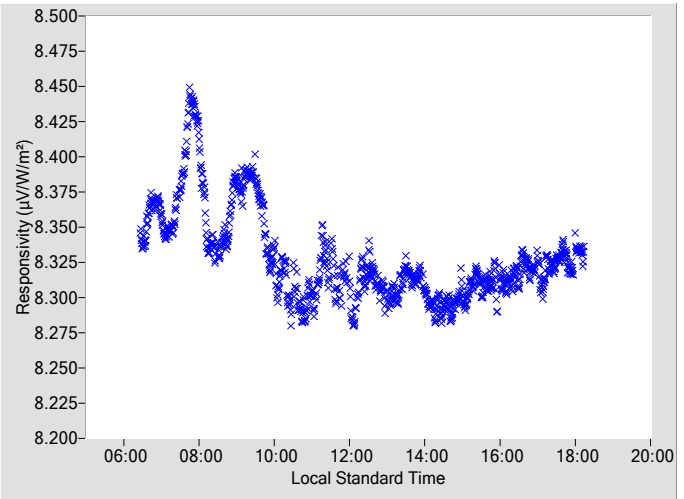


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3770	0.30	92.93	8.3127	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3788	0.31	91.34	8.3064	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3373	0.33	89.84	8.3119	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3346	0.31	88.44	8.3176	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3323	0.32	86.96	8.3248	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3344	0.29	85.58	8.3238	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3858	0.33	84.21	8.3194	0.30	275.91
14	8.3162	0.30	173.58	8.3174	0.30	186.95	60	8.4322	0.34	82.80	8.3143	0.30	277.21
16	8.3183	0.32	147.89	8.2985	0.29	211.91	62	8.4386	0.33	81.47	8.3241	0.30	278.54
18	8.3076	0.30	137.34	8.3135	0.30	222.87	64	8.3876	0.32	80.14	8.3248	N/A	279.95
20	8.3312	0.32	129.72	8.3172	0.30	230.33	66	8.3682	0.32	78.80	8.3284	N/A	281.26
22	8.3107	0.31	123.88	8.3127	0.30	236.21	68	8.3480	0.30	77.49	8.3294	N/A	282.64
24	8.3012	0.33	119.23	8.3062	0.29	240.76	70	8.3481	N/A	76.11	8.3204	N/A	283.94
26	8.2908	0.29	115.39	8.2955	0.33	244.63	72	8.3691	N/A	74.74	8.3334	N/A	285.32
28	8.3070	0.31	112.06	8.3006	0.30	248.06	74	8.3679	N/A	73.34	8.3364	N/A	286.52
30	8.2920	0.31	109.05	8.2956	0.32	250.97	76	8.3385	N/A	71.96	N/A	N/A	N/A
32	8.3241	0.33	106.49	8.2852	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3030	0.29	104.15	8.2995	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3237	0.30	101.89	8.2950	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3502	0.29	99.92	8.3115	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3752	0.31	98.00	8.3184	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3885	0.32	96.23	8.3058	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3883	0.29	94.56	8.3121	0.29	265.51	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

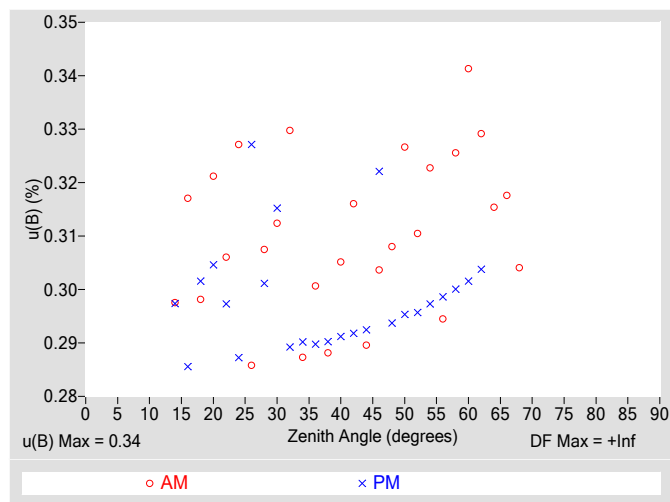


Figure 4. Residuals from Spline Interpolation

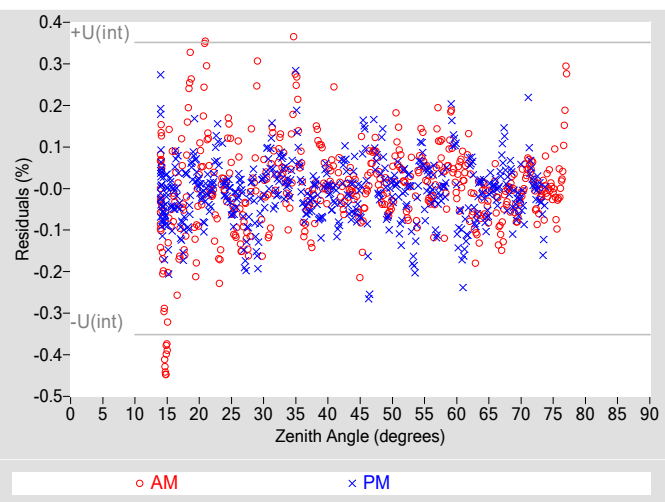


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.38
Effective degrees of freedom, $DF(c)$	20032
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.75
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

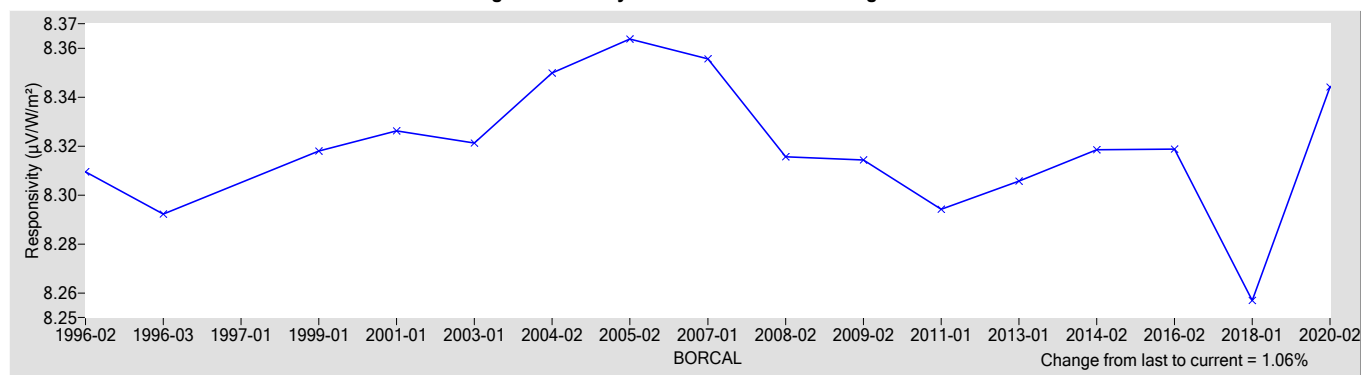
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.3441	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.1 / -0.71
Expanded Uncertainty, U (%)	+1.7 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 30569E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: TWP
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30569E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

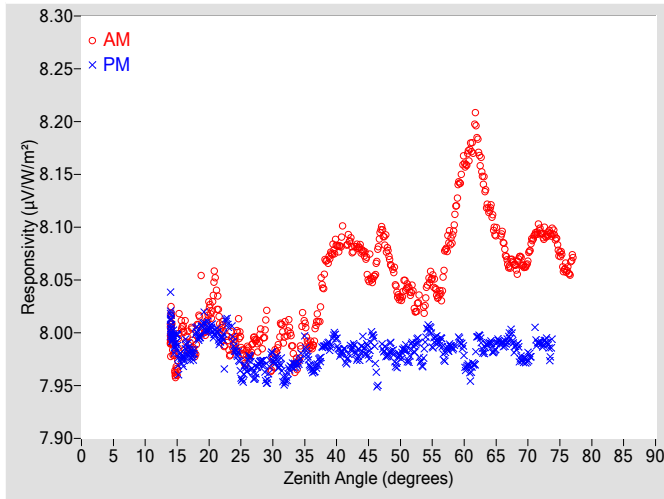


Figure 2. Responsivity vs Local Standard Time

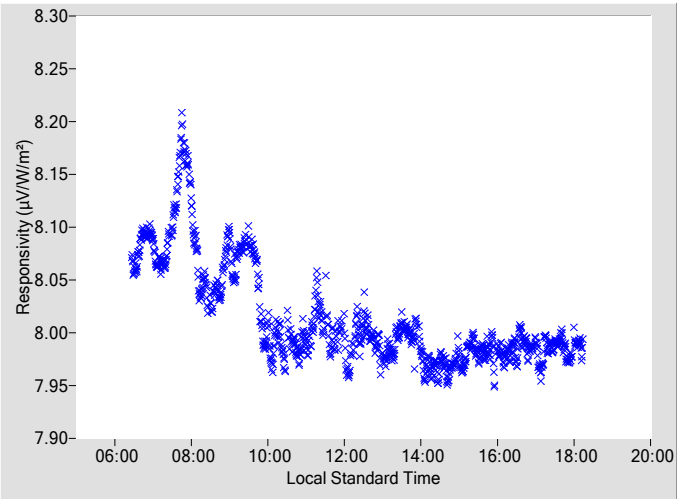


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0559	0.30	92.93	7.9828	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0768	0.31	91.34	7.9790	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0323	0.33	89.84	7.9789	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0365	0.31	88.44	7.9864	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0330	0.32	86.96	7.9960	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0356	0.29	85.58	7.9920	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0895	0.33	84.21	7.9862	0.30	275.91
14	8.0011	0.30	173.58	8.0037	0.30	186.95	60	8.1607	0.34	82.80	7.9765	0.30	277.21
16	8.0015	0.32	147.89	7.9776	0.29	211.91	62	8.1887	0.33	81.47	7.9881	0.30	278.54
18	7.9903	0.30	137.34	8.0008	0.30	223.07	64	8.1174	0.32	80.14	7.9906	N/A	279.95
20	8.0209	0.32	129.72	8.0047	0.30	230.33	66	8.0902	0.32	78.80	7.9899	N/A	281.26
22	8.0047	0.31	123.88	7.9951	0.30	236.21	68	8.0637	0.30	77.49	7.9857	N/A	282.64
24	7.9896	0.33	119.23	7.9857	0.29	240.76	70	8.0701	N/A	76.11	7.9767	N/A	283.94
26	7.9801	0.29	115.39	7.9692	0.33	244.63	72	8.0955	N/A	74.74	7.9899	N/A	285.32
28	7.9978	0.31	112.06	7.9718	0.30	248.06	74	8.0940	N/A	73.34	7.9941	N/A	286.52
30	7.9723	0.31	109.05	7.9764	0.32	250.97	76	8.0610	N/A	71.96	N/A	N/A	N/A
32	8.0012	0.33	106.49	7.9542	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9726	0.29	104.15	7.9724	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9879	0.30	101.89	7.9663	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0510	0.29	99.92	7.9871	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0839	0.31	98.00	7.9919	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0880	0.32	96.23	7.9819	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0784	0.29	94.56	7.9868	0.29	265.51	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

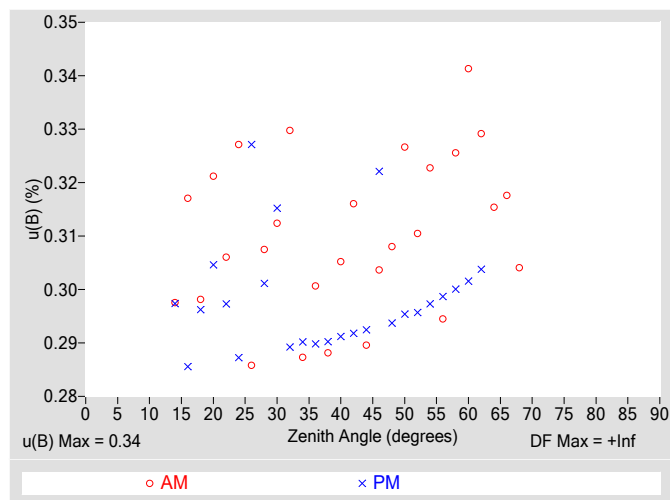


Figure 4. Residuals from Spline Interpolation

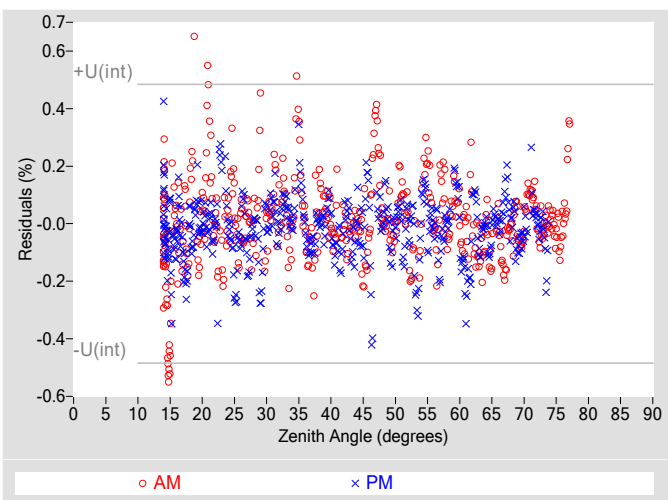


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.24
Combined Standard Uncertainty, $u(c)$ (%)	± 0.42
Effective degrees of freedom, $DF(c)$	7869
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.82
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

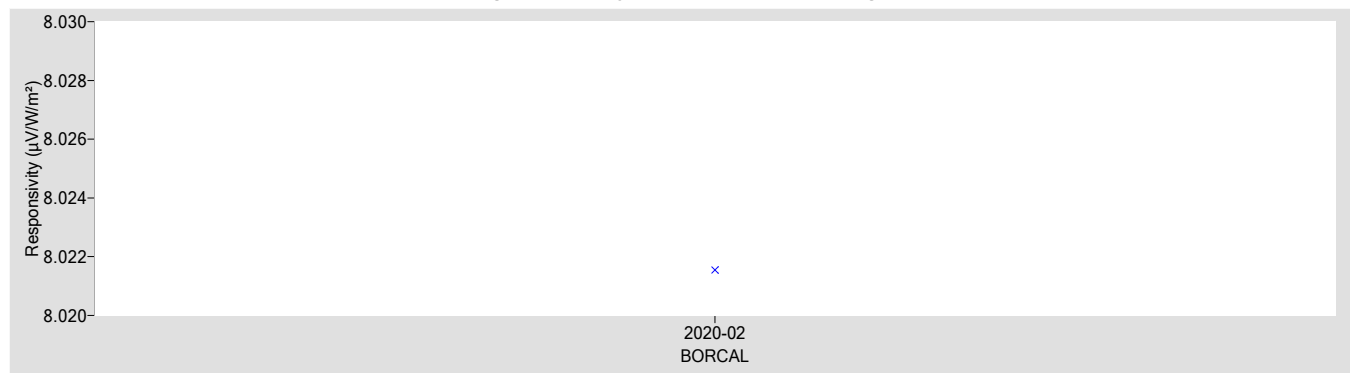
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0215	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.7 / -0.84
Expanded Uncertainty, U (%)	+2.4 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 30584E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30584E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

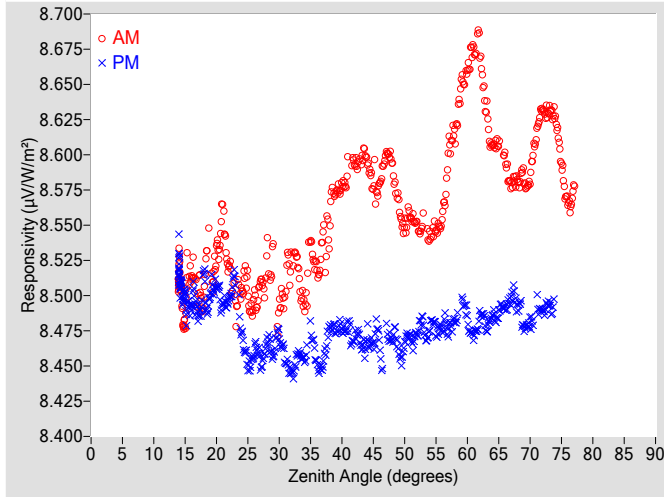


Figure 2. Responsivity vs Local Standard Time

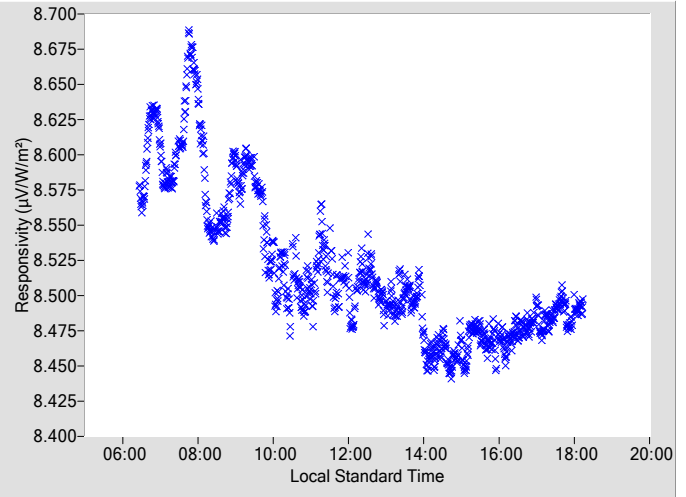


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5779	0.30	92.93	8.4671	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5925	0.31	91.34	8.4692	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5480	0.33	89.84	8.4657	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5506	0.31	88.44	8.4730	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5411	0.32	86.96	8.4769	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5554	0.29	85.58	8.4765	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6164	0.33	84.21	8.4817	0.30	275.91
14	8.5140	0.30	173.58	8.5159	0.30	186.76	60	8.6607	0.34	82.80	8.4839	0.30	277.21
16	8.5162	0.32	147.89	8.4948	0.29	211.91	62	8.6750	0.33	81.47	8.4838	0.30	278.54
18	8.5000	0.30	137.34	8.5120	0.30	223.07	64	8.6072	0.32	80.14	8.4867	N/A	279.95
20	8.5303	0.32	129.72	8.5066	0.30	230.33	66	8.5970	0.32	78.80	8.4916	N/A	281.26
22	8.5207	0.31	123.88	8.4982	0.30	236.21	68	8.5810	0.30	77.49	8.4919	N/A	282.64
24	8.5021	0.33	119.23	8.4731	0.29	240.76	70	8.5842	N/A	76.11	8.4809	N/A	283.94
26	8.4943	0.29	115.39	8.4603	0.33	244.63	72	8.6317	N/A	74.74	8.4889	N/A	285.32
28	8.5273	0.31	112.06	8.4659	0.30	248.06	74	8.6253	N/A	73.34	8.4975	N/A	286.52
30	8.4878	0.31	109.05	8.4704	0.32	250.97	76	8.5676	N/A	71.96	N/A	N/A	N/A
32	8.5229	0.33	106.49	8.4446	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4951	0.29	104.15	8.4553	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5188	0.30	101.89	8.4520	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5487	0.29	99.92	8.4759	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5785	0.31	98.00	8.4764	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5955	0.32	96.23	8.4699	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5966	0.29	94.56	8.4682	0.29	265.51	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

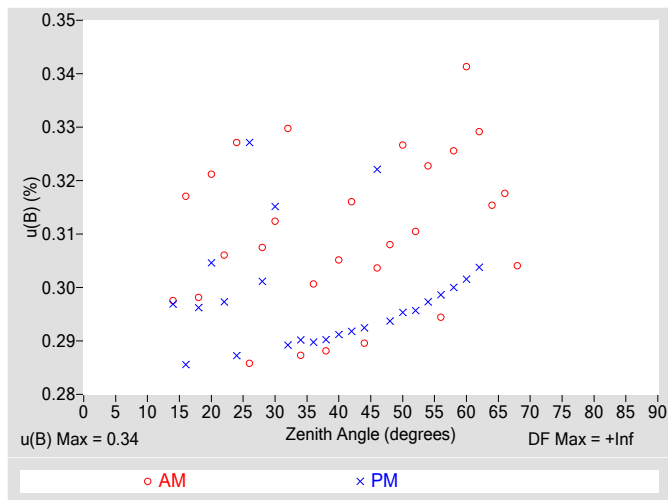


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.40
Effective degrees of freedom, $DF(c)$	11282
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.79
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

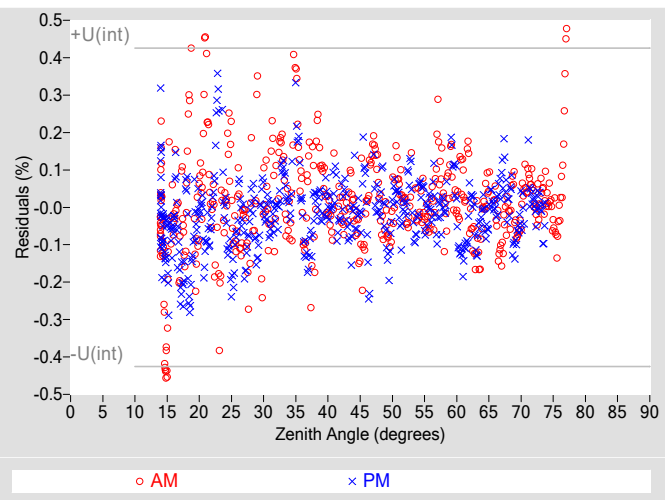


Table 4. Calibration Label Values

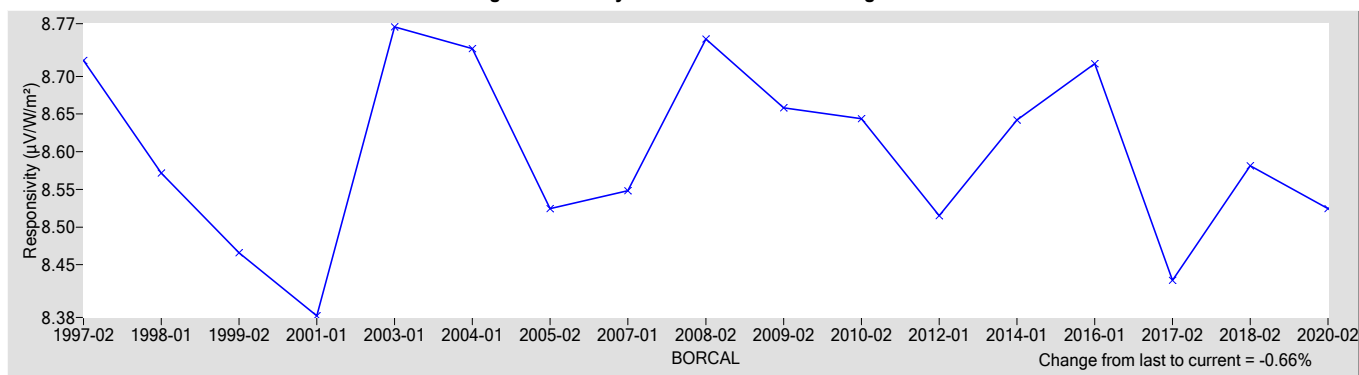
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5244	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.6 / -0.94
Expanded Uncertainty, U (%)	+2.3 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30621F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30621F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

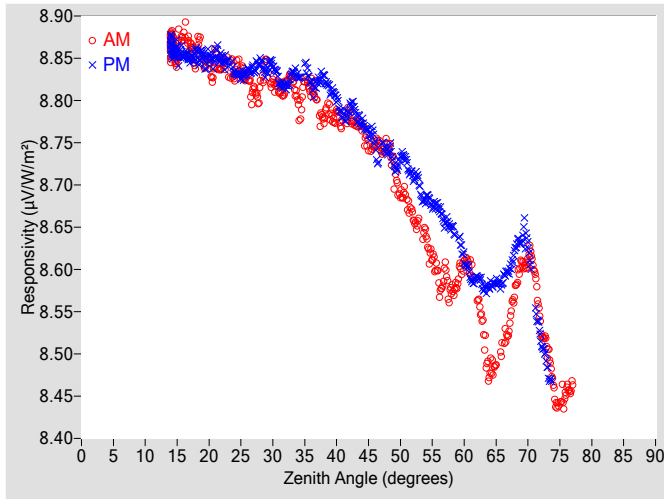


Figure 2. Responsivity vs Local Standard Time

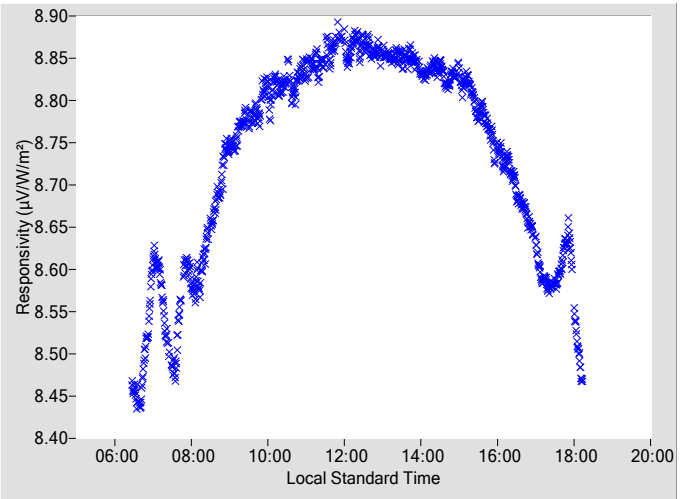


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7485	0.34	92.88	8.7464	0.33	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7463	0.32	91.34	8.7401	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6886	0.38	89.79	8.7331	0.34	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6619	0.36	88.37	8.7094	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6397	0.36	86.92	8.6844	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5847	0.39	85.54	8.6731	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5763	0.38	84.17	8.6500	0.37	275.87
14	8.8689	0.32	173.30	8.8650	0.32	187.03	60	8.6061	0.37	82.84	8.6111	0.38	277.25
16	8.8746	0.31	148.42	8.8525	0.30	211.78	62	8.5635	0.45	81.38	8.5905	0.40	278.58
18	8.8510	0.31	137.34	8.8576	0.31	222.74	64	8.4778	0.42	80.10	8.5806	N/A	279.90
20	8.8460	0.32	129.71	8.8525	0.30	230.33	66	8.5063	0.41	78.84	8.5875	N/A	281.30
22	8.8425	0.31	124.01	8.8496	0.31	236.08	68	8.5745	0.46	77.45	8.6242	N/A	282.60
24	8.8294	0.31	119.34	8.8337	0.33	240.75	70	8.6138	N/A	76.07	8.6249	N/A	283.98
26	8.8293	0.31	115.39	8.8355	0.30	244.63	72	8.5361	N/A	74.77	8.5166	N/A	285.32
28	8.8081	0.32	112.24	8.8449	0.32	247.97	74	8.4627	N/A	73.38	N/A	N/A	N/A
30	8.8221	0.33	109.13	8.8414	0.32	250.89	76	8.4554	N/A	72.00	N/A	N/A	N/A
32	8.8159	0.33	106.51	8.8181	0.31	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7955	0.32	104.08	8.8282	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8131	0.32	101.95	8.8190	0.33	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7797	0.33	99.86	8.8272	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7842	0.31	97.99	8.8026	0.32	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7852	0.35	96.18	8.7893	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7693	0.33	94.51	8.7726	0.34	265.56	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

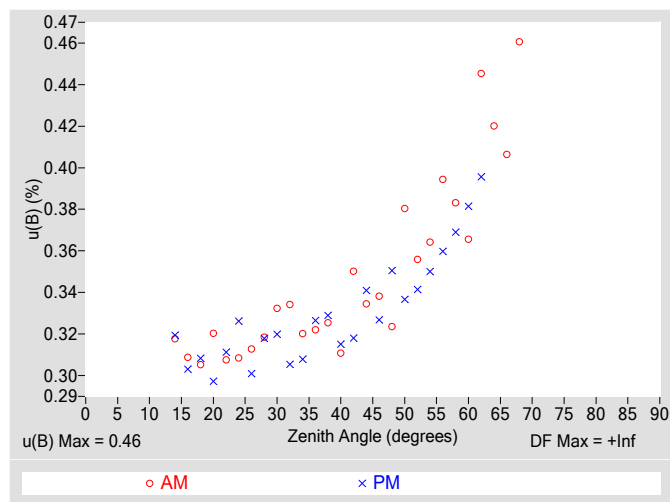


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.50
Effective degrees of freedom, $DF(c)$	47462
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.97
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

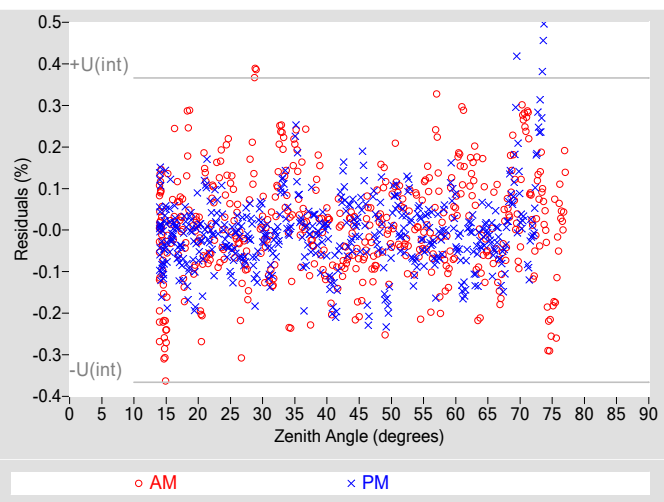


Table 4. Calibration Label Values

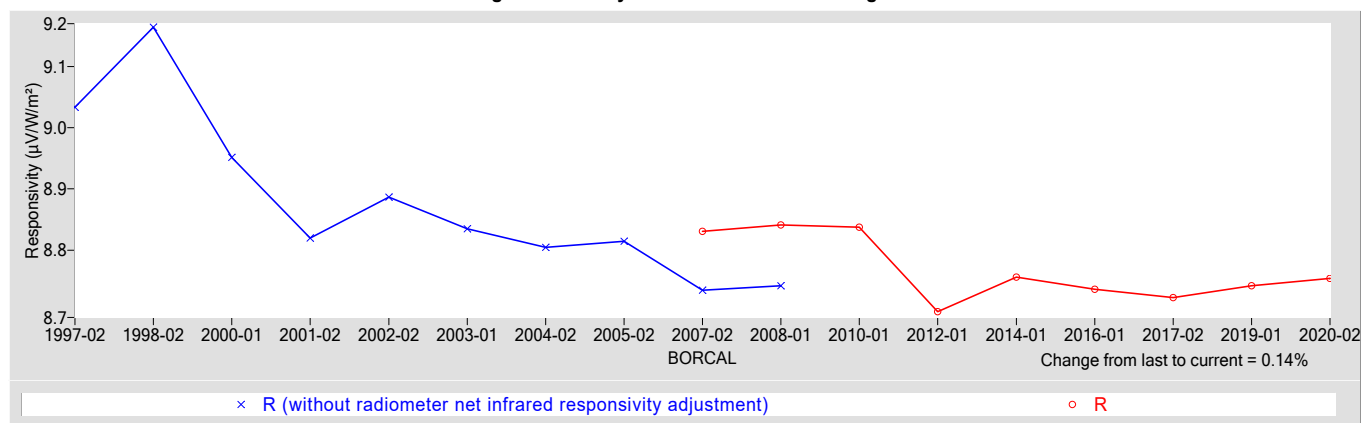
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.7540	0.66027

† R_{net} determination date: 07/18/2007

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+1.00 / -2.0
Expanded Uncertainty, U (%)	+1.8 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30654F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30654F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

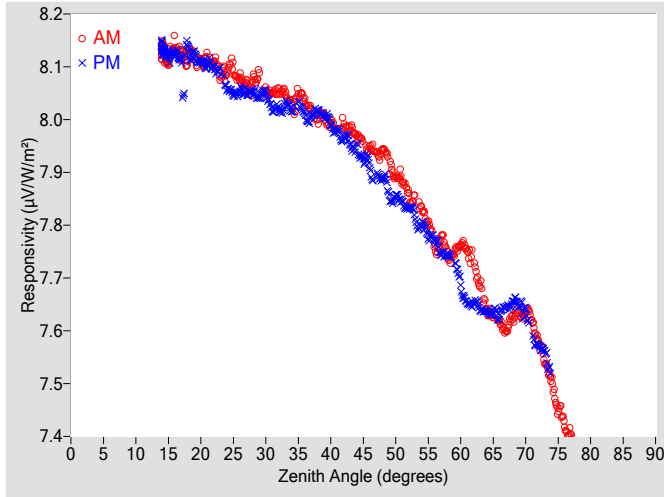


Figure 2. Responsivity vs Local Standard Time

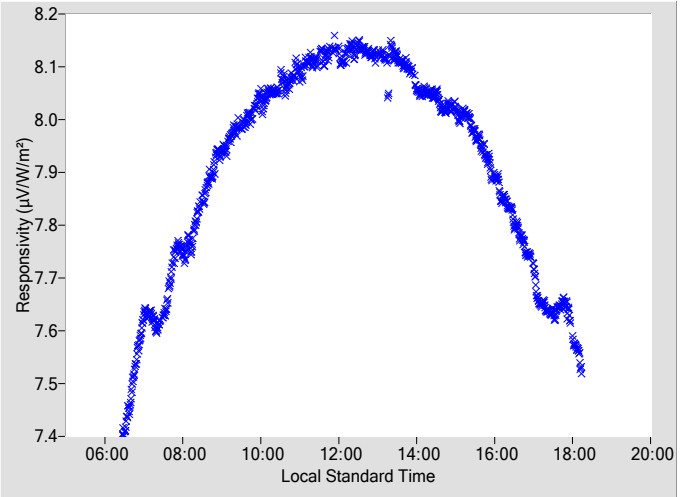


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9450	0.36	92.85	7.9088	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9435	0.35	91.31	7.8878	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8905	0.37	89.81	7.8558	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8551	0.36	88.35	7.8321	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8308	0.39	86.98	7.8020	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7584	0.37	85.52	7.7723	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7434	0.42	84.19	7.7443	0.37	275.84
14	8.1341	0.31	173.63	8.1343	0.31	187.51	60	7.7621	0.39	82.81	7.6864	0.38	277.22
16	8.1367	0.33	148.48	8.1221	0.31	211.47	62	7.7341	0.37	81.45	7.6519	0.40	278.56
18	8.1137	0.33	137.23	8.1363	0.34	222.94	64	7.6413	0.50	80.15	7.6368	N/A	279.96
20	8.1122	0.32	129.62	8.1094	0.30	230.39	66	7.6164	0.40	78.81	7.6298	N/A	281.27
22	8.1099	0.31	123.93	8.0984	0.31	236.13	68	7.6237	0.42	77.42	7.6532	N/A	282.58
24	8.0866	0.32	119.27	8.0603	0.30	240.79	70	7.6339	N/A	76.13	7.6351	N/A	283.95
26	8.0793	0.33	115.33	8.0555	0.30	244.67	72	7.5784	N/A	74.75	7.5727	N/A	285.30
28	8.0686	0.30	112.09	8.0512	0.30	248.01	74	7.5024	N/A	73.36	7.5190	N/A	286.53
30	8.0540	0.32	109.08	8.0480	0.30	250.93	76	7.4210	N/A	71.97	N/A	N/A	N/A
32	8.0527	0.30	106.47	8.0185	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0308	0.31	104.04	8.0170	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0343	0.34	101.91	8.0093	0.35	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9997	0.35	99.89	8.0172	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9930	0.35	97.96	7.9896	0.32	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9868	0.35	96.25	7.9644	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9678	0.34	94.53	7.9450	0.35	265.55	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

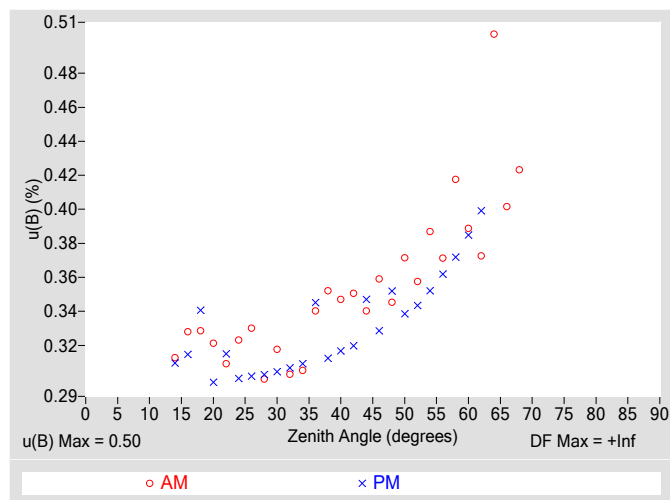


Figure 4. Residuals from Spline Interpolation

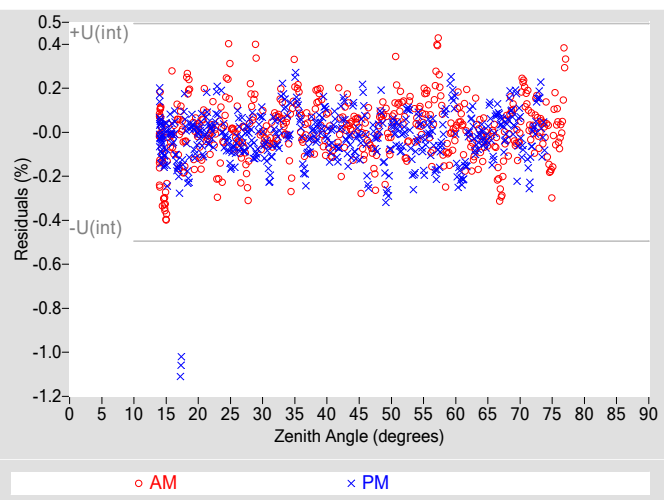


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.25
Combined Standard Uncertainty, $u(c)$ (%)	± 0.56
Effective degrees of freedom, $DF(c)$	23084
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

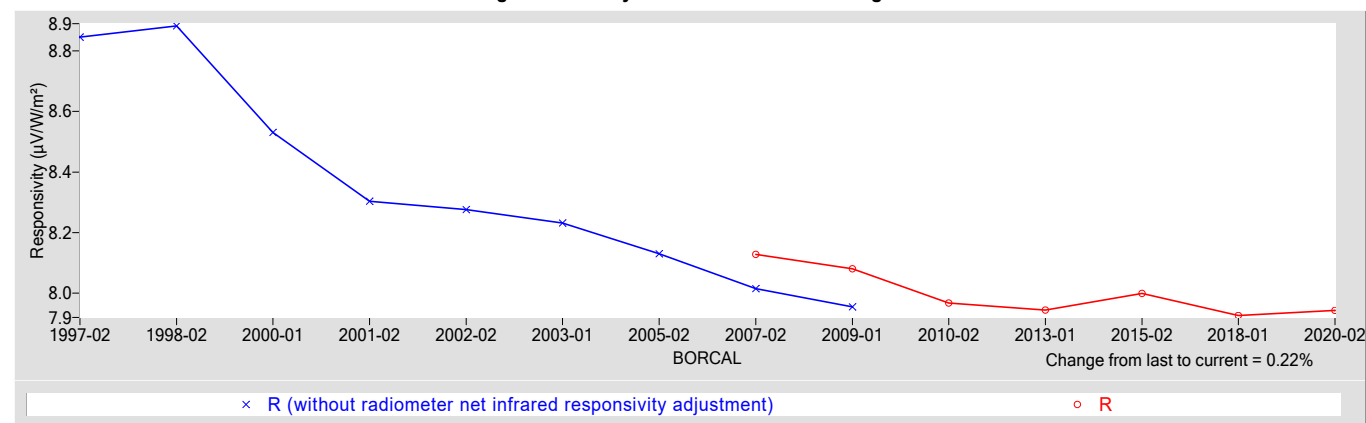
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.9429	0.67104

† R_{net} determination date: 07/18/2007

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	+1.4 / -3.2
Expanded Uncertainty, U (%)	+2.2 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30662F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30662F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

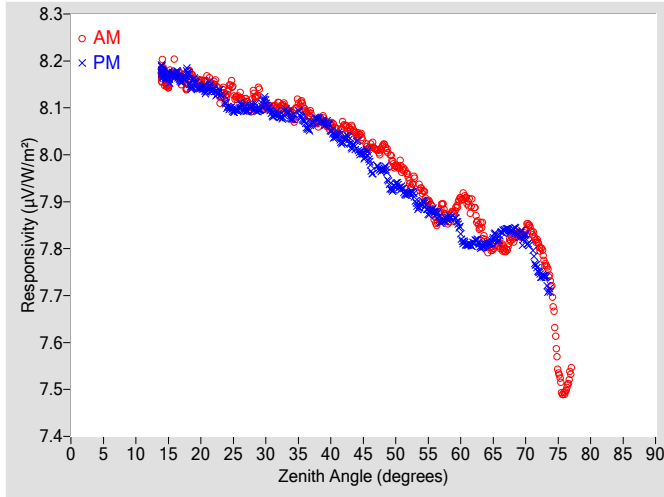


Figure 2. Responsivity vs Local Standard Time

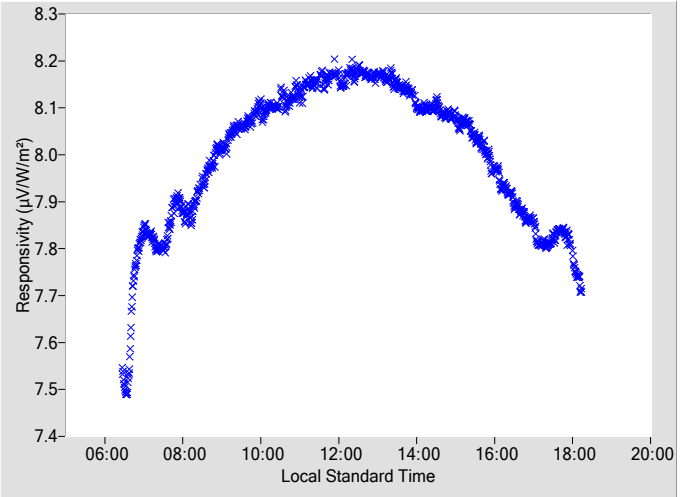


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0167	0.36	92.85	7.9833	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0196	0.34	91.31	7.9680	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9750	0.37	89.81	7.9374	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9450	0.36	88.35	7.9174	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9248	0.39	86.98	7.8972	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8627	0.37	85.52	7.8782	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8623	0.42	84.19	7.8656	0.37	275.84
14	8.1762	0.31	173.63	8.1759	0.31	187.51	60	7.9058	0.39	82.81	7.8317	0.38	277.22
16	8.1760	0.33	148.48	8.1695	0.31	211.47	62	7.8937	0.37	81.45	7.8121	0.40	278.56
18	8.1541	0.33	137.23	8.1713	0.34	222.94	64	7.8072	0.50	80.15	7.8104	N/A	279.96
20	8.1554	0.32	129.62	8.1435	0.30	230.39	66	7.8062	0.40	78.81	7.8269	N/A	281.27
22	8.1522	0.31	123.93	8.1384	0.31	236.13	68	7.8215	0.42	77.42	7.8398	N/A	282.58
24	8.1274	0.32	119.27	8.1044	0.30	240.79	70	7.8392	N/A	76.13	7.8241	N/A	283.95
26	8.1228	0.33	115.33	8.1022	0.30	244.67	72	7.8085	N/A	74.75	7.7514	N/A	285.30
28	8.1171	0.30	112.09	8.1005	0.30	248.01	74	7.7090	N/A	73.36	7.7073	N/A	286.53
30	8.1012	0.32	109.08	8.1117	0.30	250.93	76	7.4931	N/A	71.97	N/A	N/A	N/A
32	8.1037	0.30	106.47	8.0837	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0858	0.30	104.04	8.0780	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0953	0.34	101.91	8.0682	0.34	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0678	0.35	99.89	8.0772	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0625	0.35	97.96	8.0519	0.32	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0592	0.35	96.25	8.0316	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0440	0.34	94.53	8.0198	0.35	265.55	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

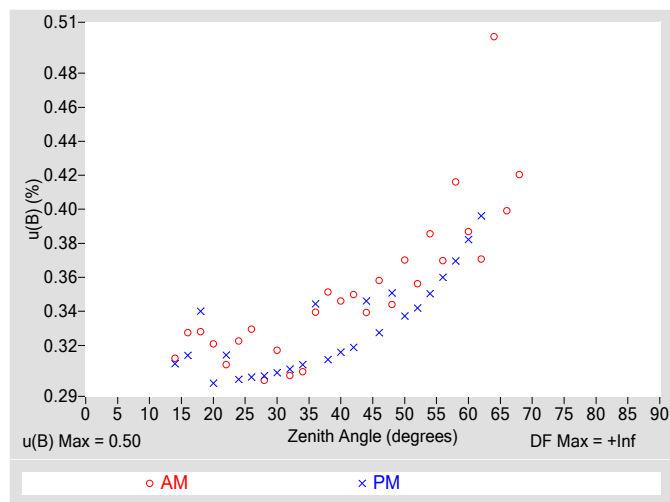


Figure 4. Residuals from Spline Interpolation

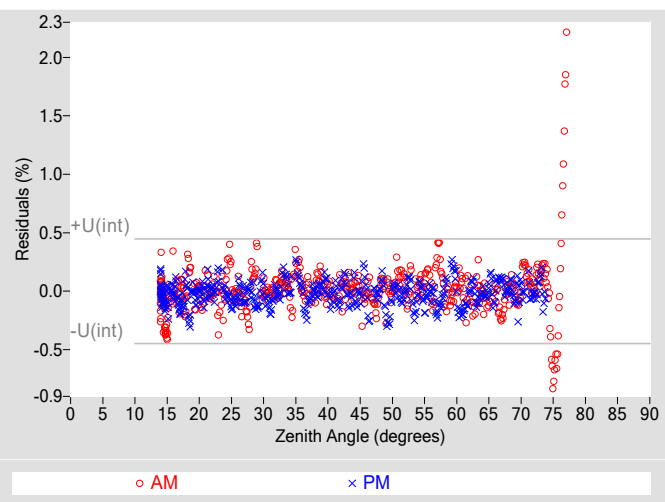


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.22
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	31722
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

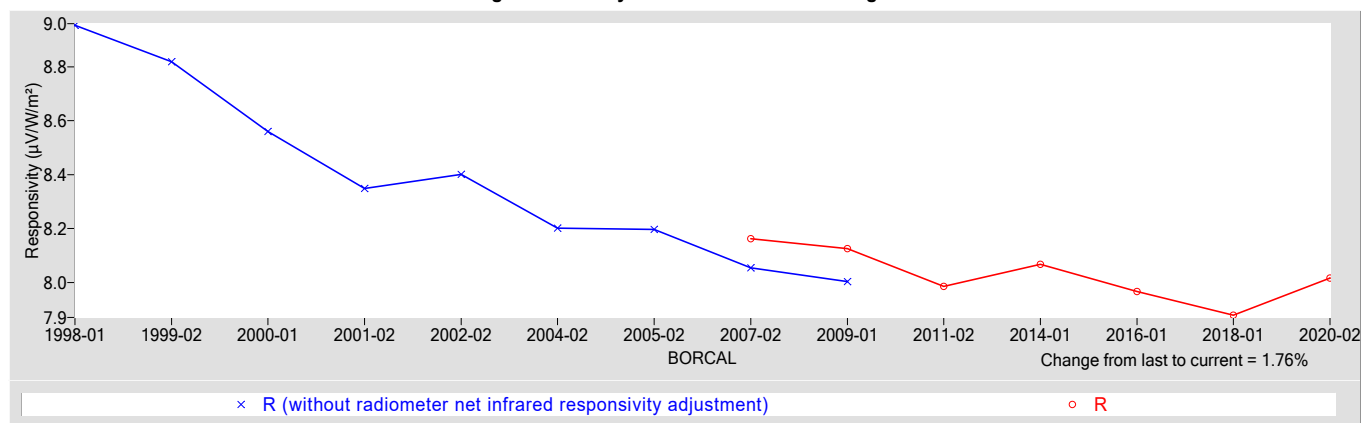
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0166	0.64629

† R_{net} determination date: 05/10/2007

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	+1.2 / -2.3
Expanded Uncertainty, U (%)	+2.0 / -3.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 30671F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30671F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

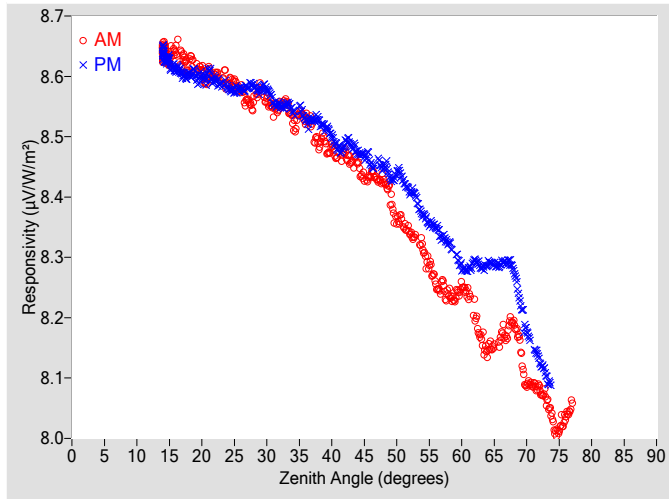


Figure 2. Responsivity vs Local Standard Time

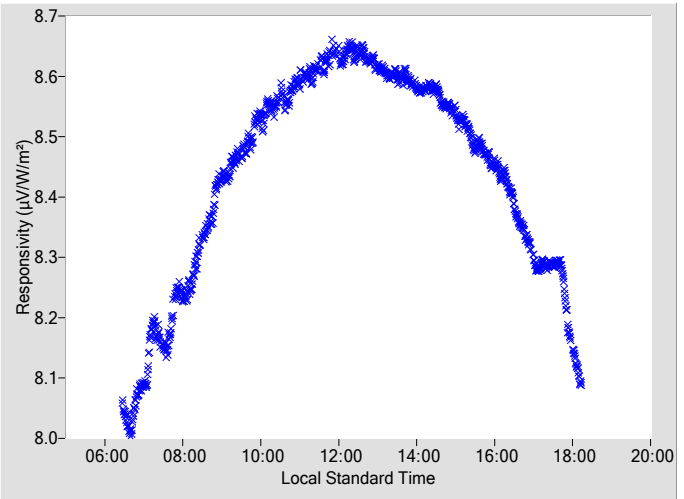


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4375	0.34	92.88	8.4543	0.33	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4274	0.32	91.34	8.4494	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3627	0.38	89.79	8.4421	0.33	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3429	0.35	88.37	8.4086	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3166	0.36	86.92	8.3704	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2566	0.39	85.54	8.3505	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2405	0.38	84.17	8.3237	0.37	275.87
14	8.6427	0.32	173.30	8.6387	0.32	187.03	60	8.2499	0.36	82.84	8.2829	0.38	277.25
16	8.6399	0.31	148.42	8.6110	0.30	211.78	62	8.2069	0.44	81.46	8.2943	0.39	278.58
18	8.6144	0.30	137.34	8.6039	0.31	222.74	64	8.1455	0.42	80.10	8.2890	N/A	279.90
20	8.6116	0.32	129.71	8.6006	0.30	230.33	66	8.1654	0.40	78.80	8.2895	N/A	281.30
22	8.6016	0.31	124.01	8.5946	0.31	236.08	68	8.1898	0.46	77.45	8.2775	N/A	282.60
24	8.5853	0.31	119.34	8.5814	0.33	240.75	70	8.0893	N/A	76.07	8.1774	N/A	283.98
26	8.5782	0.31	115.39	8.5796	0.30	244.63	72	8.0829	N/A	74.77	8.1270	N/A	285.32
28	8.5529	0.32	112.24	8.5833	0.32	247.97	74	8.0303	N/A	73.38	N/A	N/A	N/A
30	8.5606	0.33	109.13	8.5780	0.32	250.89	76	8.0352	N/A	72.00	N/A	N/A	N/A
32	8.5510	0.33	106.51	8.5521	0.30	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5263	0.32	104.08	8.5441	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5283	0.32	101.95	8.5272	0.33	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4876	0.32	99.86	8.5266	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4813	0.31	97.99	8.5019	0.31	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4727	0.35	96.18	8.4878	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4571	0.33	94.51	8.4736	0.34	265.56	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

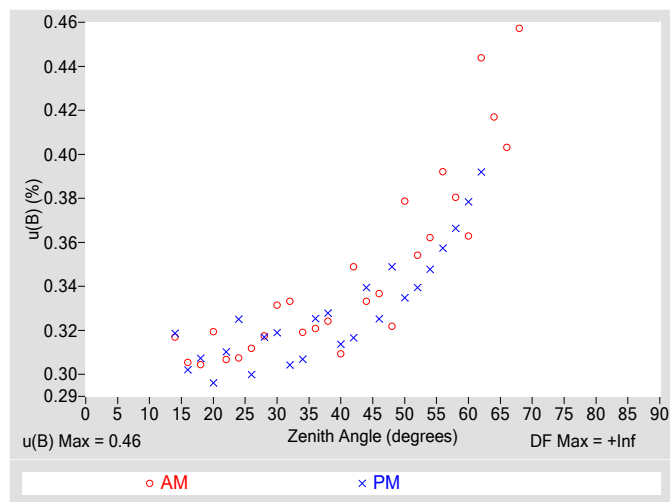


Figure 4. Residuals from Spline Interpolation

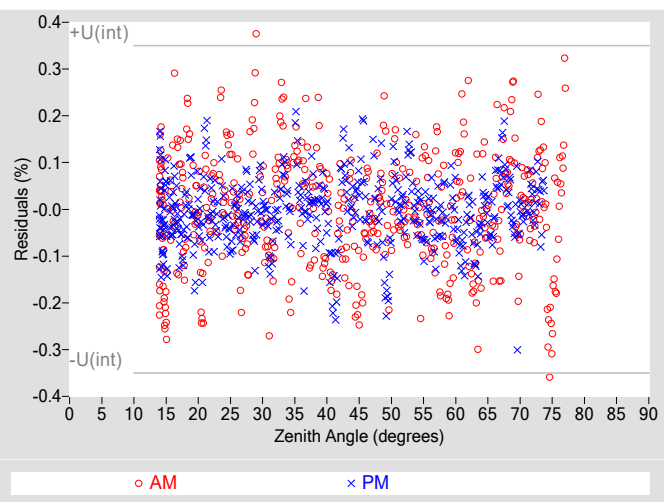


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	54102
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.96
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

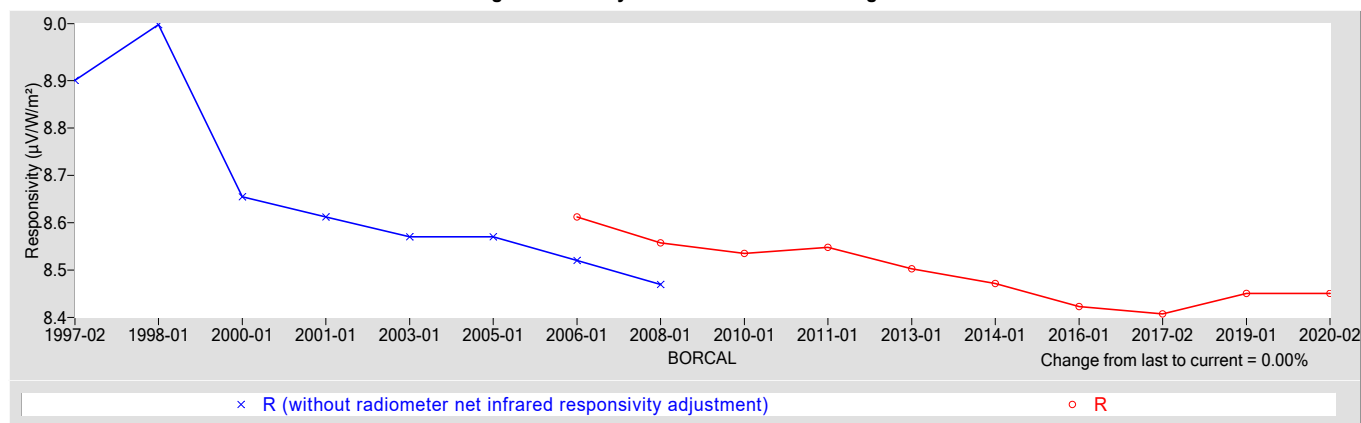
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.4504	0.58700

† R_{net} determination date: 04/05/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+1.5 / -2.5
Expanded Uncertainty, U (%)	+2.3 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 30708F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30708F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

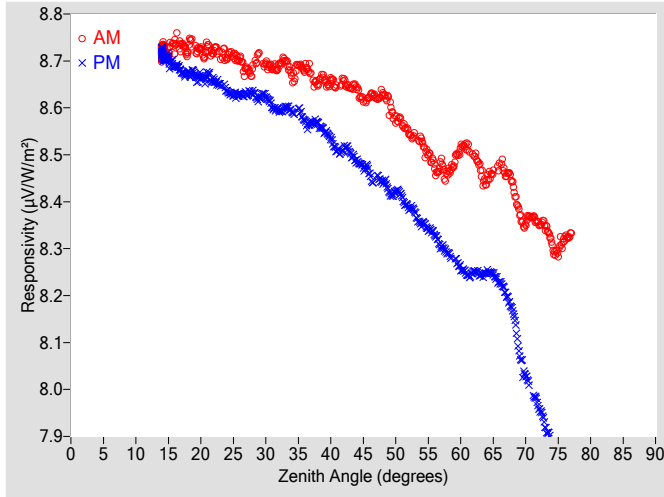


Figure 2. Responsivity vs Local Standard Time

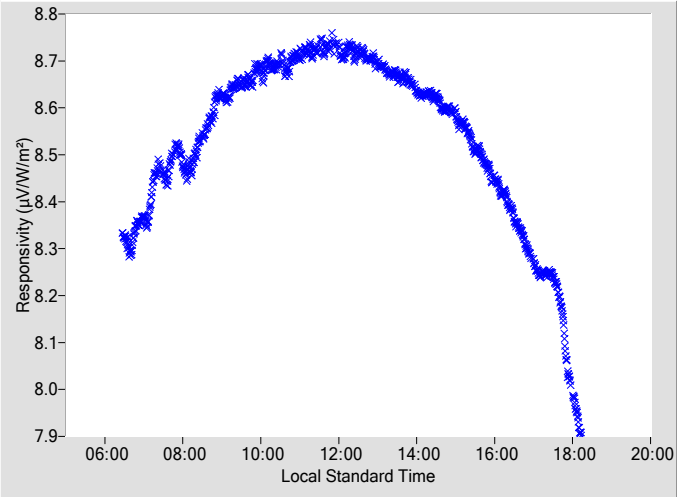


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6252	0.34	92.88	8.4575	0.33	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6304	0.32	91.34	8.4418	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5761	0.38	89.79	8.4230	0.33	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5480	0.35	88.37	8.3863	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5290	0.36	86.92	8.3535	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4714	0.39	85.54	8.3296	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4635	0.38	84.17	8.2906	0.37	275.87
14	8.7229	0.32	173.30	8.7155	0.32	187.03	60	8.5120	0.36	82.84	8.2575	0.38	277.25
16	8.7330	0.31	148.42	8.6882	0.30	211.78	62	8.4981	0.47	81.45	8.2513	0.39	278.58
18	8.7226	0.30	137.34	8.6753	0.31	222.74	64	8.4444	0.42	80.10	8.2498	N/A	279.90
20	8.7258	0.32	129.71	8.6679	0.30	230.33	66	8.4761	0.40	78.84	8.2272	N/A	281.30
22	8.7213	0.31	124.01	8.6574	0.31	236.08	68	8.4361	0.46	77.45	8.1666	N/A	282.60
24	8.7059	0.31	119.34	8.6364	0.33	240.75	70	8.3552	N/A	76.07	8.0283	N/A	283.98
26	8.7036	0.31	115.39	8.6290	0.30	244.63	72	8.3547	N/A	74.77	7.9614	N/A	285.32
28	8.6774	0.32	112.24	8.6318	0.32	247.97	74	8.3126	N/A	73.38	N/A	N/A	N/A
30	8.6938	0.33	109.13	8.6236	0.32	250.89	76	8.3209	N/A	72.00	N/A	N/A	N/A
32	8.6888	0.33	106.51	8.5951	0.30	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.6703	0.32	104.08	8.5922	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6830	0.32	101.95	8.5709	0.33	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6528	0.32	99.86	8.5665	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6581	0.31	97.99	8.5360	0.31	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6576	0.35	96.18	8.5121	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6431	0.33	94.51	8.4857	0.34	265.56	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

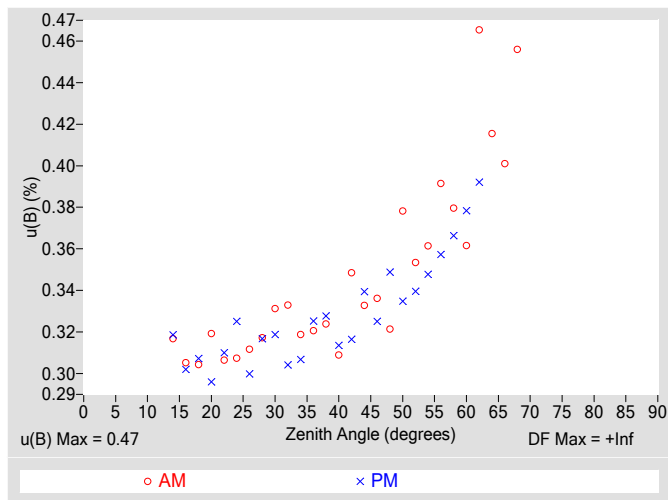


Figure 4. Residuals from Spline Interpolation

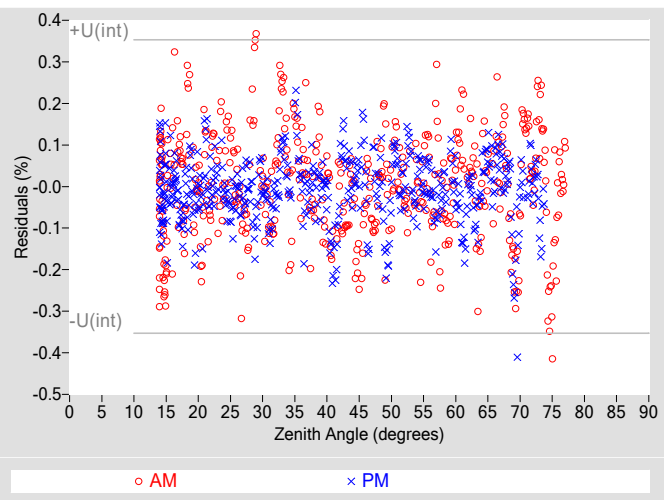


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.47
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.50
Effective degrees of freedom, $DF(c)$	55888
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.98
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

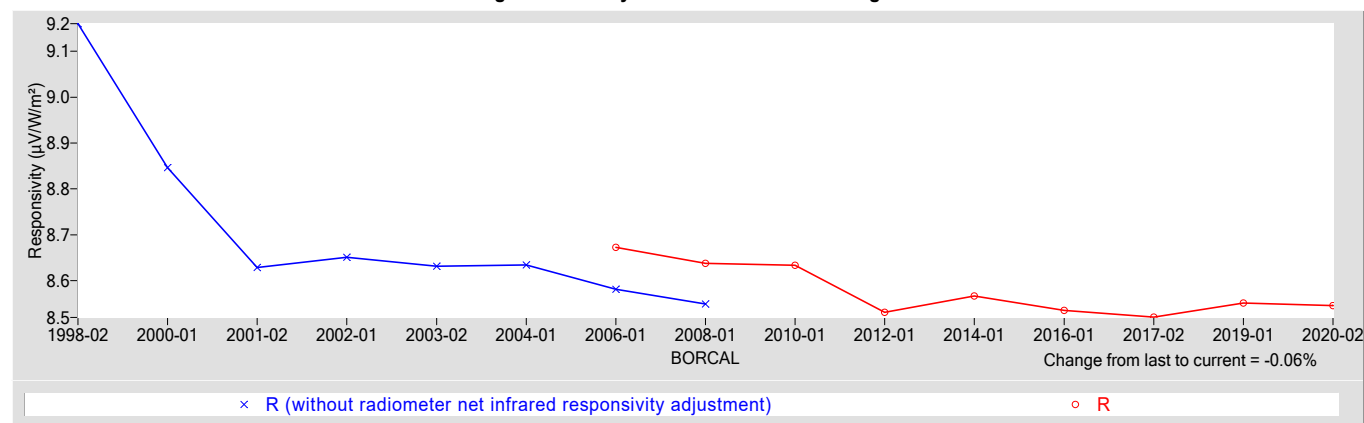
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5460	0.58600

† R_{net} determination date: 04/04/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+1.7 / -3.4
Expanded Uncertainty, U (%)	+2.5 / -4.1
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 30718E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30718E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

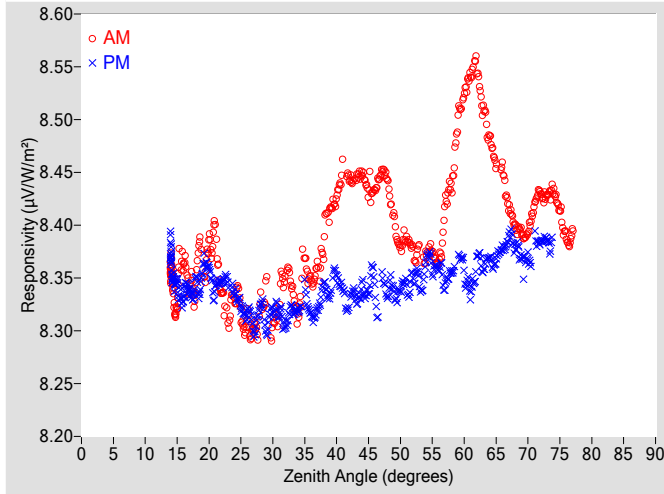


Figure 2. Responsivity vs Local Standard Time

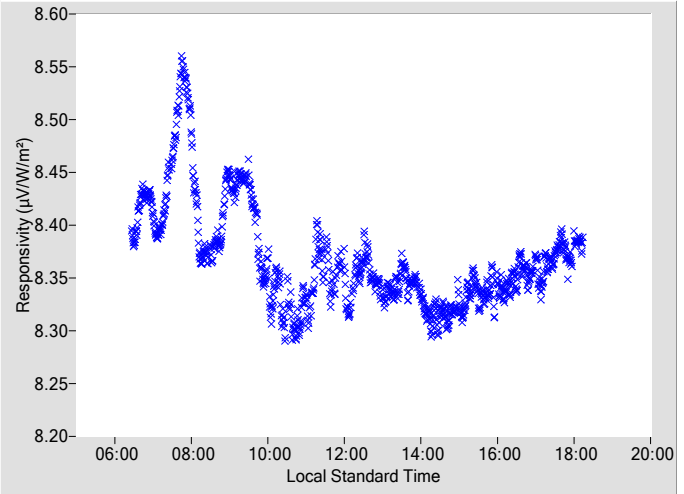


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4335	0.30	92.93	8.3419	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4409	0.31	91.34	8.3341	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3791	0.33	89.84	8.3394	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3764	0.31	88.44	8.3497	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3698	0.32	86.96	8.3642	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3668	0.29	85.58	8.3594	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4384	0.33	84.21	8.3557	0.30	275.91
14	8.3577	0.30	173.58	8.3668	0.30	186.76	60	8.5251	0.34	82.80	8.3558	0.30	277.21
16	8.3658	0.32	147.89	8.3321	0.29	211.91	62	8.5487	0.33	81.47	8.3630	0.30	278.54
18	8.3466	0.30	137.34	8.3473	0.30	223.07	64	8.4822	0.32	80.14	8.3690	N/A	279.95
20	8.3809	0.32	129.72	8.3579	0.30	230.33	66	8.4523	0.32	78.80	8.3780	N/A	281.26
22	8.3363	0.31	123.88	8.3465	0.30	236.21	68	8.4000	0.30	77.49	8.3786	N/A	282.64
24	8.3292	0.33	119.23	8.3356	0.29	240.76	70	8.3943	N/A	76.11	8.3678	N/A	283.94
26	8.3084	0.29	115.39	8.3156	0.33	244.63	72	8.4298	N/A	74.74	8.3841	N/A	285.32
28	8.3250	0.31	112.06	8.3240	0.30	248.06	74	8.4317	N/A	73.34	8.3886	N/A	286.52
30	8.3042	0.31	109.05	8.3187	0.32	250.97	76	8.3886	N/A	71.96	N/A	N/A	N/A
32	8.3518	0.33	106.49	8.3050	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3167	0.29	104.15	8.3200	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3475	0.30	101.89	8.3158	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3825	0.29	99.92	8.3435	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4261	0.31	98.00	8.3515	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4458	0.32	96.23	8.3272	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4477	0.29	94.56	8.3395	0.29	265.51	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

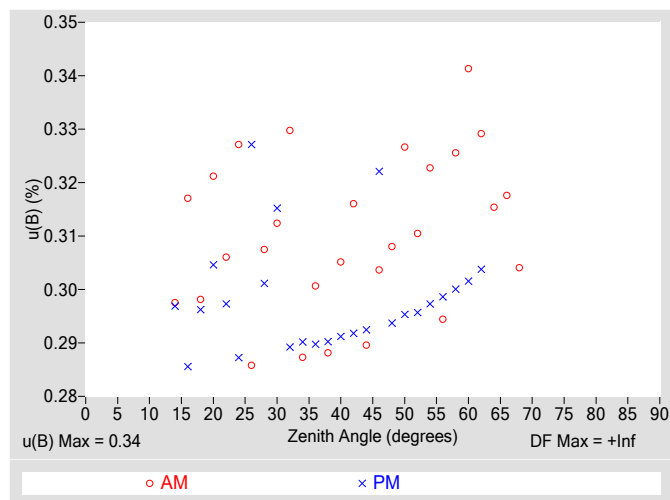


Figure 4. Residuals from Spline Interpolation

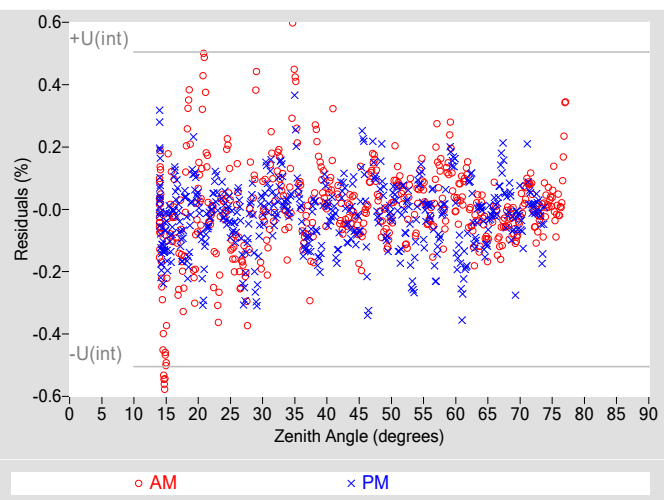


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.25
Combined Standard Uncertainty, $u(c)$ (%)	± 0.42
Effective degrees of freedom, $DF(c)$	7090
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.83
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

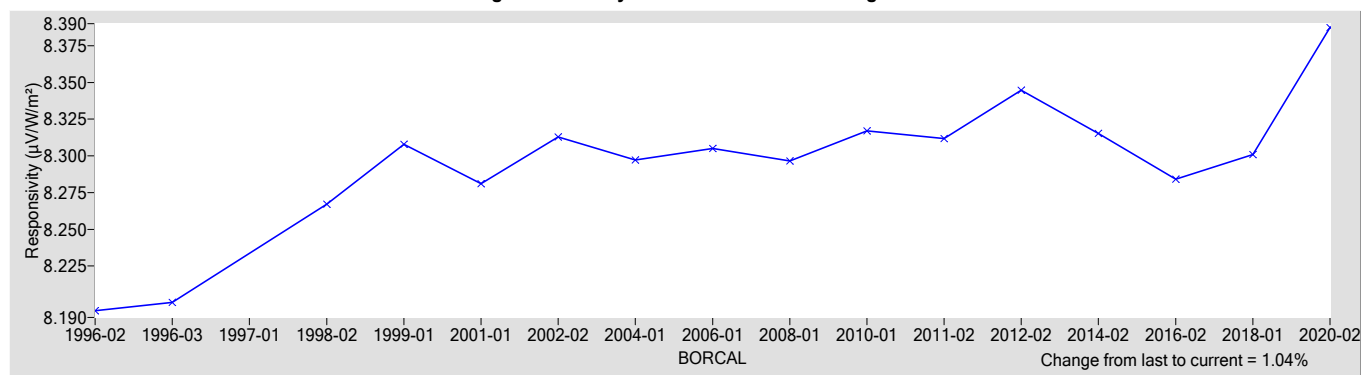
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.3874	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.6 / -0.99
Expanded Uncertainty, U (%)	+2.3 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 30778F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30778F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

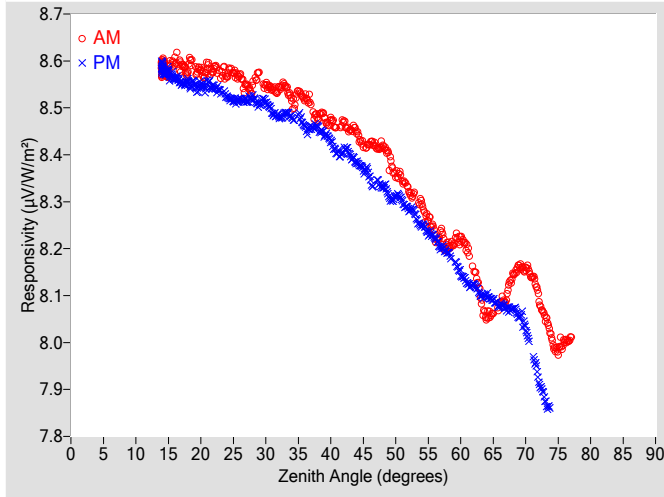


Figure 2. Responsivity vs Local Standard Time

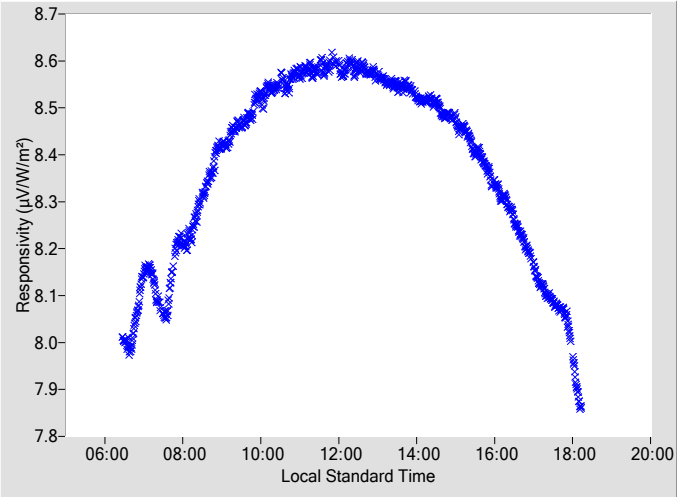


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4244	0.34	92.88	8.3502	0.33	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4191	0.32	91.34	8.3317	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3579	0.38	89.79	8.3128	0.34	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3235	0.36	88.37	8.2832	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2951	0.36	86.92	8.2496	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2299	0.39	85.54	8.2231	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2093	0.38	84.17	8.1917	0.37	275.87
14	8.5891	0.32	173.61	8.5849	0.32	187.03	60	8.2201	0.37	82.84	8.1457	0.38	277.25
16	8.5959	0.31	148.42	8.5626	0.30	211.78	62	8.1545	0.47	81.45	8.1231	0.40	278.58
18	8.5807	0.31	137.34	8.5558	0.31	222.74	64	8.0548	0.42	80.10	8.0996	N/A	279.90
20	8.5818	0.32	129.71	8.5489	0.30	230.33	66	8.0783	0.41	78.84	8.0794	N/A	281.30
22	8.5813	0.31	124.01	8.5432	0.31	236.08	68	8.1397	0.46	77.45	8.0718	N/A	282.60
24	8.5674	0.31	119.34	8.5239	0.33	240.75	70	8.1577	N/A	76.07	8.0267	N/A	283.98
26	8.5677	0.31	115.39	8.5178	0.30	244.63	72	8.1001	N/A	74.77	7.9185	N/A	285.32
28	8.5415	0.32	112.24	8.5200	0.32	247.97	74	8.0097	N/A	73.38	N/A	N/A	N/A
30	8.5484	0.33	109.13	8.5118	0.32	250.89	76	8.0023	N/A	72.00	N/A	N/A	N/A
32	8.5398	0.33	106.51	8.4819	0.31	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5159	0.32	104.08	8.4790	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5215	0.32	101.95	8.4592	0.33	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4808	0.33	99.86	8.4580	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4724	0.31	97.99	8.4304	0.32	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4690	0.35	96.18	8.4079	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4489	0.33	94.51	8.3826	0.34	265.56	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

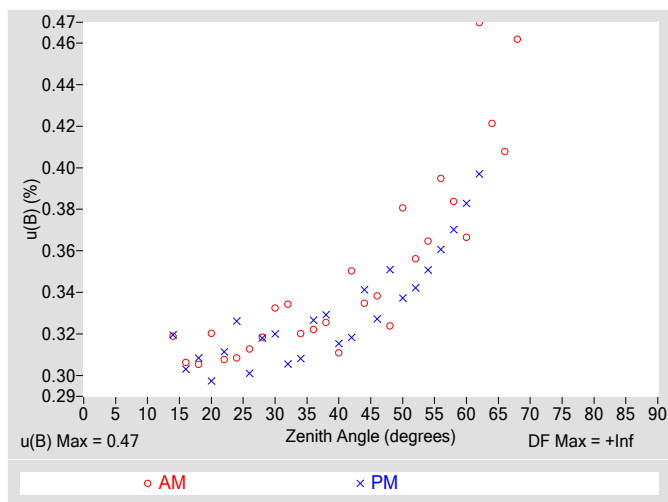


Figure 4. Residuals from Spline Interpolation

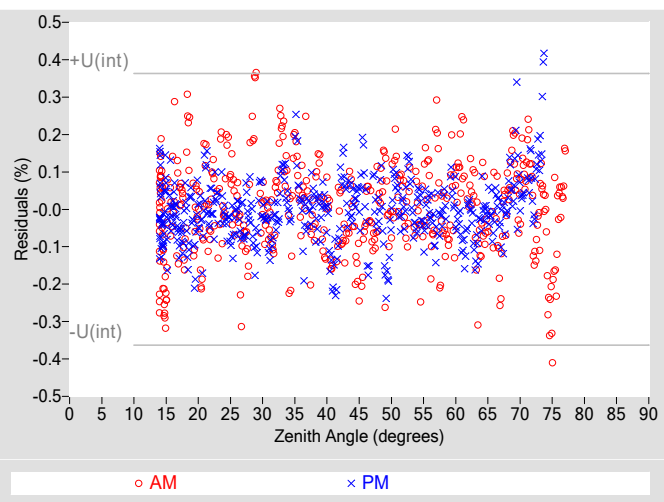


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.47
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.50
Effective degrees of freedom, $DF(c)$	52428
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.99
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

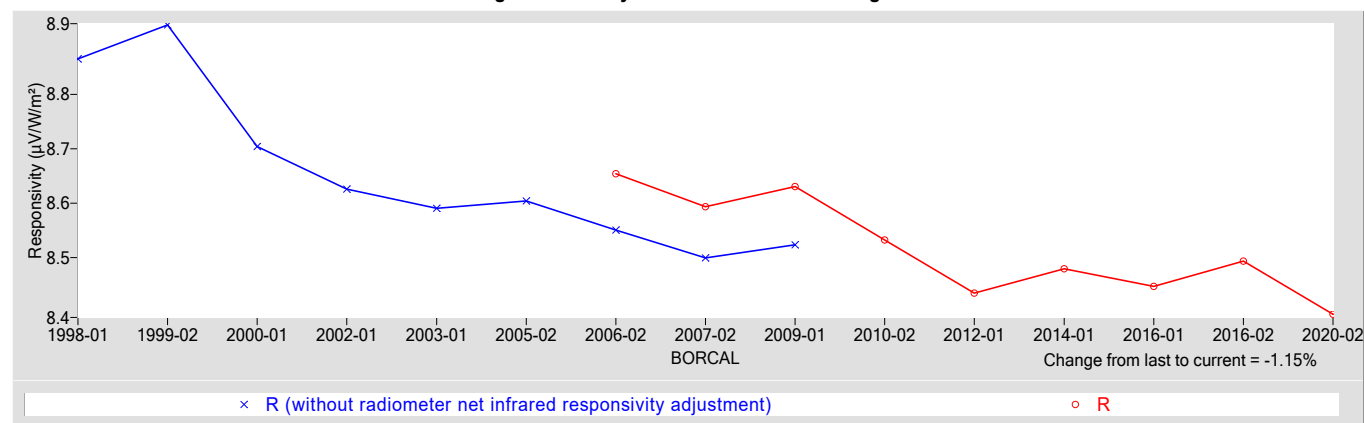
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.3959	0.64306

† R_{net} determination date: 06/06/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+1.8 / -3.0
Expanded Uncertainty, U (%)	+2.6 / -3.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 30802F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30802F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

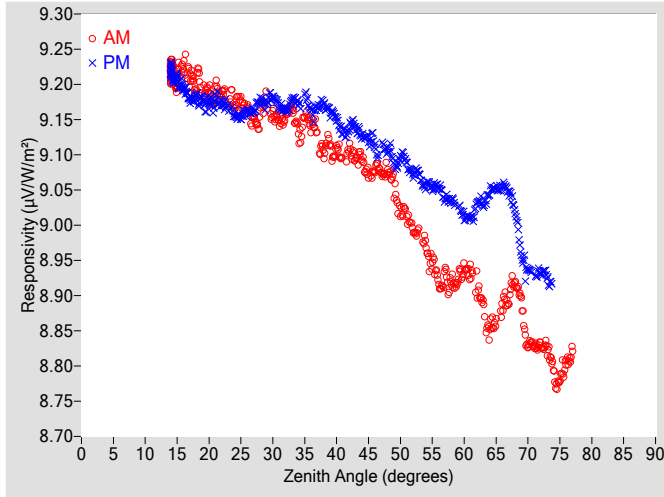


Figure 2. Responsivity vs Local Standard Time

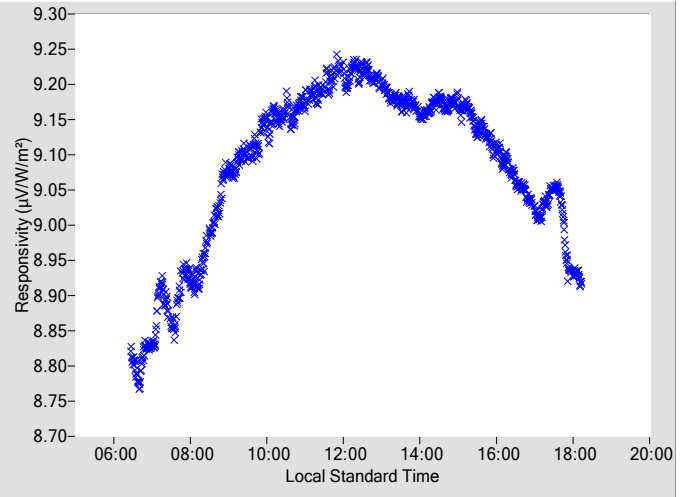


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0799	0.34	92.88	9.1106	0.33	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0774	0.32	91.34	9.1060	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0201	0.38	89.79	9.0975	0.34	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9937	0.36	88.37	9.0727	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9702	0.36	86.92	9.0575	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9174	0.39	85.54	9.0541	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9204	0.38	84.17	9.0353	0.37	275.87
14	9.2214	0.32	173.30	9.2187	0.32	187.03	60	8.9352	0.37	82.84	9.0119	0.38	277.25
16	9.2220	0.31	148.42	9.1937	0.30	211.78	62	8.9109	0.45	81.46	9.0305	0.40	278.58
18	9.1985	0.31	137.34	9.1836	0.31	222.74	64	8.8531	0.42	80.10	9.0468	N/A	279.90
20	9.1908	0.32	129.71	9.1766	0.30	230.33	66	8.8847	0.41	78.80	9.0558	N/A	281.30
22	9.1868	0.31	124.01	9.1722	0.31	236.08	68	8.9147	0.46	77.45	9.0169	N/A	282.60
24	9.1680	0.31	119.34	9.1561	0.33	240.75	70	8.8302	N/A	76.07	8.9368	N/A	283.98
26	9.1657	0.31	115.39	9.1611	0.30	244.63	72	8.8299	N/A	74.77	8.9306	N/A	285.32
28	9.1483	0.32	112.24	9.1760	0.32	247.97	74	8.7946	N/A	73.38	N/A	N/A	N/A
30	9.1574	0.33	109.13	9.1808	0.32	250.89	76	8.8049	N/A	72.00	N/A	N/A	N/A
32	9.1551	0.33	106.51	9.1647	0.31	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.1342	0.32	104.08	9.1739	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1423	0.32	101.95	9.1632	0.33	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1057	0.33	99.86	9.1713	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1074	0.31	97.99	9.1514	0.32	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1069	0.35	96.18	9.1389	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0948	0.33	94.51	9.1260	0.34	265.56	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

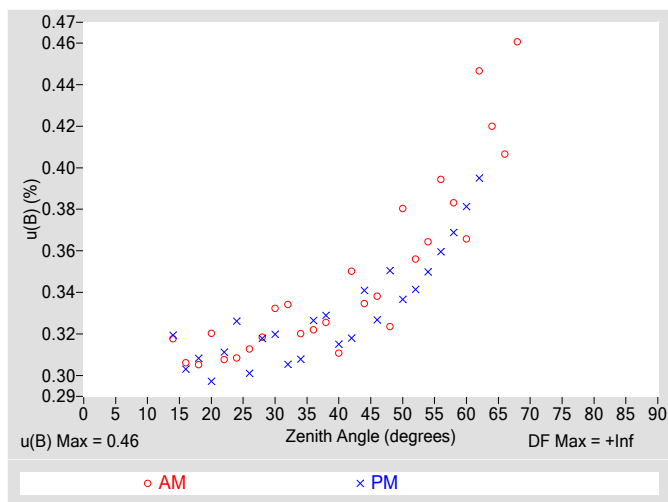


Figure 4. Residuals from Spline Interpolation

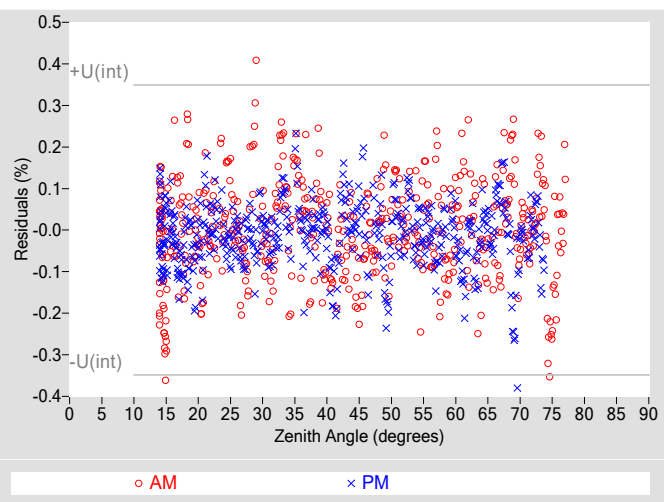


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	56283
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.97
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

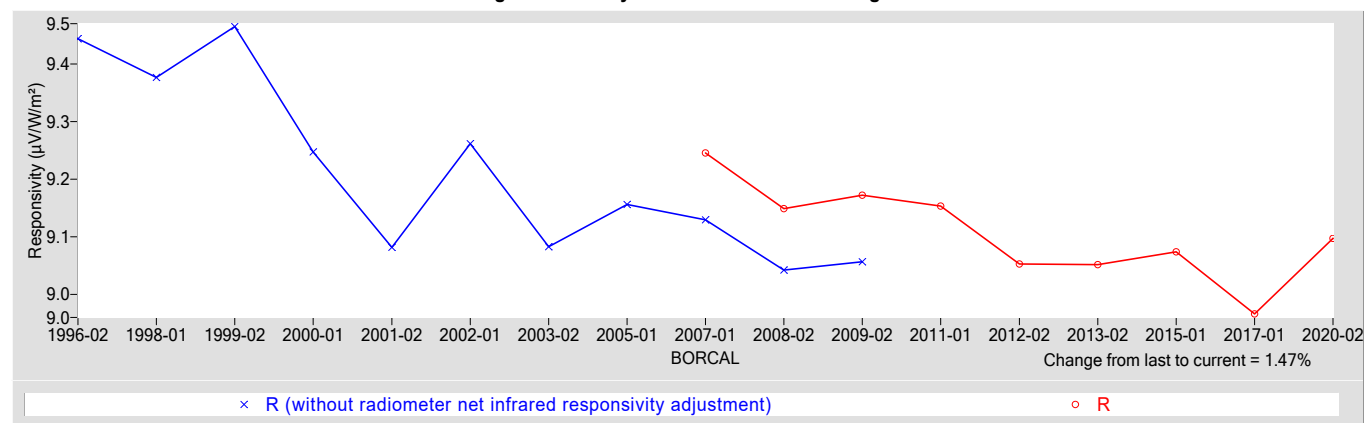
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.0973	0.68705

† R_{net} determination date: 04/25/2007

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+0.92 / -2.0
Expanded Uncertainty, U (%)	+1.7 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30894F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30894F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

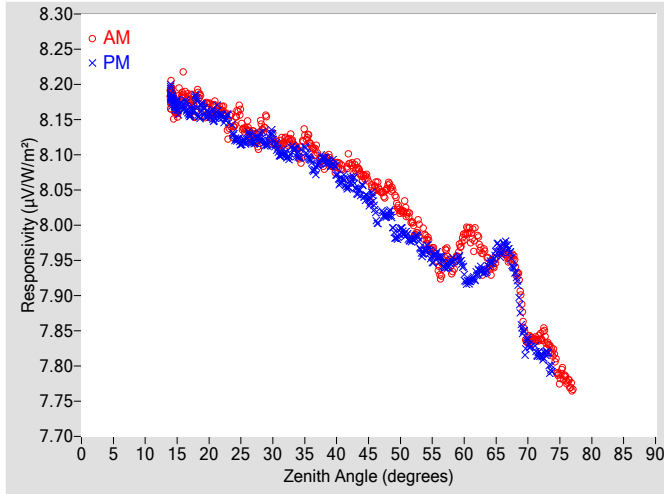


Figure 2. Responsivity vs Local Standard Time

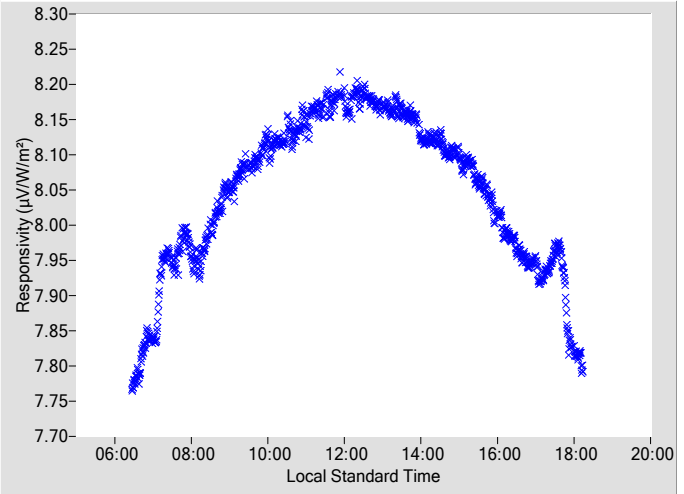


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0538	0.36	92.85	8.0217	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0560	0.34	91.31	8.0151	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0201	0.37	89.81	7.9935	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9958	0.36	88.35	7.9795	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9810	0.39	86.98	7.9674	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9358	0.37	85.52	7.9549	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9396	0.42	84.19	7.9488	0.37	275.84
14	8.1854	0.31	173.63	8.1831	0.31	187.51	60	7.9846	0.39	82.81	7.9305	0.38	277.22
16	8.1901	0.33	148.48	8.1677	0.31	211.47	62	7.9882	0.37	81.45	7.9305	0.40	278.56
18	8.1668	0.33	137.23	8.1753	0.34	222.94	64	7.9406	0.50	80.15	7.9459	N/A	279.96
20	8.1688	0.32	129.62	8.1578	0.30	230.39	66	7.9623	0.40	78.81	7.9666	N/A	281.27
22	8.1647	0.31	123.93	8.1552	0.31	236.13	68	7.9416	0.42	77.42	7.9339	N/A	282.58
24	8.1425	0.32	119.27	8.1246	0.30	240.79	70	7.8358	N/A	76.13	7.8341	N/A	283.95
26	8.1385	0.33	115.33	8.1250	0.30	244.67	72	7.8405	N/A	74.75	7.8158	N/A	285.30
28	8.1309	0.30	112.09	8.1239	0.30	248.01	74	7.8163	N/A	73.36	7.7920	N/A	286.53
30	8.1203	0.32	109.08	8.1247	0.30	250.93	76	7.7807	N/A	71.97	N/A	N/A	N/A
32	8.1187	0.30	106.47	8.0994	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1038	0.30	104.04	8.0979	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1136	0.34	101.91	8.0891	0.34	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0873	0.35	99.89	8.0953	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0832	0.35	97.96	8.0728	0.32	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0846	0.35	96.25	8.0598	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0694	0.34	94.53	8.0491	0.35	265.55	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

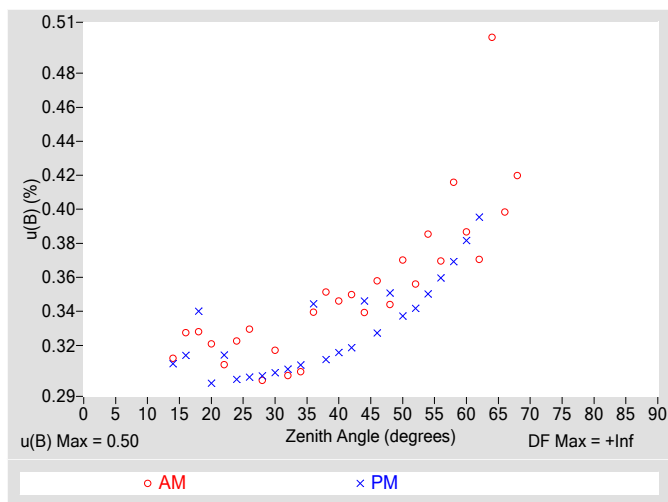


Figure 4. Residuals from Spline Interpolation

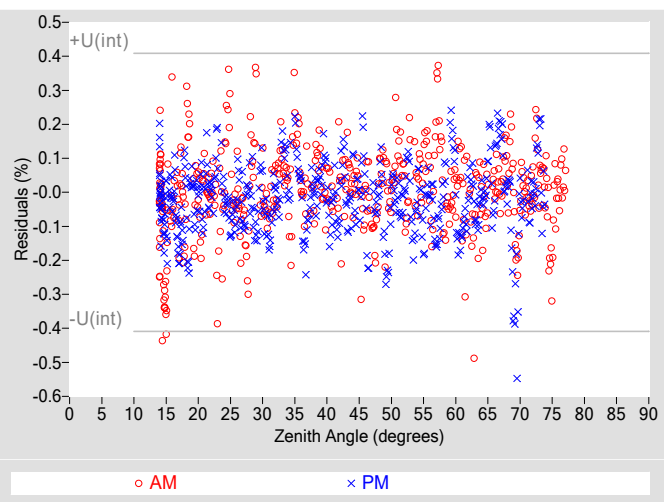


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	42822
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

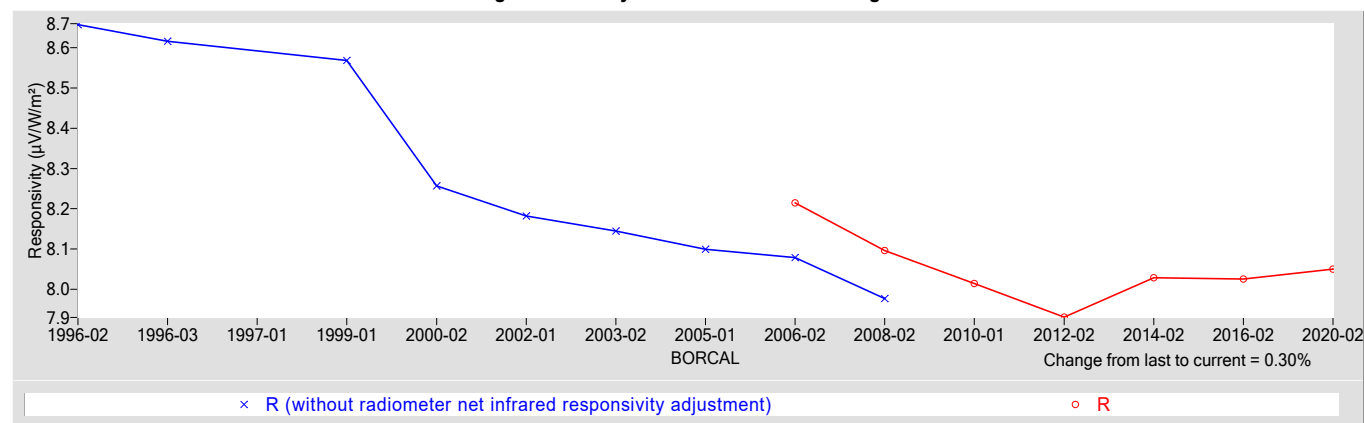
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0499	0.64666

† R_{net} determination date: 06/07/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	+0.93 / -1.5
Expanded Uncertainty, U (%)	+1.7 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 30900F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30900F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

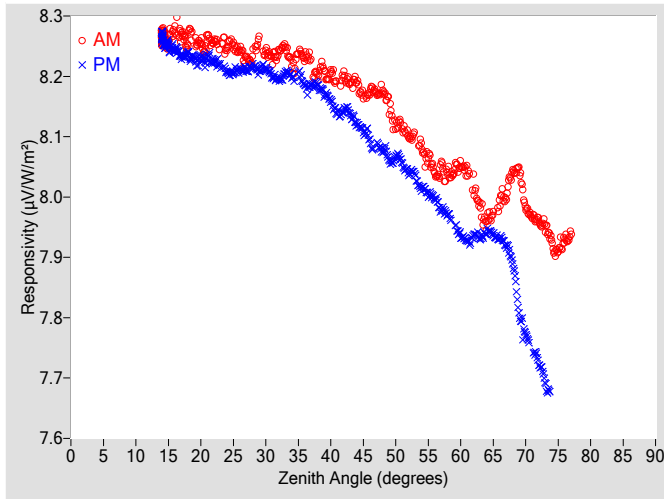


Figure 2. Responsivity vs Local Standard Time

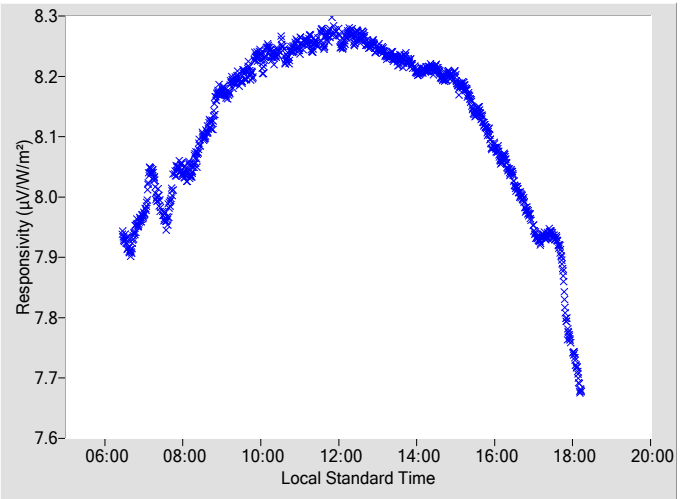


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1747	0.34	92.88	8.0924	0.33	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1760	0.32	91.34	8.0771	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1194	0.38	89.79	8.0678	0.34	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1015	0.36	88.37	8.0406	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0823	0.37	86.92	8.0150	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0399	0.40	85.54	7.9975	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0413	0.38	84.17	7.9713	0.37	275.87
14	8.2678	0.32	173.30	8.2642	0.32	187.03	60	8.0510	0.37	82.84	7.9355	0.38	277.25
16	8.2728	0.31	148.42	8.2430	0.30	211.78	62	8.0157	0.45	81.46	7.9365	0.40	278.58
18	8.2575	0.31	137.34	8.2378	0.31	222.74	64	7.9599	0.42	80.10	7.9415	N/A	279.90
20	8.2565	0.32	129.71	8.2303	0.30	230.33	66	7.9904	0.41	78.80	7.9317	N/A	281.30
22	8.2573	0.31	124.01	8.2244	0.31	236.08	68	8.0391	0.46	77.45	7.8887	N/A	282.60
24	8.2444	0.31	119.34	8.2077	0.33	240.75	70	7.9832	N/A	76.07	7.7718	N/A	283.98
26	8.2433	0.31	115.39	8.2110	0.30	244.63	72	7.9619	N/A	74.77	7.7244	N/A	285.32
28	8.2304	0.32	112.24	8.2155	0.32	247.97	74	7.9268	N/A	73.38	N/A	N/A	N/A
30	8.2402	0.33	109.13	8.2118	0.32	250.89	76	7.9298	N/A	72.00	N/A	N/A	N/A
32	8.2393	0.33	106.51	8.1959	0.31	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.2208	0.32	104.08	8.2002	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2316	0.32	101.95	8.1848	0.33	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2028	0.33	99.86	8.1841	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2047	0.31	97.99	8.1603	0.32	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2005	0.35	96.18	8.1435	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1914	0.34	94.51	8.1208	0.34	265.56	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

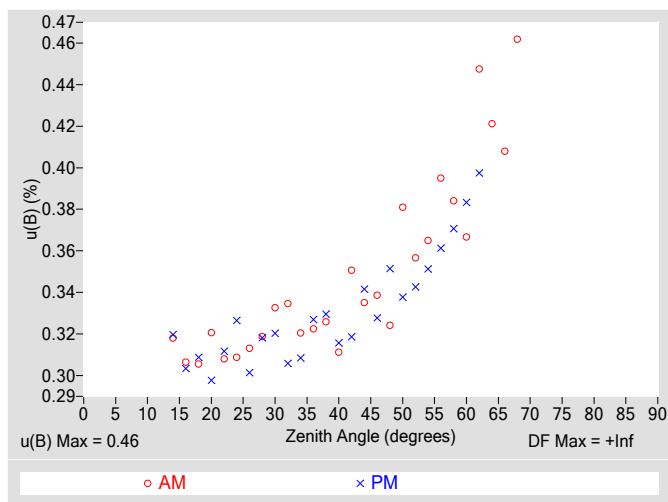


Figure 4. Residuals from Spline Interpolation

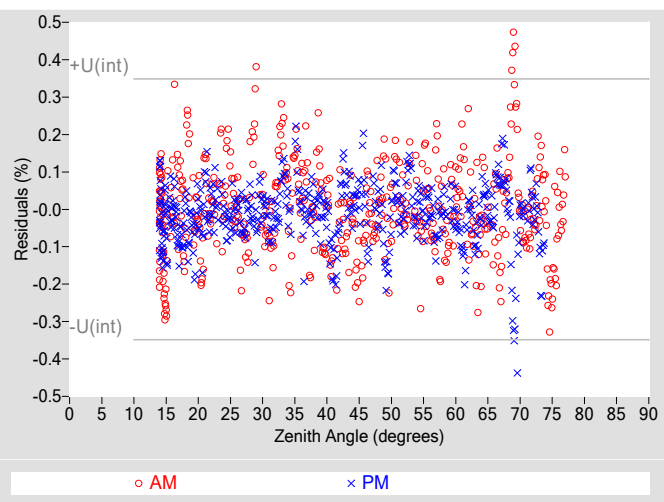


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	57098
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.97
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

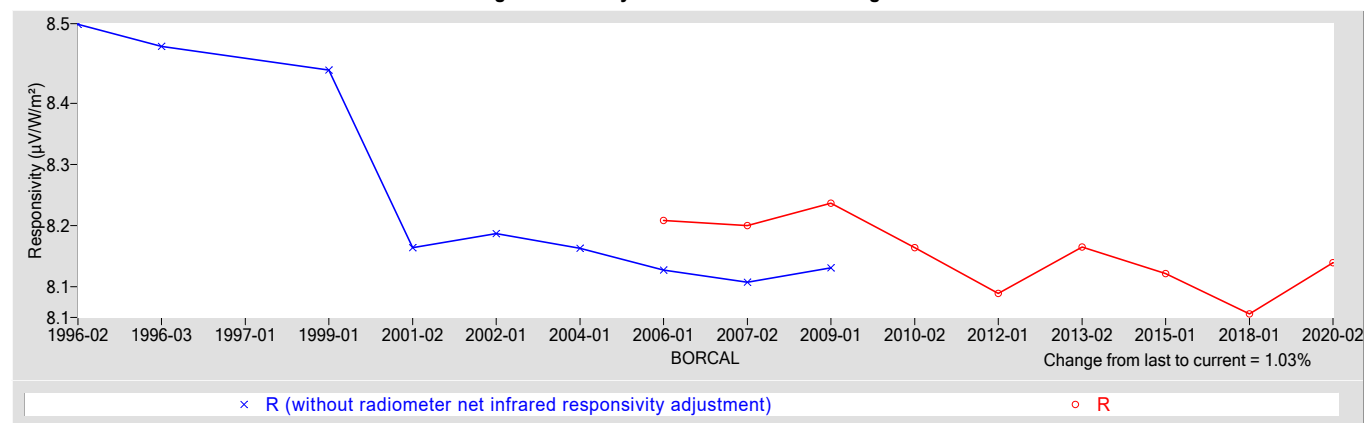
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.1393	0.63379

† R_{net} determination date: 05/08/2007

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+1.2 / -2.5
Expanded Uncertainty, U (%)	+2.0 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30903F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30903F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

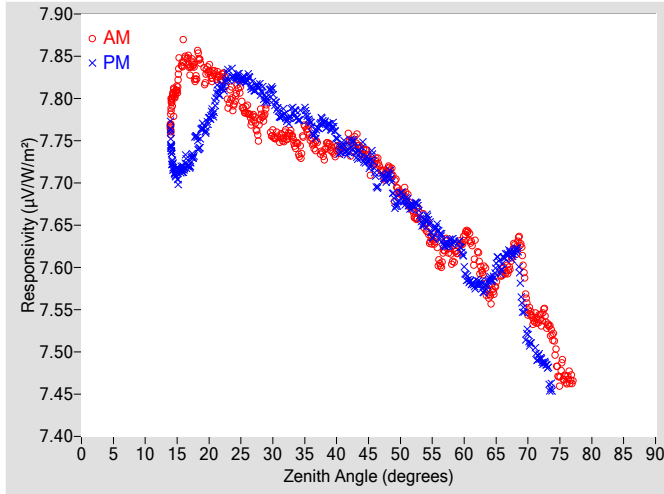


Figure 2. Responsivity vs Local Standard Time

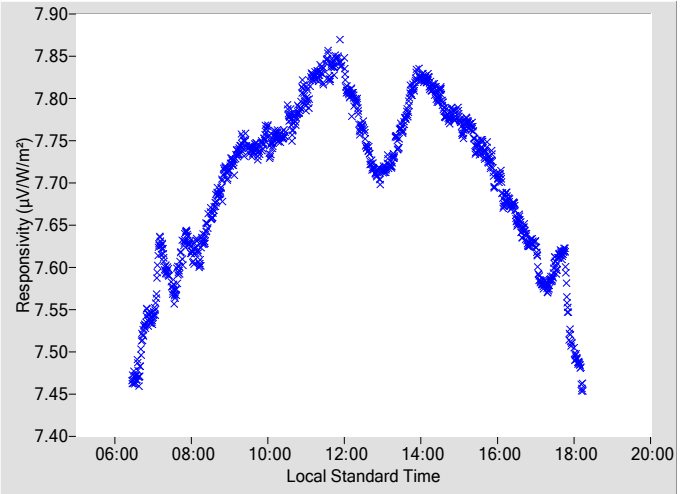


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7247	0.36	92.85	7.7118	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7165	0.34	91.31	7.7071	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6875	0.37	89.81	7.6862	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6636	0.35	88.35	7.6731	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6473	0.38	86.98	7.6587	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6081	0.37	85.52	7.6423	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6138	0.41	84.19	7.6312	0.37	275.84
14	7.7803	0.31	173.63	7.7404	0.31	187.51	60	7.6355	0.39	82.81	7.6026	0.38	277.22
16	7.8470	0.33	148.48	7.7167	0.31	211.47	62	7.6228	0.37	81.45	7.5807	0.39	278.56
18	7.8323	0.33	137.23	7.7521	0.34	222.94	64	7.5656	0.50	80.15	7.5859	N/A	279.96
20	7.8332	0.32	129.62	7.7756	0.30	230.39	66	7.5940	0.40	78.81	7.6045	N/A	281.27
22	7.8263	0.31	123.93	7.8135	0.31	236.13	68	7.6235	0.42	77.42	7.6192	N/A	282.58
24	7.7961	0.32	119.27	7.8244	0.30	240.79	70	7.5535	N/A	76.13	7.5178	N/A	283.95
26	7.7856	0.33	115.33	7.8235	0.30	244.67	72	7.5389	N/A	74.75	7.4923	N/A	285.30
28	7.7724	0.30	112.09	7.8105	0.30	248.01	74	7.5130	N/A	73.36	7.4539	N/A	286.53
30	7.7563	0.32	109.08	7.8048	0.30	250.93	76	7.4682	N/A	71.97	N/A	N/A	N/A
32	7.7549	0.30	106.47	7.7775	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7407	0.30	104.04	7.7754	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7517	0.34	101.91	7.7684	0.34	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7338	0.35	99.89	7.7723	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7392	0.35	97.96	7.7527	0.31	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7466	0.35	96.25	7.7420	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7375	0.34	94.53	7.7361	0.35	265.55	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

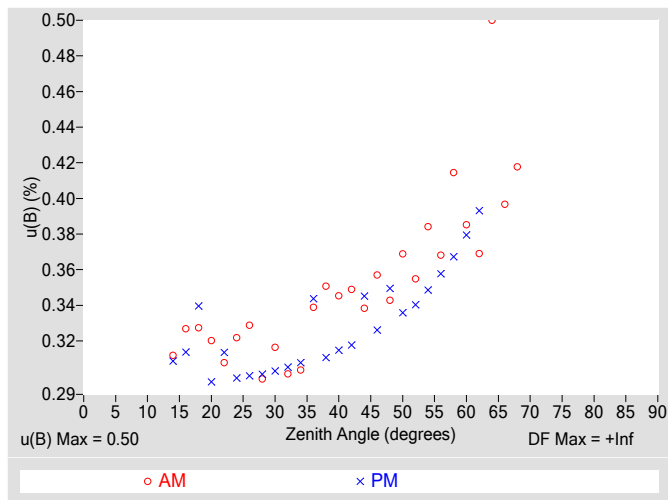


Figure 4. Residuals from Spline Interpolation

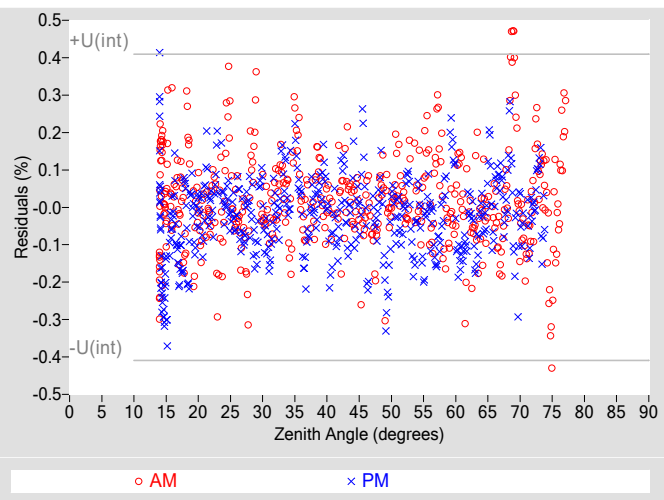


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	42500
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

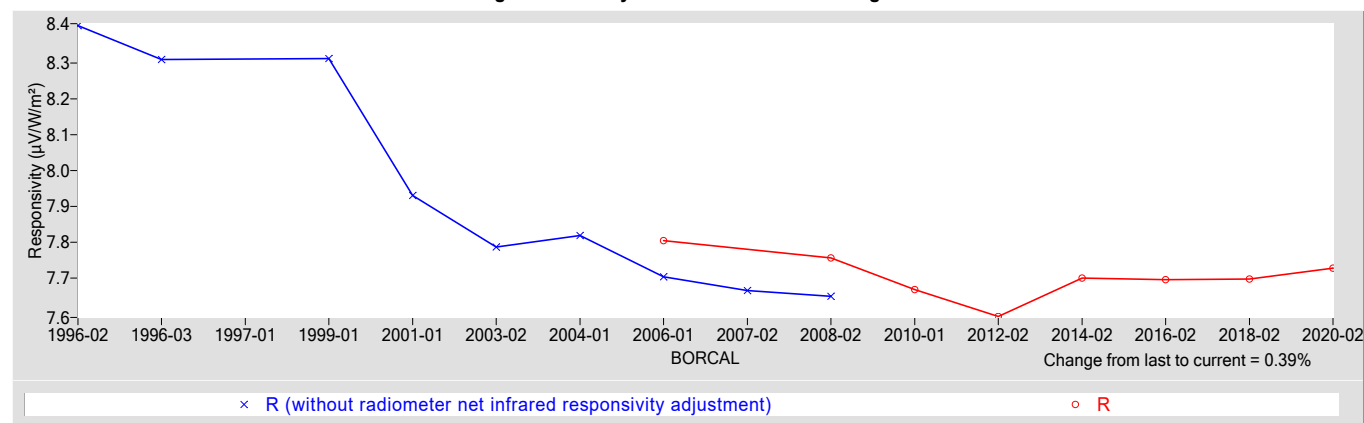
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.7277	0.58651

† R_{net} determination date: 04/18/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.00 / -1.6
Expanded Uncertainty, U (%)	+1.8 / -2.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30934F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30934F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

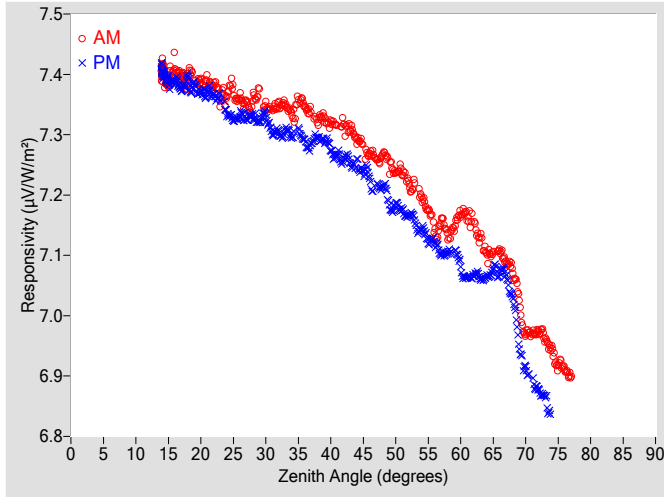


Figure 2. Responsivity vs Local Standard Time

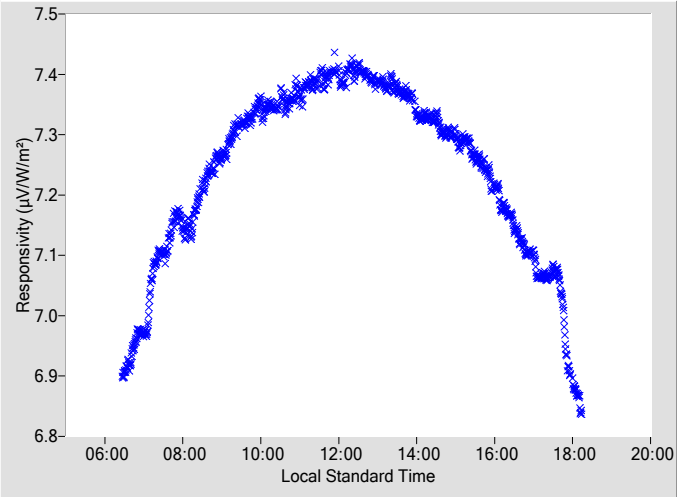


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.2678	0.36	92.85	7.2256	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2679	0.34	91.31	7.2132	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2381	0.37	89.81	7.1847	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2175	0.35	88.35	7.1655	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.1954	0.38	86.98	7.1446	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1391	0.37	85.52	7.1210	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1335	0.41	84.19	7.1056	0.37	275.84
14	7.4080	0.31	173.63	7.4050	0.31	187.51	60	7.1678	0.38	82.81	7.0801	0.38	277.22
16	7.4095	0.33	148.48	7.3863	0.31	211.47	62	7.1596	0.37	81.45	7.0661	0.39	278.56
18	7.3872	0.33	137.23	7.3917	0.34	222.94	64	7.1023	0.50	80.15	7.0650	N/A	279.96
20	7.3882	0.32	129.62	7.3705	0.30	230.39	66	7.1069	0.40	78.81	7.0706	N/A	281.27
22	7.3826	0.31	123.93	7.3657	0.31	236.13	68	7.0712	0.42	77.42	7.0300	N/A	282.58
24	7.3631	0.32	119.27	7.3357	0.30	240.79	70	6.9704	N/A	76.13	6.9117	N/A	283.95
26	7.3606	0.33	115.33	7.3319	0.30	244.67	72	6.9734	N/A	74.75	6.8774	N/A	285.30
28	7.3543	0.30	112.09	7.3287	0.30	248.01	74	6.9436	N/A	73.36	6.8366	N/A	286.53
30	7.3456	0.32	109.08	7.3294	0.30	250.93	76	6.9115	N/A	71.97	N/A	N/A	N/A
32	7.3477	0.30	106.47	7.3019	0.30	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.3359	0.30	104.04	7.2964	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3464	0.34	101.91	7.2887	0.34	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3224	0.35	99.89	7.2952	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3185	0.34	97.96	7.2743	0.31	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3146	0.35	96.25	7.2596	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2925	0.34	94.53	7.2515	0.34	265.55	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

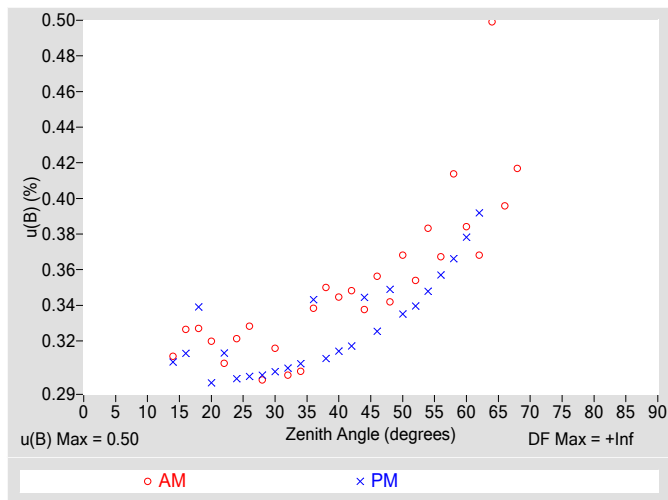


Figure 4. Residuals from Spline Interpolation

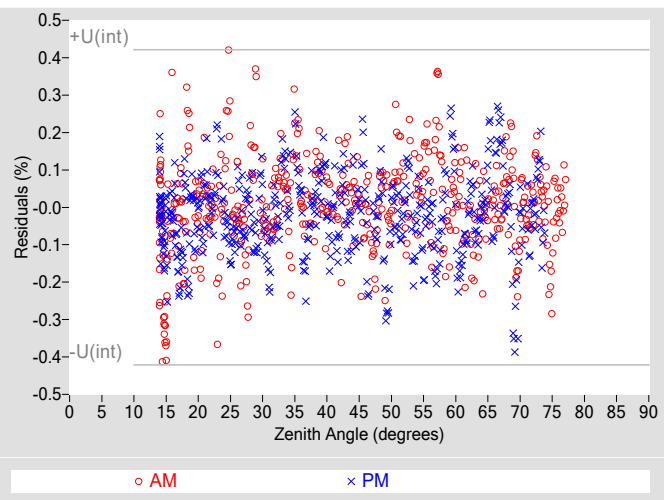


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	38244
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

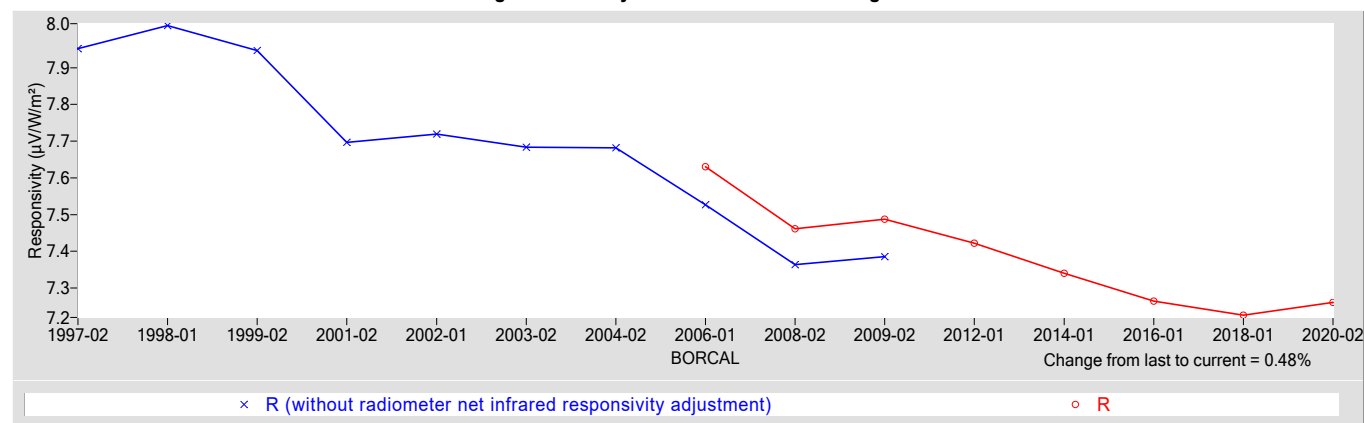
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.2614	0.53000

† R_{net} determination date: 04/18/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.2 / -2.5
Expanded Uncertainty, U (%)	+2.0 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30940F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30940F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

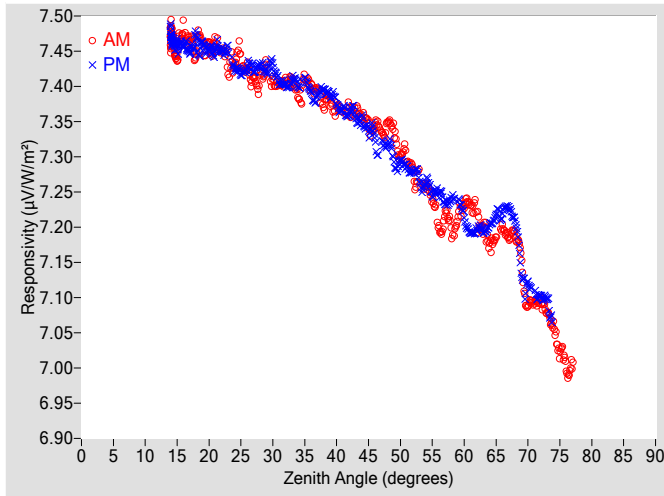


Figure 2. Responsivity vs Local Standard Time

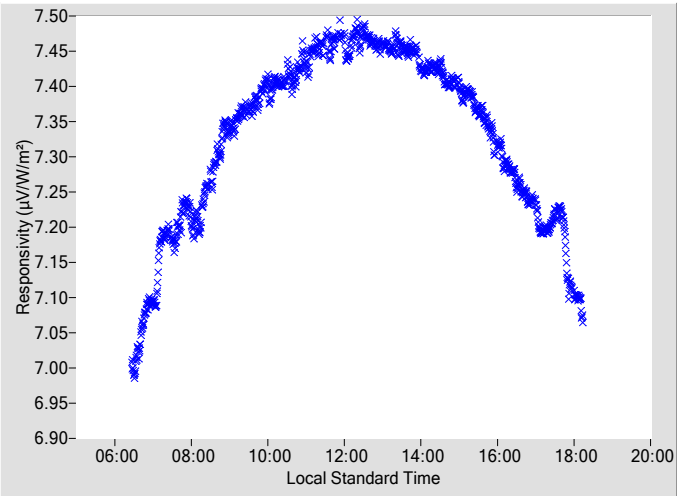


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.3461	0.36	92.85	7.3250	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3497	0.35	91.31	7.3164	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3014	0.37	89.81	7.2941	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2742	0.36	88.35	7.2783	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2584	0.39	86.98	7.2649	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1987	0.37	85.52	7.2491	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1953	0.42	84.19	7.2402	0.37	275.84
14	7.4735	0.31	173.63	7.4706	0.31	187.51	60	7.2310	0.39	82.81	7.2138	0.38	277.22
16	7.4750	0.33	148.48	7.4578	0.31	211.47	62	7.2179	0.43	81.48	7.1964	0.40	278.56
18	7.4523	0.33	137.23	7.4677	0.34	222.94	64	7.1746	0.50	80.15	7.2041	N/A	279.96
20	7.4606	0.32	129.62	7.4530	0.30	230.39	66	7.1978	0.40	78.81	7.2190	N/A	281.27
22	7.4514	0.31	123.93	7.4522	0.32	236.13	68	7.1866	0.42	77.42	7.2077	N/A	282.58
24	7.4302	0.32	119.27	7.4263	0.30	240.79	70	7.0888	N/A	76.13	7.1185	N/A	283.95
26	7.4262	0.33	115.33	7.4288	0.30	244.67	72	7.0939	N/A	74.75	7.1023	N/A	285.30
28	7.4109	0.30	112.09	7.4294	0.30	248.01	74	7.0570	N/A	73.36	7.0647	N/A	286.53
30	7.4068	0.32	109.08	7.4282	0.30	250.93	76	6.9996	N/A	71.97	N/A	N/A	N/A
32	7.4064	0.30	106.47	7.4010	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.3876	0.31	104.04	7.4005	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3994	0.34	101.91	7.3904	0.35	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3730	0.35	99.89	7.3959	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3699	0.35	97.96	7.3751	0.32	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3676	0.35	96.25	7.3637	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3580	0.34	94.53	7.3508	0.35	265.55	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

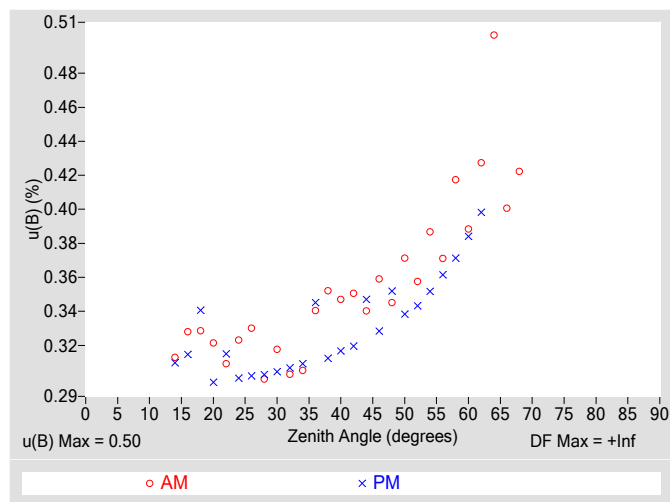


Figure 4. Residuals from Spline Interpolation

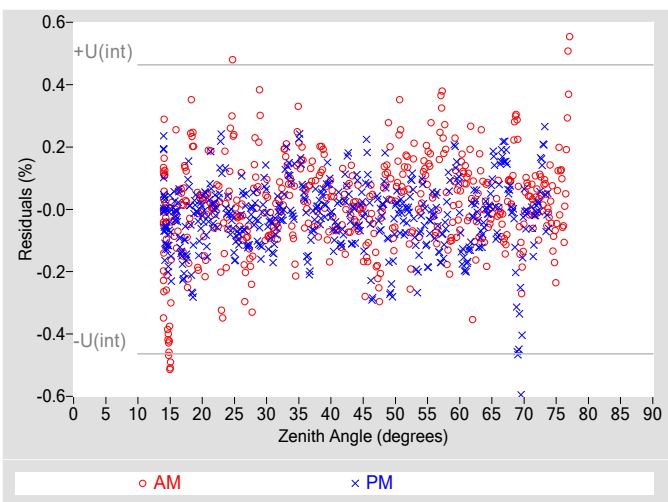


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	28595
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

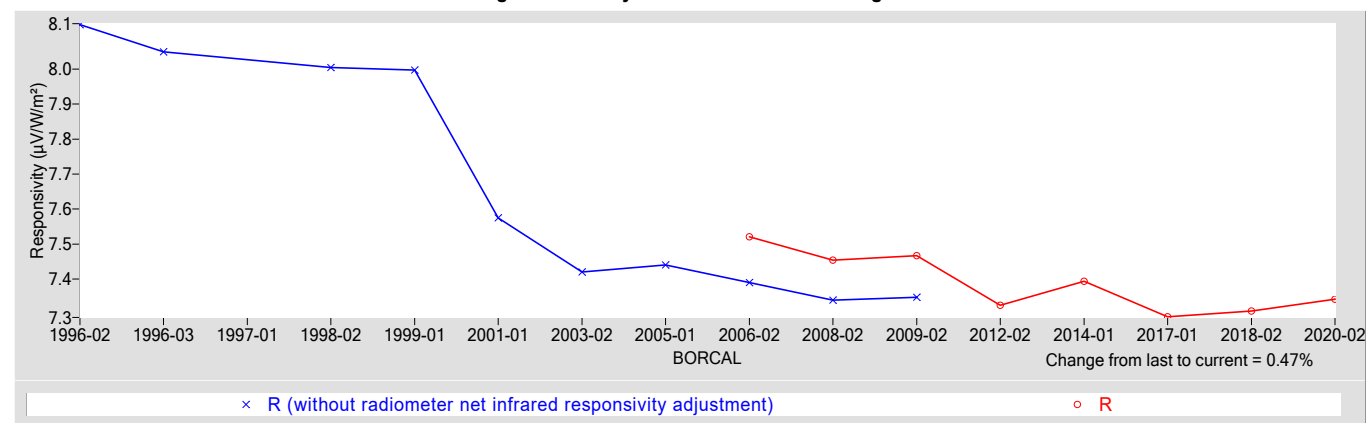
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.3425	0.61870

† R_{net} determination date: 06/07/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	+1.2 / -2.0
Expanded Uncertainty, U (%)	+2.0 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 30944F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30944F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

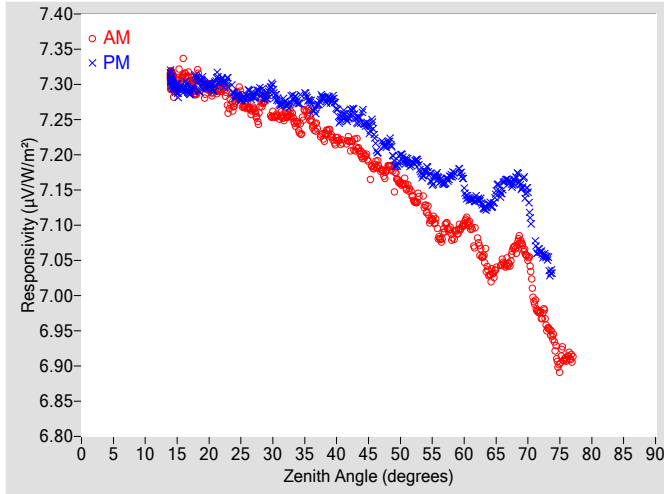


Figure 2. Responsivity vs Local Standard Time

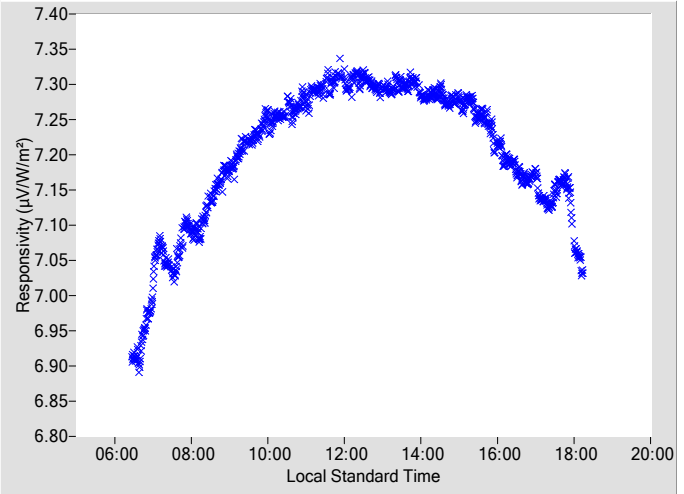


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.1843	0.36	92.85	7.2223	0.33	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.1818	0.34	91.31	7.2156	0.35	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.1594	0.37	89.81	7.1980	0.34	270.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.1370	0.36	88.35	7.1885	0.34	271.67
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.1237	0.38	86.98	7.1790	0.35	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.0840	0.37	85.52	7.1672	0.36	274.48
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.0864	0.42	84.19	7.1712	0.37	275.84
14	7.3099	0.31	173.63	7.3061	0.31	187.51	60	7.1031	0.39	82.81	7.1546	0.38	277.22
16	7.3164	0.33	148.48	7.2936	0.31	211.47	62	7.0844	0.37	81.45	7.1372	0.39	278.56
18	7.2960	0.33	137.23	7.3068	0.34	222.94	64	7.0287	0.50	80.15	7.1290	N/A	279.96
20	7.2963	0.32	129.62	7.2984	0.30	230.39	66	7.0462	0.40	78.81	7.1526	N/A	281.27
22	7.2933	0.31	123.93	7.3057	0.31	236.13	68	7.0674	0.42	77.42	7.1650	N/A	282.58
24	7.2722	0.32	119.27	7.2848	0.30	240.79	70	7.0545	N/A	76.13	7.1405	N/A	283.95
26	7.2689	0.33	115.33	7.2864	0.30	244.67	72	6.9731	N/A	74.75	7.0624	N/A	285.30
28	7.2649	0.30	112.09	7.2891	0.30	248.01	74	6.9361	N/A	73.36	7.0317	N/A	286.53
30	7.2555	0.32	109.08	7.2932	0.30	250.93	76	6.9103	N/A	71.97	N/A	N/A	N/A
32	7.2549	0.30	106.47	7.2724	0.31	253.61	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.2402	0.30	104.04	7.2739	0.31	255.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.2479	0.34	101.91	7.2726	0.34	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.2252	0.35	99.89	7.2806	0.31	260.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.2208	0.35	97.96	7.2647	0.32	262.08	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2179	0.35	96.25	7.2568	0.32	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.1999	0.34	94.53	7.2533	0.35	265.55	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

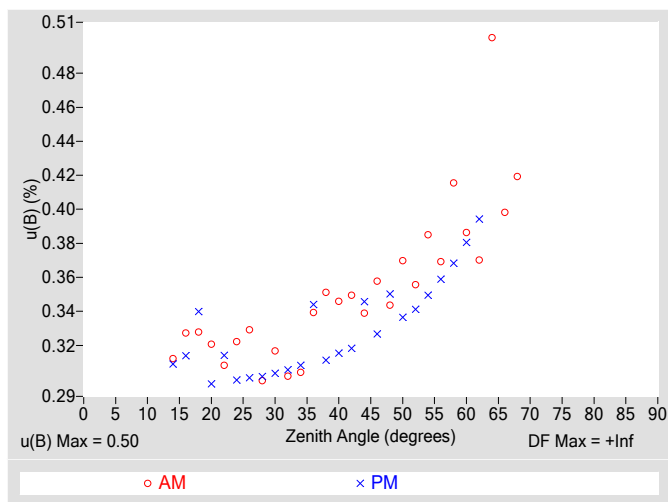


Figure 4. Residuals from Spline Interpolation

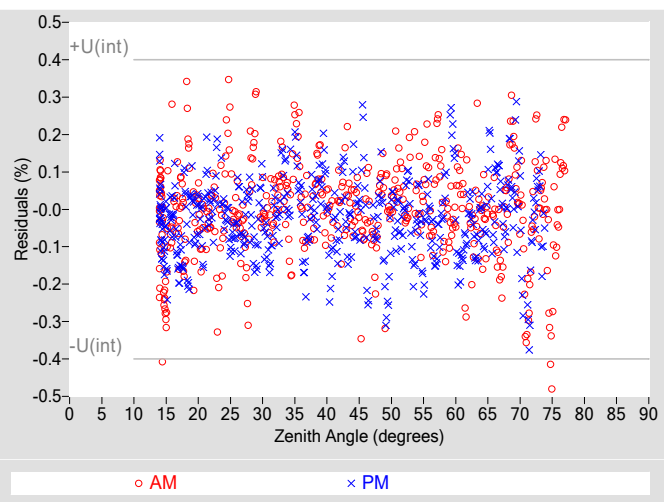


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	46116
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

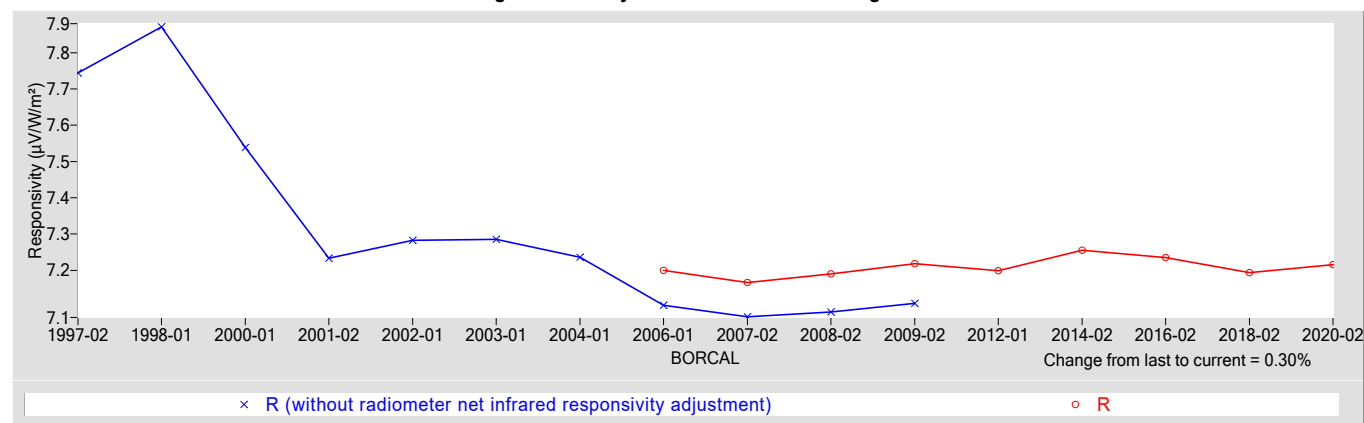
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.2152	0.56695

† R_{net} determination date: 04/18/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.1 / -1.8
Expanded Uncertainty, U (%)	+1.9 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 30955F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30955F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

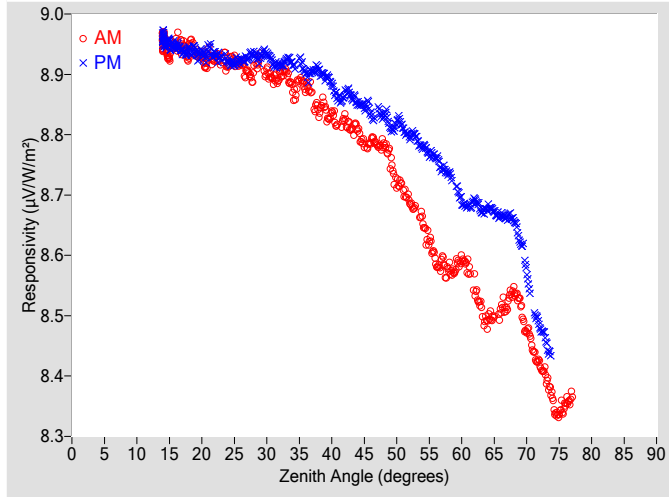


Figure 2. Responsivity vs Local Standard Time

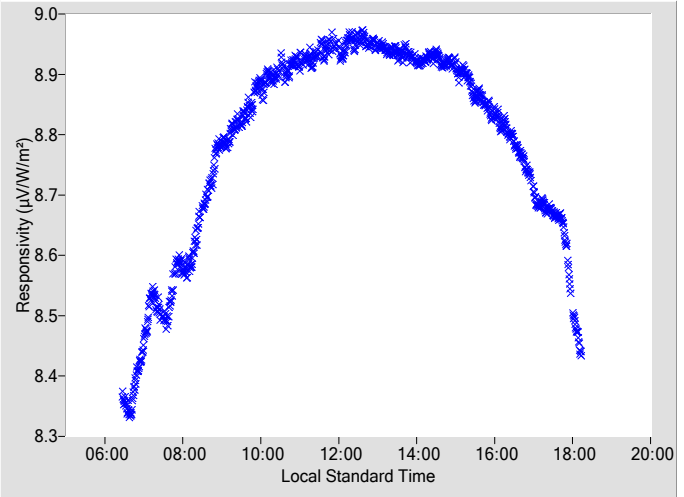


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7895	0.34	92.88	8.8344	0.33	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7836	0.32	91.34	8.8314	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7205	0.38	89.79	8.8232	0.33	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6899	0.35	88.37	8.7971	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6562	0.36	86.92	8.7800	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5893	0.39	85.54	8.7630	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5778	0.38	84.17	8.7357	0.37	275.87
14	8.9572	0.32	173.30	8.9593	0.32	187.03	60	8.5921	0.36	82.84	8.6888	0.38	277.25
16	8.9472	0.31	148.42	8.9452	0.30	211.78	62	8.5462	0.44	81.46	8.6916	0.39	278.58
18	8.9342	0.30	137.34	8.9418	0.31	222.74	64	8.4916	0.42	80.10	8.6780	N/A	279.90
20	8.9310	0.32	129.71	8.9361	0.30	230.33	66	8.5072	0.40	78.80	8.6659	N/A	281.30
22	8.9263	0.31	124.01	8.9328	0.31	236.08	68	8.5380	0.46	77.45	8.6581	N/A	282.60
24	8.9124	0.31	119.34	8.9218	0.33	240.75	70	8.4756	N/A	76.07	8.5691	N/A	283.98
26	8.9182	0.31	115.39	8.9238	0.30	244.63	72	8.4213	N/A	74.77	8.4815	N/A	285.32
28	8.8979	0.32	112.24	8.9324	0.32	247.97	74	8.3616	N/A	73.38	N/A	N/A	N/A
30	8.9037	0.33	109.13	8.9333	0.32	250.89	76	8.3544	N/A	72.00	N/A	N/A	N/A
32	8.8961	0.33	106.51	8.9164	0.30	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8745	0.32	104.08	8.9172	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8781	0.32	101.95	8.9018	0.33	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8400	0.32	99.86	8.9063	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8342	0.31	97.99	8.8841	0.31	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8247	0.35	96.18	8.8668	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8090	0.33	94.51	8.8513	0.34	265.56	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

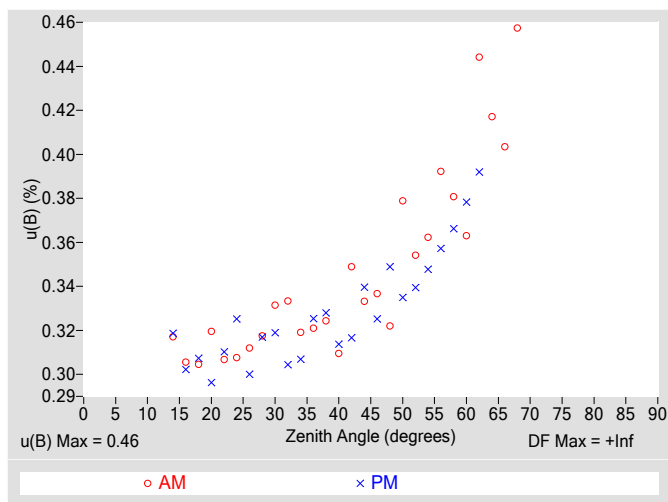


Figure 4. Residuals from Spline Interpolation

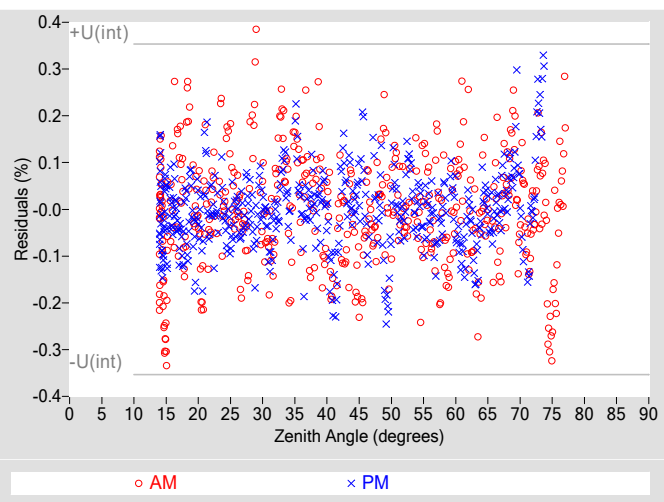


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	52498
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.96
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

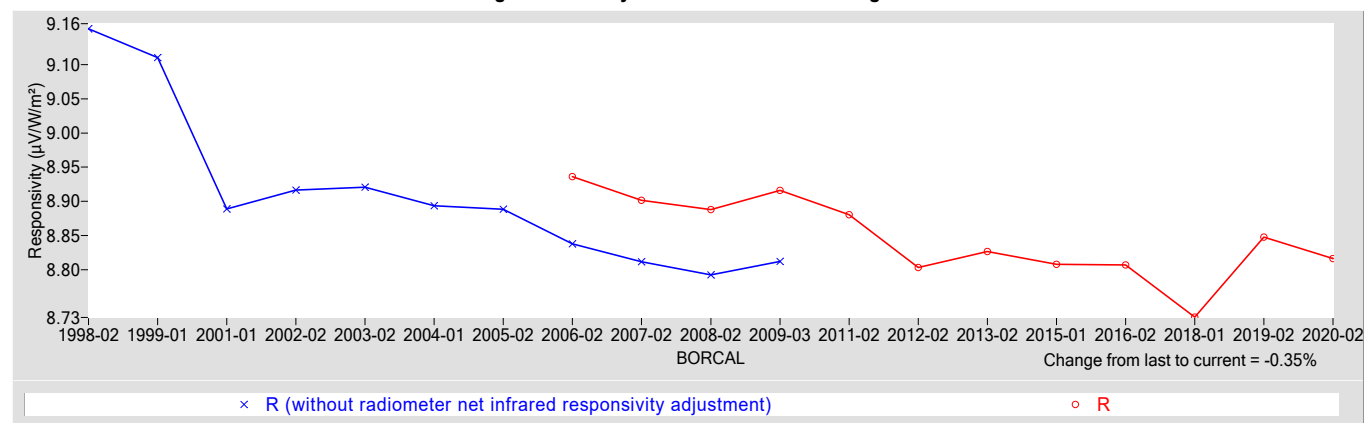
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.8164	0.61498

† R_{net} determination date: 07/06/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+1.3 / -2.7
Expanded Uncertainty, U (%)	+2.1 / -3.5
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 30956F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30956F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

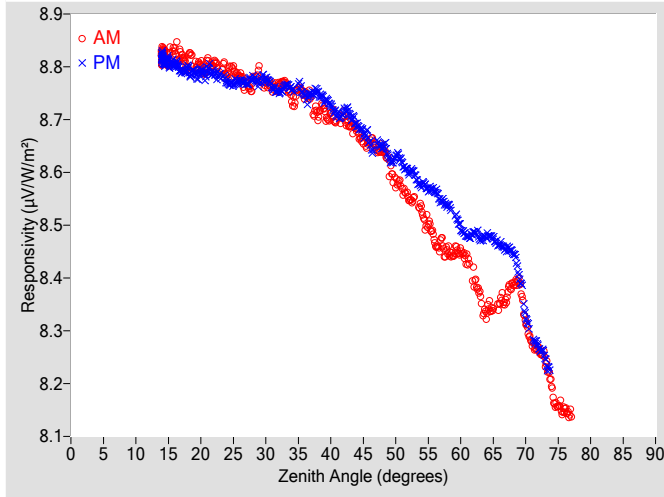


Figure 2. Responsivity vs Local Standard Time

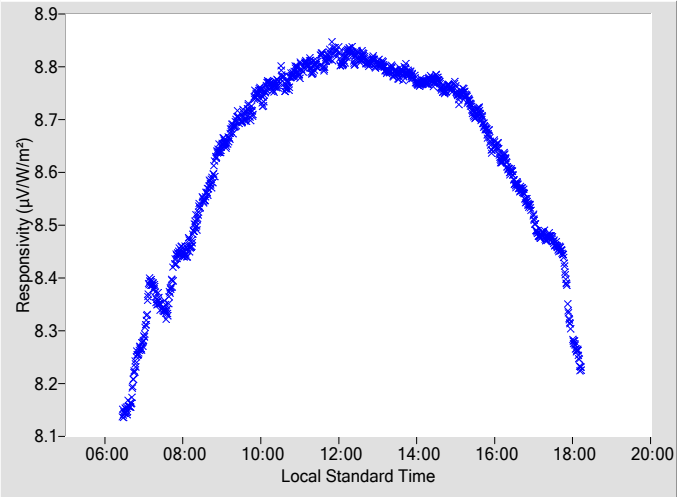


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6590	0.34	92.88	8.6550	0.32	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6427	0.32	91.34	8.6490	0.35	268.73
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5813	0.38	89.79	8.6315	0.33	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5516	0.35	88.37	8.6010	0.34	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5270	0.36	86.92	8.5771	0.35	273.13
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4682	0.39	85.54	8.5655	0.36	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4519	0.38	84.17	8.5376	0.36	275.87
14	8.8236	0.32	173.30	8.8173	0.32	187.03	60	8.4488	0.36	82.84	8.4943	0.38	277.25
16	8.8267	0.31	148.42	8.8037	0.30	211.78	62	8.3985	0.44	81.46	8.4859	0.39	278.58
18	8.8051	0.30	137.34	8.7967	0.31	222.74	64	8.3366	0.42	80.10	8.4794	N/A	279.90
20	8.8033	0.32	129.71	8.7922	0.30	230.33	66	8.3523	0.40	78.80	8.4633	N/A	281.30
22	8.8056	0.31	124.01	8.7876	0.31	236.08	68	8.3862	0.46	77.45	8.4482	N/A	282.60
24	8.7849	0.31	119.34	8.7715	0.32	240.75	70	8.3156	N/A	76.07	8.3259	N/A	283.98
26	8.7828	0.31	115.39	8.7726	0.30	244.63	72	8.2656	N/A	74.77	8.2678	N/A	285.32
28	8.7642	0.32	112.24	8.7771	0.32	247.97	74	8.1954	N/A	73.38	N/A	N/A	N/A
30	8.7690	0.33	109.13	8.7760	0.32	250.89	76	8.1508	N/A	72.00	N/A	N/A	N/A
32	8.7656	0.33	106.51	8.7535	0.30	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7407	0.32	104.08	8.7587	0.31	255.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7467	0.32	101.95	8.7452	0.32	258.14	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7100	0.32	99.86	8.7514	0.33	260.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7081	0.31	97.99	8.7281	0.31	262.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7060	0.35	96.18	8.7143	0.32	263.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6816	0.33	94.51	8.6891	0.34	265.56	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

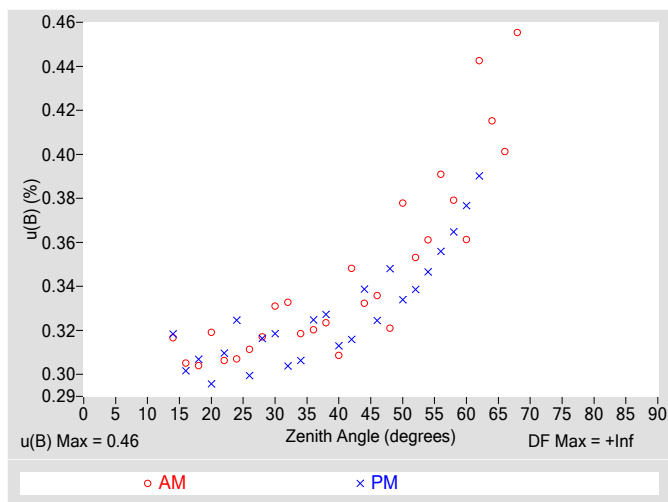


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	55252
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.95
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

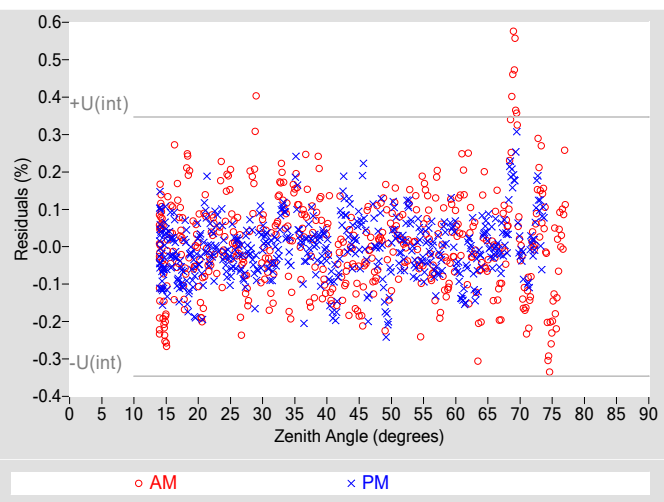


Table 4. Calibration Label Values

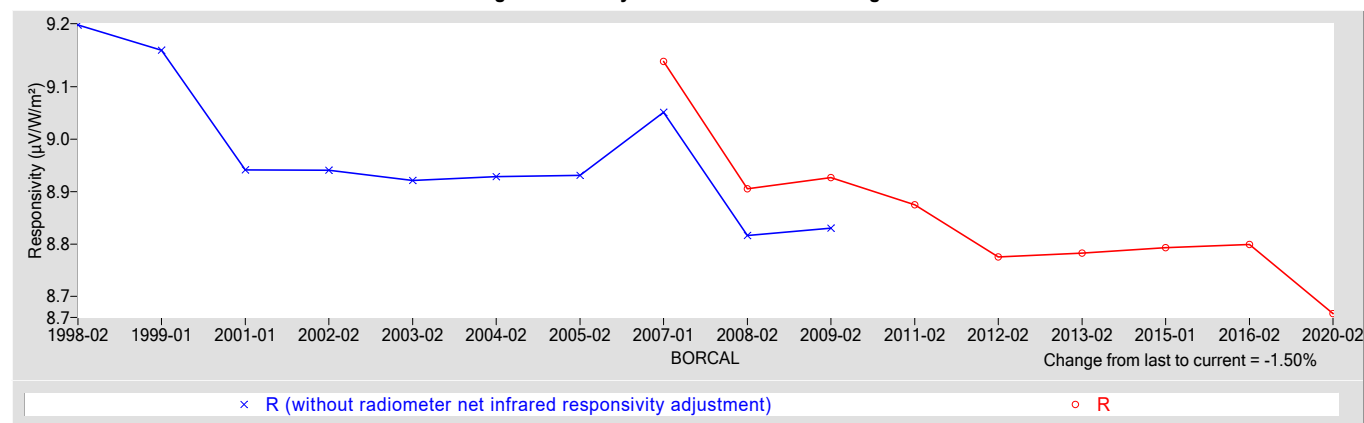
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.6671	0.57387

† R_{net} determination date: 04/26/2007

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.77
Offset Uncertainty, $U(off)$ (%)	+1.3 / -2.5
Expanded Uncertainty, U (%)	+2.0 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31099F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: Calibration System **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31099F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

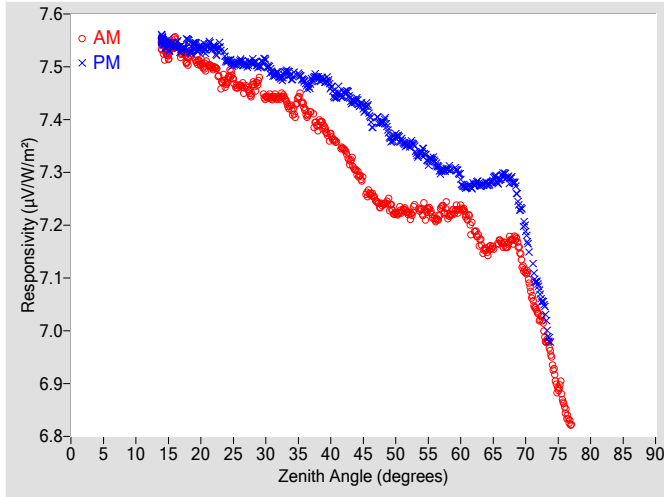


Figure 2. Responsivity vs Local Standard Time

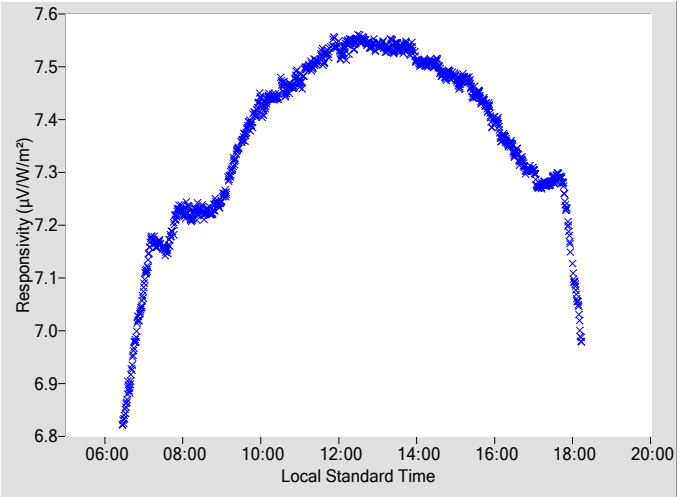


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.2600	0.34	92.86	7.4091	0.35	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2398	0.32	91.32	7.3957	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2216	0.33	89.82	7.3691	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2203	0.36	88.35	7.3524	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2255	0.36	86.99	7.3410	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2104	0.35	85.48	7.3205	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2224	0.36	84.15	7.3079	0.37	275.85
14	7.5457	0.31	173.15	7.5505	0.31	187.07	60	7.2314	0.39	82.82	7.2865	0.38	277.23
16	7.5444	0.33	148.49	7.5395	0.29	211.51	62	7.1937	0.51	81.46	7.2758	0.40	278.57
18	7.5155	0.32	137.19	7.5464	0.31	223.04	64	7.1509	0.47	80.16	7.2787	N/A	279.89
20	7.5077	0.29	129.65	7.5352	0.31	230.42	66	7.1683	0.46	78.82	7.2863	N/A	281.28
22	7.4983	0.33	123.95	7.5365	0.32	236.02	68	7.1722	0.42	77.43	7.2843	N/A	282.58
24	7.4705	0.31	119.29	7.5125	0.31	240.70	70	7.1121	N/A	76.13	7.1888	N/A	283.96
26	7.4647	0.32	115.29	7.5104	0.30	244.69	72	7.0282	N/A	74.76	7.0826	N/A	285.30
28	7.4599	0.30	112.02	7.5088	0.32	248.02	74	6.9455	N/A	73.36	6.9787	N/A	286.54
30	7.4418	0.33	109.10	7.5082	0.32	250.92	76	6.8556	N/A	71.98	N/A	N/A	N/A
32	7.4408	0.30	106.51	7.4826	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.4185	0.30	103.99	7.4802	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.4200	0.30	101.92	7.4702	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3889	0.32	99.84	7.4797	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3671	0.33	97.97	7.4608	0.32	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3443	0.31	96.21	7.4483	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2997	0.32	94.48	7.4357	0.32	265.54	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

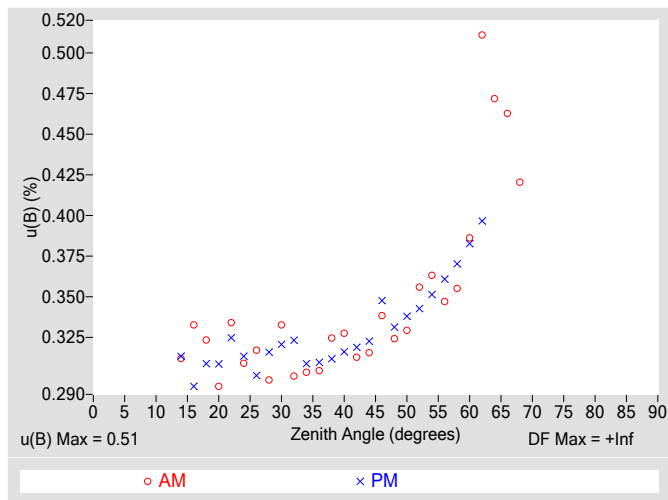


Figure 4. Residuals from Spline Interpolation

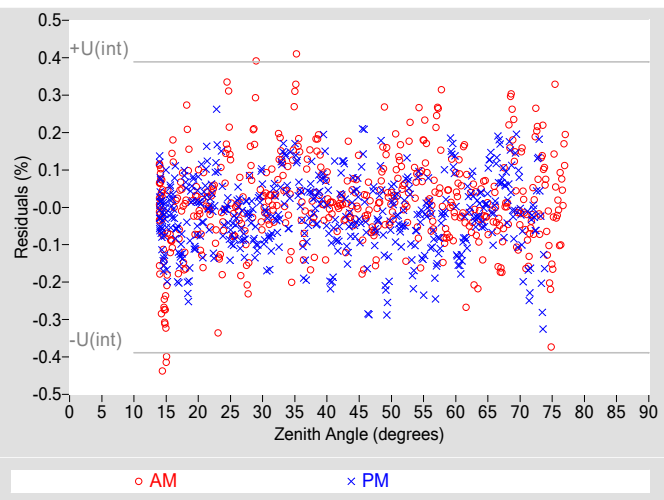


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	55076
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

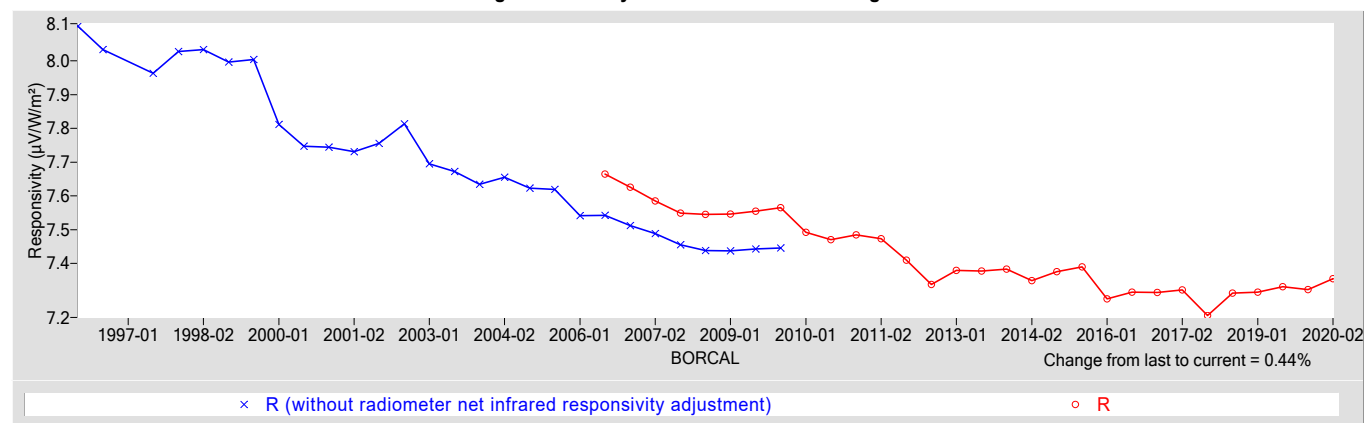
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.3546	0.57866

† R_{net} determination date: 05/08/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+2.1 / -2.0
Expanded Uncertainty, U (%)	+2.8 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31100F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: Calibration System **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31100F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

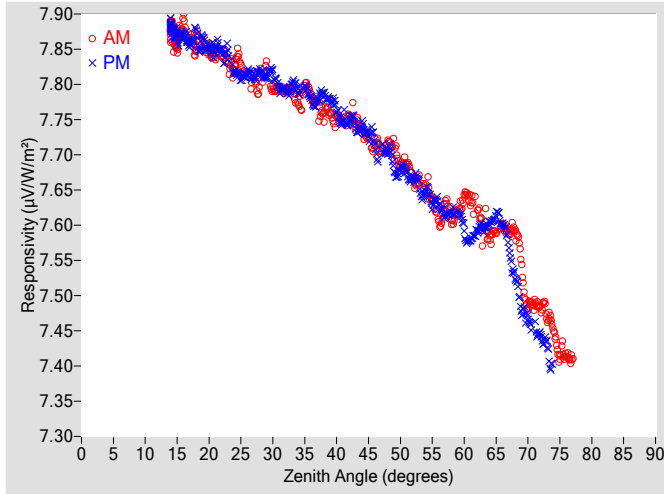


Figure 2. Responsivity vs Local Standard Time

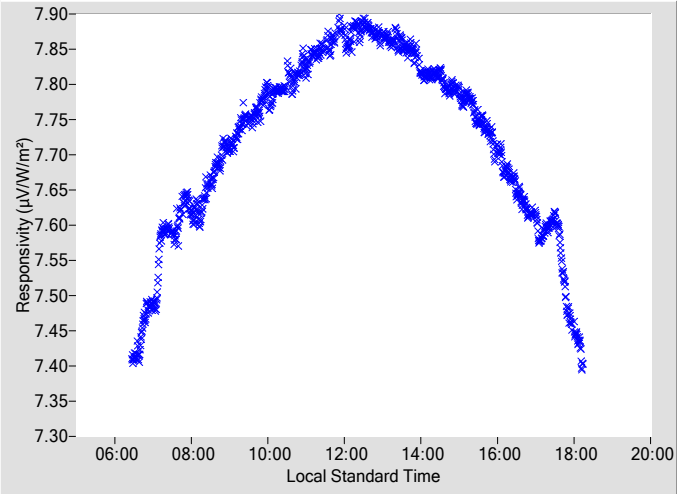


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7169	0.34	92.86	7.7151	0.35	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7164	0.33	91.32	7.7050	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6829	0.33	89.82	7.6809	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6654	0.36	88.35	7.6661	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6503	0.37	86.99	7.6493	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6023	0.35	85.48	7.6313	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6087	0.36	84.15	7.6188	0.37	275.85
14	7.8796	0.31	173.15	7.8814	0.31	187.07	60	7.6400	0.39	82.82	7.5915	0.38	277.23
16	7.8842	0.33	148.49	7.8662	0.30	211.51	62	7.6280	0.51	81.46	7.5906	0.40	278.57
18	7.8529	0.32	137.19	7.8714	0.31	223.04	64	7.5816	0.47	80.16	7.6032	N/A	279.89
20	7.8498	0.30	129.65	7.8512	0.31	230.42	66	7.5975	0.46	78.82	7.6007	N/A	281.28
22	7.8424	0.34	123.95	7.8479	0.33	236.02	68	7.5896	0.42	77.43	7.5261	N/A	282.58
24	7.8216	0.31	119.29	7.8190	0.31	240.70	70	7.4840	N/A	76.13	7.4672	N/A	283.96
26	7.8156	0.32	115.29	7.8167	0.30	244.69	72	7.4816	N/A	74.76	7.4431	N/A	285.30
28	7.8069	0.30	112.02	7.8171	0.32	248.02	74	7.4498	N/A	73.36	7.4028	N/A	286.54
30	7.7930	0.33	109.10	7.8154	0.32	250.92	76	7.4151	N/A	71.98	N/A	N/A	N/A
32	7.7898	0.30	106.51	7.7913	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7741	0.31	103.99	7.7904	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7850	0.31	101.92	7.7788	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7583	0.33	99.84	7.7868	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7516	0.33	97.97	7.7617	0.32	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7555	0.31	96.21	7.7483	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7333	0.32	94.48	7.7405	0.32	265.54	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

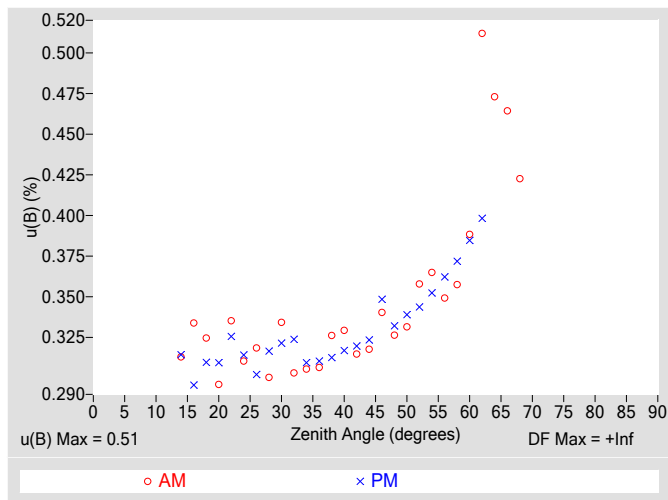


Figure 4. Residuals from Spline Interpolation

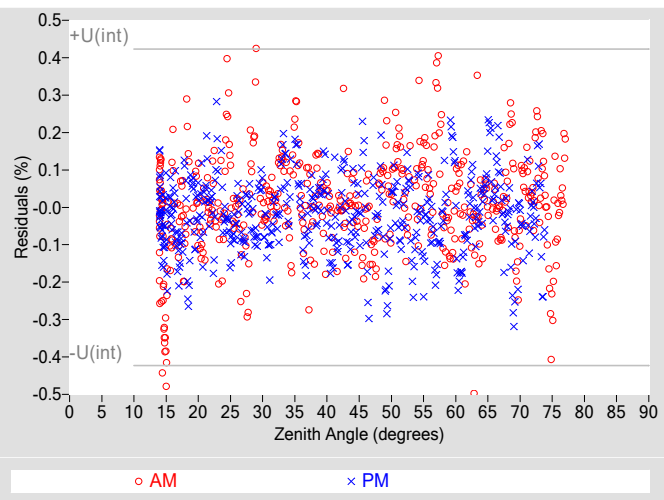


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	41640
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

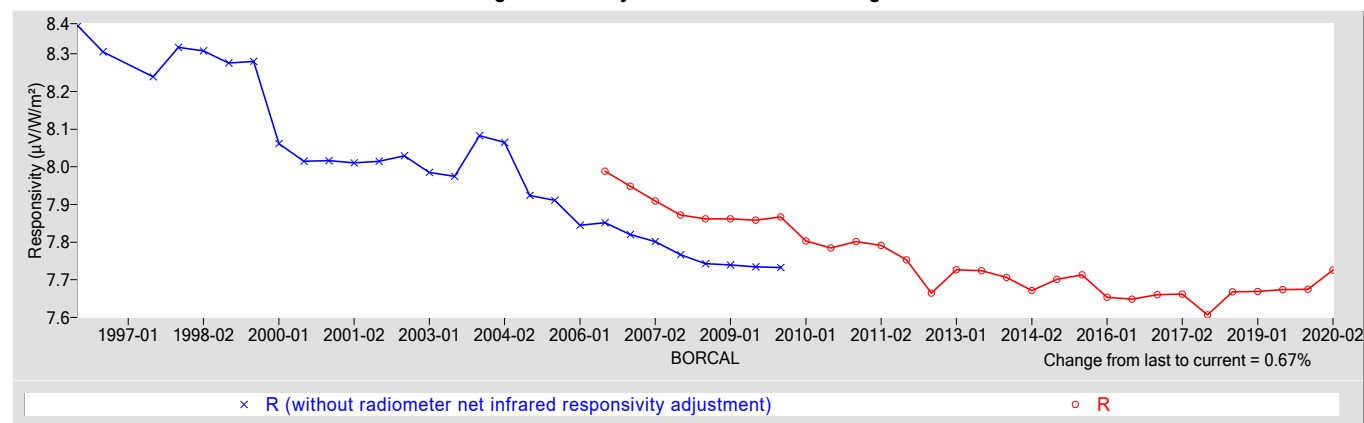
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.7260	0.64729

† R_{net} determination date: 05/09/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+1.2 / -1.7
Expanded Uncertainty, U (%)	+1.9 / -2.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31101F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: Calibration System **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31101F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

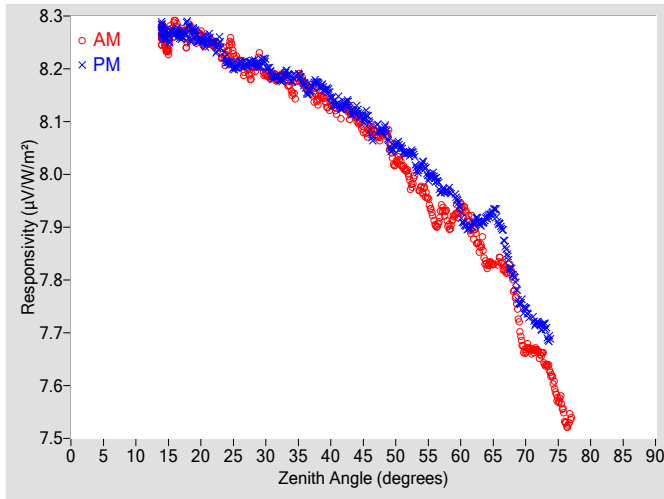


Figure 2. Responsivity vs Local Standard Time

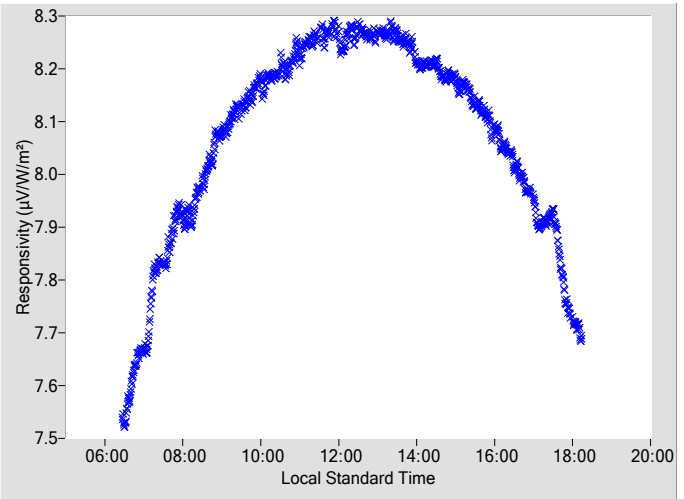


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0868	0.34	92.86	8.0940	0.35	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0788	0.32	91.32	8.0834	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0206	0.33	89.82	8.0569	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9933	0.36	88.35	8.0393	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9704	0.36	86.99	8.0198	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9050	0.35	85.48	7.9943	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9092	0.36	84.15	7.9701	0.37	275.85
14	8.2688	0.31	173.15	8.2711	0.31	187.07	60	7.9369	0.39	82.82	7.9264	0.38	277.23
16	8.2796	0.33	148.49	8.2675	0.29	211.51	62	7.8981	0.48	81.49	7.9068	0.39	278.57
18	8.2599	0.32	137.19	8.2782	0.31	223.04	64	7.8289	0.47	80.16	7.9180	N/A	279.89
20	8.2645	0.30	129.65	8.2539	0.31	230.42	66	7.8363	0.46	78.82	7.9037	N/A	281.28
22	8.2464	0.33	123.95	8.2485	0.32	236.02	68	7.7968	0.42	77.43	7.8139	N/A	282.58
24	8.2244	0.31	119.29	8.2143	0.31	240.70	70	7.6654	N/A	76.13	7.7451	N/A	283.96
26	8.2151	0.32	115.29	8.2116	0.30	244.69	72	7.6615	N/A	74.76	7.7183	N/A	285.30
28	8.2011	0.30	112.02	8.2128	0.32	248.02	74	7.6164	N/A	73.36	7.6885	N/A	286.54
30	8.1896	0.33	109.10	8.2107	0.32	250.92	76	7.5393	N/A	71.98	N/A	N/A	N/A
32	8.1812	0.30	106.51	8.1814	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1588	0.31	103.99	8.1801	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1714	0.31	101.92	8.1662	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1422	0.33	99.84	8.1738	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1331	0.33	97.97	8.1459	0.32	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1299	0.31	96.21	8.1302	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1049	0.32	94.48	8.1216	0.32	265.54	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

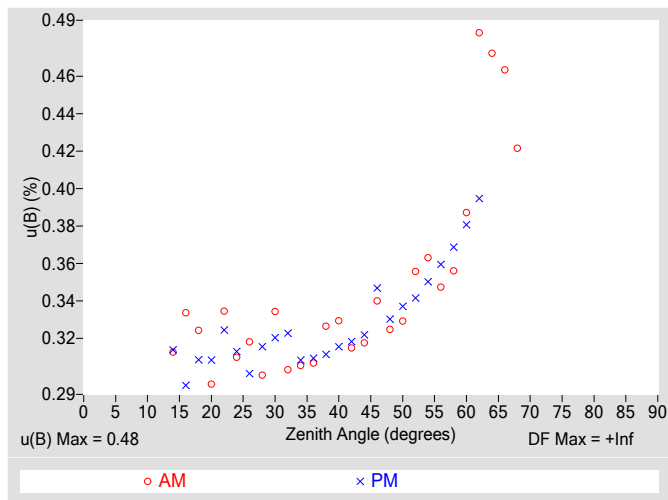


Figure 4. Residuals from Spline Interpolation

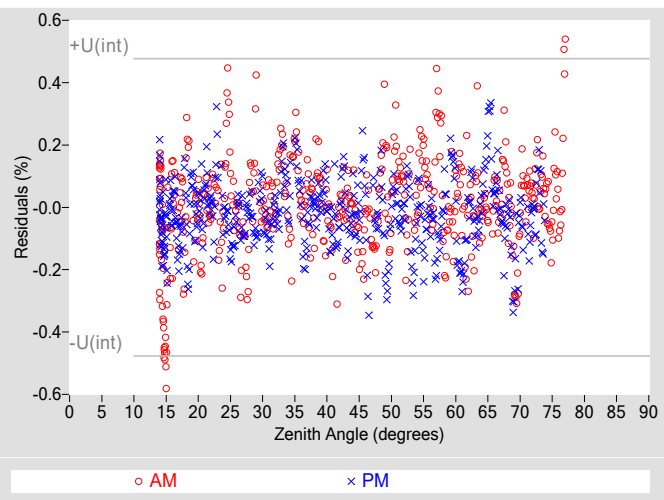


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.48
Type-A Interpolating Function, $u(int)$ (%)	± 0.24
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	23153
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

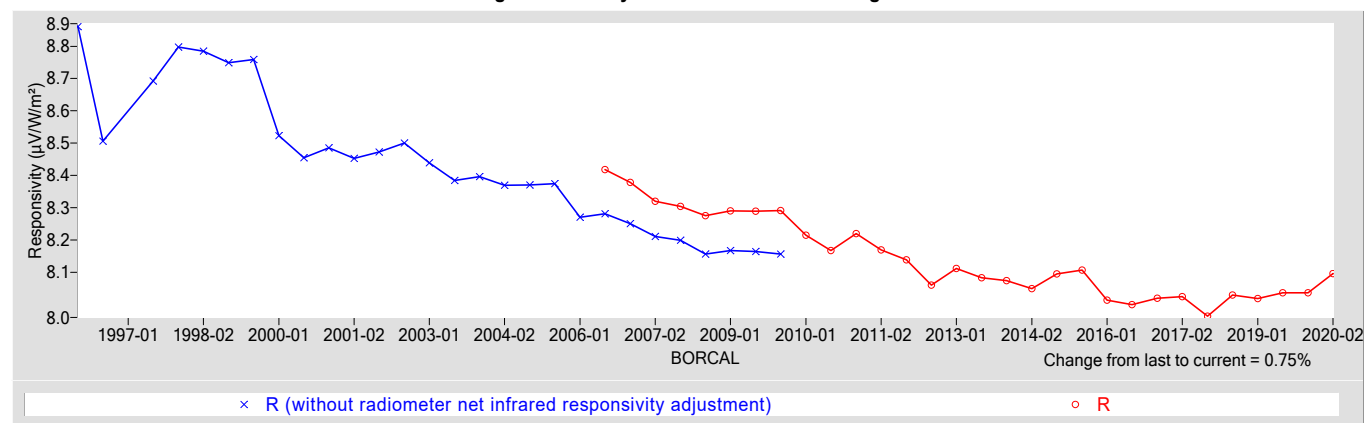
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0962	0.64834

† R_{net} determination date: 05/09/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+1.4 / -2.4
Expanded Uncertainty, U (%)	+2.2 / -3.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: Calibration System
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31120E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31120E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

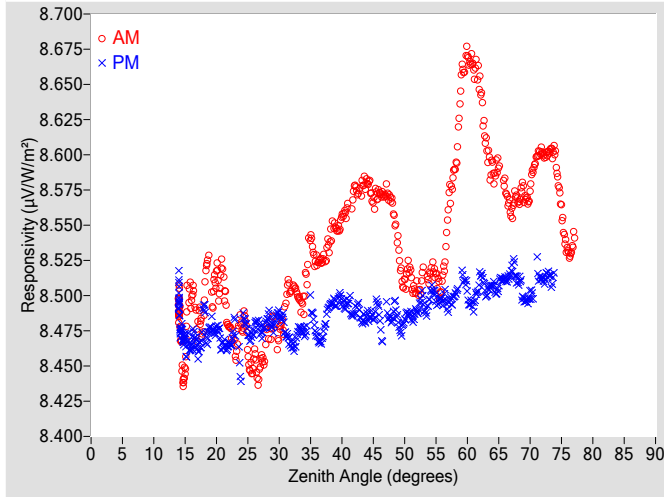


Figure 2. Responsivity vs Local Standard Time

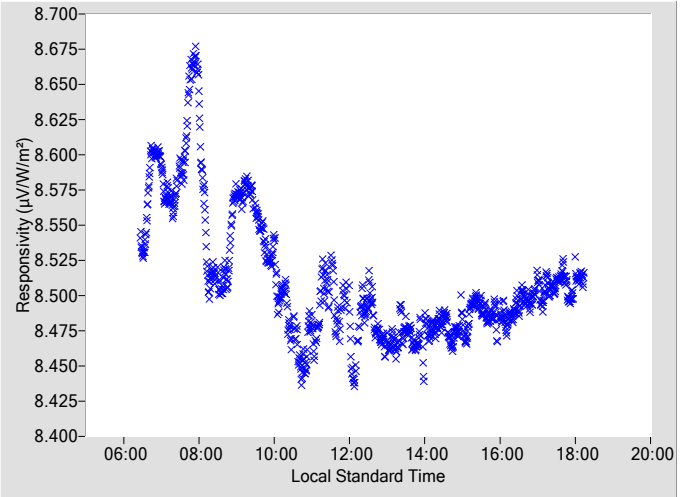


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5723	0.30	92.93	8.4861	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5649	0.31	91.34	8.4840	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5083	0.33	89.84	8.4829	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5035	0.31	88.44	8.4892	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5143	0.32	86.96	8.4987	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5102	0.29	85.58	8.4963	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5894	0.33	84.21	8.5011	0.30	275.91
14	8.4911	0.30	173.58	8.4907	0.30	186.76	60	8.6701	0.34	82.80	8.5023	0.30	277.21
16	8.5008	0.32	147.89	8.4651	0.29	211.91	62	8.6505	0.33	81.47	8.5111	0.30	278.54
18	8.4879	0.30	137.34	8.4881	0.30	223.07	64	8.5885	0.32	80.14	8.5077	N/A	279.95
20	8.5141	0.32	129.72	8.4753	0.30	230.33	66	8.5775	0.32	78.80	8.5116	N/A	281.26
22	8.4782	0.31	123.88	8.4651	0.30	236.21	68	8.5687	0.30	77.49	8.5106	N/A	282.64
24	8.4789	0.33	119.23	8.4564	0.29	240.68	70	8.5746	N/A	76.11	8.5002	N/A	283.94
26	8.4538	0.29	115.39	8.4766	0.33	244.63	72	8.6011	N/A	74.74	8.5112	N/A	285.32
28	8.4732	0.31	112.06	8.4834	0.30	248.06	74	8.5974	N/A	73.34	8.5161	N/A	286.52
30	8.4740	0.31	109.05	8.4867	0.32	250.97	76	8.5308	N/A	71.96	N/A	N/A	N/A
32	8.5044	0.33	106.49	8.4646	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4992	0.29	104.15	8.4739	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5243	0.30	101.89	8.4717	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5385	0.29	99.92	8.4930	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5558	0.31	98.00	8.4963	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5752	0.32	96.23	8.4881	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5793	0.29	94.56	8.4849	0.29	265.51	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

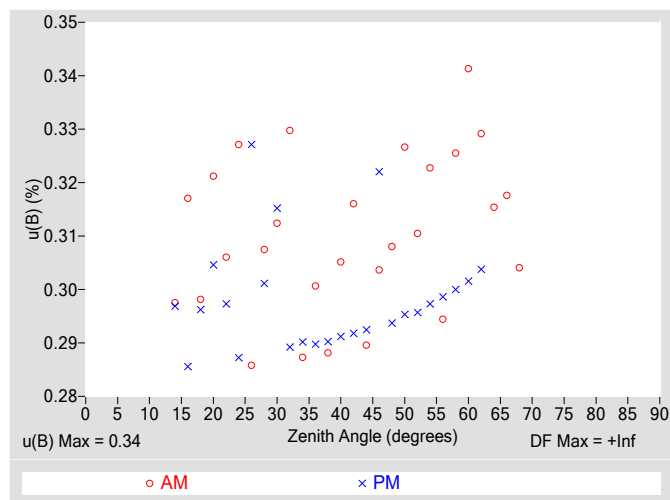


Figure 4. Residuals from Spline Interpolation

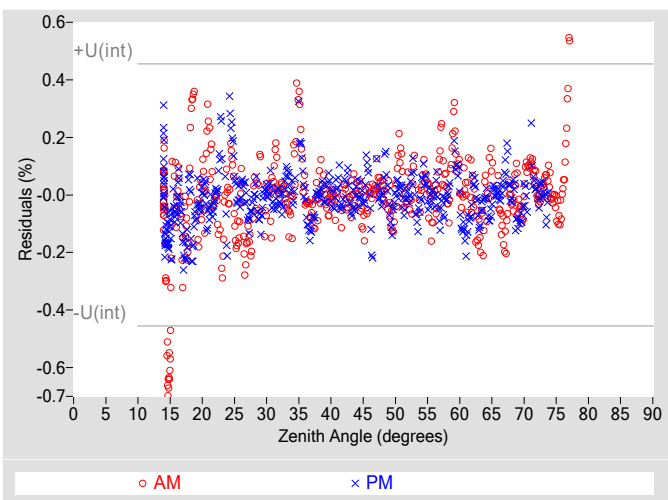


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.41
Effective degrees of freedom, $DF(c)$	9305
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.80
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

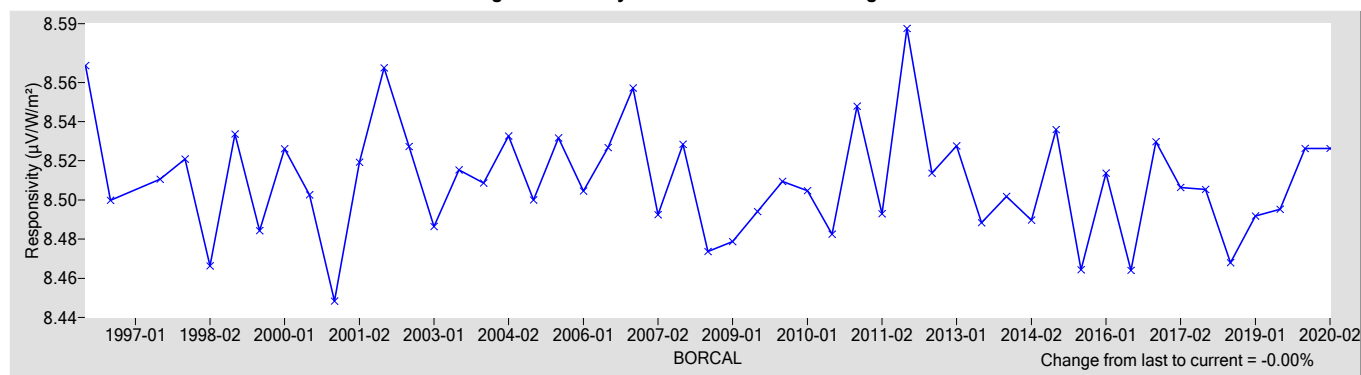
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5263	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.7 / -0.72
Expanded Uncertainty, U (%)	+2.4 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 31121E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: Calibration System
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31121E6 Eppley NIP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of pyrgeometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

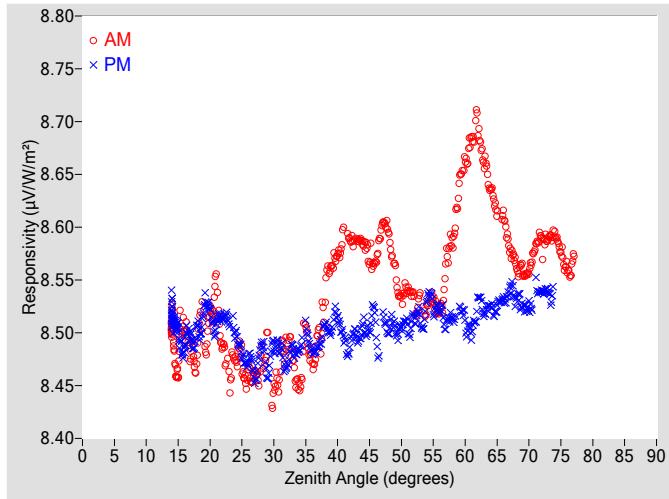


Figure 2. Responsivity vs Local Standard Time

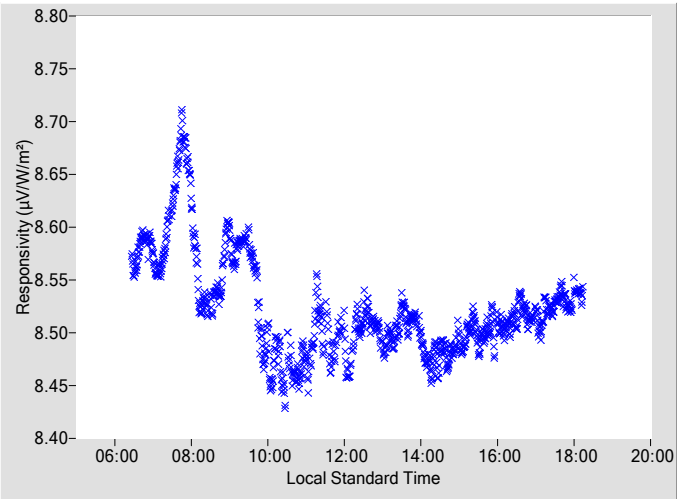


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5680	0.30	92.93	8.5070	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5931	0.31	91.34	8.5007	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5333	0.33	89.84	8.5056	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5323	0.31	88.44	8.5134	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5226	0.32	86.96	8.5303	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5220	0.29	85.58	8.5221	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5874	0.33	84.21	8.5131	0.30	275.91
14	8.5067	0.30	173.58	8.5169	0.30	186.76	60	8.6614	0.34	82.80	8.5092	0.30	277.21
16	8.5046	0.32	147.89	8.4883	0.29	211.91	62	8.6963	0.33	81.47	8.5262	0.30	278.54
18	8.4810	0.30	137.34	8.5055	0.30	223.07	64	8.6362	0.32	80.14	8.5252	N/A	279.95
20	8.5181	0.32	129.72	8.5207	0.30	230.33	66	8.6094	0.32	78.80	8.5315	N/A	281.26
22	8.4877	0.31	123.88	8.5138	0.30	236.21	68	8.5649	0.30	77.49	8.5316	N/A	282.64
24	8.4735	0.33	119.23	8.4986	0.29	240.76	70	8.5594	N/A	76.11	8.5244	N/A	283.94
26	8.4603	0.29	115.39	8.4742	0.33	244.63	72	8.5907	N/A	74.76	8.5388	N/A	285.32
28	8.4765	0.31	112.06	8.4874	0.30	248.06	74	8.5926	N/A	73.34	8.5438	N/A	286.52
30	8.4437	0.31	109.05	8.4864	0.32	250.97	76	8.5609	N/A	71.96	N/A	N/A	N/A
32	8.4860	0.33	106.49	8.4678	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4498	0.29	104.15	8.4852	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4734	0.30	101.89	8.4827	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5239	0.29	99.92	8.5075	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5747	0.31	98.00	8.5139	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5888	0.32	96.23	8.4889	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5853	0.29	94.56	8.5057	0.29	265.51	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

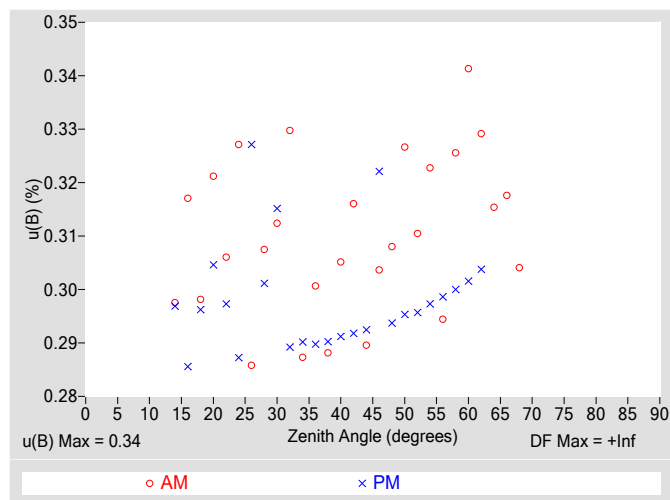


Figure 4. Residuals from Spline Interpolation

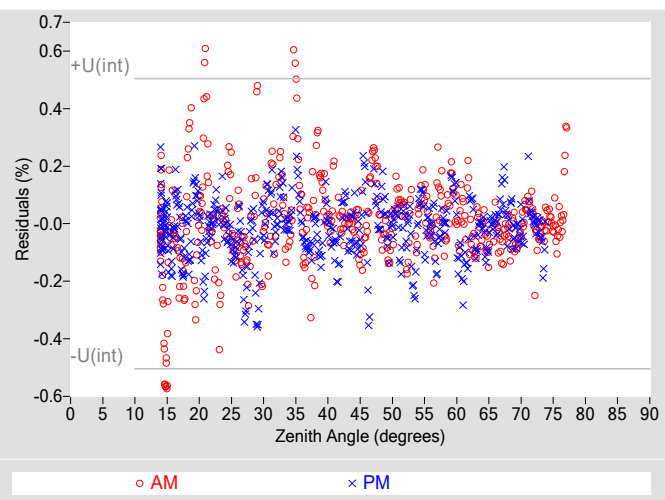


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.25
Combined Standard Uncertainty, $u(c)$ (%)	± 0.42
Effective degrees of freedom, $DF(c)$	7090
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.83
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

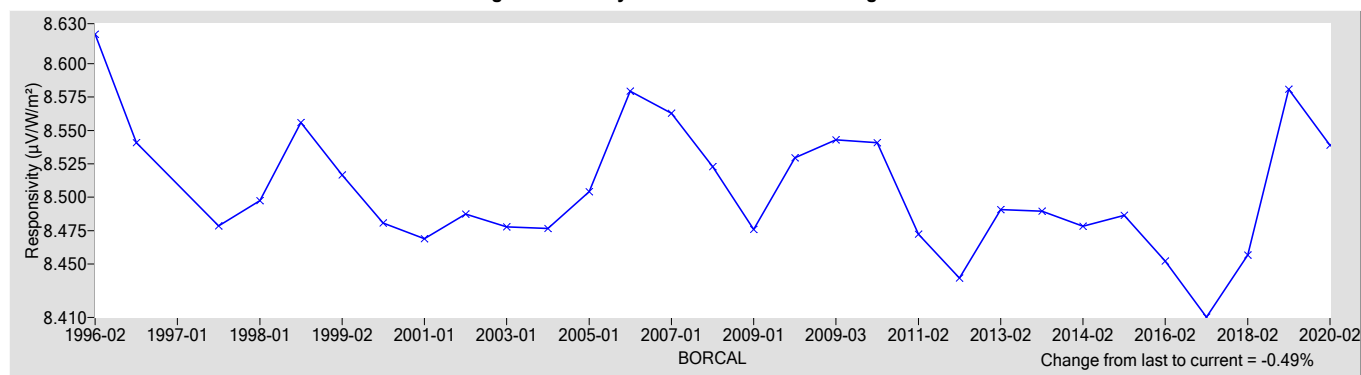
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5389	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.4 / -1.1
Expanded Uncertainty, U (%)	+2.1 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31146F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: Calibration System **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31146F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

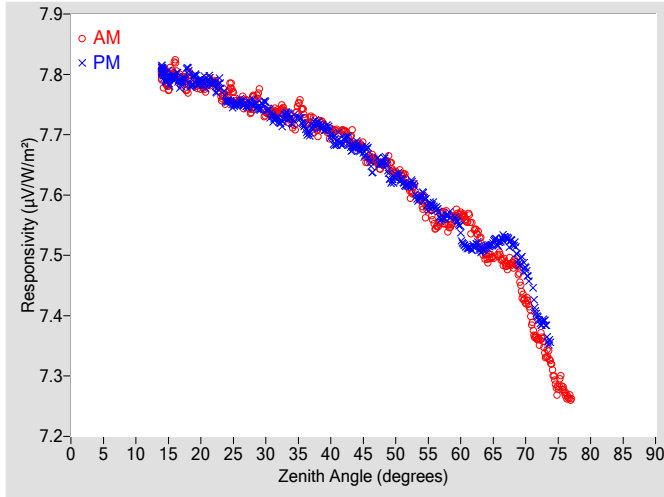


Figure 2. Responsivity vs Local Standard Time

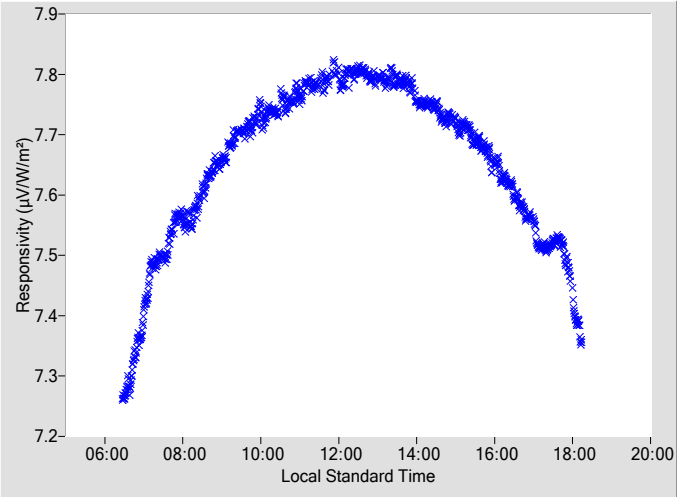


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6609	0.34	92.86	7.6605	0.35	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6522	0.32	91.32	7.6548	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6351	0.33	89.82	7.6316	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6096	0.35	88.35	7.6162	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5878	0.36	86.99	7.5998	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5470	0.35	85.48	7.5806	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5520	0.35	84.15	7.5677	0.37	275.85
14	7.8021	0.31	173.38	7.8053	0.31	187.07	60	7.5670	0.39	82.82	7.5360	0.38	277.23
16	7.8086	0.33	148.49	7.7931	0.29	211.51	62	7.5467	0.51	81.46	7.5135	0.39	278.57
18	7.7826	0.32	137.19	7.8036	0.31	223.04	64	7.4953	0.47	80.16	7.5141	N/A	279.89
20	7.7827	0.29	129.65	7.7871	0.31	230.42	66	7.5000	0.46	78.82	7.5226	N/A	281.28
22	7.7868	0.33	123.95	7.7843	0.32	236.02	68	7.4864	0.42	77.43	7.5205	N/A	282.58
24	7.7611	0.31	119.29	7.7570	0.31	240.70	70	7.4250	N/A	76.13	7.4776	N/A	283.96
26	7.7559	0.32	115.29	7.7542	0.30	244.69	72	7.3590	N/A	74.76	7.3939	N/A	285.30
28	7.7551	0.30	112.02	7.7519	0.31	248.02	74	7.3152	N/A	73.36	7.3561	N/A	286.54
30	7.7341	0.33	109.10	7.7490	0.32	250.92	76	7.2744	N/A	71.98	N/A	N/A	N/A
32	7.7379	0.30	106.51	7.7233	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7222	0.30	103.99	7.7229	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7300	0.30	101.92	7.7113	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7096	0.32	99.84	7.7182	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7040	0.33	97.97	7.6997	0.31	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7070	0.31	96.21	7.6895	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6819	0.31	94.48	7.6829	0.32	265.54	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

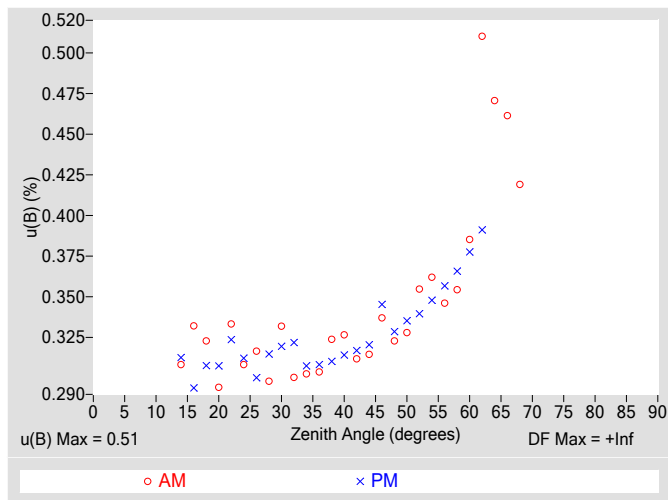


Figure 4. Residuals from Spline Interpolation

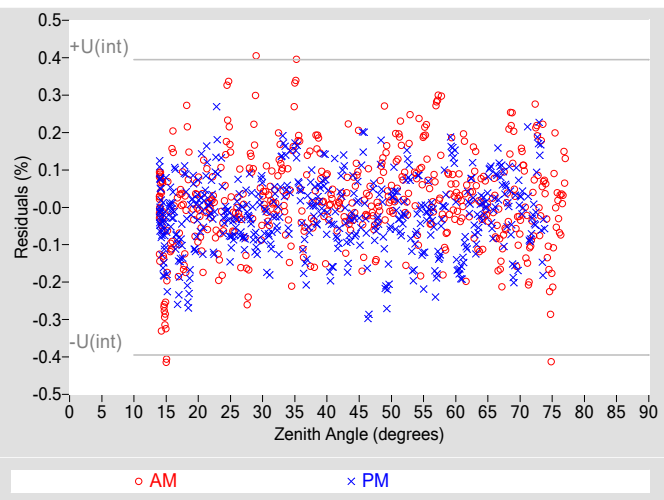


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	51656
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

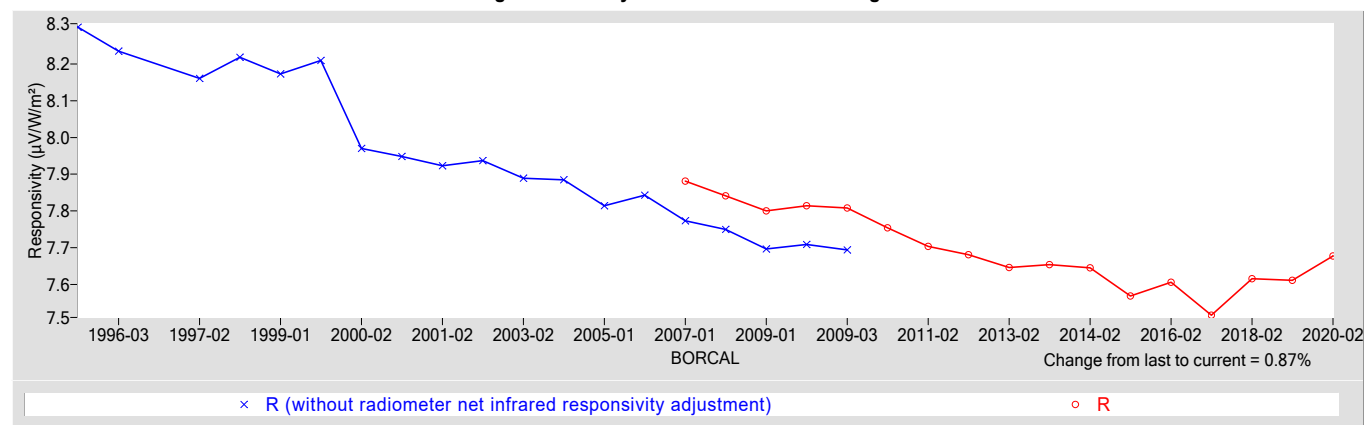
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.6774	0.54900

† R_{net} determination date: 03/30/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+0.93 / -1.8
Expanded Uncertainty, U (%)	+1.7 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31147F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: Calibration System **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31147F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

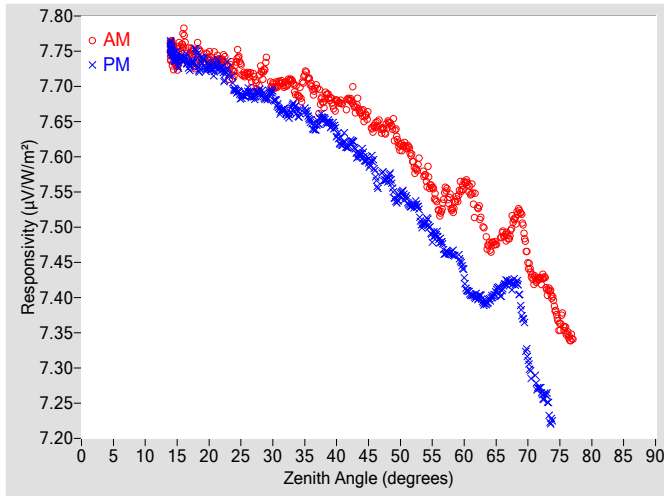


Figure 2. Responsivity vs Local Standard Time

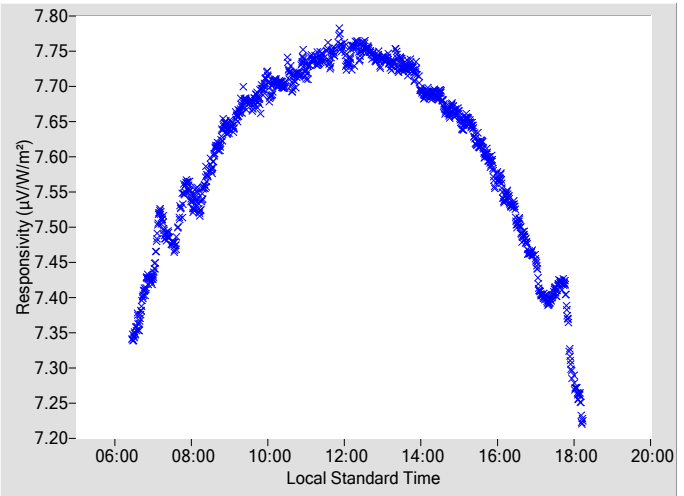


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6443	0.34	92.86	7.5795	0.35	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6469	0.32	91.32	7.5688	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6135	0.33	89.82	7.5478	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5904	0.36	88.35	7.5305	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5685	0.36	86.99	7.5086	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5211	0.35	85.48	7.4850	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5288	0.35	84.15	7.4640	0.37	275.85
14	7.7530	0.31	173.38	7.7529	0.31	187.07	60	7.5607	0.39	82.82	7.4284	0.38	277.23
16	7.7652	0.33	148.49	7.7374	0.29	211.51	62	7.5342	0.51	81.46	7.4002	0.39	278.57
18	7.7382	0.32	137.19	7.7451	0.31	223.04	64	7.4718	0.47	80.16	7.3968	N/A	279.89
20	7.7407	0.29	129.65	7.7263	0.31	230.42	66	7.4888	0.46	78.82	7.4120	N/A	281.28
22	7.7391	0.33	123.95	7.7242	0.32	236.02	68	7.5124	0.42	77.43	7.4212	N/A	282.58
24	7.7220	0.31	119.29	7.6967	0.31	240.70	70	7.4540	N/A	76.13	7.3115	N/A	283.96
26	7.7186	0.32	115.29	7.6923	0.30	244.69	72	7.4255	N/A	74.76	7.2684	N/A	285.30
28	7.7135	0.30	112.02	7.6913	0.31	248.02	74	7.3929	N/A	73.36	7.2251	N/A	286.54
30	7.7005	0.33	109.10	7.6879	0.32	250.92	76	7.3529	N/A	71.98	N/A	N/A	N/A
32	7.7012	0.30	106.51	7.6629	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6895	0.30	103.99	7.6606	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7027	0.30	101.92	7.6480	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6799	0.32	99.84	7.6548	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6764	0.33	97.97	7.6315	0.31	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6818	0.31	96.21	7.6182	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6605	0.32	94.48	7.6053	0.32	265.54	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

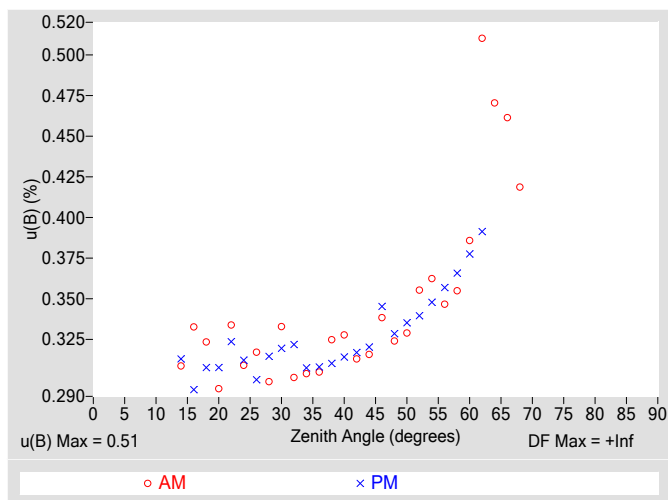


Figure 4. Residuals from Spline Interpolation

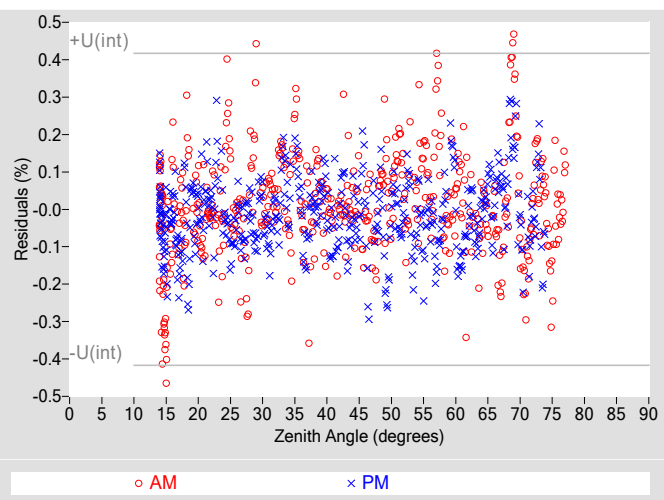


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	42872
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

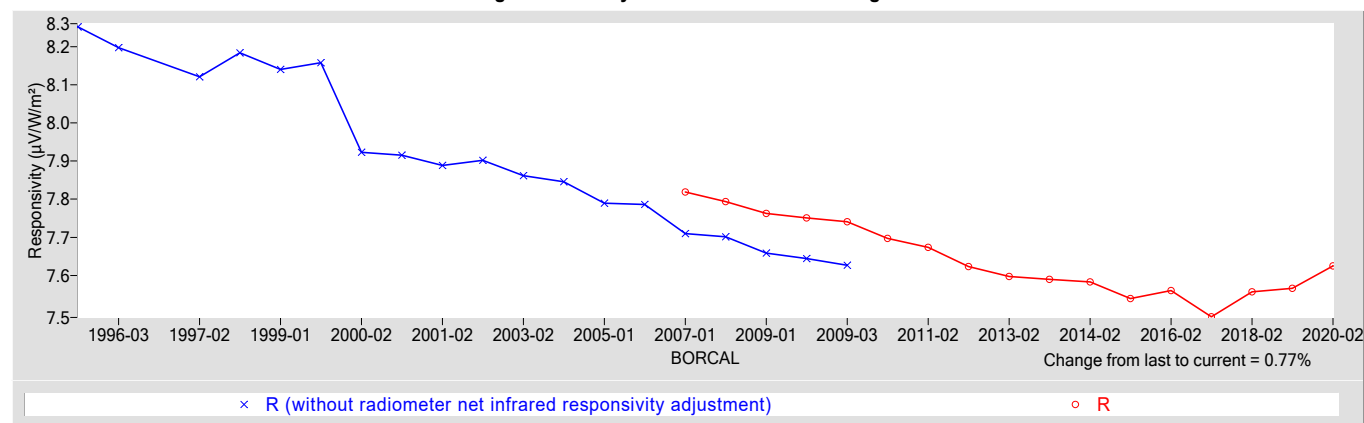
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.6253	0.55100

† R_{net} determination date: 03/30/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+1.0 / -2.6
Expanded Uncertainty, U (%)	+1.8 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31148F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: Calibration System **Environmental Conditions:** see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31148F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

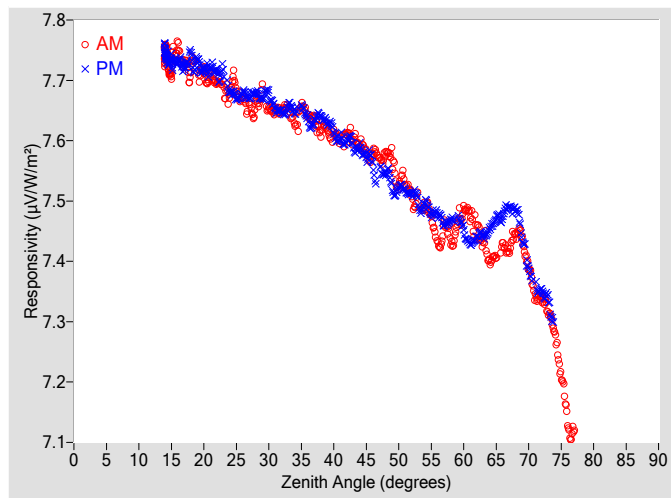


Figure 2. Responsivity vs Local Standard Time

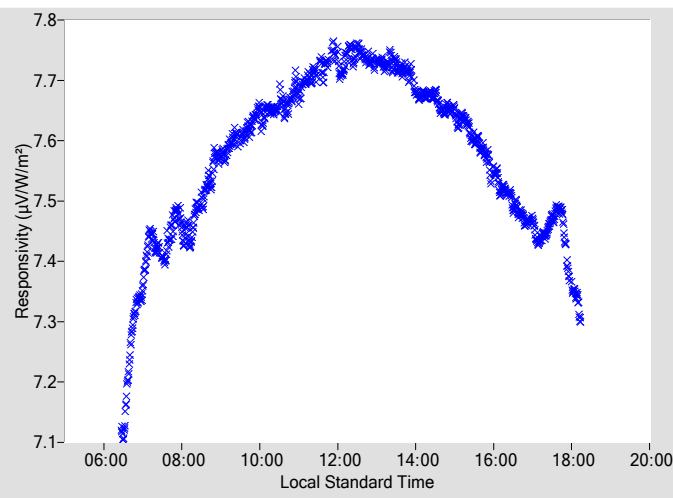


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5803	0.34	92.86	7.5598	0.34	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5793	0.32	91.32	7.5465	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5263	0.33	89.82	7.5232	0.33	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5066	0.35	88.35	7.5116	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4897	0.36	86.99	7.4969	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4287	0.34	85.48	7.4783	0.35	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4367	0.35	84.15	7.4688	0.36	275.85
14	7.7455	0.31	173.15	7.7457	0.31	187.07	60	7.4823	0.39	82.82	7.4502	0.37	277.23
16	7.7498	0.33	148.49	7.7301	0.29	211.51	62	7.4589	0.48	81.49	7.4387	0.39	278.57
18	7.7154	0.32	137.19	7.7399	0.31	223.04	64	7.3997	0.47	80.16	7.4532	N/A	279.89
20	7.7155	0.29	129.65	7.7177	0.31	230.42	66	7.4244	0.46	78.82	7.4743	N/A	281.28
22	7.6979	0.33	123.95	7.7147	0.32	236.02	68	7.4446	0.42	77.43	7.4852	N/A	282.58
24	7.6769	0.31	119.29	7.6829	0.31	240.70	70	7.3915	N/A	76.13	7.3884	N/A	283.96
26	7.6697	0.32	115.29	7.6797	0.30	244.69	72	7.3373	N/A	74.76	7.3518	N/A	285.30
28	7.6598	0.30	112.02	7.6792	0.31	248.02	74	7.2792	N/A	73.36	7.2992	N/A	286.54
30	7.6518	0.33	109.10	7.6758	0.32	250.92	76	7.1371	N/A	71.98	N/A	N/A	N/A
32	7.6489	0.30	106.51	7.6471	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6315	0.30	103.99	7.6476	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6431	0.31	101.92	7.6348	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6174	0.32	99.84	7.6415	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6103	0.33	97.97	7.6127	0.31	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6117	0.31	96.21	7.6004	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5940	0.32	94.48	7.5881	0.32	265.54	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

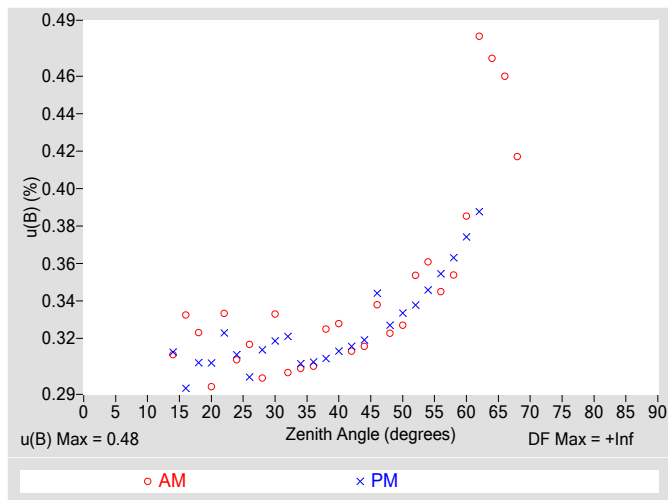


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.48
Type-A Interpolating Function, $u(int)$ (%)	± 0.25
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	18802
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

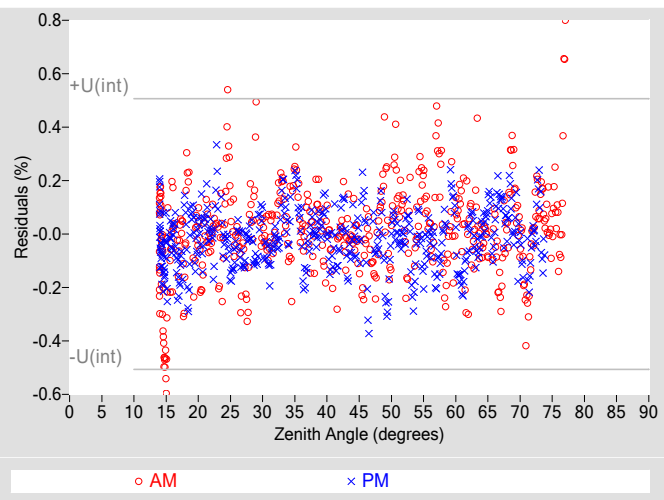


Table 4. Calibration Label Values

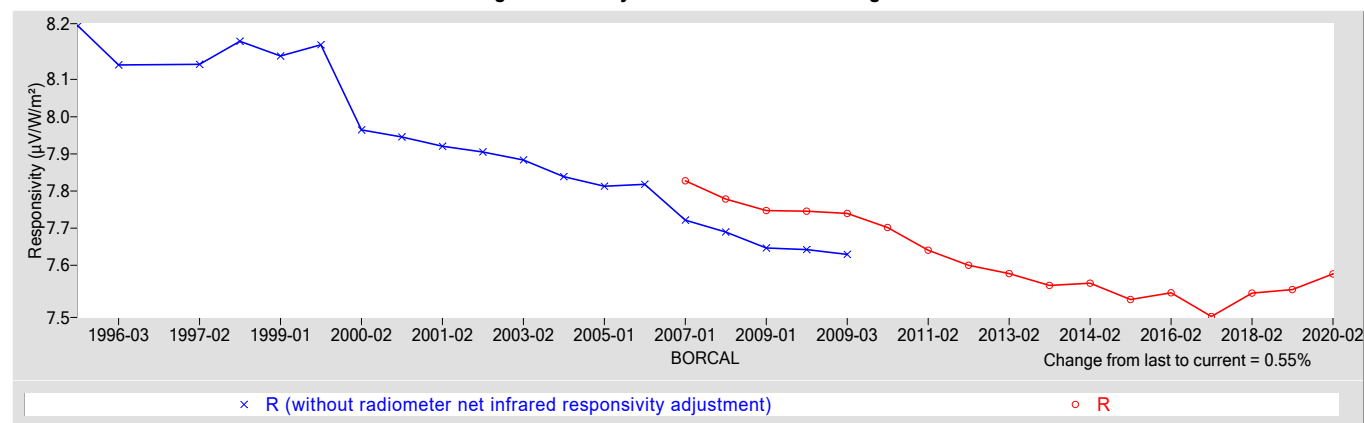
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.5769	0.53300

† R_{net} determination date: 03/30/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+1.3 / -2.0
Expanded Uncertainty, U (%)	+2.1 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: Calibration System
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31152F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31152F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

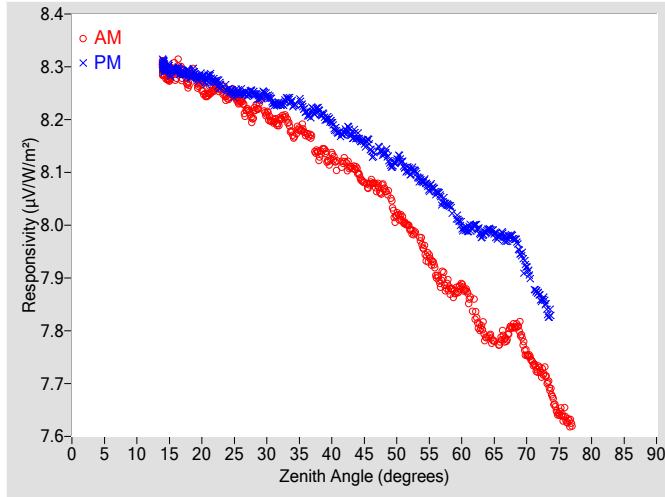


Figure 2. Responsivity vs Local Standard Time

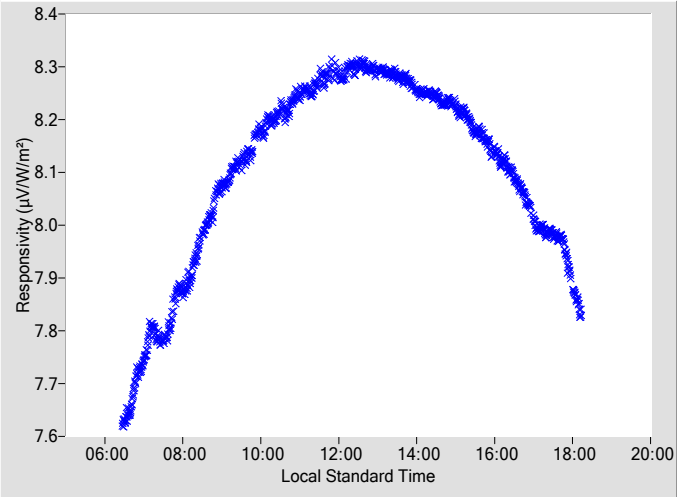


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0804	0.36	92.89	8.1417	0.33	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0713	0.32	91.34	8.1351	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0169	0.33	89.84	8.1248	0.34	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9948	0.36	88.38	8.1011	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9627	0.34	86.93	8.0835	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9109	0.37	85.55	8.0633	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8831	0.36	84.18	8.0375	0.37	275.87
14	8.2999	0.30	173.34	8.3025	0.33	187.72	60	7.8850	0.42	82.85	7.9967	0.38	277.25
16	8.2904	0.36	148.27	8.2932	0.30	211.82	62	7.8394	0.43	81.43	8.0004	0.40	278.59
18	8.2740	0.29	137.12	8.2905	0.33	222.71	64	7.7888	0.39	80.10	7.9915	N/A	279.91
20	8.2645	0.32	129.74	8.2821	0.30	230.36	66	7.7847	0.44	78.76	7.9815	N/A	281.22
22	8.2577	0.33	124.11	8.2723	0.30	236.10	68	7.8076	0.43	77.45	7.9751	N/A	282.61
24	8.2410	0.34	119.19	8.2560	0.30	240.77	70	7.7554	N/A	76.07	7.9187	N/A	283.99
26	8.2343	0.31	115.41	8.2511	0.31	244.65	72	7.7237	N/A	74.74	7.8643	N/A	285.33
28	8.2091	0.35	112.07	8.2495	0.30	247.98	74	7.6754	N/A	73.39	7.8289	N/A	286.48
30	8.2120	0.33	109.15	8.2454	0.30	250.91	76	7.6370	N/A	72.01	N/A	N/A	N/A
32	8.1972	0.35	106.52	8.2289	0.31	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1717	0.34	104.10	8.2297	0.33	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1738	0.31	101.99	8.2140	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1339	0.31	99.87	8.2178	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1298	0.31	97.95	8.1944	0.32	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1208	0.31	96.22	8.1769	0.34	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1021	0.34	94.52	8.1659	0.36	265.57	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

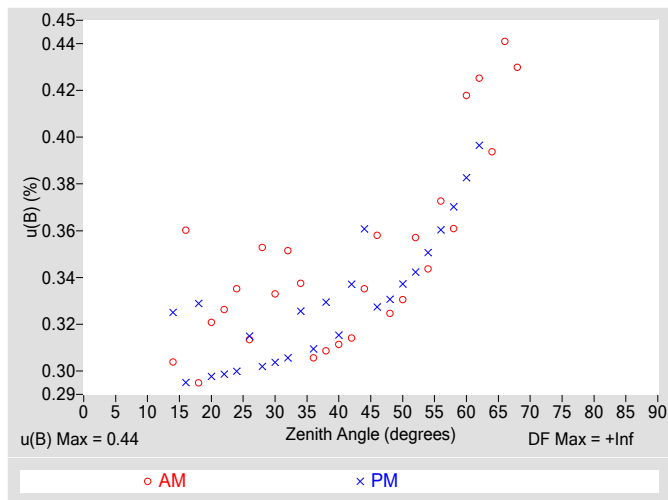


Figure 4. Residuals from Spline Interpolation

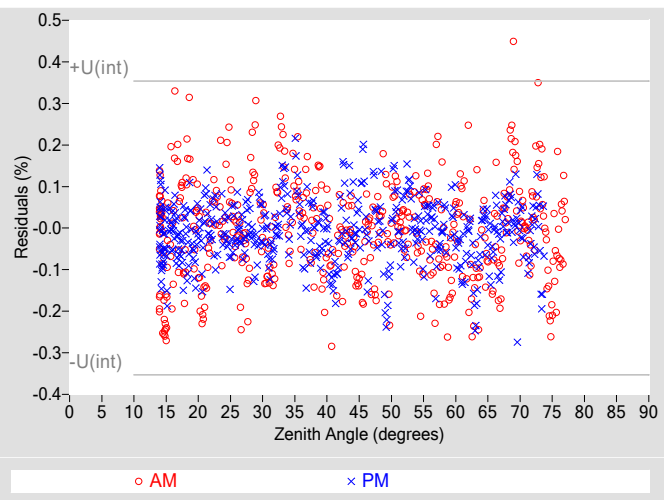


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.44
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	45648
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.93
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

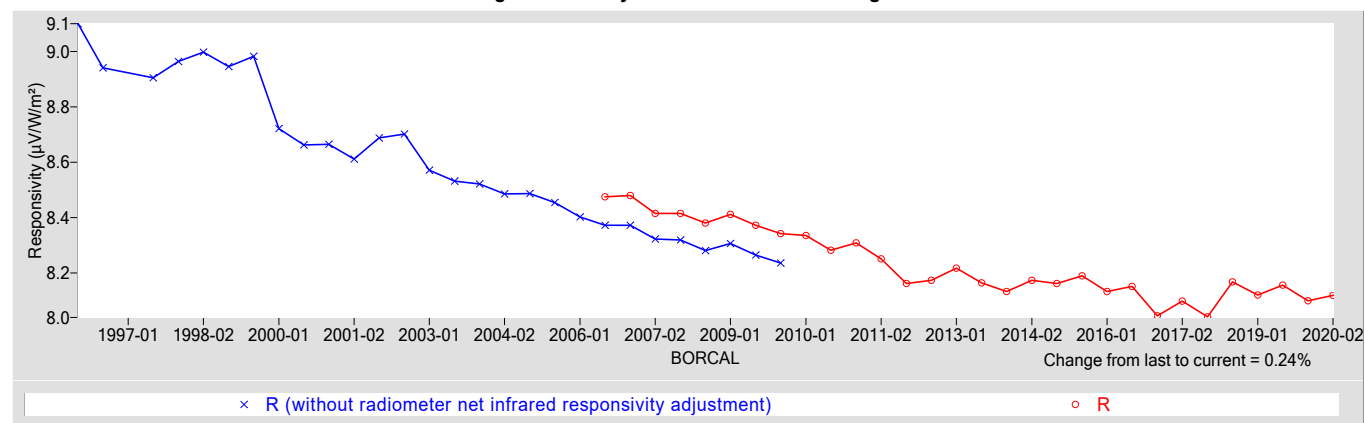
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.1191	0.63390

† R_{net} determination date: 05/09/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	+1.6 / -2.9
Expanded Uncertainty, U (%)	+2.4 / -3.7
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: Calibration System
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31153F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31153F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

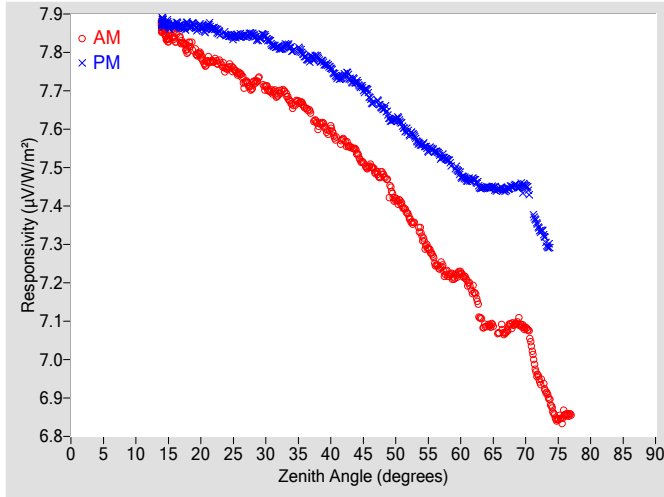


Figure 2. Responsivity vs Local Standard Time

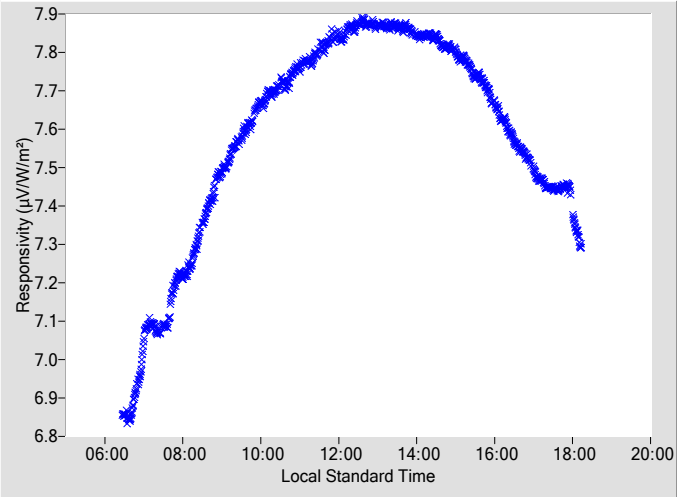


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5033	0.36	92.89	7.6812	0.33	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4837	0.33	91.34	7.6533	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4161	0.33	89.84	7.6272	0.34	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3737	0.36	88.38	7.5893	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3243	0.35	86.93	7.5602	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2549	0.38	85.55	7.5429	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2236	0.37	84.18	7.5205	0.37	275.87
14	7.8669	0.30	173.34	7.8771	0.32	187.98	60	7.2261	0.42	82.85	7.4787	0.39	277.25
16	7.8380	0.36	148.27	7.8699	0.30	211.82	62	7.1782	0.42	81.47	7.4698	0.40	278.59
18	7.8118	0.30	137.12	7.8731	0.33	222.71	64	7.0877	0.40	80.10	7.4491	N/A	279.91
20	7.7921	0.32	129.74	7.8680	0.30	230.36	66	7.0769	0.47	78.79	7.4450	N/A	281.22
22	7.7781	0.33	124.11	7.8619	0.30	236.10	68	7.0899	0.44	77.45	7.4509	N/A	282.61
24	7.7576	0.34	119.19	7.8445	0.30	240.77	70	7.0807	N/A	76.07	7.4521	N/A	283.99
26	7.7444	0.31	115.41	7.8432	0.32	244.65	72	6.9500	N/A	74.74	7.3413	N/A	285.33
28	7.7128	0.35	112.07	7.8464	0.30	247.98	74	6.8790	N/A	73.39	7.2914	N/A	286.48
30	7.7103	0.33	109.15	7.8393	0.30	250.91	76	6.8570	N/A	72.01	N/A	N/A	N/A
32	7.6917	0.35	106.52	7.8121	0.31	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6644	0.34	104.10	7.8073	0.33	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6585	0.31	101.99	7.7883	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6116	0.31	99.87	7.7866	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6005	0.31	97.95	7.7592	0.32	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5723	0.32	96.22	7.7394	0.34	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5402	0.34	94.52	7.7208	0.36	265.57	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

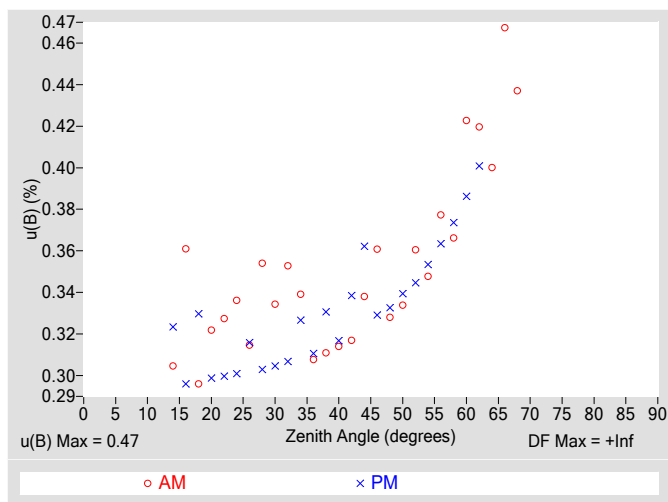


Figure 4. Residuals from Spline Interpolation

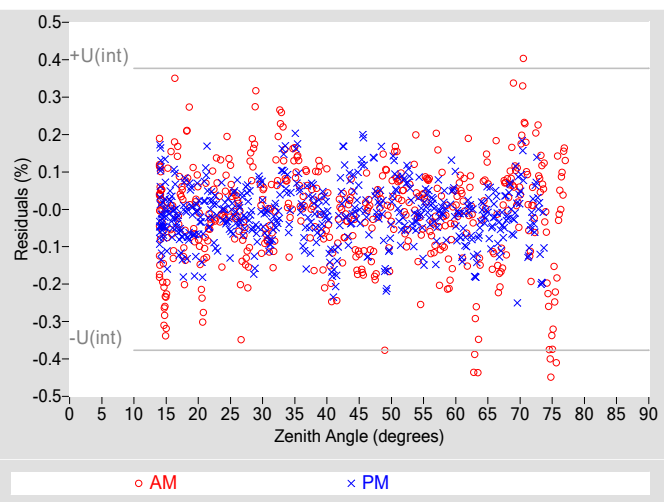


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.47
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.50
Effective degrees of freedom, $DF(c)$	44552
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.99
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

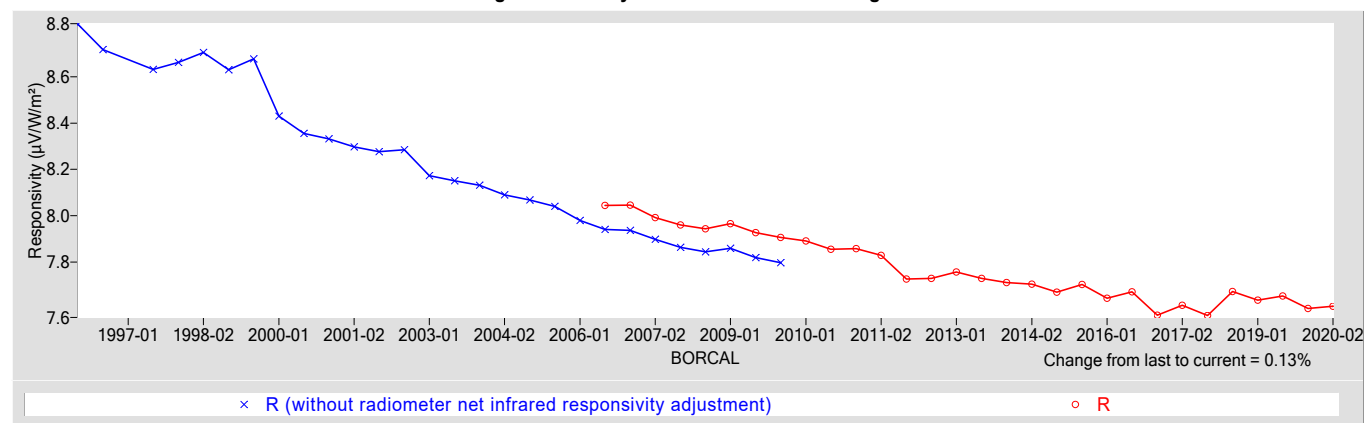
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.6090	0.64286

† R_{net} determination date: 05/09/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.83
Offset Uncertainty, $U(off)$ (%)	+3.0 / -5.1
Expanded Uncertainty, U (%)	+3.9 / -5.9
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: Calibration System
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31154F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31154F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

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

T_{c} = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

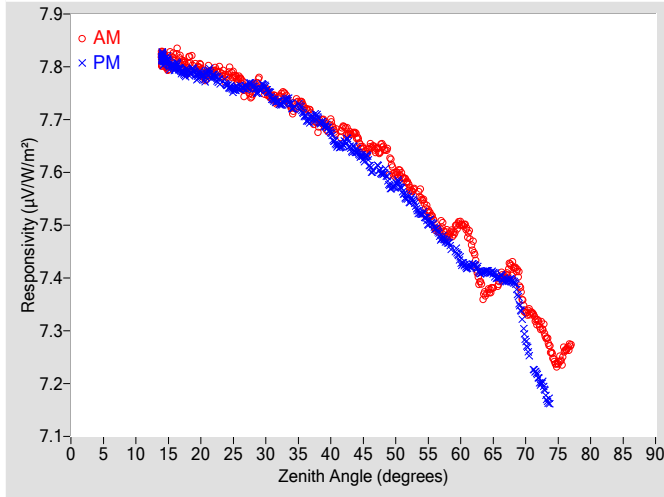


Figure 2. Responsivity vs Local Standard Time

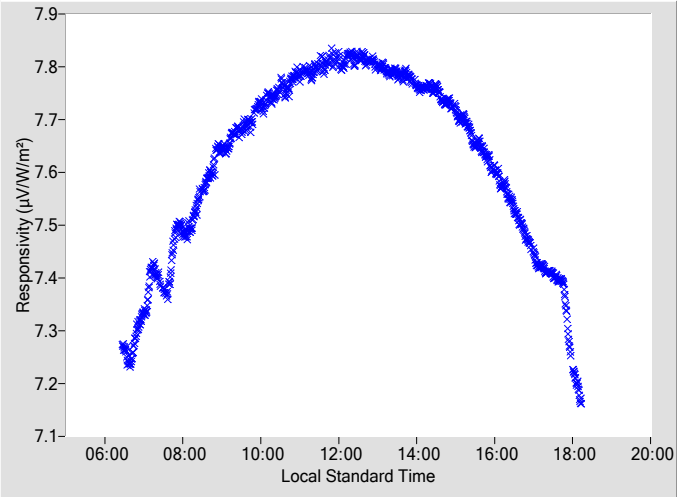


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6476	0.36	92.89	7.6116	0.33	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6497	0.32	91.34	7.5974	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5978	0.33	89.84	7.5788	0.34	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5757	0.36	88.38	7.5477	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5531	0.34	86.93	7.5216	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4999	0.37	85.55	7.4957	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4836	0.36	84.18	7.4678	0.37	275.87
14	7.8188	0.30	173.34	7.8161	0.32	187.98	60	7.5035	0.42	82.85	7.4310	0.38	277.25
16	7.8116	0.36	148.27	7.7996	0.29	211.82	62	7.4535	0.41	81.47	7.4252	0.39	278.59
18	7.8023	0.29	137.12	7.7923	0.33	222.71	64	7.3719	0.39	80.10	7.4135	N/A	279.91
20	7.7976	0.32	129.74	7.7865	0.30	230.36	66	7.3973	0.46	78.79	7.4019	N/A	281.22
22	7.7933	0.33	124.11	7.7826	0.30	236.10	68	7.4194	0.43	77.45	7.3939	N/A	282.61
24	7.7835	0.33	119.19	7.7650	0.30	240.77	70	7.3347	N/A	76.07	7.2793	N/A	283.99
26	7.7784	0.31	115.41	7.7594	0.31	244.65	72	7.3125	N/A	74.74	7.2073	N/A	285.33
28	7.7536	0.35	112.07	7.7645	0.30	247.98	74	7.2590	N/A	73.39	7.1616	N/A	286.48
30	7.7548	0.33	109.15	7.7602	0.30	250.91	76	7.2614	N/A	72.01	N/A	N/A	N/A
32	7.7389	0.35	106.52	7.7323	0.30	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7195	0.34	104.10	7.7244	0.32	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7240	0.30	101.99	7.7053	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6901	0.31	99.87	7.7038	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6936	0.31	97.95	7.6755	0.31	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6856	0.31	96.22	7.6544	0.34	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6688	0.33	94.52	7.6387	0.36	265.57	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

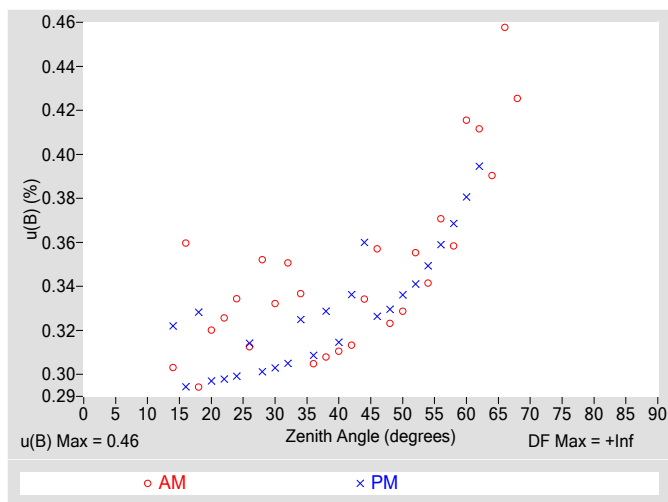


Figure 4. Residuals from Spline Interpolation

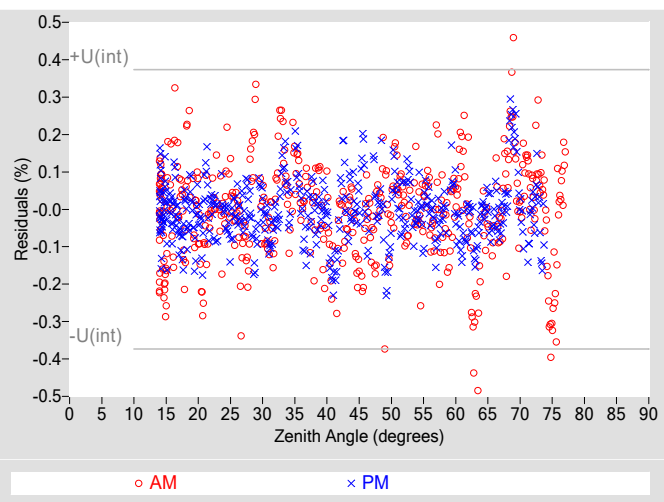


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	43043
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.97
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

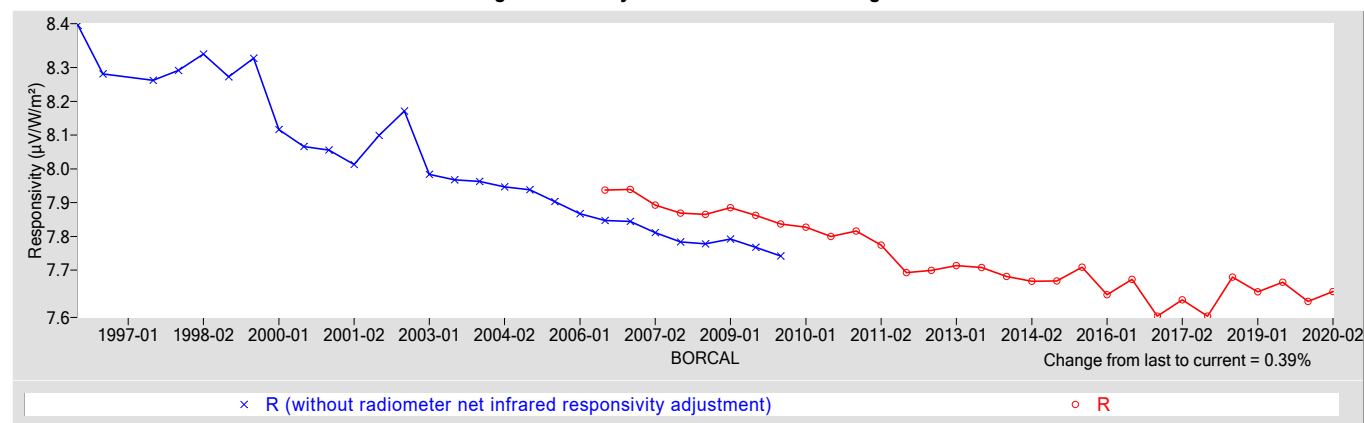
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.6370	0.56158

† R_{net} determination date: 05/09/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.6 / -2.7
Expanded Uncertainty, U (%)	+2.4 / -3.5
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: Calibration System
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31155F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31155F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

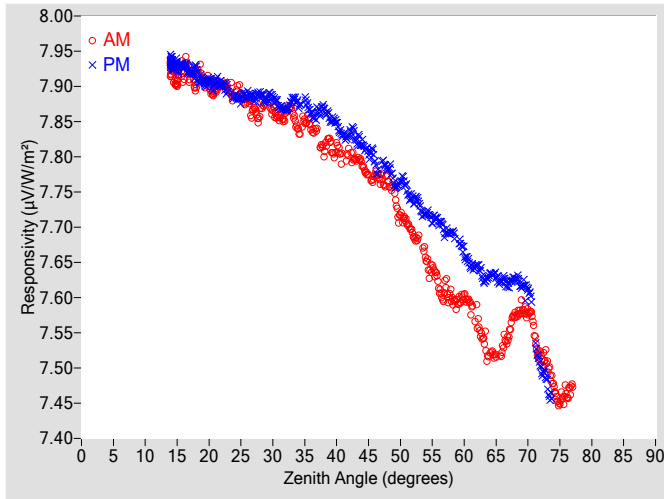


Figure 2. Responsivity vs Local Standard Time

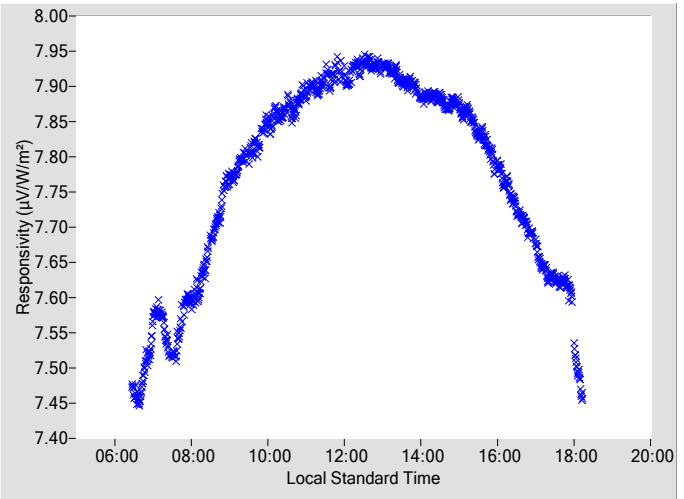


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7732	0.36	92.89	7.7908	0.32	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7667	0.32	91.34	7.7827	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7151	0.33	89.84	7.7662	0.33	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6891	0.35	88.38	7.7383	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6575	0.34	86.93	7.7196	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6170	0.37	85.55	7.7080	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6003	0.36	84.18	7.6931	0.37	275.87
14	7.9290	0.30	173.34	7.9338	0.32	187.72	60	7.6011	0.41	82.85	7.6611	0.38	277.25
16	7.9203	0.36	148.27	7.9291	0.29	211.82	62	7.5722	0.42	81.43	7.6459	0.39	278.59
18	7.9072	0.29	137.12	7.9235	0.33	222.71	64	7.5200	0.39	80.10	7.6328	N/A	279.91
20	7.9041	0.32	129.74	7.9087	0.30	230.36	66	7.5295	0.44	78.76	7.6253	N/A	281.22
22	7.9031	0.33	124.11	7.9023	0.30	236.10	68	7.5746	0.42	77.45	7.6261	N/A	282.61
24	7.8853	0.33	119.19	7.8855	0.30	240.77	70	7.5774	N/A	76.07	7.6104	N/A	283.99
26	7.8798	0.31	115.41	7.8869	0.31	244.65	72	7.5154	N/A	74.74	7.4986	N/A	285.33
28	7.8624	0.35	112.07	7.8883	0.30	247.98	74	7.4771	N/A	73.39	7.4566	N/A	286.48
30	7.8669	0.33	109.15	7.8839	0.30	250.91	76	7.4629	N/A	72.01	N/A	N/A	N/A
32	7.8590	0.35	106.52	7.8677	0.30	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.8379	0.34	104.10	7.8748	0.32	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8413	0.30	101.99	7.8615	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8119	0.31	99.87	7.8690	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8119	0.31	97.95	7.8479	0.31	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8066	0.31	96.23	7.8328	0.33	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7900	0.33	94.52	7.8177	0.36	265.57	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

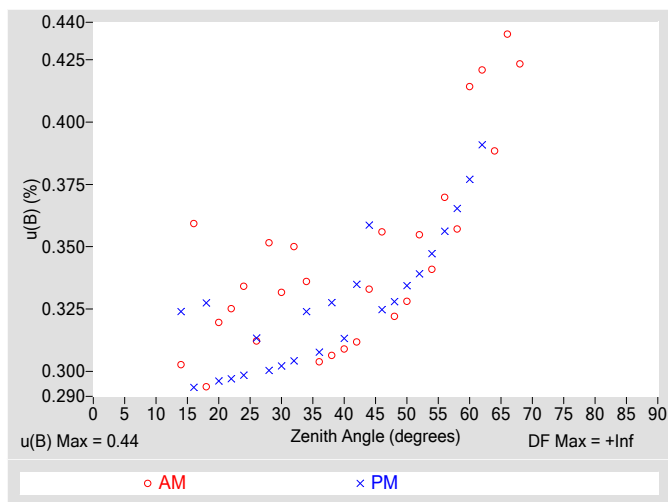


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.44
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	40991
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.92
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

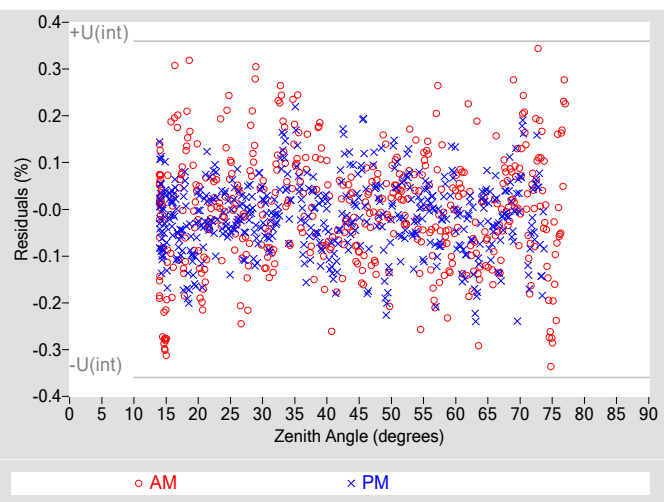


Table 4. Calibration Label Values

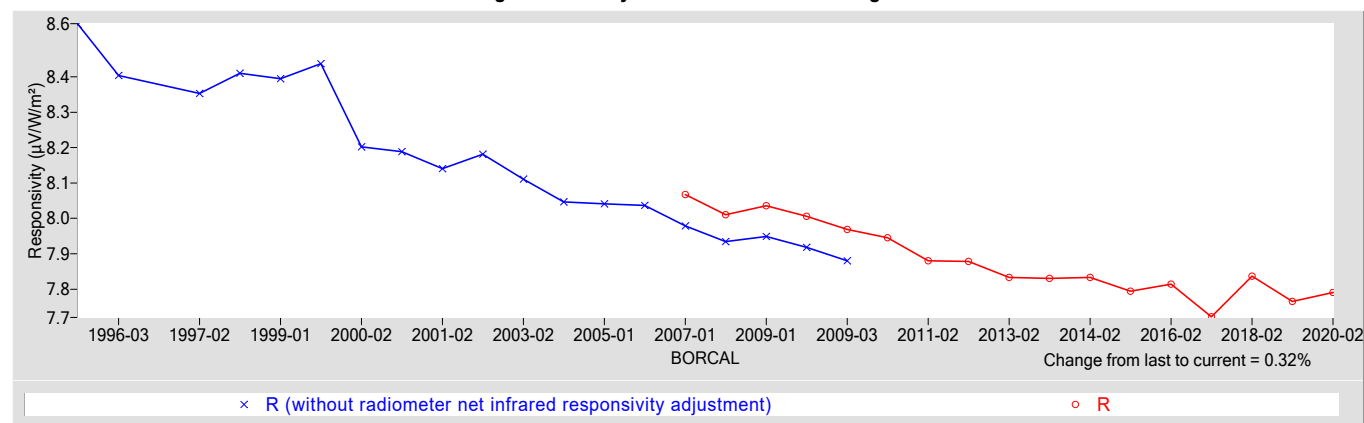
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.7902	0.52400

† R_{net} determination date: 03/30/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.2 / -2.4
Expanded Uncertainty, U (%)	+2.0 / -3.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Manufacturer: Eppley
Model: PSP
Serial Number: 31156F3
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: Calibration System
Environmental Conditions: see page 4
Test Dates: 6/5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31156F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

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

Z = zenith angle (degrees),

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

Figure 1. Responsivity vs Zenith Angle

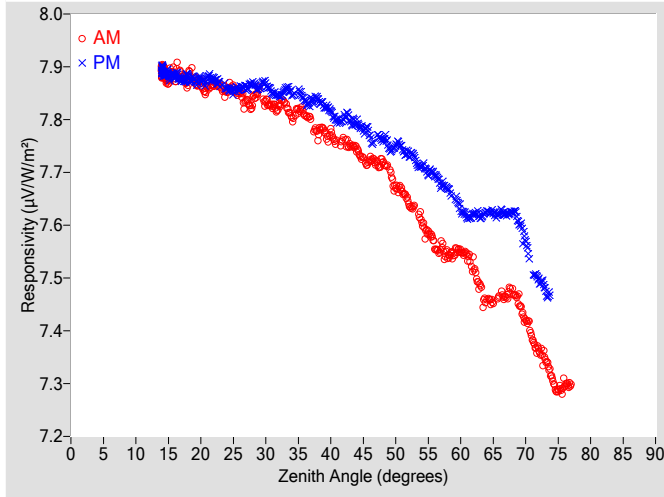


Figure 2. Responsivity vs Local Standard Time

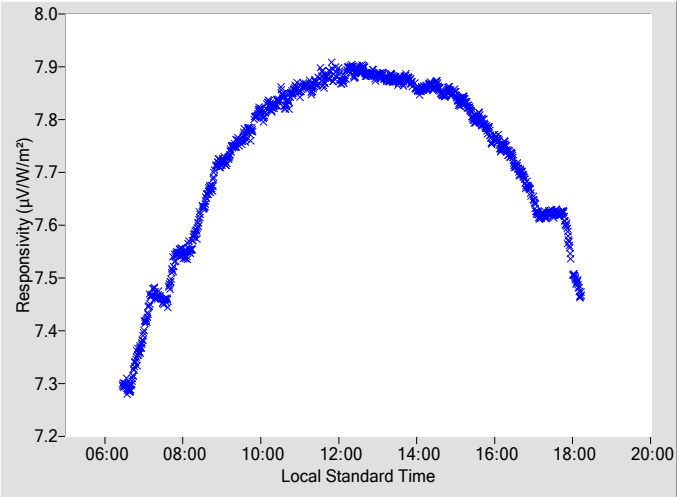


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7230	0.36	92.89	7.7680	0.33	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7206	0.32	91.34	7.7614	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6707	0.33	89.84	7.7524	0.33	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6420	0.36	88.38	7.7334	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6087	0.34	86.93	7.7122	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5610	0.37	85.55	7.6953	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5446	0.36	84.18	7.6695	0.37	275.87
14	7.8942	0.30	173.34	7.8925	0.32	187.72	60	7.5511	0.42	82.85	7.6289	0.38	277.25
16	7.8838	0.36	148.27	7.8825	0.29	211.82	62	7.5213	0.41	81.47	7.6220	0.39	278.59
18	7.8761	0.29	137.12	7.8825	0.33	222.71	64	7.4577	0.39	80.10	7.6258	N/A	279.91
20	7.8691	0.32	129.74	7.8772	0.30	230.36	66	7.4684	0.46	78.79	7.6228	N/A	281.22
22	7.8654	0.33	124.11	7.8768	0.30	236.10	68	7.4724	0.43	77.37	7.6247	N/A	282.61
24	7.8538	0.33	119.19	7.8583	0.30	240.77	70	7.4180	N/A	76.07	7.5677	N/A	283.99
26	7.8511	0.31	115.41	7.8590	0.31	244.65	72	7.3616	N/A	74.74	7.4949	N/A	285.33
28	7.8328	0.35	112.07	7.8673	0.30	247.98	74	7.3147	N/A	73.39	7.4671	N/A	286.48
30	7.8342	0.33	109.15	7.8670	0.30	250.91	76	7.2982	N/A	72.01	N/A	N/A	N/A
32	7.8235	0.35	106.52	7.8457	0.30	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.8046	0.34	104.10	7.8492	0.32	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8105	0.30	101.99	7.8349	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7746	0.31	99.87	7.8393	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7747	0.31	97.95	7.8166	0.31	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7631	0.31	96.23	7.8027	0.34	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7448	0.33	94.52	7.7926	0.36	265.57	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

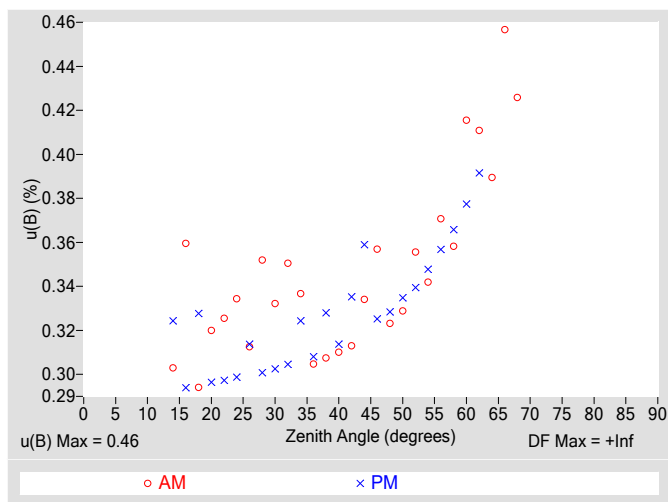


Figure 4. Residuals from Spline Interpolation

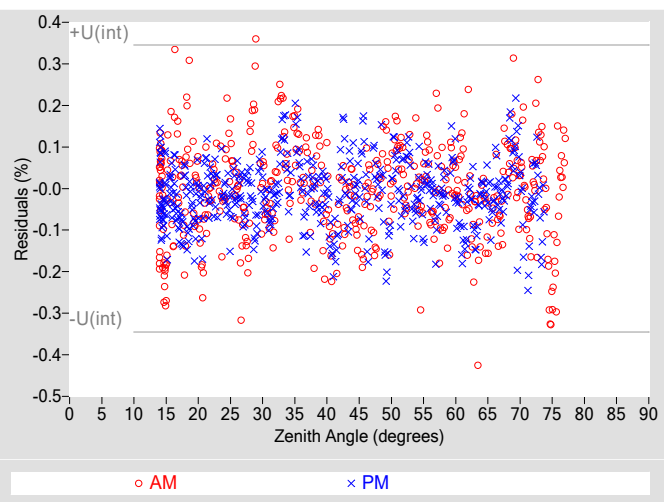


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	55634
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.96
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

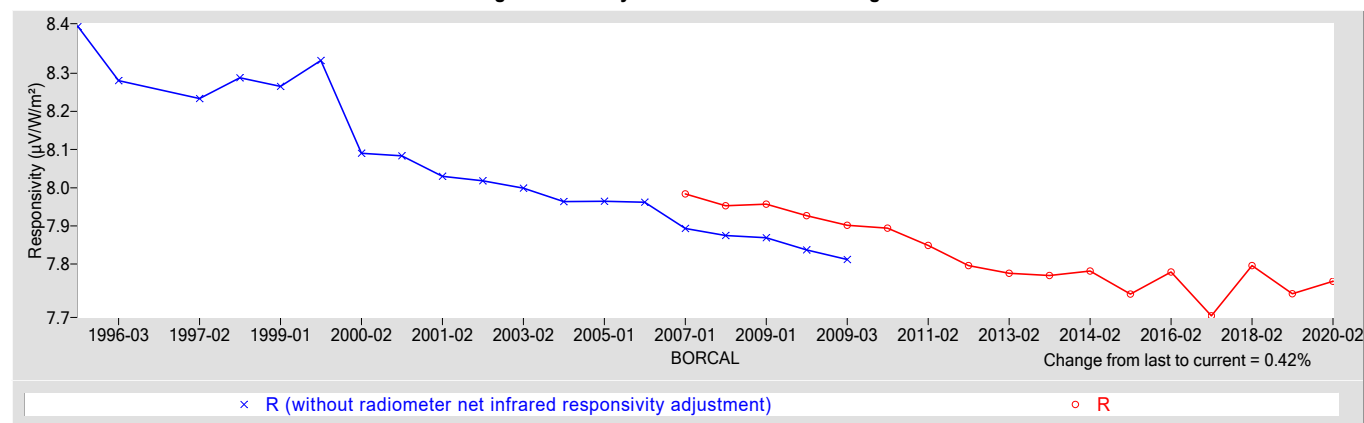
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.7544	0.53200

† R_{net} determination date: 03/30/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.5 / -2.7
Expanded Uncertainty, U (%)	+2.3 / -3.5
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: Calibration System
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31157F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31157F3 Eppley PSP

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

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

[1]

where,

V = radiometer output voltage (microvolts),

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

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

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

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

T_c = case temperature of radiometer (K).

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

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

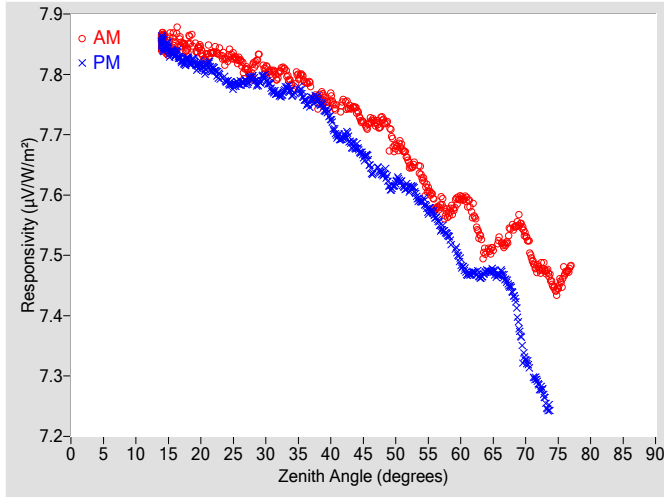


Figure 2. Responsivity vs Local Standard Time

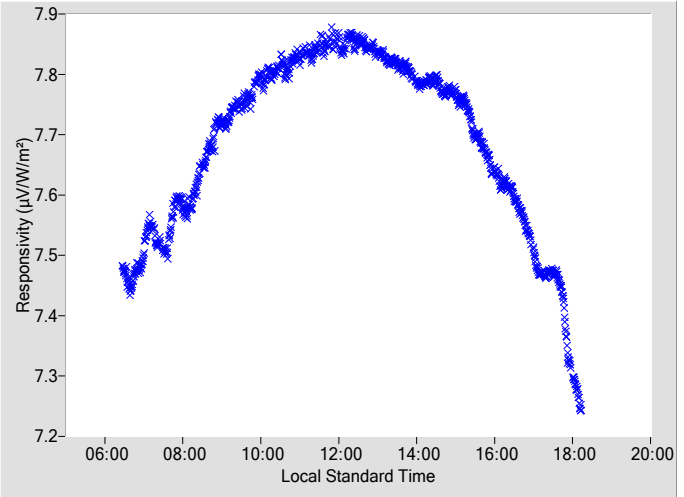


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7209	0.36	92.89	7.6475	0.32	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7254	0.32	91.34	7.6336	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6790	0.33	89.84	7.6224	0.33	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6538	0.35	88.38	7.6104	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6327	0.34	86.93	7.5900	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5838	0.37	85.55	7.5652	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5696	0.36	84.18	7.5337	0.36	275.87
14	7.8581	0.30	173.34	7.8517	0.32	187.72	60	7.5948	0.41	82.85	7.4857	0.38	277.25
16	7.8533	0.36	148.27	7.8333	0.29	211.82	62	7.5692	0.41	81.47	7.4722	0.39	278.59
18	7.8464	0.29	137.12	7.8252	0.33	222.71	64	7.5065	0.39	80.10	7.4741	N/A	279.91
20	7.8412	0.32	129.74	7.8156	0.30	230.36	66	7.5251	0.45	78.79	7.4691	N/A	281.22
22	7.8379	0.32	124.11	7.8084	0.30	236.10	68	7.5465	0.42	77.37	7.4381	N/A	282.61
24	7.8255	0.33	119.19	7.7877	0.30	240.77	70	7.5312	N/A	76.07	7.3260	N/A	283.99
26	7.8240	0.31	115.41	7.7848	0.31	244.65	72	7.4769	N/A	74.74	7.2836	N/A	285.33
28	7.8058	0.35	112.07	7.7938	0.30	247.98	74	7.4570	N/A	73.39	7.2428	N/A	286.48
30	7.8095	0.33	109.15	7.7927	0.30	250.91	76	7.4704	N/A	72.01	N/A	N/A	N/A
32	7.7993	0.35	106.52	7.7670	0.30	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7813	0.34	104.10	7.7681	0.32	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7906	0.30	101.99	7.7563	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7571	0.31	99.87	7.7589	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7613	0.31	97.95	7.7260	0.31	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7556	0.31	96.23	7.6963	0.33	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7406	0.33	94.52	7.6782	0.36	265.57	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

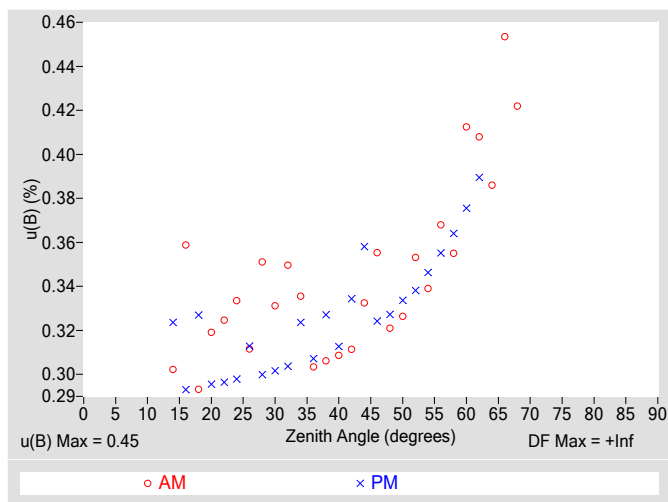


Figure 4. Residuals from Spline Interpolation

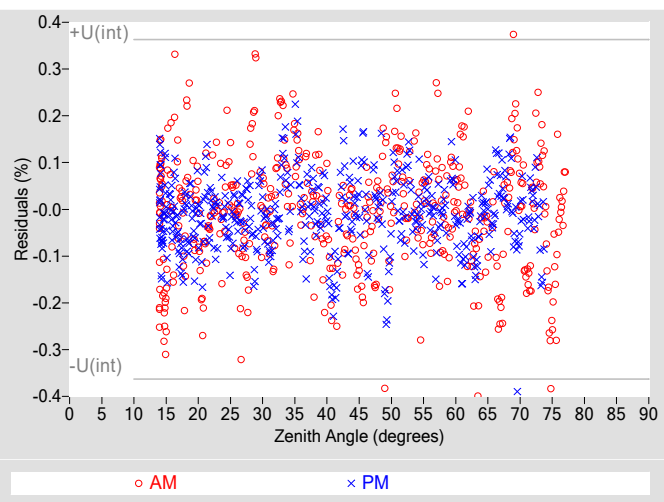


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.45
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	45656
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.96
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

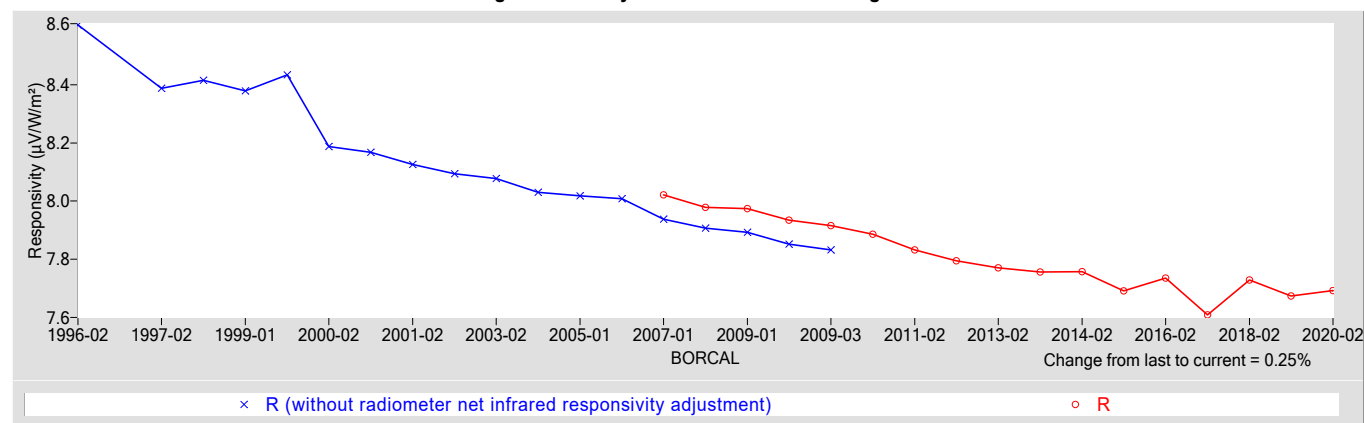
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.6927	0.49000

† R_{net} determination date: 03/30/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.5 / -2.7
Expanded Uncertainty, U (%)	+2.3 / -3.5
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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: TWP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31275F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31275F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

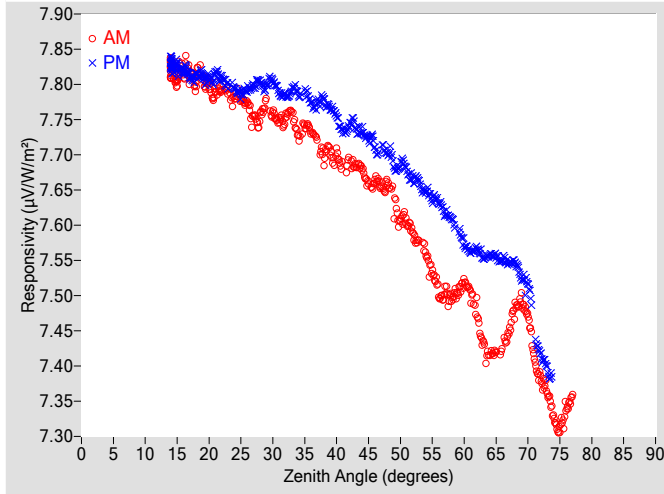


Figure 2. Responsivity vs Local Standard Time

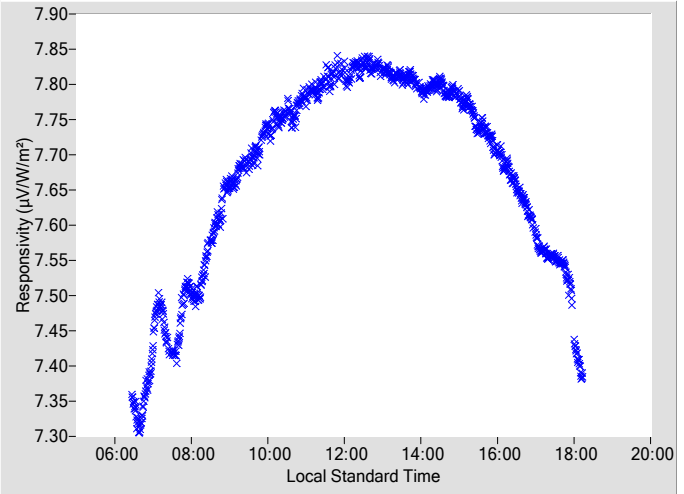


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6630	0.36	92.89	7.7095	0.33	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6594	0.32	91.34	7.7013	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6065	0.33	89.84	7.6879	0.34	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5879	0.36	88.38	7.6642	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5602	0.34	86.93	7.6484	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5042	0.37	85.55	7.6328	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4975	0.36	84.18	7.6095	0.37	275.87
14	7.8251	0.30	173.34	7.8282	0.32	187.72	60	7.5181	0.42	82.85	7.5721	0.38	277.25
16	7.8178	0.36	148.27	7.8196	0.29	211.82	62	7.4768	0.41	81.47	7.5667	0.40	278.59
18	7.8068	0.29	137.12	7.8142	0.33	222.71	64	7.4174	0.39	80.10	7.5577	N/A	279.91
20	7.8003	0.32	129.74	7.8098	0.30	230.36	66	7.4286	0.46	78.79	7.5504	N/A	281.22
22	7.7928	0.33	124.11	7.8089	0.30	236.10	68	7.4809	0.43	77.45	7.5457	N/A	282.61
24	7.7811	0.33	119.19	7.7940	0.30	240.77	70	7.4675	N/A	76.07	7.5137	N/A	283.99
26	7.7738	0.31	115.41	7.7926	0.31	244.65	72	7.3795	N/A	74.74	7.4144	N/A	285.33
28	7.7504	0.35	112.07	7.8030	0.30	247.98	74	7.3296	N/A	73.39	7.3846	N/A	286.48
30	7.7586	0.33	109.15	7.8045	0.30	250.91	76	7.3390	N/A	72.01	N/A	N/A	N/A
32	7.7498	0.35	106.52	7.7852	0.31	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7275	0.34	104.10	7.7855	0.33	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7336	0.31	101.99	7.7732	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6995	0.31	99.87	7.7786	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7011	0.31	97.95	7.7555	0.32	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6935	0.31	96.23	7.7417	0.34	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6803	0.34	94.52	7.7319	0.36	265.57	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

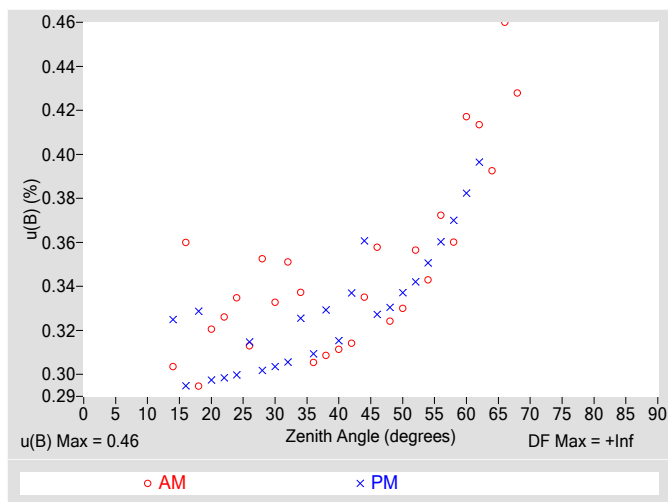


Figure 4. Residuals from Spline Interpolation

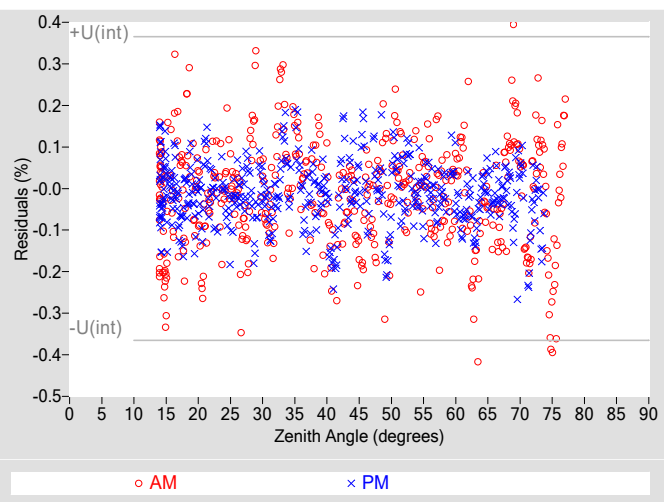


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.46
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	47135
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.97
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

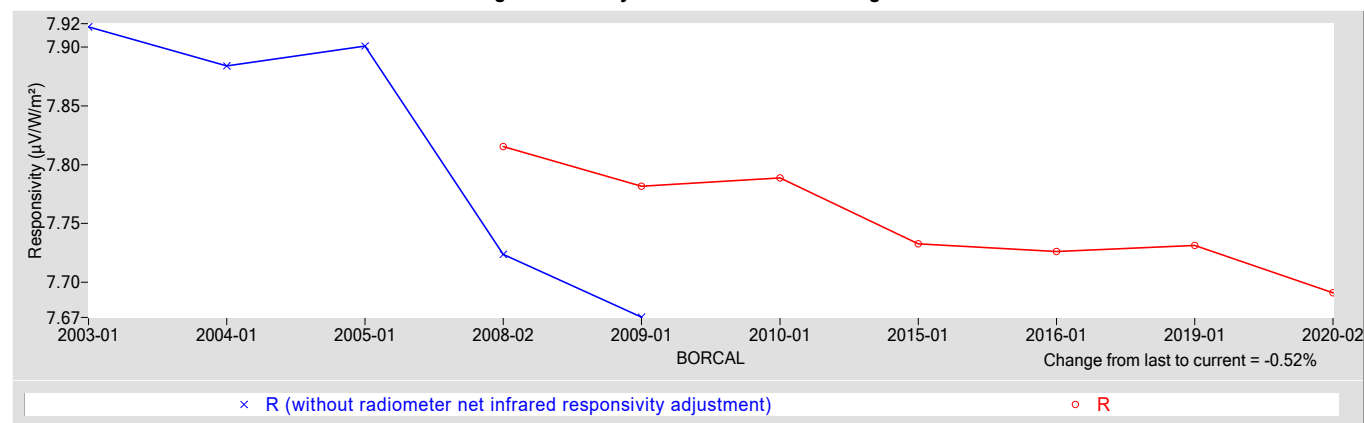
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.6910	0.59150

† R_{net} determination date: 07/03/2008

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	+1.5 / -2.5
Expanded Uncertainty, U (%)	+2.3 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31276F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31276F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

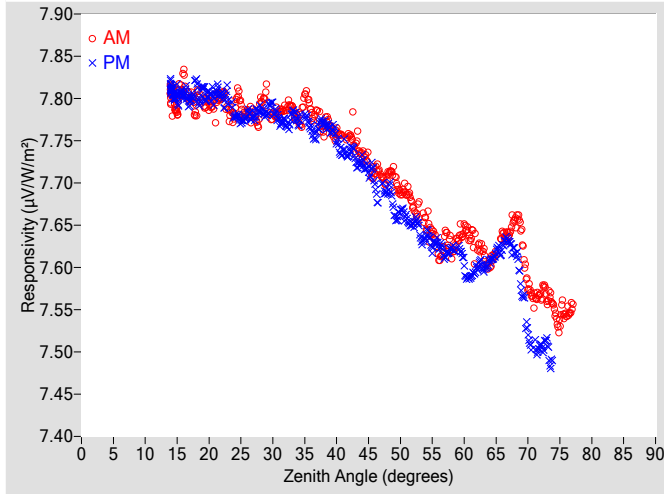


Figure 2. Responsivity vs Local Standard Time

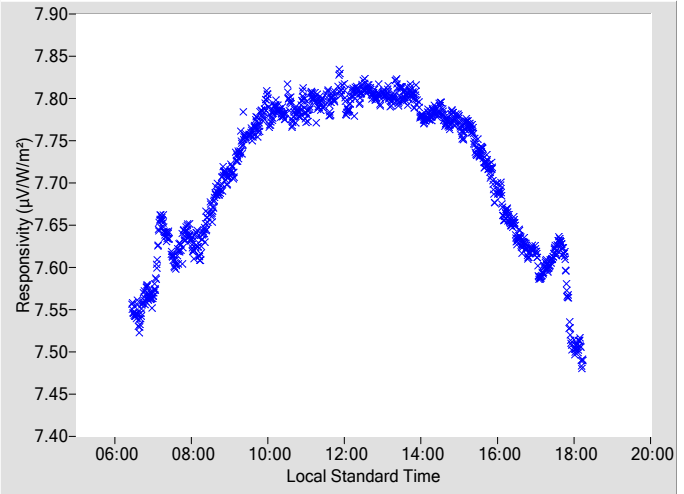


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7150	0.34	92.86	7.6997	0.35	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7095	0.32	91.32	7.6910	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6879	0.33	89.82	7.6670	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6681	0.35	88.35	7.6511	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6519	0.36	86.99	7.6391	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6114	0.34	85.48	7.6282	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6215	0.35	84.15	7.6230	0.37	275.85
14	7.8060	0.31	173.38	7.8116	0.31	187.07	60	7.6443	0.38	82.82	7.6010	0.38	277.23
16	7.8172	0.33	148.49	7.8038	0.29	211.51	62	7.6292	0.51	81.46	7.5989	0.39	278.57
18	7.7914	0.32	137.19	7.8157	0.31	223.04	64	7.6026	0.47	80.16	7.6071	N/A	279.89
20	7.7957	0.29	129.65	7.8041	0.31	230.42	66	7.6382	0.46	78.82	7.6240	N/A	281.28
22	7.8024	0.33	123.95	7.8042	0.32	236.02	68	7.6559	0.42	77.43	7.6183	N/A	282.58
24	7.7834	0.31	119.29	7.7805	0.31	240.70	70	7.5804	N/A	76.13	7.5215	N/A	283.96
26	7.7850	0.32	115.29	7.7819	0.30	244.69	72	7.5656	N/A	74.76	7.5069	N/A	285.30
28	7.7880	0.30	112.02	7.7861	0.31	248.02	74	7.5528	N/A	73.36	7.4896	N/A	286.54
30	7.7788	0.33	109.10	7.7898	0.32	250.92	76	7.5458	N/A	71.98	N/A	N/A	N/A
32	7.7872	0.30	106.51	7.7703	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7749	0.30	103.99	7.7719	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7859	0.30	101.92	7.7630	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7648	0.32	99.84	7.7715	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7589	0.33	97.97	7.7504	0.31	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7565	0.31	96.21	7.7372	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7326	0.31	94.48	7.7259	0.32	265.54	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

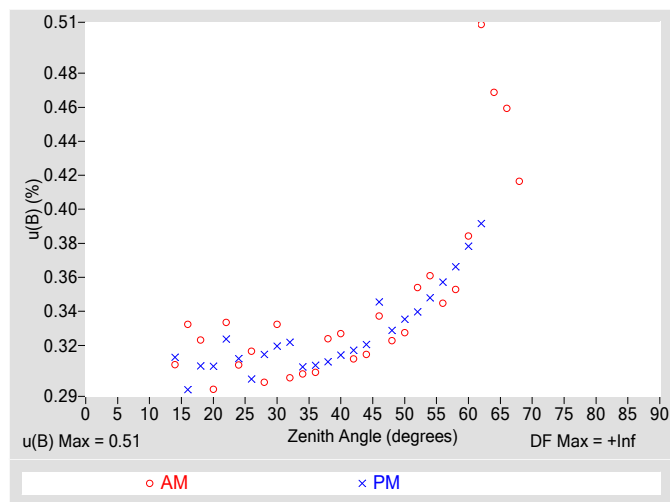


Figure 4. Residuals from Spline Interpolation

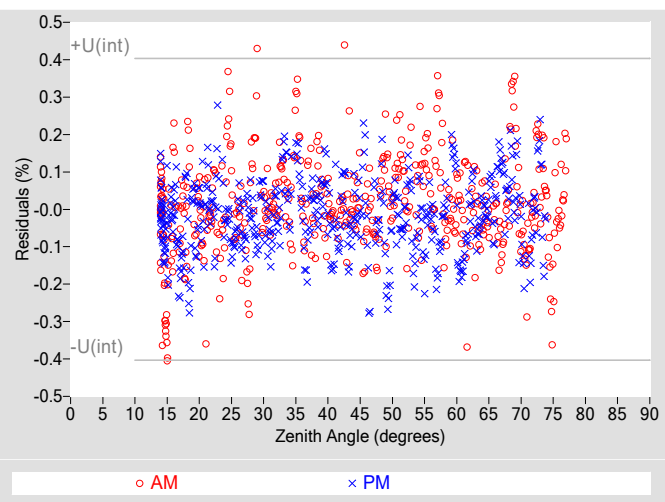


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.55
Effective degrees of freedom, $DF(c)$	47641
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

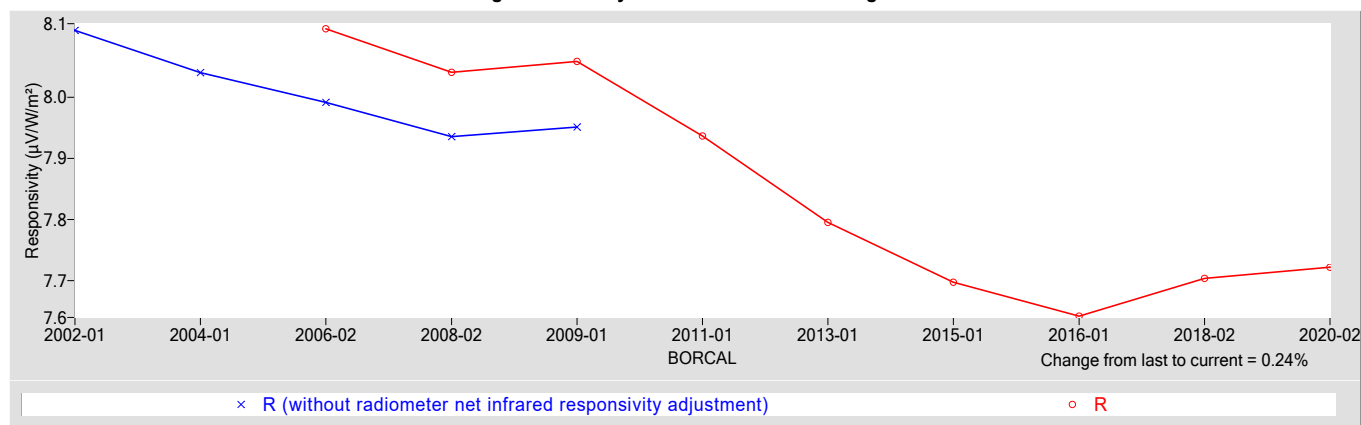
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.7221	0.56944

† R_{net} determination date: 06/09/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.75
Offset Uncertainty, $U(off)$ (%)	+0.88 / -1.6
Expanded Uncertainty, U (%)	+1.6 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: TWP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31280F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31280F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

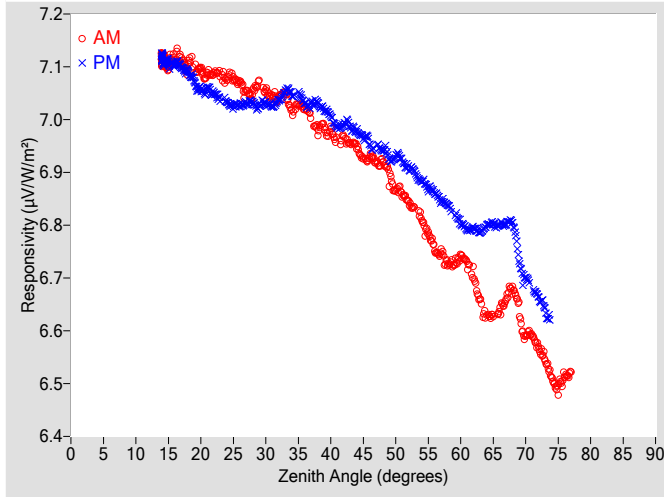


Figure 2. Responsivity vs Local Standard Time

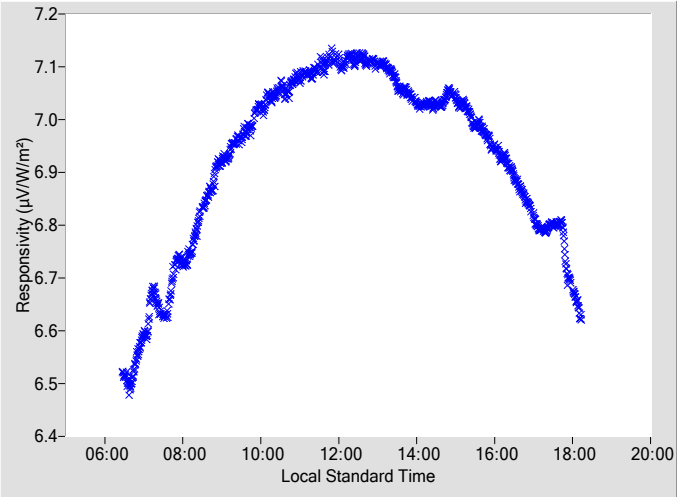


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	6.9287	0.36	92.89	6.9528	0.33	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.9204	0.32	91.34	6.9415	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.8667	0.33	89.84	6.9316	0.34	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.8437	0.35	88.38	6.9071	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.8115	0.34	86.93	6.8834	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.7546	0.37	85.55	6.8613	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.7286	0.36	84.18	6.8381	0.37	275.87
14	7.1163	0.30	173.34	7.1146	0.32	187.72	60	6.7397	0.41	82.85	6.8032	0.38	277.25
16	7.1144	0.36	148.27	7.1049	0.29	211.82	62	6.7037	0.41	81.47	6.7948	0.39	278.59
18	7.0999	0.29	137.12	7.0913	0.33	222.71	64	6.6283	0.39	80.10	6.7996	N/A	279.91
20	7.0955	0.32	129.74	7.0580	0.30	230.36	66	6.6392	0.44	78.76	6.8011	N/A	281.22
22	7.0873	0.33	124.11	7.0495	0.30	236.10	68	6.6776	0.42	77.45	6.8018	N/A	282.61
24	7.0772	0.33	119.19	7.0324	0.30	240.77	70	6.5894	N/A	76.07	6.6996	N/A	283.99
26	7.0713	0.31	115.41	7.0271	0.31	244.65	72	6.5660	N/A	74.74	6.6612	N/A	285.33
28	7.0493	0.35	112.07	7.0316	0.30	247.98	74	6.5136	N/A	73.39	6.6208	N/A	286.48
30	7.0551	0.33	109.15	7.0303	0.30	250.91	76	6.5138	N/A	72.01	N/A	N/A	N/A
32	7.0410	0.35	106.52	7.0368	0.30	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.0167	0.34	104.10	7.0474	0.32	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.0202	0.30	101.99	7.0301	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	6.9823	0.31	99.87	7.0313	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	6.9802	0.31	97.95	7.0069	0.31	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.9681	0.31	96.22	6.9909	0.34	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.9489	0.33	94.52	6.9767	0.36	265.57	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

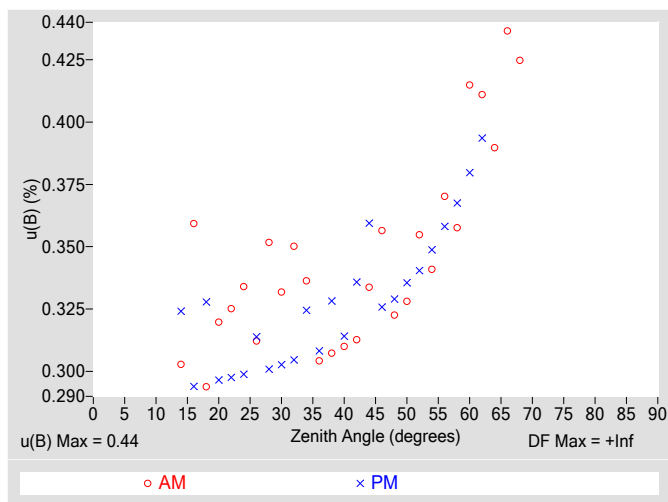


Figure 4. Residuals from Spline Interpolation

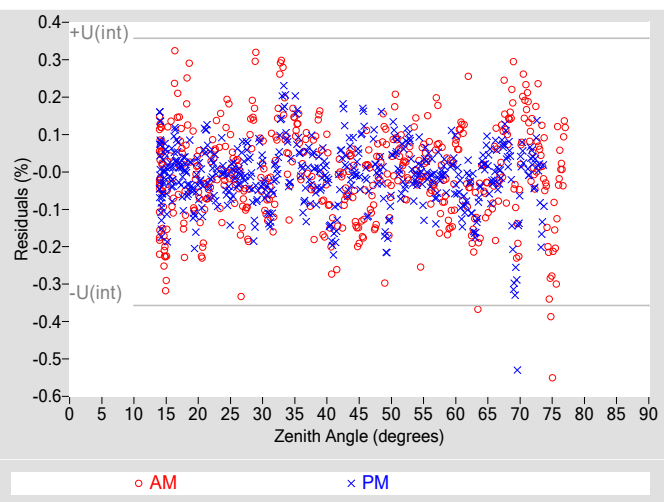


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.44
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	42563
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.92
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

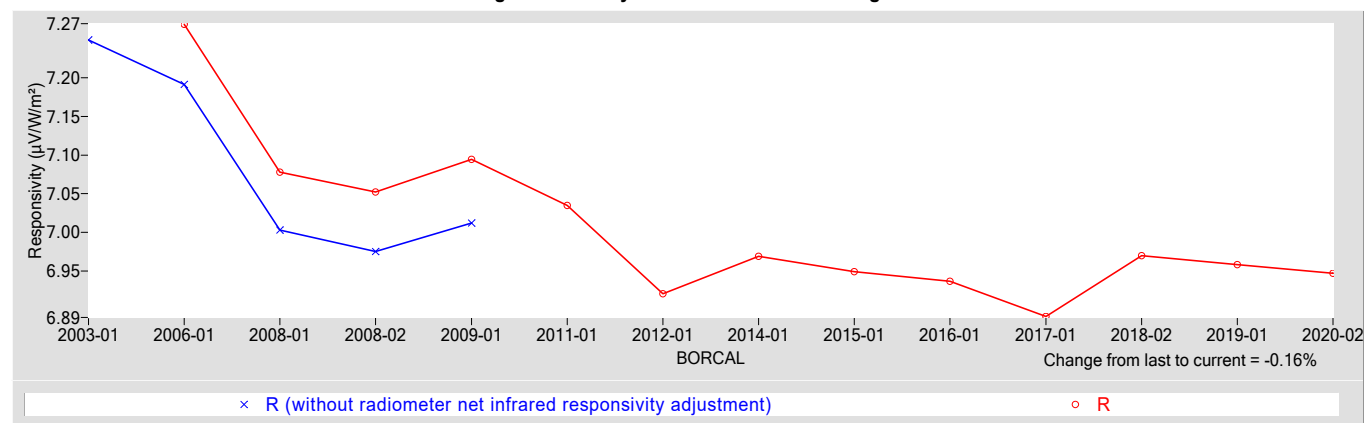
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
6.9471	0.49700

† R_{net} determination date: 03/30/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.6 / -3.1
Expanded Uncertainty, U (%)	+2.4 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31295F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31295F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

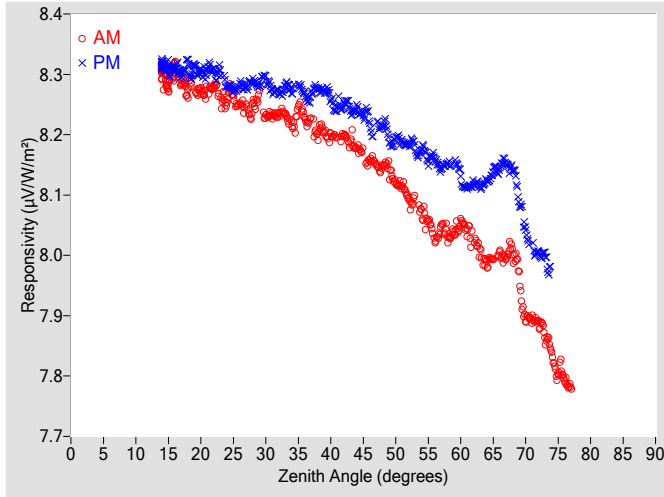


Figure 2. Responsivity vs Local Standard Time

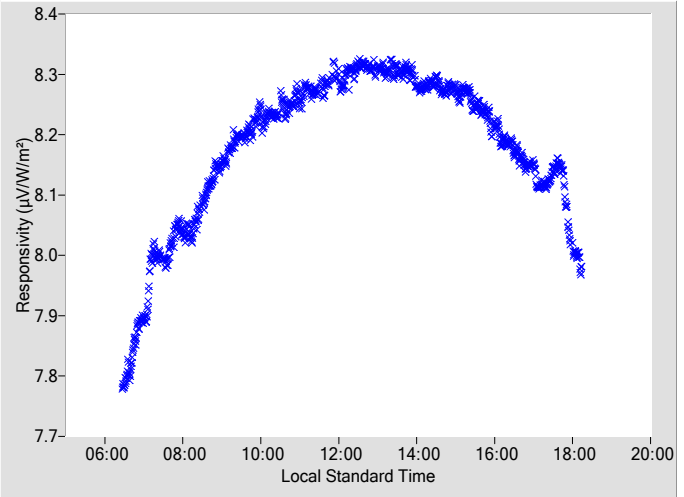


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1576	0.34	92.86	8.2190	0.34	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1481	0.32	91.32	8.2160	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1197	0.33	89.82	8.1947	0.33	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0910	0.35	88.35	8.1841	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0685	0.36	86.99	8.1772	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0257	0.34	85.48	8.1612	0.35	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0329	0.35	84.15	8.1526	0.36	275.85
14	8.3050	0.31	173.38	8.3157	0.31	187.07	60	8.0521	0.38	82.82	8.1297	0.37	277.23
16	8.3045	0.33	148.49	8.3084	0.29	211.51	62	8.0298	0.51	81.46	8.1172	0.39	278.57
18	8.2739	0.32	137.19	8.3173	0.31	223.04	64	7.9854	0.47	80.16	8.1234	N/A	279.89
20	8.2732	0.29	129.65	8.3035	0.31	230.42	66	8.0016	0.46	78.82	8.1446	N/A	281.28
22	8.2789	0.33	123.95	8.3064	0.32	236.02	68	8.0039	0.41	77.43	8.1436	N/A	282.58
24	8.2545	0.31	119.29	8.2819	0.31	240.70	70	7.8961	N/A	76.13	8.0408	N/A	283.96
26	8.2509	0.32	115.29	8.2831	0.30	244.69	72	7.8865	N/A	74.76	8.0045	N/A	285.30
28	8.2451	0.30	112.02	8.2876	0.31	248.02	74	7.8364	N/A	73.36	7.9814	N/A	286.54
30	8.2303	0.33	109.10	8.2919	0.32	250.92	76	7.7950	N/A	71.98	N/A	N/A	N/A
32	8.2326	0.30	106.51	8.2702	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.2169	0.30	103.99	8.2726	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2283	0.30	101.92	8.2657	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2030	0.32	99.84	8.2765	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1971	0.33	97.97	8.2586	0.31	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1996	0.31	96.21	8.2498	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1774	0.31	94.48	8.2426	0.32	265.54	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

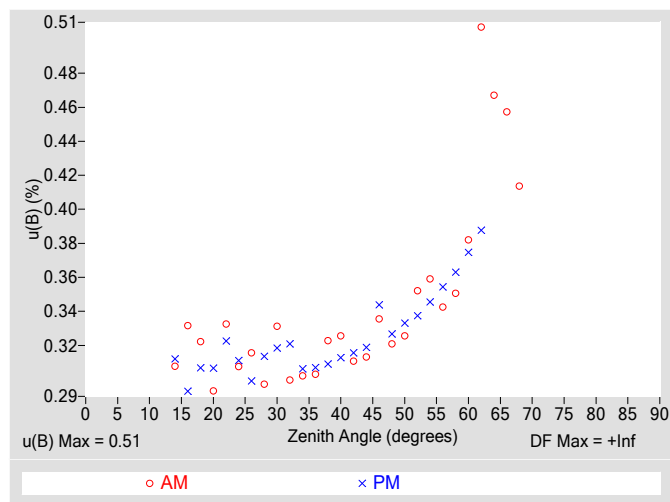


Figure 4. Residuals from Spline Interpolation

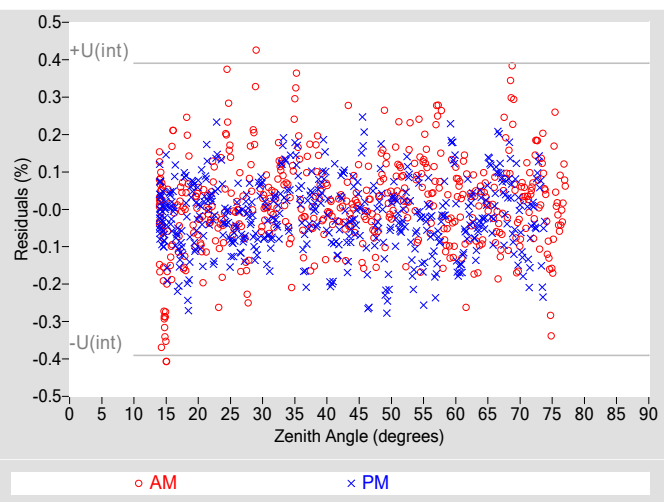


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	52386
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

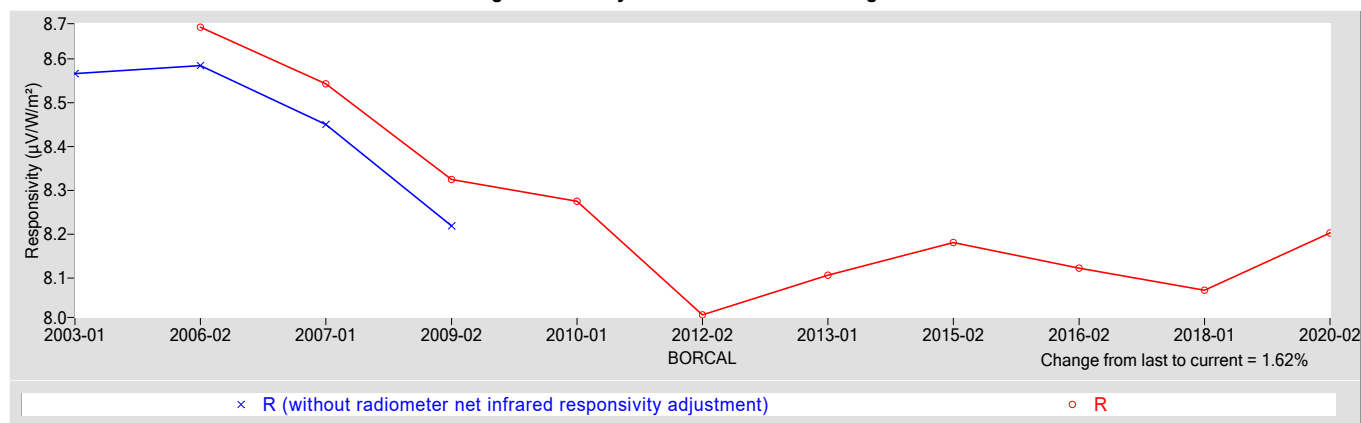
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.2030	0.54645

† R_{net} determination date: 06/13/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.75
Offset Uncertainty, $U(off)$ (%)	+1.1 / -2.2
Expanded Uncertainty, U (%)	+1.8 / -2.9
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31627F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31627F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

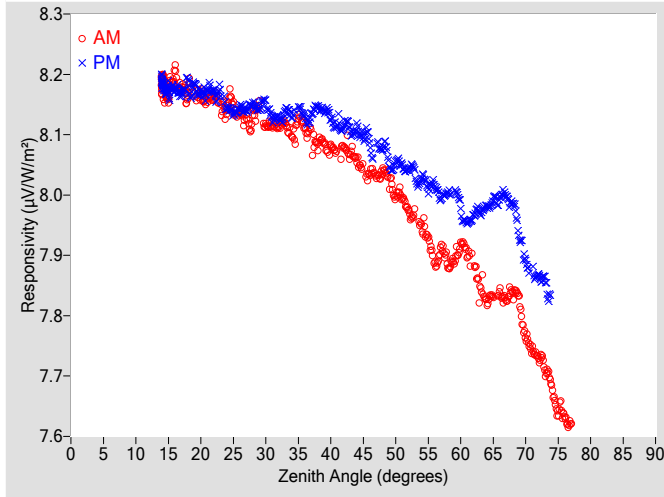


Figure 2. Responsivity vs Local Standard Time

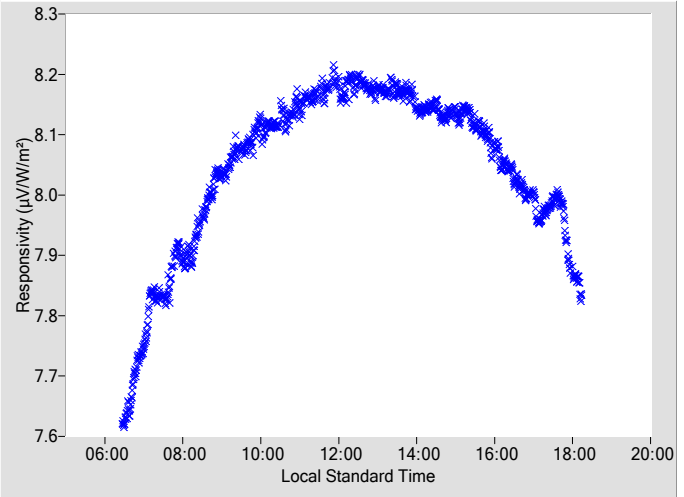


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0362	0.34	92.86	8.0862	0.35	267.13
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0402	0.32	91.32	8.0792	0.33	268.71
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9978	0.33	89.82	8.0543	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9717	0.35	88.35	8.0433	0.34	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9458	0.36	86.99	8.0289	0.35	273.11
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8846	0.35	85.48	8.0154	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8853	0.35	84.15	8.0042	0.37	275.85
14	8.1863	0.31	173.15	8.1866	0.31	187.07	60	7.9150	0.39	82.82	7.9768	0.38	277.23
16	8.1961	0.33	148.49	8.1737	0.29	211.51	62	7.8885	0.51	81.46	7.9658	0.39	278.57
18	8.1669	0.32	137.19	8.1865	0.31	223.04	64	7.8241	0.47	80.16	7.9809	N/A	279.89
20	8.1670	0.29	129.65	8.1689	0.31	230.42	66	7.8368	0.46	78.82	7.9937	N/A	281.28
22	8.1613	0.33	123.95	8.1706	0.32	236.02	68	7.8381	0.42	77.43	7.9854	N/A	282.58
24	8.1406	0.31	119.29	8.1454	0.31	240.70	70	7.7674	N/A	76.13	7.8905	N/A	283.96
26	8.1360	0.32	115.29	8.1451	0.30	244.69	72	7.7291	N/A	74.76	7.8665	N/A	285.30
28	8.1287	0.30	112.02	8.1493	0.32	248.02	74	7.6814	N/A	73.36	7.8339	N/A	286.54
30	8.1144	0.33	109.10	8.1510	0.32	250.92	76	7.6340	N/A	71.98	N/A	N/A	N/A
32	8.1118	0.30	106.51	8.1275	0.32	253.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0998	0.30	103.99	8.1315	0.31	255.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1109	0.30	101.92	8.1286	0.31	258.11	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0856	0.32	99.84	8.1465	0.31	260.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0781	0.33	97.97	8.1264	0.31	262.09	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0795	0.31	96.21	8.1145	0.32	263.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0573	0.32	94.48	8.1102	0.32	265.54	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

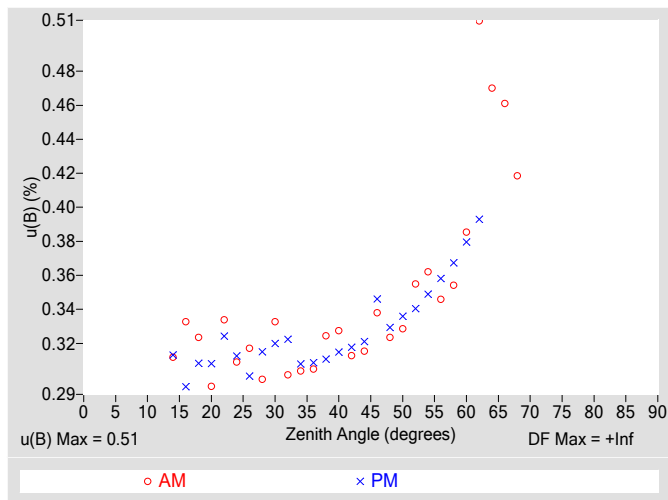


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.51
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.56
Effective degrees of freedom, $DF(c)$	31989
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

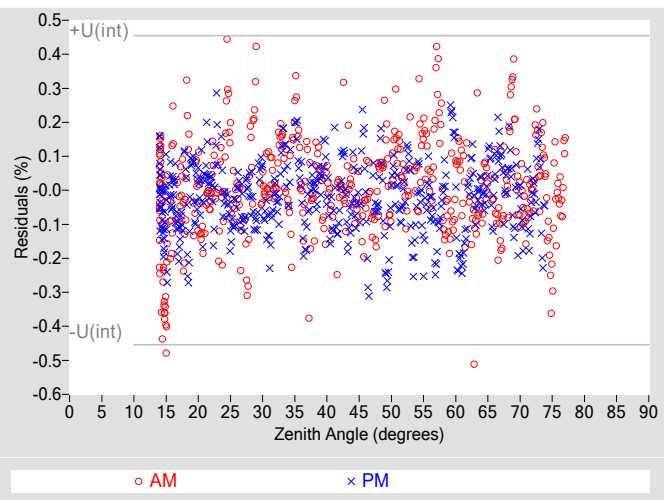


Table 4. Calibration Label Values

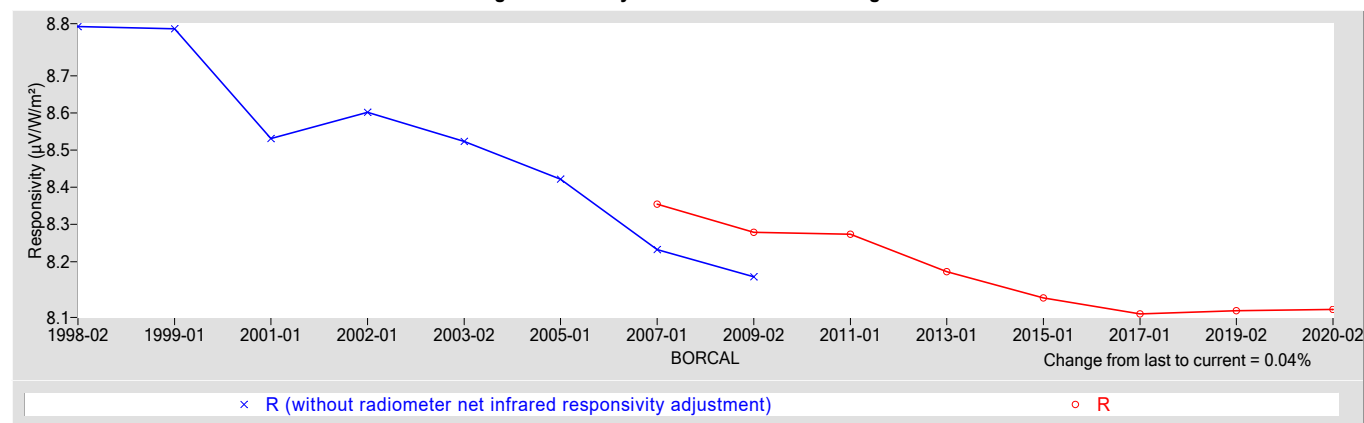
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0718	0.61800

† R_{net} determination date: 06/29/2005

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+0.98 / -2.3
Expanded Uncertainty, U (%)	+1.7 / -3.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31632F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31632F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

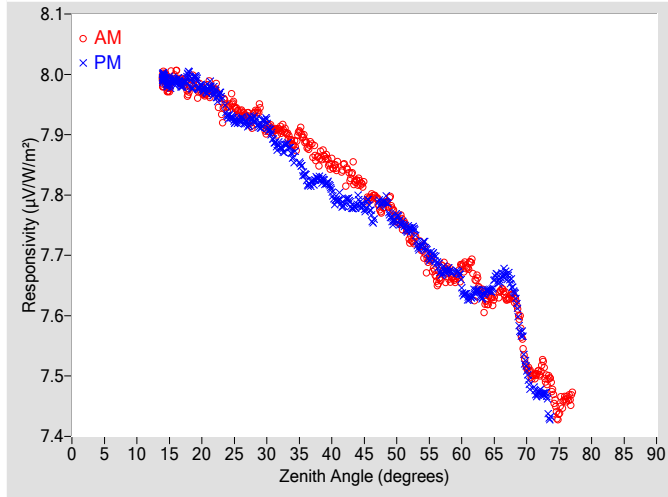


Figure 2. Responsivity vs Local Standard Time

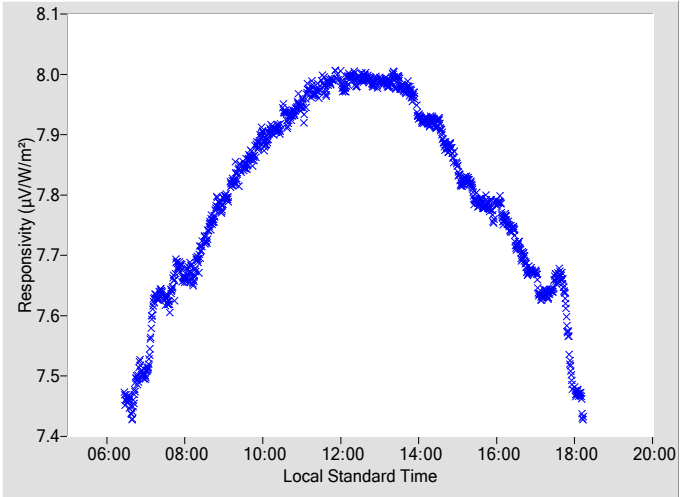


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith			AM			PM			Zenith			AM			PM		
Angle	R		$u(B)$	Azimuth		R	$u(B)$	Azimuth	Angle	R		$u(B)$	Azimuth		R	$u(B)$	Azimuth
(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)		± (%)	Angle		($\mu\text{V}/\text{W}/\text{m}^2$)	± (%)	Angle	(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)		± (%)	Angle		($\mu\text{V}/\text{W}/\text{m}^2$)	± (%)	Angle
0	N/A		N/A	N/A		N/A	N/A	N/A	46	7.7963		0.35	92.87		7.7710	0.35	267.14
2	N/A		N/A	N/A		N/A	N/A	N/A	48	7.7834		0.35	91.32		7.7881	0.36	268.72
4	N/A		N/A	N/A		N/A	N/A	N/A	50	7.7584		0.40	89.82		7.7647	0.37	270.22
6	N/A		N/A	N/A		N/A	N/A	N/A	52	7.7291		0.37	88.36		7.7446	0.39	271.68
8	N/A		N/A	N/A		N/A	N/A	N/A	54	7.7066		0.37	86.96		7.7199	0.39	273.12
10	N/A		N/A	N/A		N/A	N/A	N/A	56	7.6629		0.40	85.53		7.6928	0.40	274.49
12	N/A		N/A	N/A		N/A	N/A	N/A	58	7.6707		0.41	84.16		7.6754	0.41	275.86
14	7.9926		0.32	173.47		7.9943	0.33	187.56	60	7.6787		0.40	82.83		7.6490	0.43	277.23
16	7.9990		0.34	147.99		7.9869	0.33	211.71	62	7.6531		0.44	81.48		7.6393	0.48	278.57
18	7.9759		0.33	137.21		7.9968	0.32	222.82	64	7.6237		0.45	80.17		7.6419	N/A	279.89
20	7.9718		0.33	129.44		7.9789	0.34	230.38	66	7.6391		0.44	78.83		7.6631	N/A	281.29
22	7.9765		0.32	123.98		7.9704	0.34	236.04	68	7.6305		0.50	77.44		7.6423	N/A	282.59
24	7.9457		0.33	119.20		7.9315	0.33	240.72	70	7.5171		N/A	76.14		7.5089	N/A	283.97
26	7.9364		0.33	115.36		7.9256	0.33	244.70	72	7.5056		N/A	74.76		7.4740	N/A	285.31
28	7.9304		0.34	112.03		7.9250	0.32	247.94	74	7.4732		N/A	73.37		N/A	N/A	N/A
30	7.9075		0.32	109.11		7.9188	0.32	250.95	76	7.4624		N/A	71.99		N/A	N/A	N/A
32	7.9083		0.35	106.49		7.8810	0.36	253.63	78	N/A		N/A	N/A		N/A	N/A	N/A
34	7.8863		0.36	104.07		7.8628	0.33	255.91	80	N/A		N/A	N/A		N/A	N/A	N/A
36	7.8884		0.33	101.93		7.8282	0.33	258.12	82	N/A		N/A	N/A		N/A	N/A	N/A
38	7.8615		0.34	99.85		7.8276	0.35	260.12	84	N/A		N/A	N/A		N/A	N/A	N/A
40	7.8488		0.37	97.98		7.8035	0.34	262.10	86	N/A		N/A	N/A		N/A	N/A	N/A
42	7.8406		0.38	96.16		7.7886	0.36	263.89	88	N/A		N/A	N/A		N/A	N/A	N/A
44	7.8234		0.36	94.49		7.7885	0.38	265.54	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

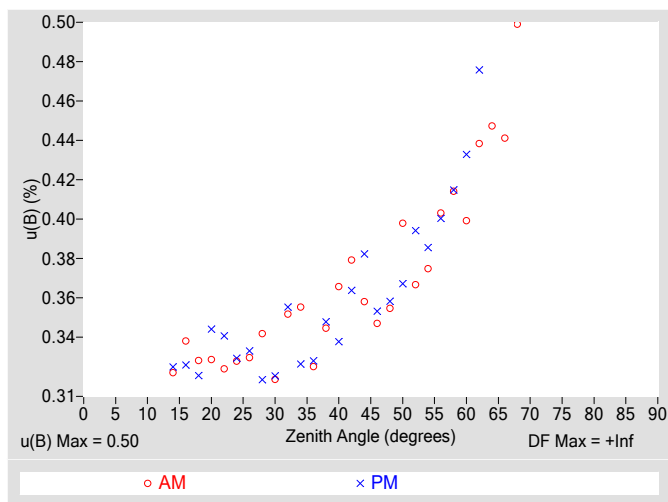


Figure 4. Residuals from Spline Interpolation

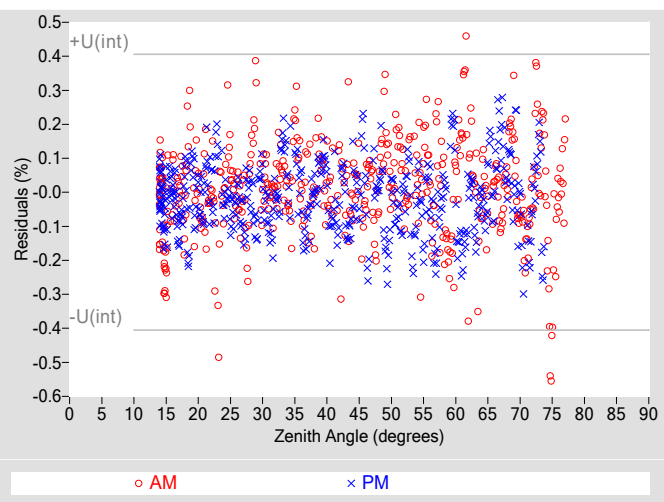


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	43978
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

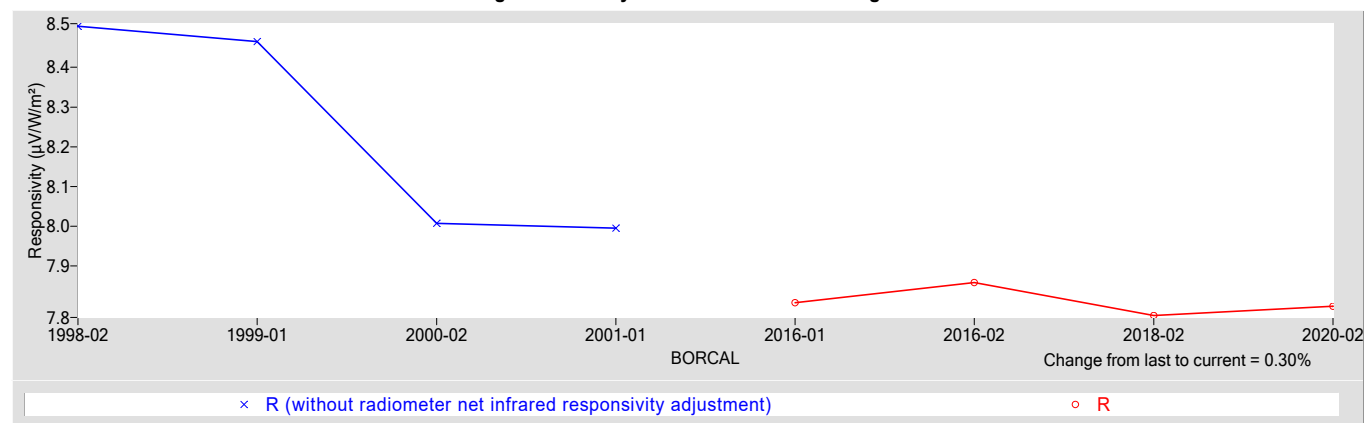
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.7981	0.60000

† R_{net} determination date: 06/24/2013

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+1.5 / -1.9
Expanded Uncertainty, U (%)	+2.4 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 31635F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31635F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

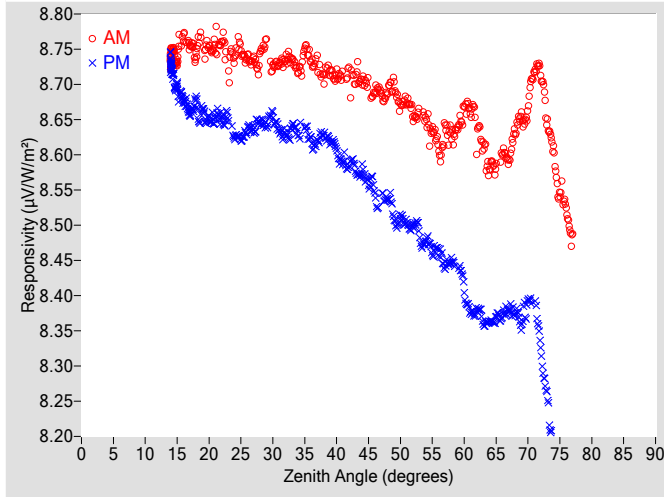


Figure 2. Responsivity vs Local Standard Time

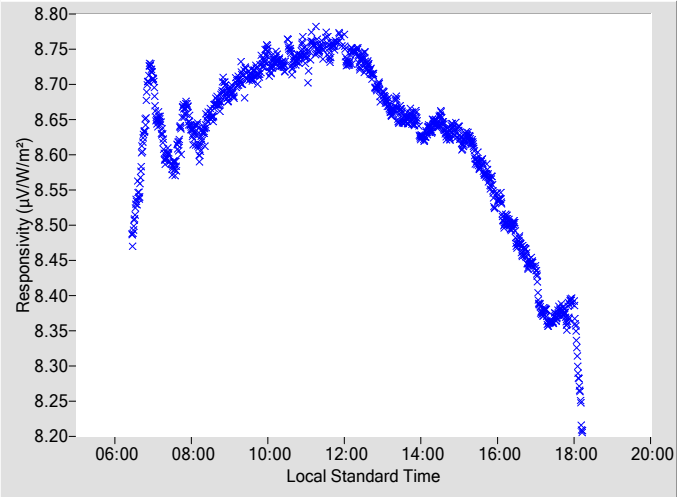


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6900	0.32	92.87	8.5433	0.32	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6916	0.32	91.32	8.5364	0.33	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6701	0.37	89.82	8.5112	0.33	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6563	0.33	88.36	8.5002	0.36	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6475	0.34	86.96	8.4788	0.35	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6070	0.37	85.53	8.4627	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6291	0.38	84.16	8.4487	0.37	275.86
14	8.7397	0.31	173.47	8.7257	0.31	187.33	60	8.6640	0.36	82.83	8.4068	0.38	277.23
16	8.7669	0.32	147.99	8.6770	0.31	211.71	62	8.6324	0.40	81.48	8.3786	0.42	278.57
18	8.7452	0.31	137.21	8.6714	0.30	222.82	64	8.5818	0.41	80.17	8.3631	N/A	279.89
20	8.7527	0.31	129.44	8.6510	0.33	230.38	66	8.6005	0.39	78.83	8.3730	N/A	281.29
22	8.7611	0.31	123.98	8.6511	0.32	236.04	68	8.6343	0.45	77.44	8.3751	N/A	282.59
24	8.7400	0.31	119.20	8.6258	0.31	240.72	70	8.6632	N/A	76.14	8.3925	N/A	283.97
26	8.7381	0.31	115.36	8.6366	0.32	244.70	72	8.7155	N/A	74.76	8.3251	N/A	285.31
28	8.7384	0.32	112.03	8.6457	0.30	247.94	74	8.6042	N/A	73.37	N/A	N/A	N/A
30	8.7233	0.30	109.11	8.6531	0.30	250.95	76	8.5230	N/A	71.99	N/A	N/A	N/A
32	8.7346	0.33	106.49	8.6304	0.34	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7212	0.34	104.07	8.6284	0.31	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7349	0.30	101.93	8.6191	0.31	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7135	0.32	99.85	8.6278	0.33	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7110	0.34	97.98	8.6039	0.31	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7122	0.36	96.16	8.5873	0.34	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7065	0.33	94.49	8.5755	0.36	265.54	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

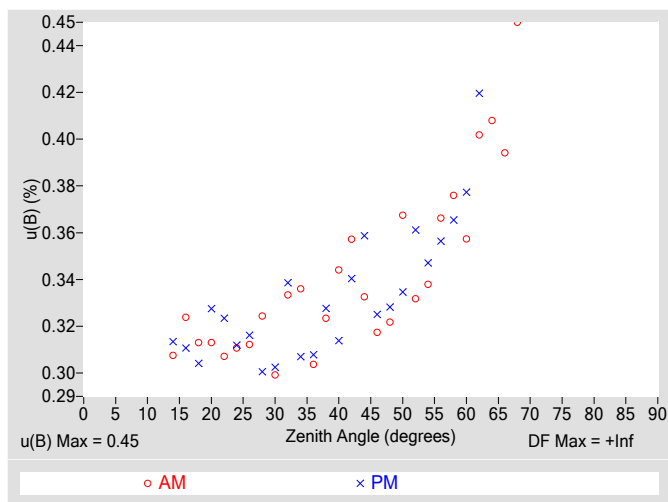


Figure 4. Residuals from Spline Interpolation

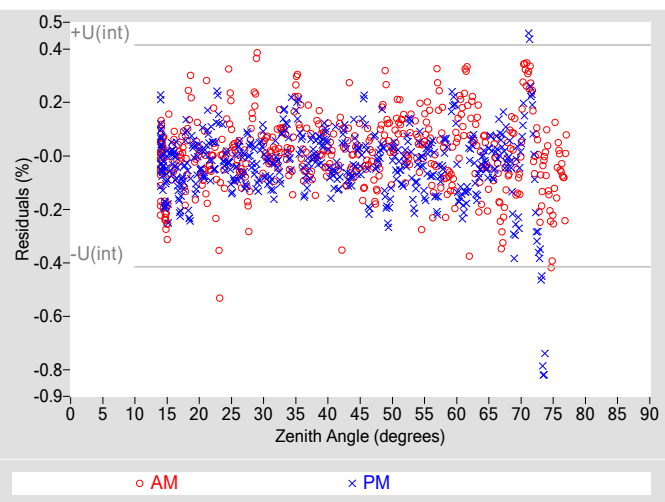


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.45
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.50
Effective degrees of freedom, $DF(c)$	28688
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.97
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

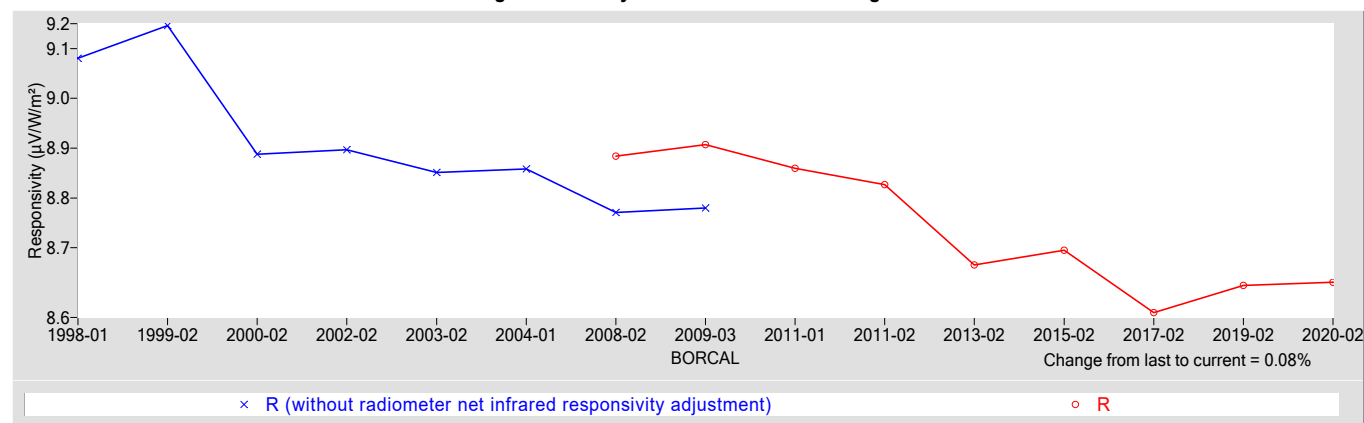
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.6307	0.61365

† R_{net} determination date: 06/06/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.74
Offset Uncertainty, $U(off)$ (%)	+1.2 / -2.6
Expanded Uncertainty, U (%)	+1.9 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31746E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31746E6 Eppley NIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

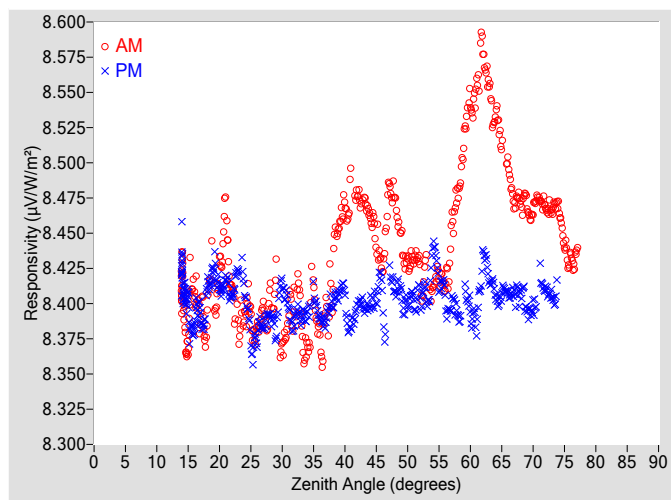


Figure 2. Responsivity vs Local Standard Time

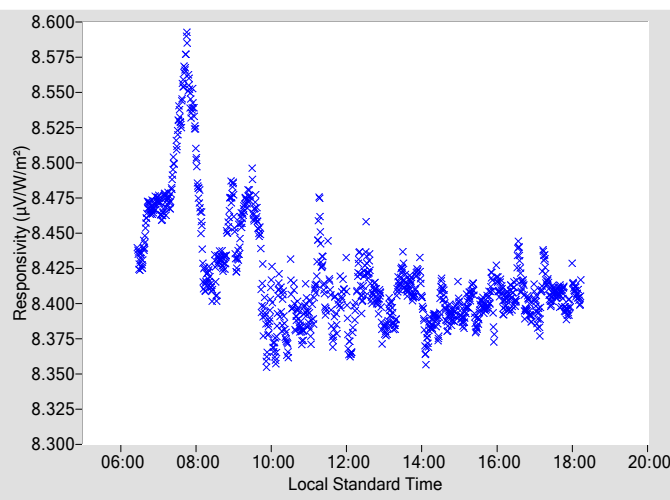


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4270	0.30	92.93	8.4050	0.32	267.10
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4730	0.31	91.34	8.4079	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4294	0.33	89.84	8.4003	0.30	270.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4244	0.31	88.44	8.4047	0.30	271.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4095	0.32	86.96	8.4366	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4147	0.29	85.58	8.4040	0.30	274.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4782	0.33	84.21	8.3906	0.30	275.91
14	8.4153	0.30	173.58	8.4181	0.30	186.95	60	8.5415	0.34	82.80	8.3933	0.30	277.21
16	8.4085	0.32	147.89	8.3865	0.29	211.91	62	8.5809	0.33	81.47	8.4290	0.30	278.54
18	8.3861	0.30	137.34	8.4120	0.30	223.07	64	8.5337	0.32	80.14	8.4054	N/A	279.95
20	8.4226	0.32	129.72	8.4116	0.30	230.33	66	8.4979	0.32	78.80	8.4070	N/A	281.26
22	8.4100	0.31	123.88	8.4065	0.30	236.21	68	8.4731	0.30	77.49	8.4060	N/A	282.64
24	8.3892	0.33	119.23	8.4093	0.29	240.76	70	8.4667	N/A	76.11	8.3973	N/A	283.94
26	8.3809	0.29	115.39	8.3769	0.33	244.63	72	8.4678	N/A	74.74	8.4093	N/A	285.32
28	8.4080	0.31	112.06	8.3901	0.30	248.06	74	8.4675	N/A	73.34	8.4168	N/A	286.52
30	8.3692	0.31	109.05	8.4132	0.32	250.97	76	8.4321	N/A	71.96	N/A	N/A	N/A
32	8.3987	0.33	106.49	8.3883	0.29	253.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3689	0.29	104.15	8.3930	0.29	256.00	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3750	0.30	101.89	8.3897	0.29	258.08	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4111	0.29	99.92	8.3995	0.29	260.19	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4711	0.31	98.00	8.4026	0.29	262.06	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4775	0.32	96.23	8.3989	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4624	0.29	94.56	8.3992	0.29	265.51	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

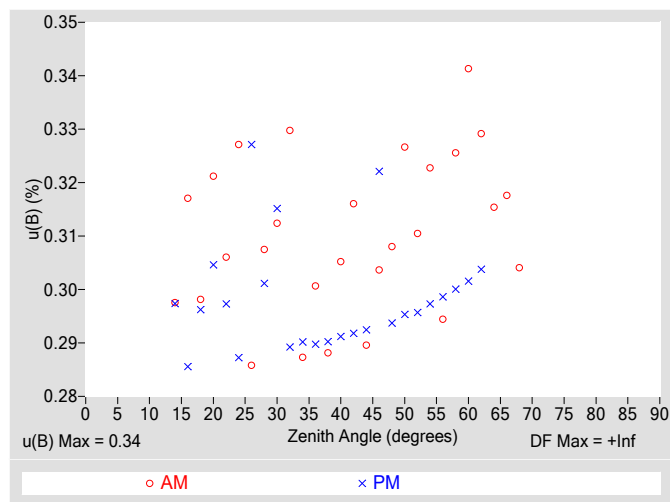


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.27
Combined Standard Uncertainty, $u(c)$ (%)	± 0.43
Effective degrees of freedom, $DF(c)$	6224
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.85
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

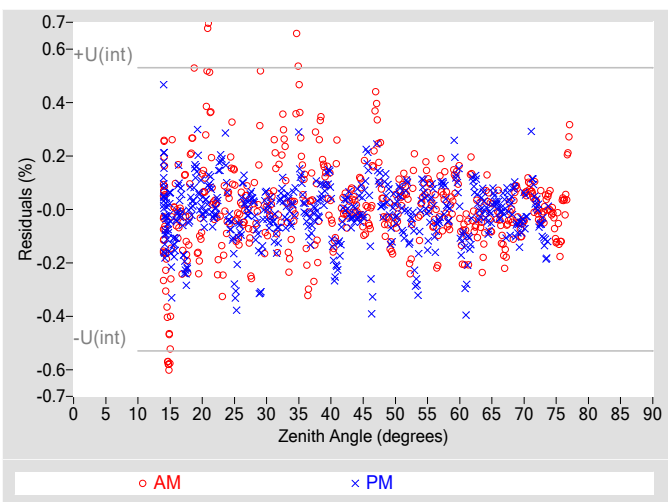


Table 4. Calibration Label Values

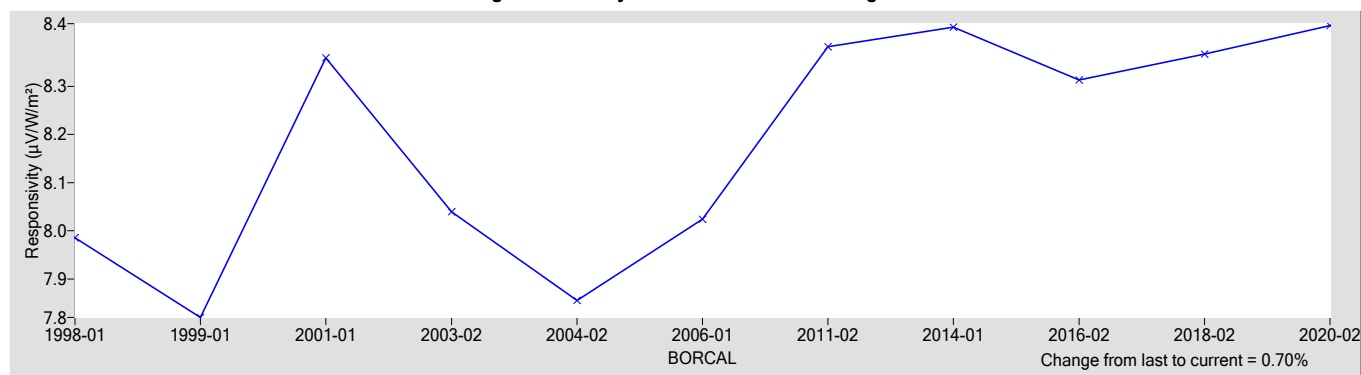
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.4258	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.4 / -0.67
Expanded Uncertainty, U (%)	+2.0 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: NSA
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 31762E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31762E6 Eppley NIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

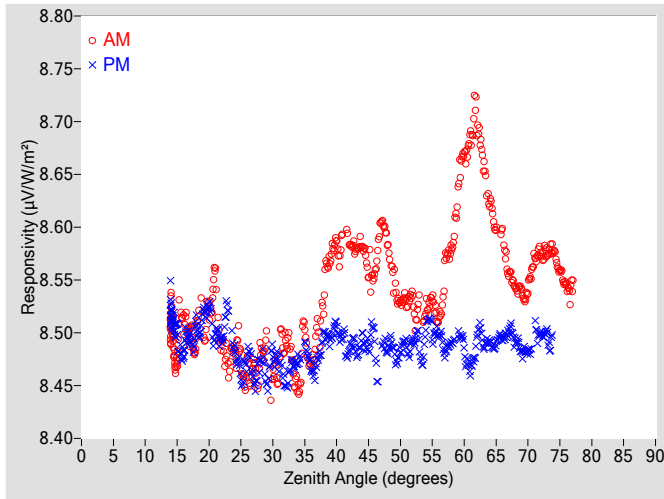


Figure 2. Responsivity vs Local Standard Time

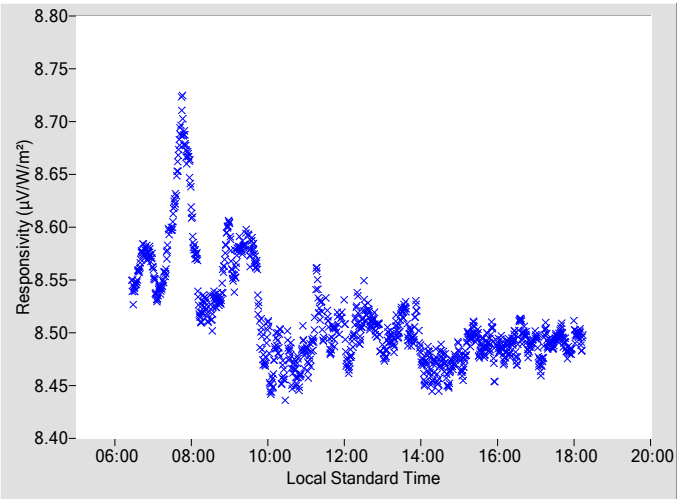


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5553	0.30	92.94	8.4895	0.29	267.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5841	0.29	91.34	8.4838	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5286	0.34	89.84	8.4827	0.30	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5292	0.29	88.38	8.4918	0.30	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5197	0.29	86.97	8.5020	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5130	0.34	85.59	8.4993	0.30	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5774	0.30	84.22	8.4903	0.30	275.83
14	8.5095	0.29	173.41	8.5160	0.30	187.43	60	8.6680	0.30	82.80	8.4843	0.30	277.21
16	8.5092	0.33	148.10	8.4840	0.33	211.94	62	8.7011	0.31	81.47	8.4920	0.30	278.55
18	8.4954	0.30	137.29	8.5071	0.30	223.09	64	8.6250	0.32	80.14	8.4904	N/A	279.95
20	8.5236	0.29	129.35	8.5244	0.30	230.35	66	8.5930	0.30	78.82	8.4951	N/A	281.26
22	8.4898	0.29	123.89	8.4946	0.31	236.22	68	8.5425	0.30	77.41	8.4916	N/A	282.60
24	8.4787	0.32	119.13	8.4820	0.30	240.77	70	8.5425	N/A	76.11	8.4830	N/A	283.94
26	8.4642	0.31	115.40	8.4763	0.29	244.64	72	8.5757	N/A	74.74	8.4991	N/A	285.29
28	8.4743	0.31	112.07	8.4718	0.30	247.98	74	8.5783	N/A	73.34	8.4978	N/A	286.52
30	8.4589	0.30	108.98	8.4780	0.30	250.98	76	8.5446	N/A	71.96	N/A	N/A	N/A
32	8.4893	0.29	106.45	8.4495	0.29	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4486	0.31	104.10	8.4745	0.29	256.01	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4732	0.34	101.92	8.4677	0.29	258.09	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5335	0.31	99.93	8.4973	0.29	260.20	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5832	0.29	97.95	8.5053	0.29	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5862	0.31	96.21	8.4849	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5802	0.31	94.52	8.4936	0.29	265.51	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

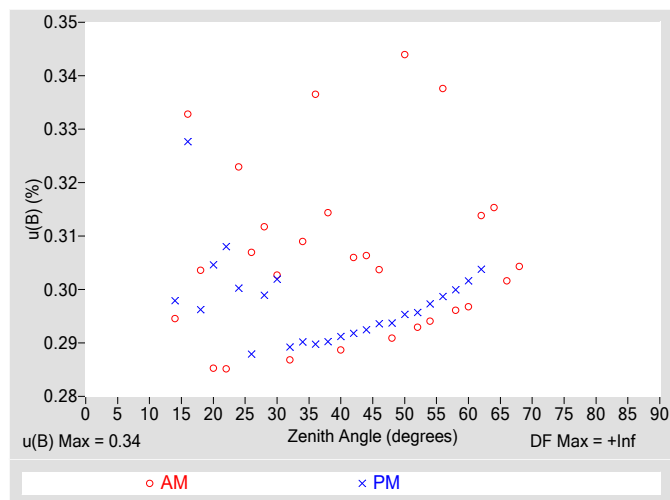


Figure 4. Residuals from Spline Interpolation

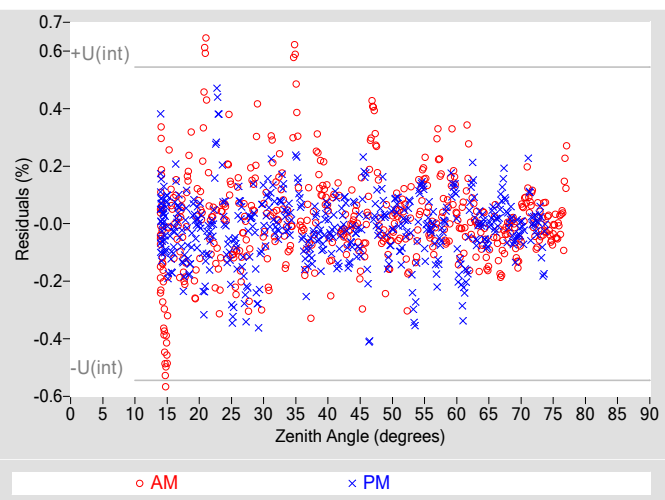


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.27
Combined Standard Uncertainty, $u(c)$ (%)	± 0.44
Effective degrees of freedom, $DF(c)$	5946
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.86
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

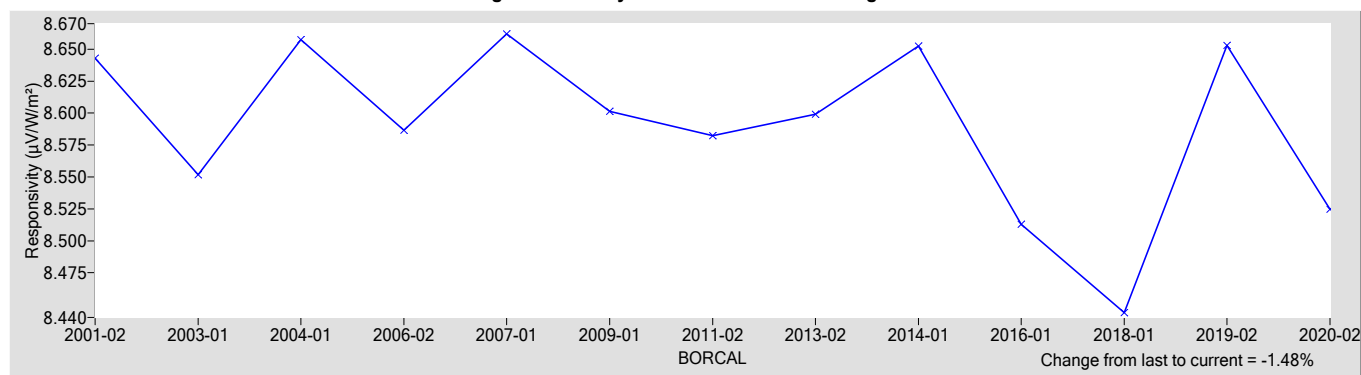
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5248	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+1.7 / -0.89
Expanded Uncertainty, U (%)	+2.4 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 32015F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: NSA **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32015F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

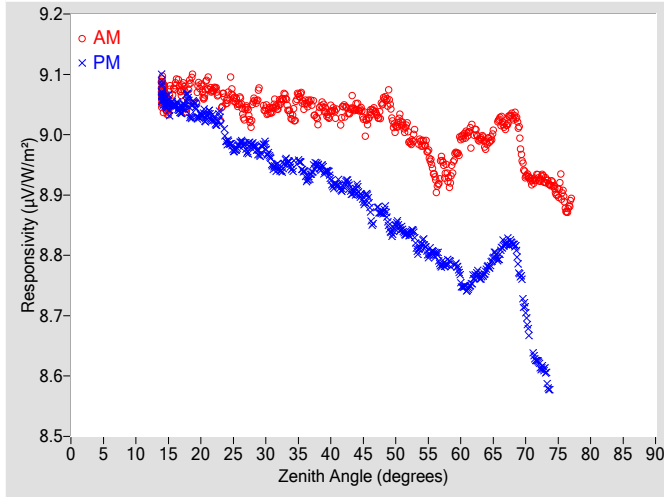


Figure 2. Responsivity vs Local Standard Time

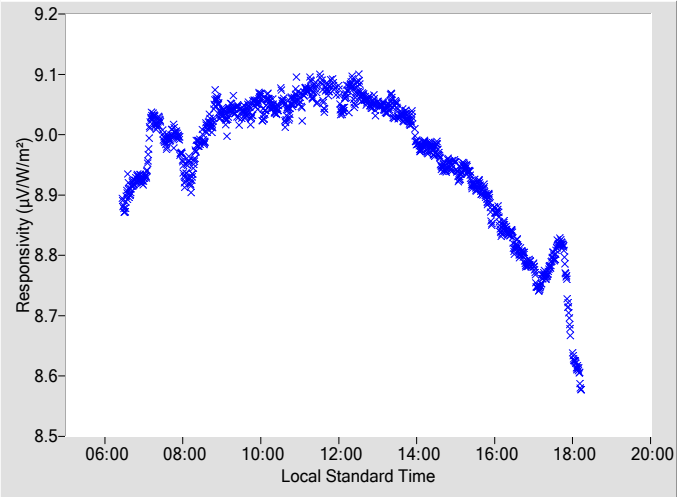


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	AM			PM			Zenith Angle (deg.)	AM			PM		
	R ($\mu\text{V}/\text{W}/\text{m}^2$)	$u(B)$ (\pm %)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	$u(B)$ (\pm %)	Azimuth Angle		R ($\mu\text{V}/\text{W}/\text{m}^2$)	$u(B)$ (\pm %)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	$u(B)$ (\pm %)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0332	0.31	92.87	8.8780	0.32	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0547	0.32	91.32	8.8718	0.32	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0124	0.36	89.82	8.8516	0.33	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9972	0.33	88.36	8.8357	0.36	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9853	0.33	86.96	8.8207	0.34	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9260	0.36	85.53	8.8026	0.35	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9302	0.37	84.16	8.7877	0.36	275.86
14	9.0732	0.30	173.25	9.0645	0.31	187.56	60	8.9897	0.35	82.83	8.7580	0.37	277.23
16	9.0824	0.32	147.99	9.0482	0.31	211.71	62	9.0084	0.41	81.47	8.7626	0.41	278.57
18	9.0602	0.31	137.21	9.0564	0.30	222.82	64	8.9842	0.40	80.17	8.7769	N/A	279.89
20	9.0779	0.31	129.44	9.0316	0.32	230.38	66	9.0229	0.39	78.83	8.8021	N/A	281.29
22	9.0751	0.30	123.98	9.0248	0.32	236.04	68	9.0301	0.44	77.44	8.8195	N/A	282.59
24	9.0575	0.31	119.20	8.9897	0.31	240.72	70	8.9346	N/A	76.14	8.7044	N/A	283.97
26	9.0551	0.31	115.36	8.9863	0.31	244.70	72	8.9286	N/A	74.76	8.6215	N/A	285.31
28	9.0428	0.32	112.03	8.9828	0.30	247.94	74	8.9184	N/A	73.37	N/A	N/A	N/A
30	9.0415	0.30	109.11	8.9779	0.30	250.95	76	8.8890	N/A	71.99	N/A	N/A	N/A
32	9.0483	0.33	106.49	8.9443	0.34	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.0322	0.33	104.07	8.9446	0.30	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0518	0.30	101.93	8.9340	0.30	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0308	0.32	99.85	8.9490	0.32	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0386	0.34	97.98	8.9230	0.31	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0435	0.34	96.16	8.9163	0.34	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0452	0.33	94.49	8.9094	0.35	265.54	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

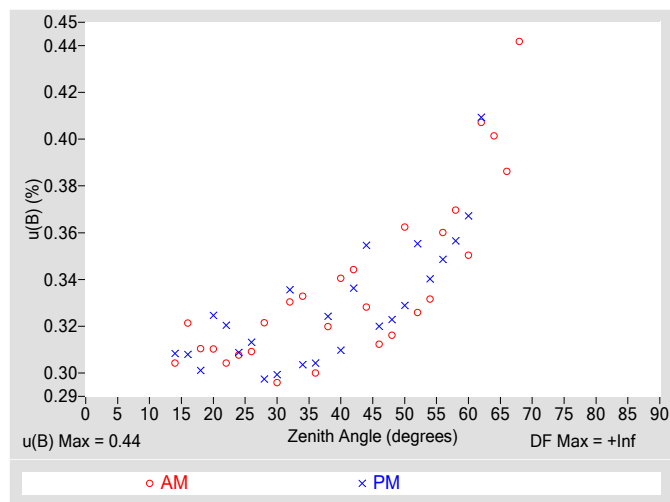


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.44
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.50
Effective degrees of freedom, $DF(c)$	19153
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.98
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

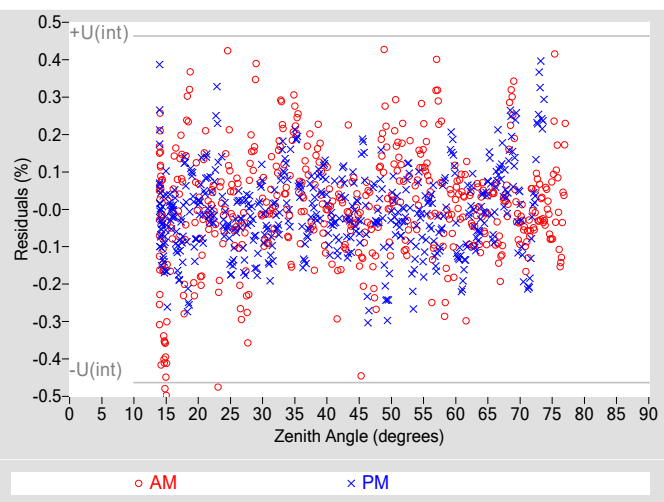


Table 4. Calibration Label Values

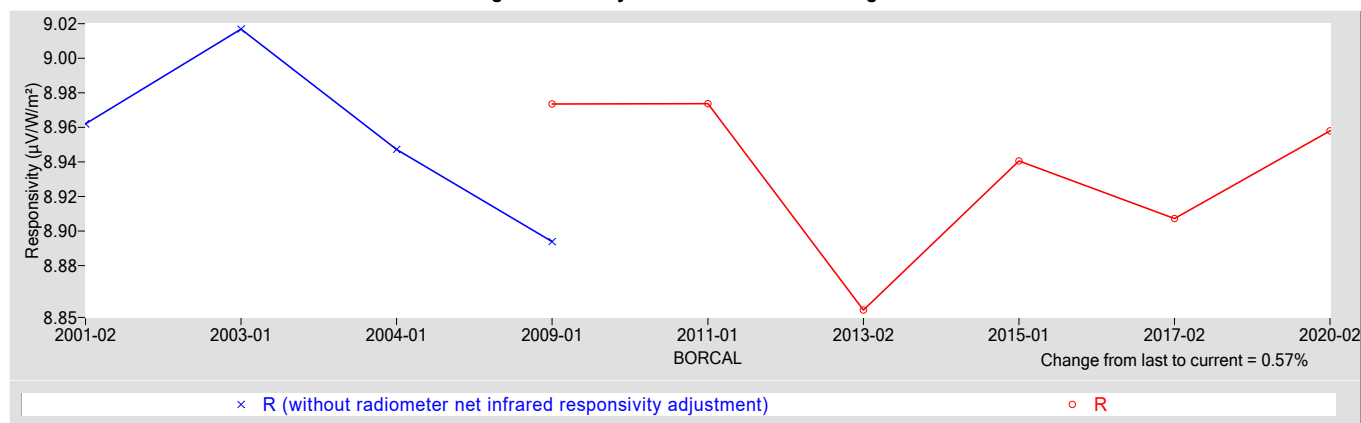
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.9580	0.42210

† R_{net} determination date: 03/25/2009

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.72
Offset Uncertainty, $U(off)$ (%)	+1.1 / -2.2
Expanded Uncertainty, U (%)	+1.8 / -3.0
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 32023F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: NSA **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32023F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

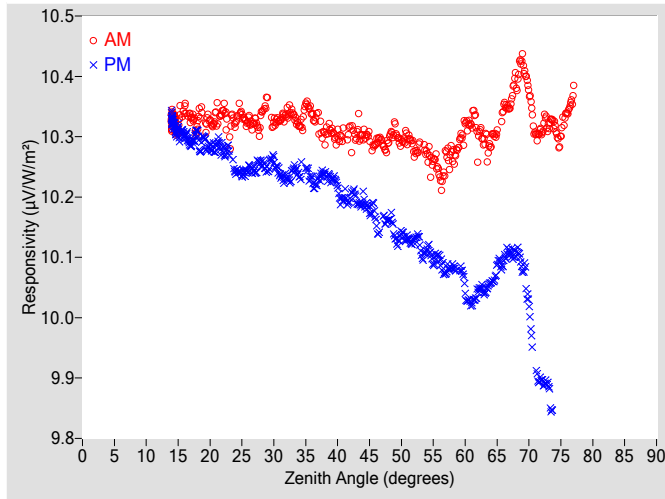


Figure 2. Responsivity vs Local Standard Time

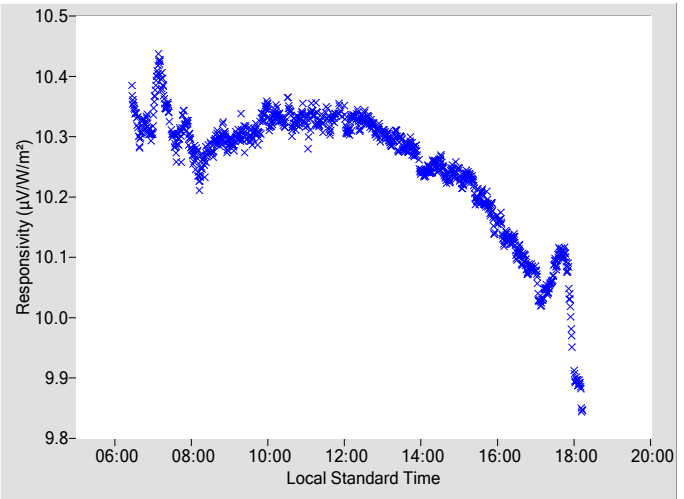


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.289	0.32	92.87	10.160	0.32	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.296	0.32	91.32	10.162	0.33	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.292	0.37	89.82	10.140	0.33	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.277	0.33	88.36	10.130	0.36	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.269	0.34	86.96	10.115	0.35	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.231	0.37	85.53	10.097	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.270	0.38	84.16	10.084	0.36	275.86
14	10.329	0.31	173.47	10.327	0.31	187.56	60	10.317	0.36	82.83	10.044	0.38	277.23
16	10.345	0.32	147.99	10.302	0.31	211.71	62	10.298	0.39	81.50	10.044	0.42	278.57
18	10.319	0.31	137.21	10.303	0.30	222.82	64	10.289	0.41	80.17	10.058	N/A	279.89
20	10.325	0.31	129.44	10.283	0.33	230.38	66	10.343	0.39	78.83	10.094	N/A	281.29
22	10.343	0.31	123.98	10.278	0.32	236.04	68	10.391	0.45	77.44	10.108	N/A	282.59
24	10.324	0.31	119.20	10.243	0.31	240.72	70	10.378	N/A	76.14	10.014	N/A	283.97
26	10.327	0.31	115.36	10.248	0.32	244.70	72	10.309	N/A	74.76	9.8957	N/A	285.31
28	10.329	0.32	112.03	10.256	0.30	247.94	74	10.318	N/A	73.37	N/A	N/A	N/A
30	10.321	0.30	109.11	10.259	0.30	250.95	76	10.340	N/A	71.99	N/A	N/A	N/A
32	10.337	0.33	106.49	10.232	0.34	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	10.321	0.34	104.07	10.235	0.31	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	10.338	0.30	101.93	10.227	0.31	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	10.304	0.32	99.85	10.238	0.33	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	10.298	0.34	97.98	10.212	0.31	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.306	0.36	96.16	10.201	0.34	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.303	0.33	94.49	10.193	0.36	265.54	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

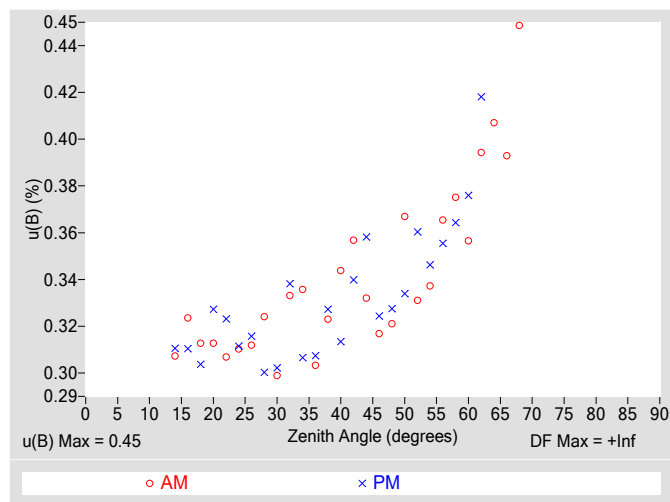


Figure 4. Residuals from Spline Interpolation

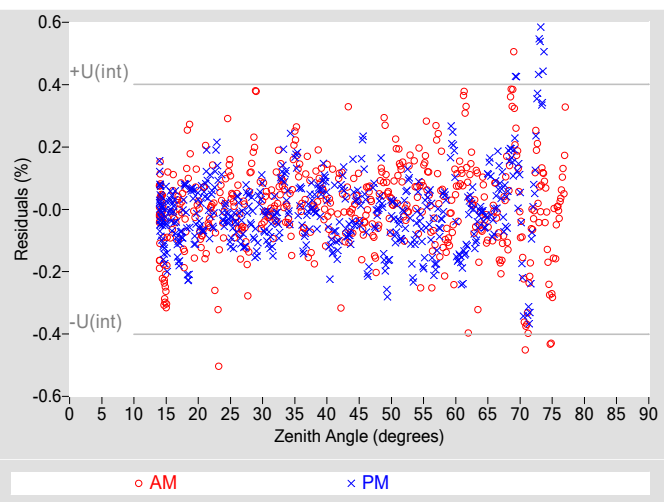


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.45
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	32061
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.96
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

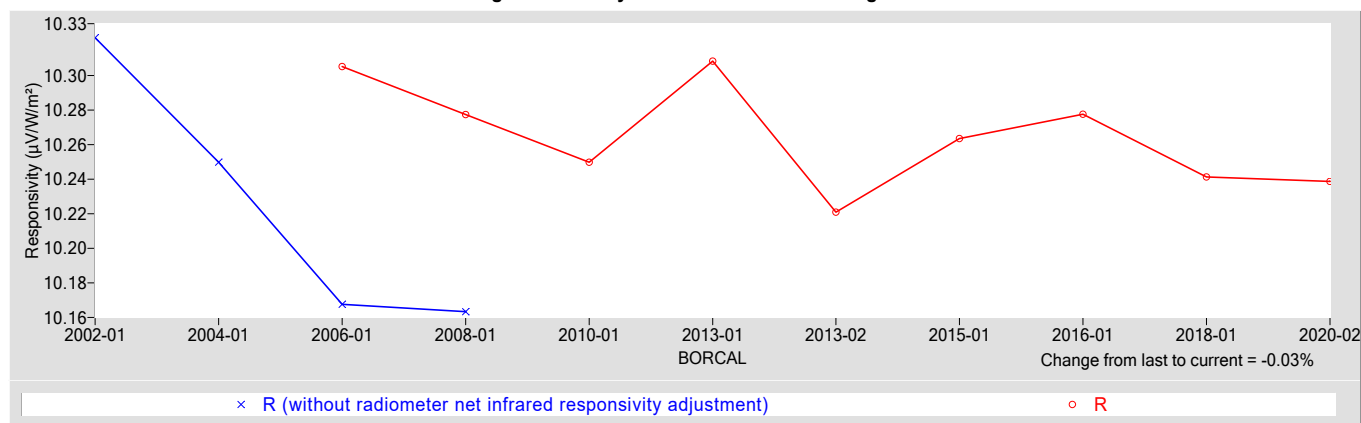
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
10.239	0.70600

† R_{net} determination date: 04/04/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.74
Offset Uncertainty, $U(off)$ (%)	+0.97 / -1.9
Expanded Uncertainty, U (%)	+1.7 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 32039F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: NSA **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32039F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \text{COS}(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

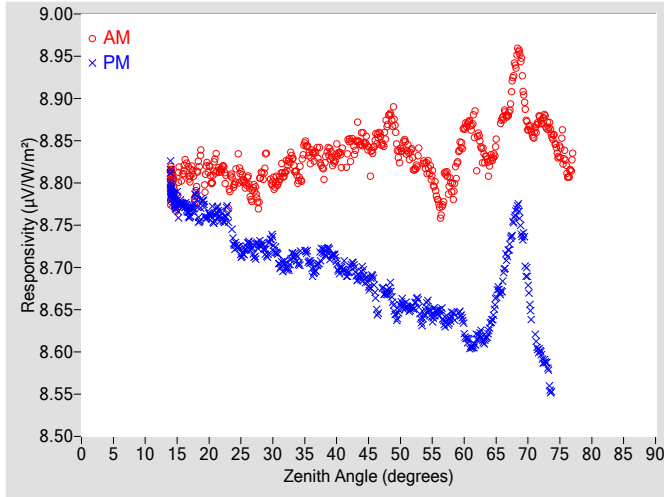


Figure 2. Responsivity vs Local Standard Time

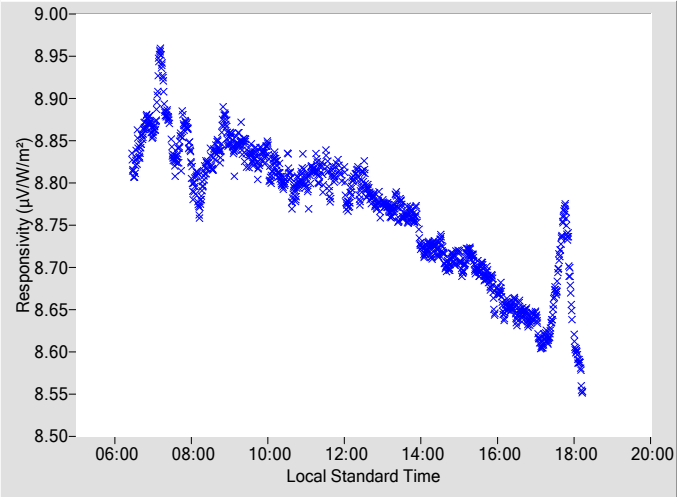


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8480	0.32	92.87	8.6701	0.33	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8743	0.32	91.32	8.6711	0.33	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8357	0.37	89.82	8.6568	0.34	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8237	0.33	88.36	8.6537	0.36	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8190	0.34	86.96	8.6533	0.35	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7730	0.37	85.53	8.6474	0.36	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7952	0.38	84.16	8.6422	0.37	275.86
14	8.8018	0.30	173.78	8.7920	0.31	187.56	60	8.8609	0.36	82.83	8.6250	0.38	277.23
16	8.8169	0.32	147.99	8.7734	0.31	211.71	62	8.8534	0.40	81.48	8.6160	0.42	278.57
18	8.7978	0.31	137.21	8.7783	0.30	222.82	64	8.8224	0.41	80.17	8.6290	N/A	279.89
20	8.8153	0.31	129.44	8.7621	0.33	230.38	66	8.8749	0.40	78.83	8.6839	N/A	281.29
22	8.8170	0.31	123.98	8.7594	0.32	236.04	68	8.9391	0.45	77.44	8.7621	N/A	282.59
24	8.8018	0.31	119.20	8.7276	0.31	240.72	70	8.8678	N/A	76.14	8.6787	N/A	283.97
26	8.8022	0.31	115.36	8.7272	0.32	244.70	72	8.8745	N/A	74.76	8.5986	N/A	285.31
28	8.7971	0.33	112.03	8.7273	0.30	247.94	74	8.8530	N/A	73.37	N/A	N/A	N/A
30	8.7996	0.30	109.11	8.7287	0.30	250.95	76	8.8209	N/A	71.99	N/A	N/A	N/A
32	8.8146	0.33	106.49	8.7017	0.34	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8076	0.34	104.07	8.7062	0.31	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8328	0.30	101.93	8.7012	0.31	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8189	0.32	99.85	8.7187	0.33	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8345	0.34	97.98	8.7032	0.31	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8455	0.35	96.16	8.6982	0.34	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8511	0.33	94.49	8.6938	0.36	265.54	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

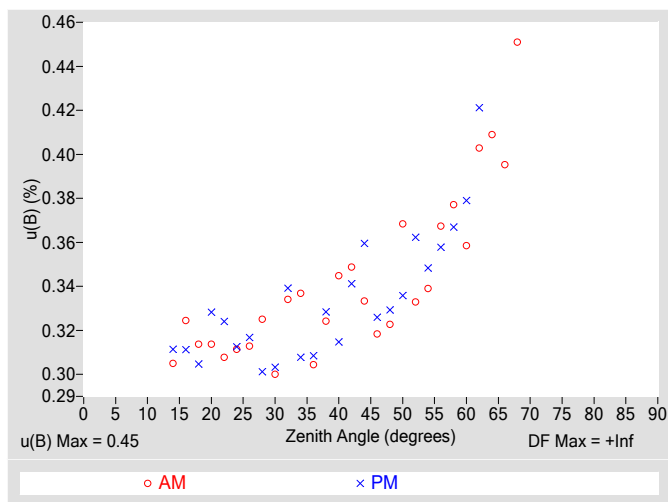


Figure 4. Residuals from Spline Interpolation

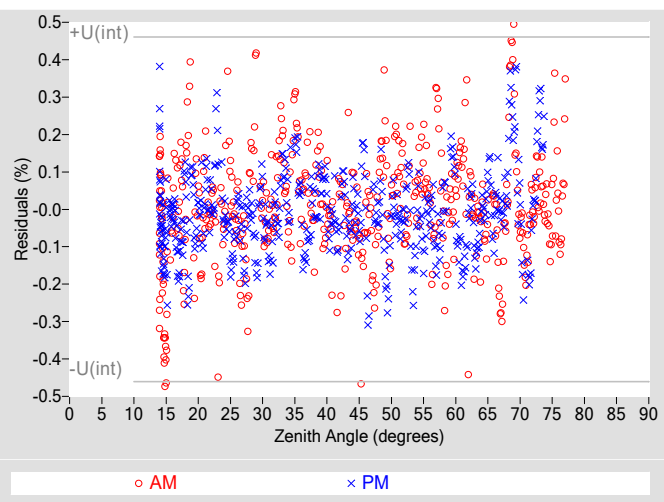


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.45
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.51
Effective degrees of freedom, $DF(c)$	20781
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.99
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

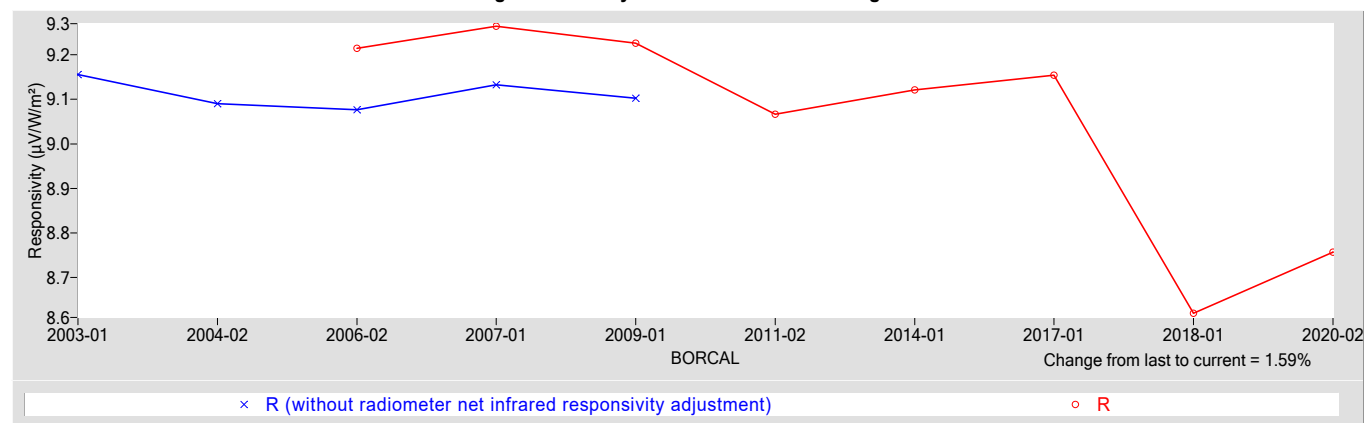
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.7564	0.65771

† R_{net} determination date: 06/13/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.74
Offset Uncertainty, $U(off)$ (%)	+1.3 / -1.5
Expanded Uncertainty, U (%)	+2.1 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 32330
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32330 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

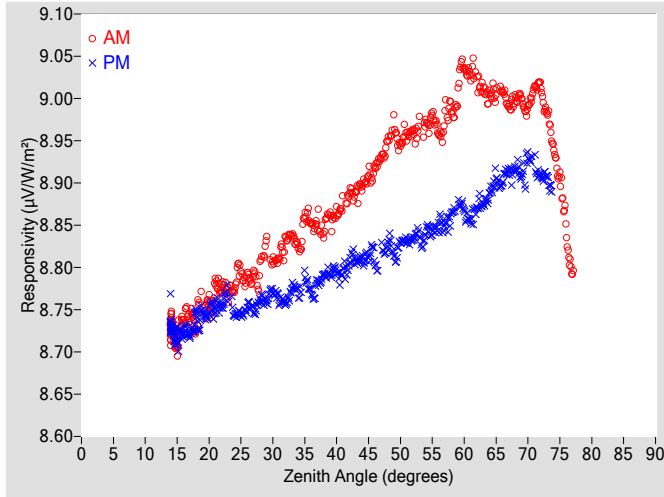


Figure 2. Responsivity vs Local Standard Time

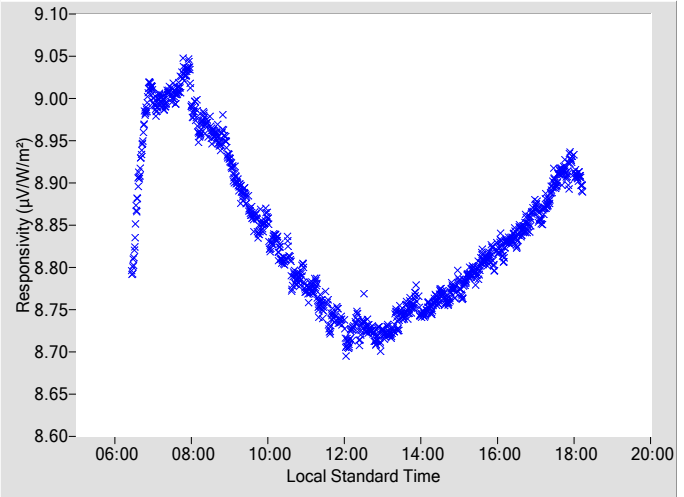


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9179	0.31	92.91	8.8066	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9490	0.31	91.37	8.8256	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9447	0.36	89.87	8.8289	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9598	0.32	88.40	8.8336	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9710	0.35	86.95	8.8418	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9606	0.33	85.57	8.8521	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9890	0.39	84.20	8.8621	0.38	275.89
14	8.7312	0.31	173.58	8.7283	0.30	187.53	60	9.0348	0.40	82.78	8.8651	0.36	277.23
16	8.7393	0.32	148.50	8.7225	0.30	211.69	62	9.0226	0.39	81.43	8.8714	0.37	278.61
18	8.7316	0.31	137.26	8.7421	0.32	222.80	64	9.0035	0.43	80.12	8.8888	N/A	279.93
20	8.7597	0.30	129.66	8.7482	0.33	230.42	66	9.0075	0.38	78.78	8.9012	N/A	281.24
22	8.7752	0.32	123.83	8.7546	0.30	236.16	68	8.9973	0.43	77.47	8.9155	N/A	282.62
24	8.7742	0.32	119.30	8.7432	0.32	240.82	70	8.9886	N/A	76.09	8.9303	N/A	283.92
26	8.7894	0.33	115.35	8.7532	0.31	244.59	72	9.0118	N/A	74.72	8.9078	N/A	285.35
28	8.7983	0.34	112.03	8.7618	0.31	248.03	74	8.9408	N/A	73.37	8.8896	N/A	286.50
30	8.8066	0.33	109.10	8.7706	0.30	250.94	76	8.8454	N/A	71.98	N/A	N/A	N/A
32	8.8270	0.29	106.48	8.7579	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8253	0.32	104.16	8.7712	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8522	0.33	101.86	8.7690	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8435	0.30	99.84	8.7913	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8634	0.32	97.97	8.7954	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8880	0.34	96.21	8.8042	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8970	0.32	94.54	8.8096	0.31	265.49	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

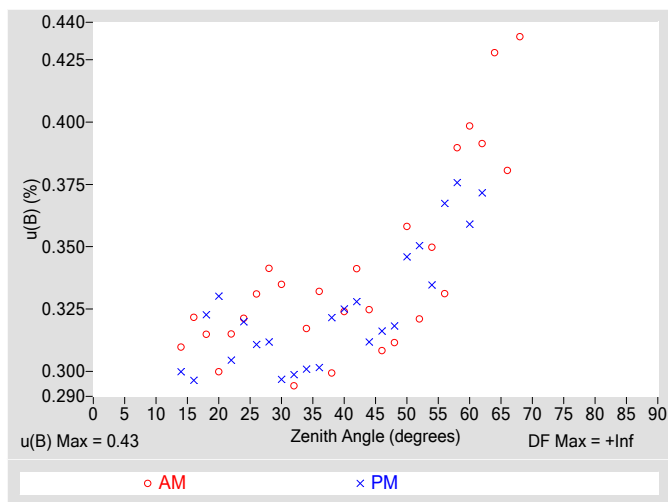


Figure 4. Residuals from Spline Interpolation

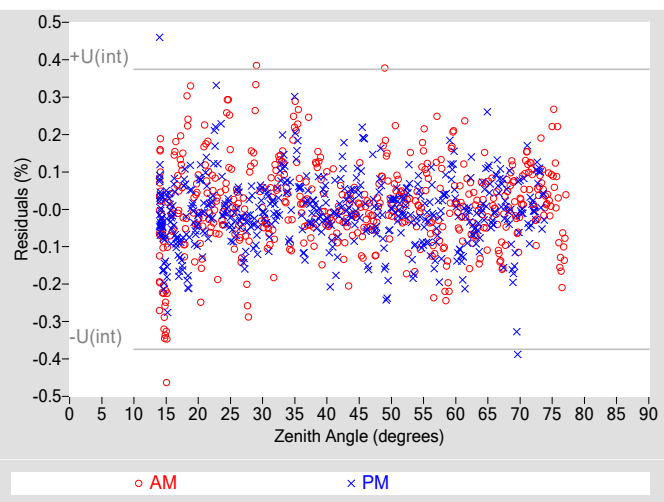


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	36441
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.93
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

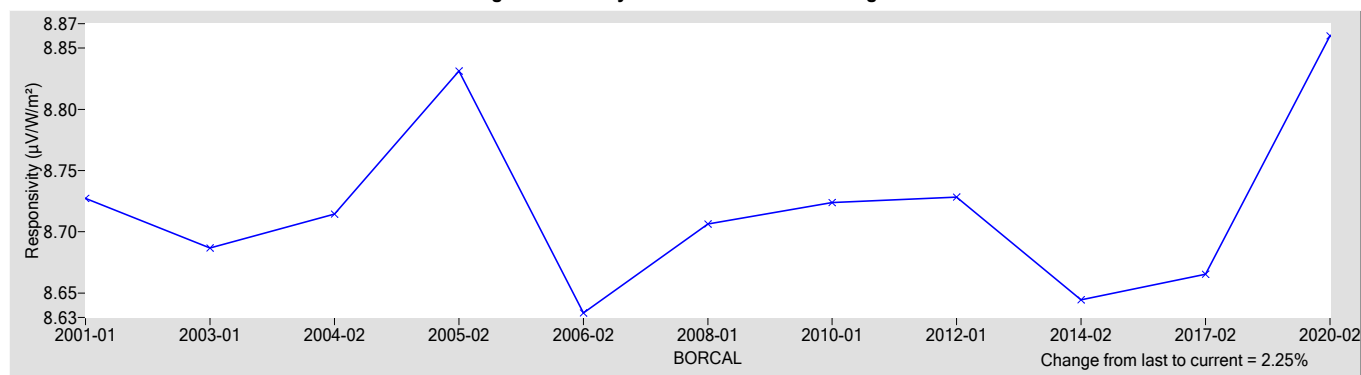
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.8600	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+2.0 / -1.2
Expanded Uncertainty, U (%)	+2.8 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 32815F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32815F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

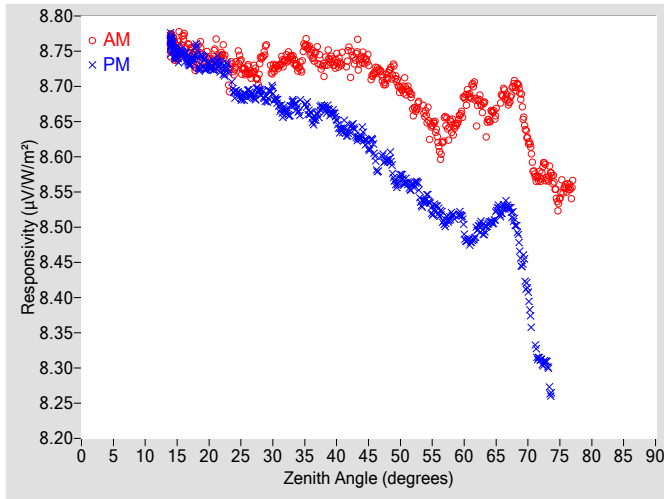


Figure 2. Responsivity vs Local Standard Time

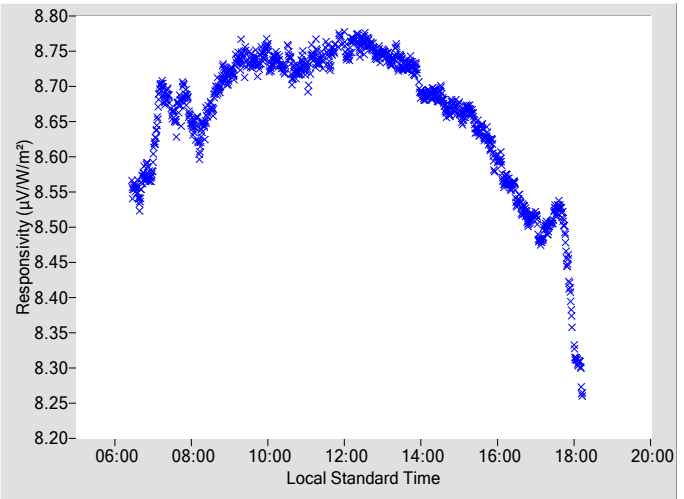


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7208	0.34	92.87	8.6000	0.35	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7165	0.35	91.32	8.5955	0.35	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6960	0.39	89.82	8.5719	0.36	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6708	0.36	88.36	8.5610	0.39	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6574	0.37	86.96	8.5419	0.38	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6135	0.39	85.53	8.5229	0.39	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6443	0.40	84.16	8.5164	0.40	275.86
14	8.7625	0.32	173.78	8.7612	0.32	187.33	60	8.6792	0.39	82.83	8.4937	0.42	277.23
16	8.7683	0.34	147.99	8.7447	0.32	211.71	62	8.6720	0.42	81.50	8.4959	0.46	278.57
18	8.7365	0.33	137.21	8.7478	0.32	222.82	64	8.6544	0.44	80.17	8.5067	N/A	279.89
20	8.7381	0.33	129.44	8.7300	0.34	230.38	66	8.6871	0.43	78.83	8.5257	N/A	281.29
22	8.7471	0.32	123.98	8.7263	0.34	236.04	68	8.7017	0.49	77.44	8.5055	N/A	282.59
24	8.7246	0.32	119.20	8.6919	0.33	240.72	70	8.6262	N/A	76.14	8.4041	N/A	283.97
26	8.7234	0.33	115.36	8.6918	0.33	244.70	72	8.5725	N/A	74.76	8.3109	N/A	285.31
28	8.7291	0.34	112.03	8.6919	0.31	247.94	74	8.5653	N/A	73.37	N/A	N/A	N/A
30	8.7228	0.31	109.11	8.6907	0.32	250.95	76	8.5569	N/A	71.99	N/A	N/A	N/A
32	8.7380	0.35	106.49	8.6658	0.35	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7281	0.35	104.07	8.6650	0.32	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7482	0.32	101.93	8.6579	0.32	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7295	0.34	99.85	8.6701	0.34	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7343	0.36	97.98	8.6493	0.33	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7424	0.37	96.16	8.6395	0.36	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7411	0.35	94.49	8.6310	0.38	265.54	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

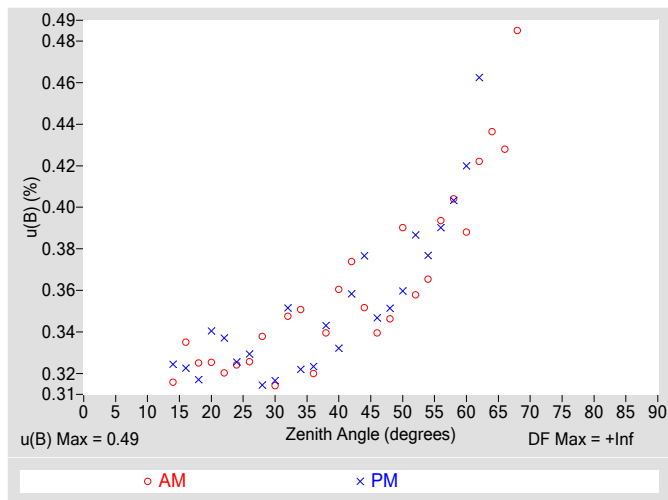


Figure 4. Residuals from Spline Interpolation

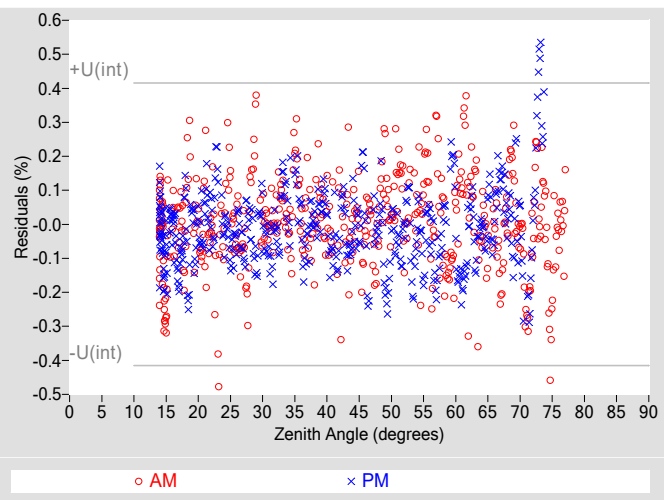


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.49
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.53
Effective degrees of freedom, $DF(c)$	36805
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.0
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

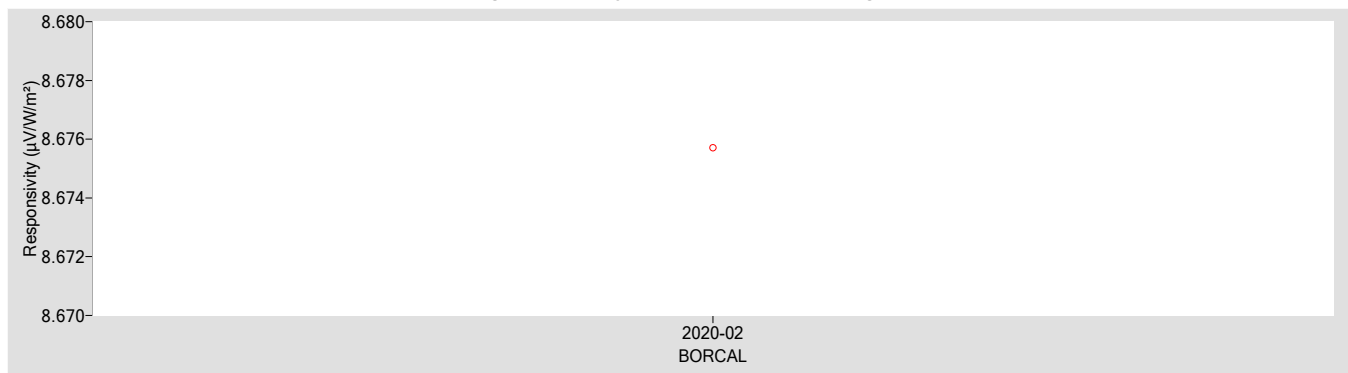
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.6757	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	+0.84 / -2.1
Expanded Uncertainty, U (%)	+1.7 / -2.9
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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 32872
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: Calibration System **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32872 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \text{COS}(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

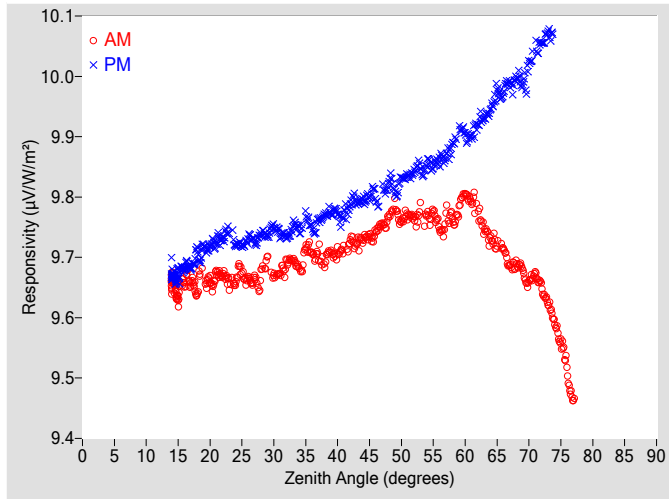


Figure 2. Responsivity vs Local Standard Time

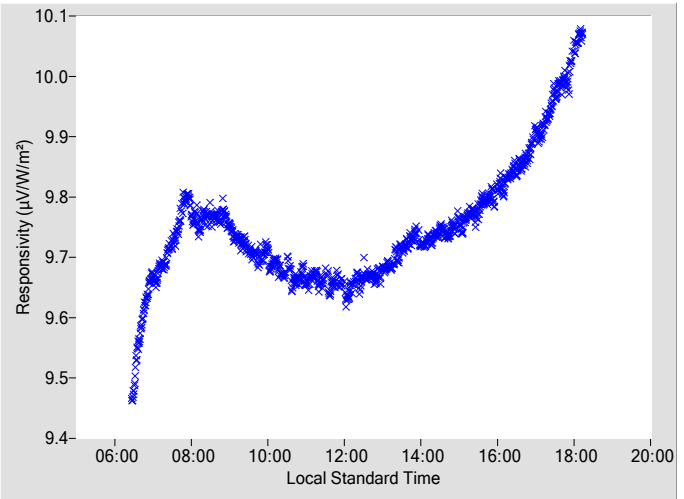


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.7426	0.31	92.91	9.7957	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7662	0.31	91.37	9.8218	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7598	0.36	89.87	9.8304	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7653	0.32	88.40	9.8413	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7711	0.35	86.95	9.8551	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7498	0.33	85.57	9.8627	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7652	0.39	84.20	9.8853	0.38	275.89
14	9.6615	0.31	173.58	9.6689	0.30	187.53	60	9.8042	0.40	82.78	9.9020	0.36	277.23
16	9.6598	0.32	148.50	9.6829	0.30	211.69	62	9.7768	0.39	81.43	9.9205	0.37	278.61
18	9.6454	0.31	137.26	9.7098	0.32	222.80	64	9.7284	0.43	80.12	9.9474	N/A	279.93
20	9.6614	0.30	129.66	9.7183	0.33	230.42	66	9.7126	0.38	78.78	9.9728	N/A	281.24
22	9.6709	0.32	123.83	9.7305	0.30	236.16	68	9.6859	0.43	77.47	9.9966	N/A	282.62
24	9.6580	0.32	119.30	9.7198	0.32	240.82	70	9.6591	N/A	76.09	10.020	N/A	283.92
26	9.6647	0.33	115.35	9.7311	0.31	244.59	72	9.6479	N/A	74.72	10.056	N/A	285.35
28	9.6706	0.34	112.03	9.7387	0.31	248.03	74	9.5913	N/A	73.37	10.070	N/A	286.50
30	9.6689	0.33	109.10	9.7499	0.30	250.94	76	9.5111	N/A	71.98	N/A	N/A	N/A
32	9.6864	0.29	106.48	9.7338	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.6830	0.32	104.16	9.7476	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.7065	0.33	101.86	9.7469	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.6923	0.30	99.84	9.7709	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.7061	0.32	97.97	9.7734	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7272	0.34	96.21	9.7866	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7302	0.32	94.54	9.7948	0.31	265.49	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

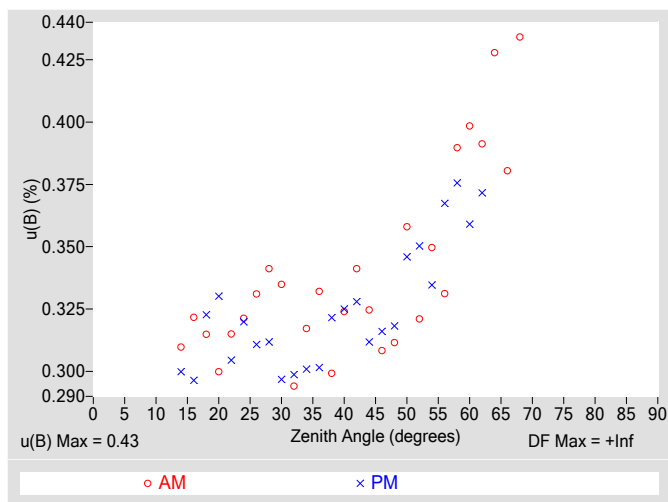


Figure 4. Residuals from Spline Interpolation

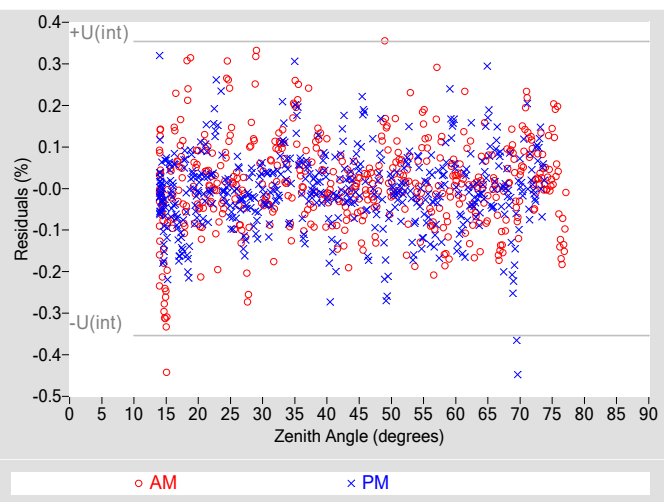


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	44035
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.92
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

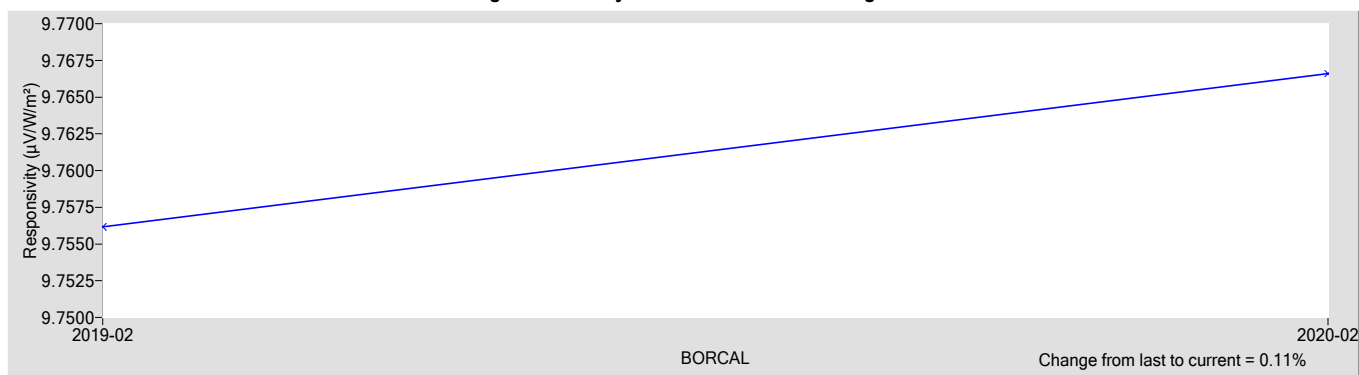
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.7666	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+1.4 / -1.0
Expanded Uncertainty, U (%)	+2.2 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 32991F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32991F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \text{COS}(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

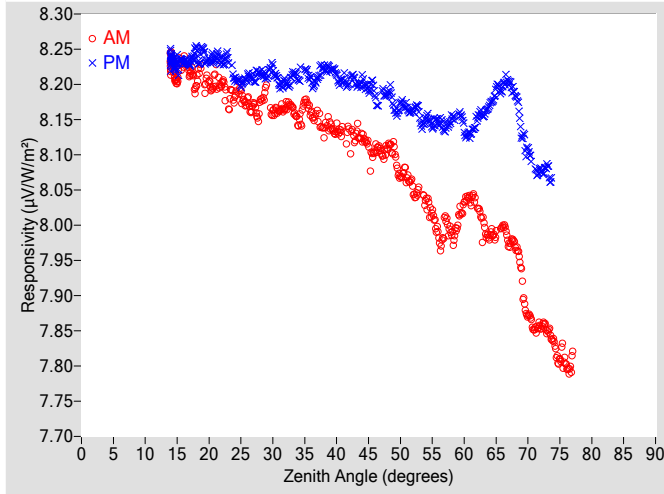


Figure 2. Responsivity vs Local Standard Time

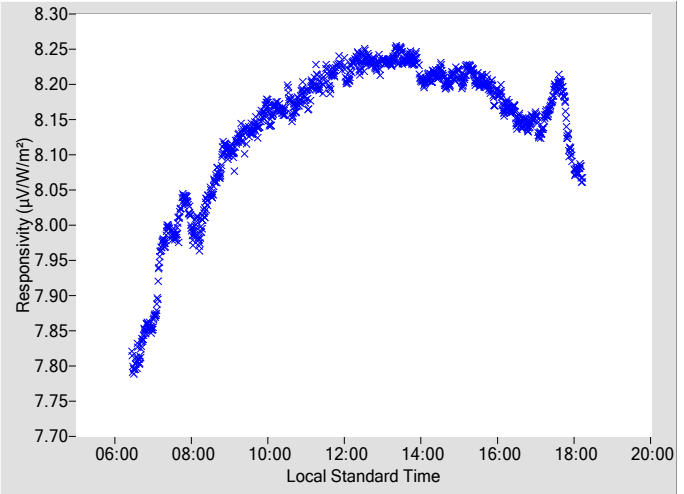


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1060	0.34	92.87	8.1849	0.35	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1121	0.35	91.32	8.1871	0.35	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0691	0.40	89.82	8.1728	0.36	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0494	0.36	88.36	8.1636	0.39	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0308	0.37	86.96	8.1526	0.38	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9818	0.40	85.53	8.1479	0.39	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9871	0.41	84.16	8.1507	0.41	275.86
14	8.2330	0.32	173.53	8.2349	0.33	187.33	60	8.0305	0.39	82.83	8.1353	0.42	277.23
16	8.2308	0.34	147.99	8.2320	0.32	211.71	62	8.0289	0.45	81.47	8.1500	0.47	278.57
18	8.2013	0.33	137.21	8.2466	0.32	222.82	64	7.9848	0.44	80.17	8.1708	N/A	279.89
20	8.2021	0.33	129.44	8.2347	0.34	230.38	66	7.9969	0.44	78.83	8.1965	N/A	281.29
22	8.2013	0.32	123.98	8.2330	0.34	236.04	68	7.9711	0.49	77.44	8.1855	N/A	282.59
24	8.1816	0.33	119.20	8.2090	0.33	240.72	70	7.8723	N/A	76.14	8.1065	N/A	283.97
26	8.1761	0.33	115.36	8.2110	0.33	244.70	72	7.8564	N/A	74.76	8.0786	N/A	285.31
28	8.1690	0.34	112.03	8.2153	0.32	247.94	74	7.8351	N/A	73.37	N/A	N/A	N/A
30	8.1592	0.32	109.11	8.2209	0.32	250.95	76	7.8017	N/A	71.99	N/A	N/A	N/A
32	8.1667	0.35	106.49	8.2031	0.35	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1491	0.35	104.07	8.2075	0.32	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1602	0.32	101.93	8.2048	0.33	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1369	0.34	99.85	8.2233	0.35	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1339	0.36	97.98	8.2102	0.33	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1280	0.38	96.16	8.2055	0.36	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1249	0.36	94.49	8.2037	0.38	265.54	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

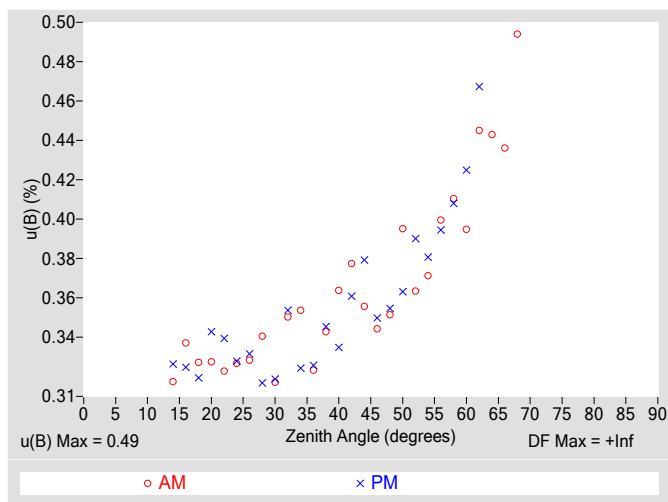


Figure 4. Residuals from Spline Interpolation

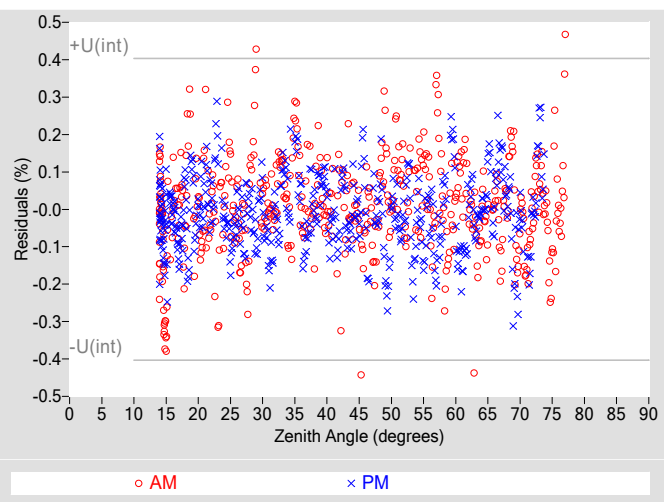


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.49
Type-A Interpolating Function, $u(int)$ (%)	± 0.20
Combined Standard Uncertainty, $u(c)$ (%)	± 0.53
Effective degrees of freedom, $DF(c)$	43558
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.0
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

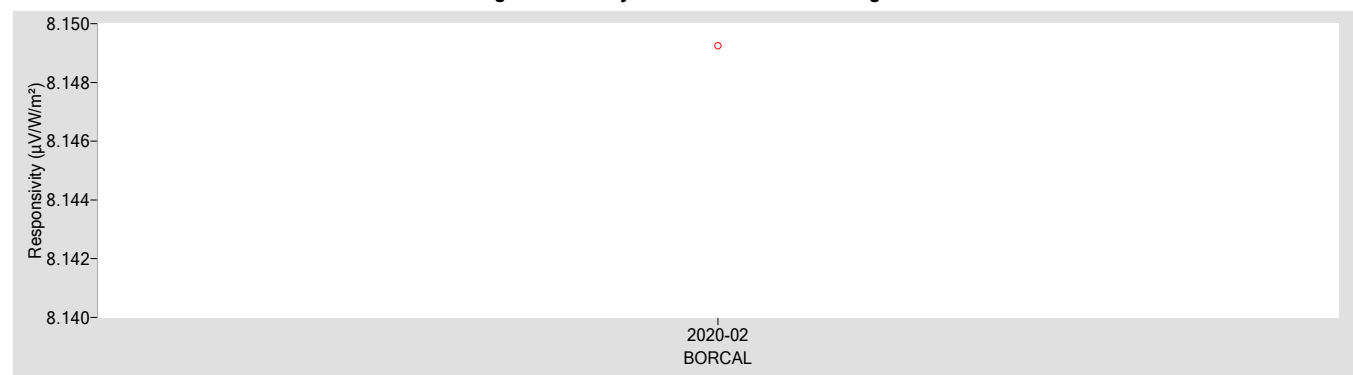
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.1492	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.83
Offset Uncertainty, $U(off)$ (%)	+0.91 / -2.1
Expanded Uncertainty, U (%)	+1.7 / -2.9
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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33237
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33237 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

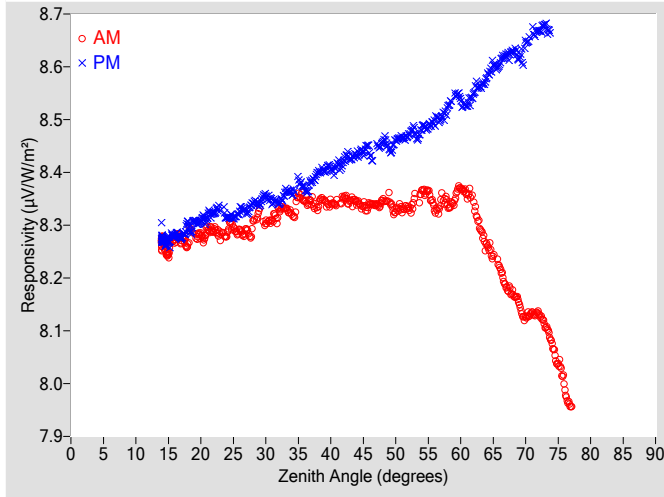


Figure 2. Responsivity vs Local Standard Time

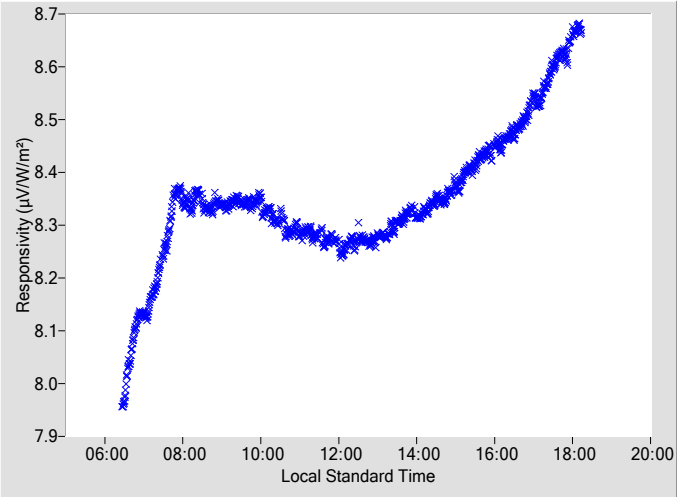


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3391	0.31	92.91	8.4347	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3462	0.31	91.37	8.4562	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3265	0.36	89.87	8.4595	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3321	0.32	88.40	8.4702	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3628	0.35	86.95	8.4823	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3323	0.33	85.57	8.4983	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3413	0.39	84.20	8.5226	0.38	275.89
14	8.2690	0.31	173.58	8.2730	0.30	187.53	60	8.3694	0.40	82.78	8.5361	0.36	277.23
16	8.2722	0.32	148.50	8.2804	0.30	211.69	62	8.3406	0.39	81.43	8.5512	0.37	278.61
18	8.2669	0.31	137.26	8.3010	0.32	222.80	64	8.2598	0.43	80.12	8.5806	N/A	279.93
20	8.2808	0.30	129.66	8.3089	0.33	230.42	66	8.2189	0.38	78.78	8.6057	N/A	281.24
22	8.2910	0.32	123.83	8.3234	0.30	236.16	68	8.1699	0.43	77.47	8.6290	N/A	282.62
24	8.2821	0.32	119.30	8.3141	0.32	240.82	70	8.1252	N/A	76.09	8.6444	N/A	283.96
26	8.2892	0.33	115.35	8.3277	0.31	244.59	72	8.1318	N/A	74.72	8.6680	N/A	285.35
28	8.2998	0.34	112.03	8.3415	0.31	248.03	74	8.0764	N/A	73.37	8.6641	N/A	286.50
30	8.3037	0.33	109.10	8.3549	0.30	250.94	76	7.9948	N/A	71.98	N/A	N/A	N/A
32	8.3229	0.29	106.48	8.3422	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3224	0.32	104.16	8.3622	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3454	0.33	101.86	8.3678	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3354	0.30	99.84	8.3998	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3406	0.32	97.97	8.4083	0.33	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3525	0.34	96.21	8.4211	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3446	0.32	94.54	8.4341	0.31	265.49	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

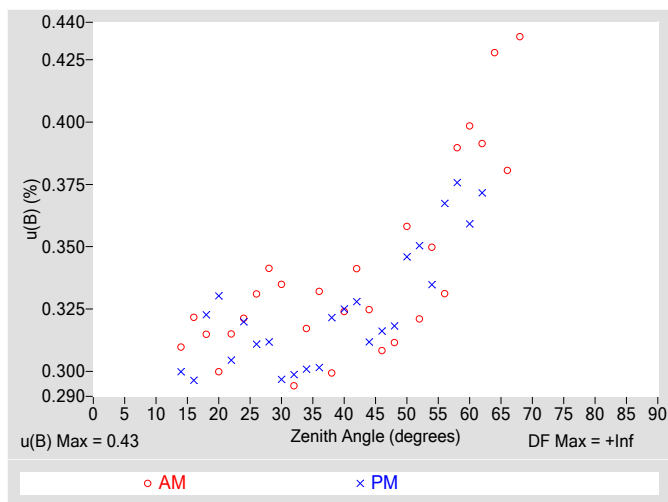


Figure 4. Residuals from Spline Interpolation

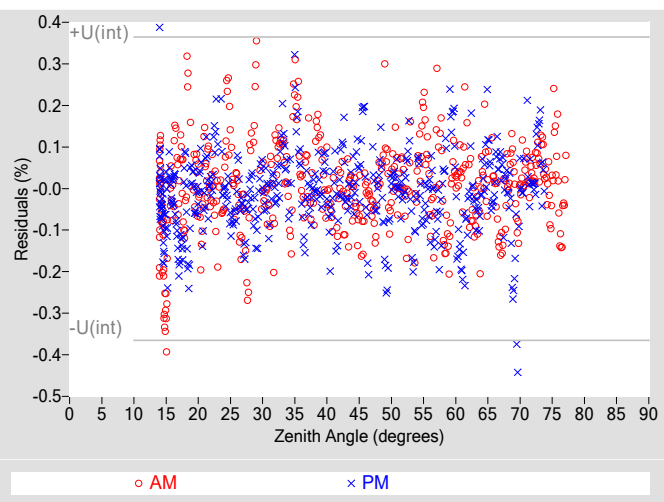


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	39583
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.92
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

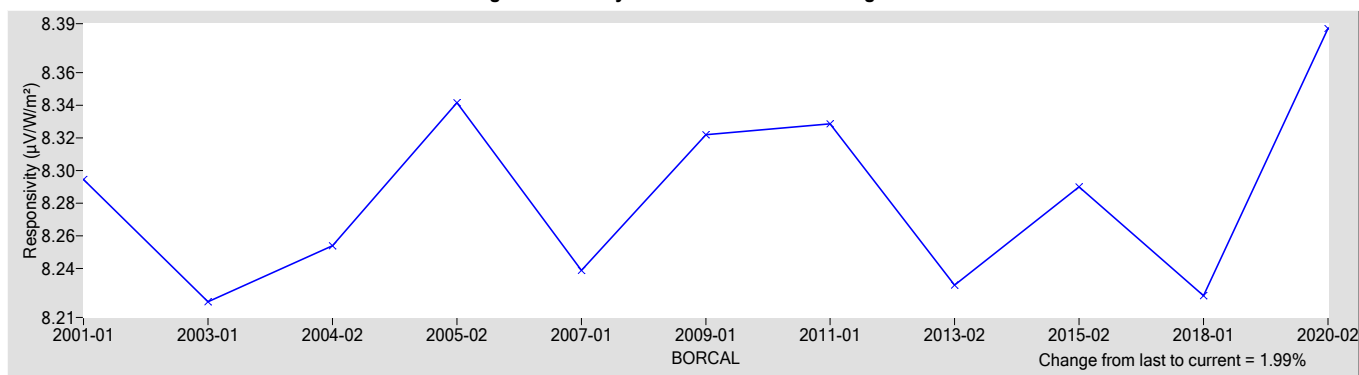
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.3870	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+1.8 / -0.99
Expanded Uncertainty, U (%)	+2.6 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33243
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33243 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

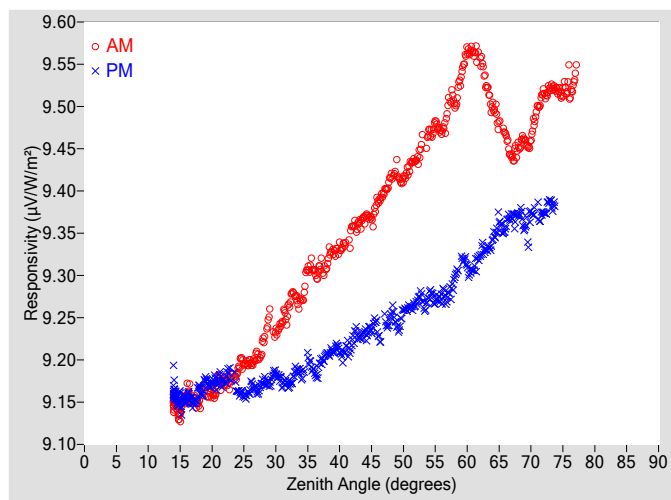


Figure 2. Responsivity vs Local Standard Time

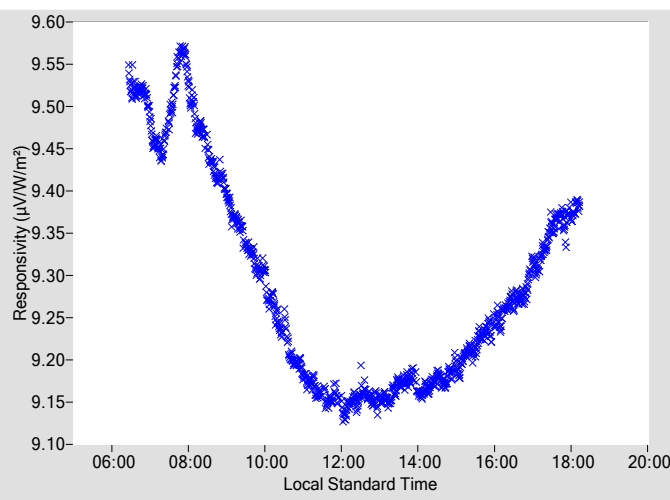


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.3878	0.31	92.91	9.2315	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4152	0.31	91.37	9.2498	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.4136	0.36	89.87	9.2575	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.4364	0.32	88.40	9.2667	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4676	0.35	86.95	9.2758	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4711	0.33	85.57	9.2763	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5046	0.39	84.20	9.2959	0.38	275.89
14	9.1520	0.31	173.30	9.1603	0.30	187.30	60	9.5647	0.40	82.78	9.3092	0.36	277.23
16	9.1574	0.33	148.39	9.1535	0.30	211.69	62	9.5571	0.39	81.43	9.3249	0.37	278.61
18	9.1504	0.31	137.26	9.1669	0.32	222.80	64	9.4977	0.43	80.12	9.3434	N/A	279.93
20	9.1607	0.30	129.66	9.1722	0.33	230.42	66	9.4660	0.38	78.78	9.3564	N/A	281.24
22	9.1735	0.32	123.83	9.1755	0.30	236.16	68	9.4491	0.43	77.47	9.3722	N/A	282.62
24	9.1852	0.32	119.30	9.1621	0.32	240.82	70	9.4614	N/A	76.09	9.3722	N/A	283.92
26	9.1970	0.33	115.35	9.1671	0.31	244.59	72	9.5150	N/A	74.72	9.3742	N/A	285.35
28	9.2204	0.34	112.03	9.1746	0.31	248.03	74	9.5192	N/A	73.37	9.3818	N/A	286.50
30	9.2316	0.33	109.10	9.1833	0.30	250.94	76	9.5171	N/A	71.98	N/A	N/A	N/A
32	9.2591	0.29	106.48	9.1702	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.2716	0.32	104.16	9.1839	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.3051	0.33	101.86	9.1846	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.3122	0.30	99.84	9.2073	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.3310	0.32	97.97	9.2108	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3571	0.34	96.21	9.2203	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3686	0.32	94.54	9.2314	0.31	265.49	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

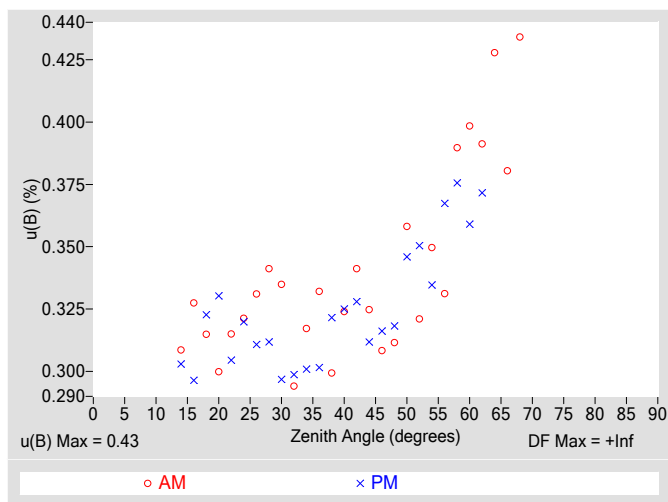


Figure 4. Residuals from Spline Interpolation

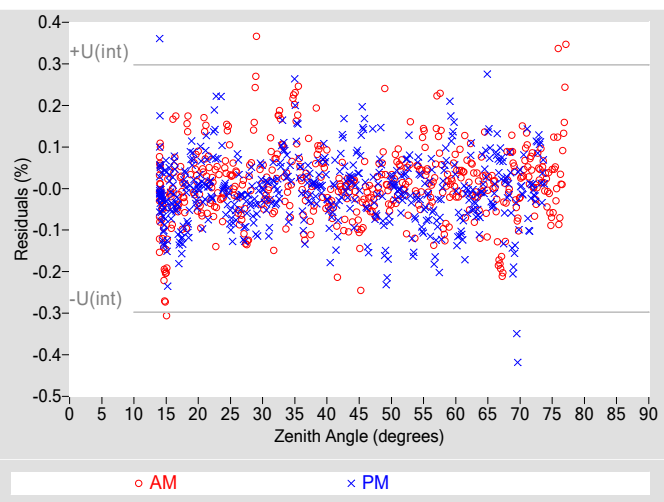


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.15
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	80805
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.90
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

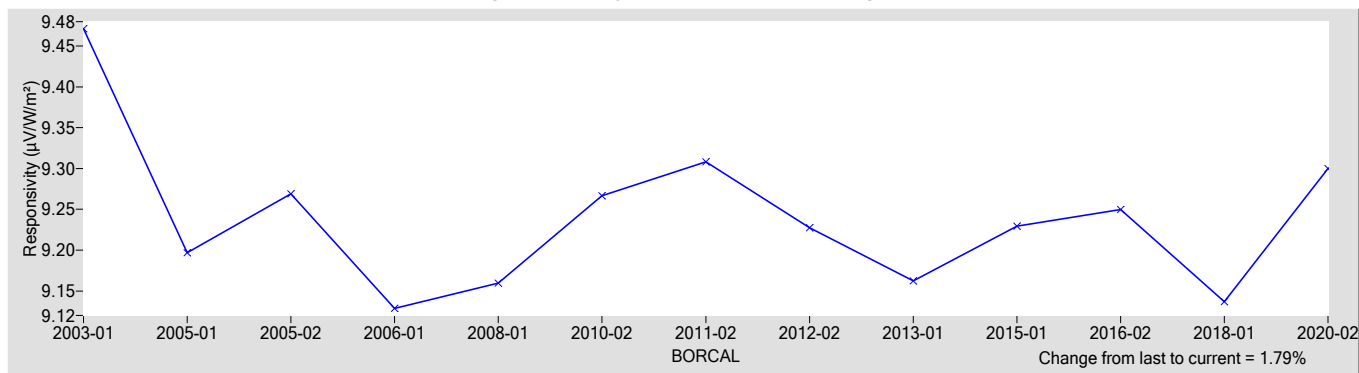
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.3002	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+2.8 / -1.4
Expanded Uncertainty, U (%)	+3.6 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33267
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33267 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

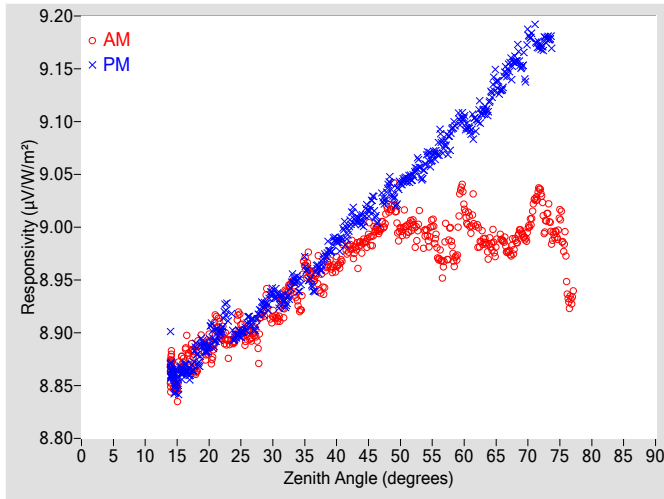


Figure 2. Responsivity vs Local Standard Time

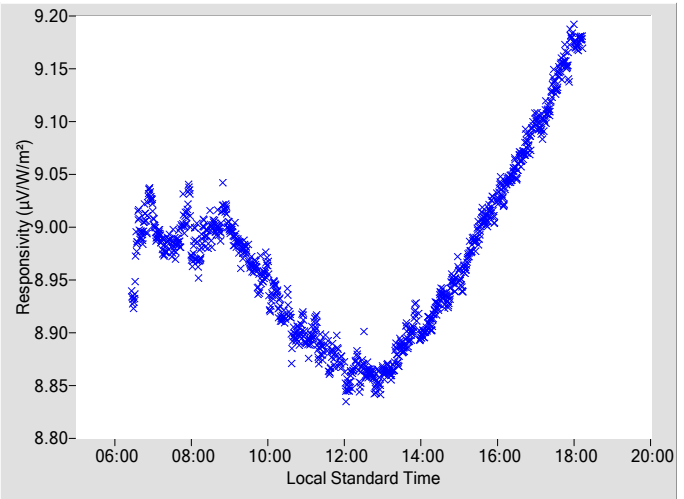


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9970	0.31	92.91	9.0136	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0171	0.31	91.37	9.0362	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9954	0.36	89.87	9.0407	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0020	0.32	88.40	9.0479	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9952	0.35	86.95	9.0628	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9739	0.33	85.57	9.0796	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9886	0.39	84.20	9.0886	0.38	275.89
14	8.8667	0.31	173.58	8.8633	0.30	187.53	60	9.0192	0.40	82.78	9.1009	0.36	277.23
16	8.8752	0.32	148.50	8.8636	0.30	211.69	62	8.9959	0.39	81.43	9.1011	0.37	278.61
18	8.8681	0.31	137.26	8.8823	0.32	222.80	64	8.9819	0.43	80.12	9.1207	N/A	279.93
20	8.8896	0.30	129.66	8.8942	0.33	230.42	66	8.9873	0.38	78.78	9.1331	N/A	281.24
22	8.8978	0.32	123.83	8.9047	0.30	236.16	68	8.9831	0.43	77.47	9.1577	N/A	282.62
24	8.8944	0.32	119.30	8.8948	0.32	240.82	70	8.9965	N/A	76.09	9.1806	N/A	283.96
26	8.9011	0.33	115.35	8.9090	0.31	244.59	72	9.0313	N/A	74.72	9.1711	N/A	285.35
28	8.9032	0.34	112.03	8.9222	0.31	248.03	74	8.9911	N/A	73.37	9.1695	N/A	286.50
30	8.9152	0.33	109.10	8.9375	0.30	250.94	76	8.9617	N/A	71.98	N/A	N/A	N/A
32	8.9317	0.29	106.48	8.9275	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.9284	0.32	104.16	8.9467	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9562	0.33	101.86	8.9462	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.9453	0.30	99.84	8.9711	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9641	0.32	97.97	8.9878	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9806	0.34	96.21	8.9999	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9837	0.32	94.54	9.0063	0.31	265.49	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

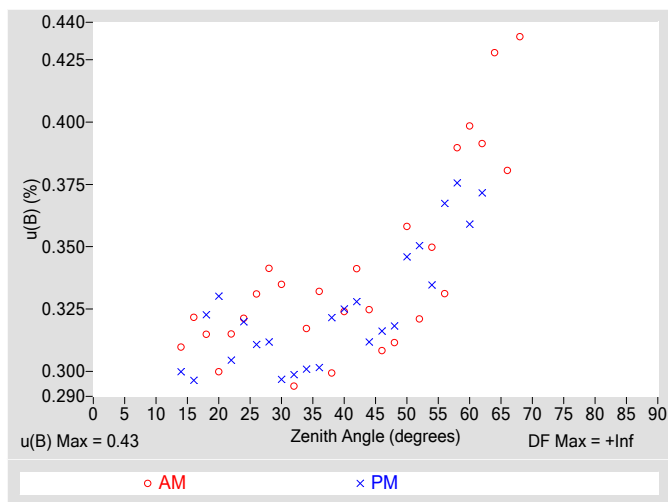


Figure 4. Residuals from Spline Interpolation

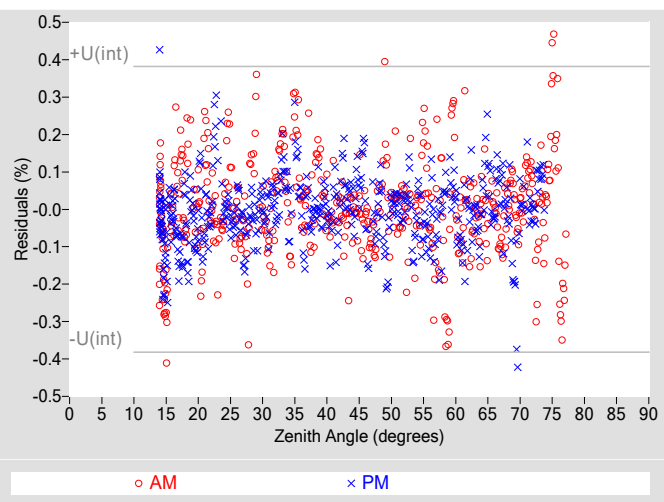


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	33784
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.93
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

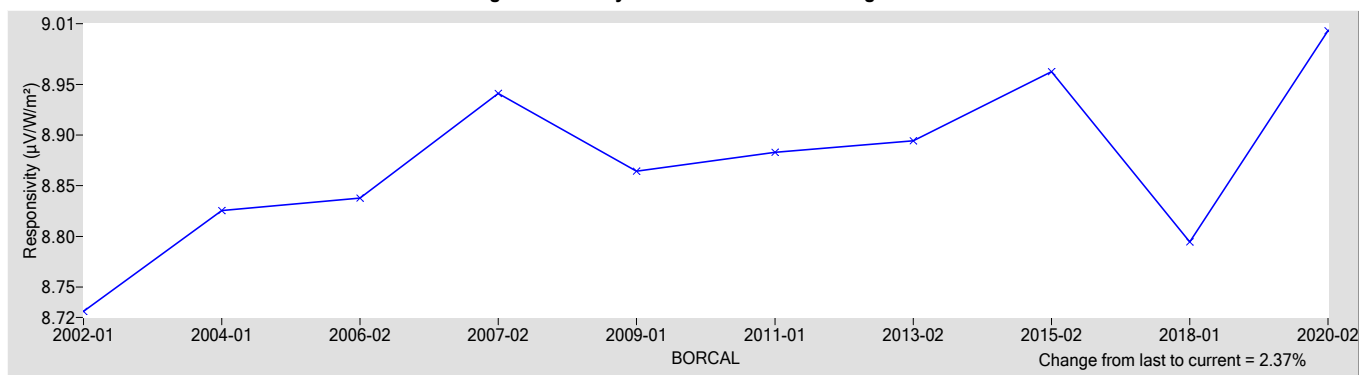
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.0032	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+1.1 / -0.98
Expanded Uncertainty, U (%)	+1.9 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33269
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33269 Eppeley 8-48

The responsivity (R , $\mu\text{V/W/m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V/W/m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

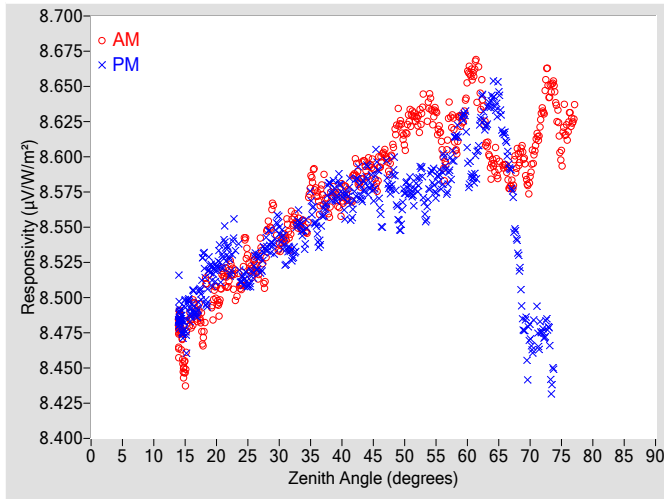


Figure 2. Responsivity vs Local Standard Time

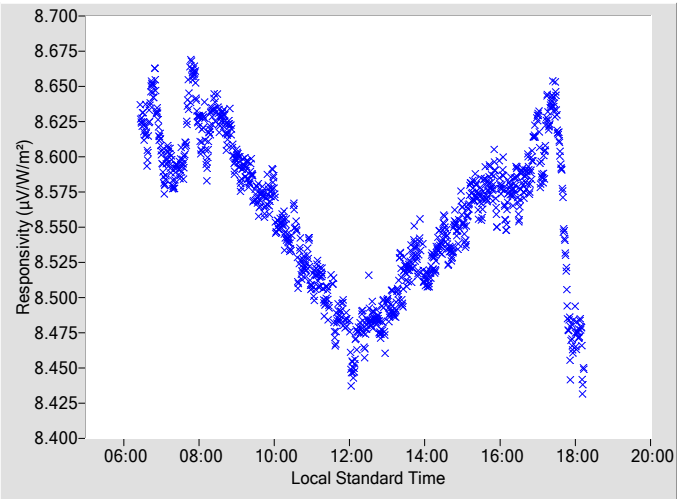


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V/W/m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V/W/m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V/W/m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V/W/m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5936	0.31	92.91	8.5668	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6025	0.31	91.37	8.5817	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6115	0.36	89.87	8.5749	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6264	0.32	88.40	8.5796	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6385	0.35	86.95	8.5804	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6050	0.33	85.57	8.5898	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6133	0.39	84.20	8.6110	0.38	275.89
14	8.4779	0.31	173.58	8.4852	0.30	187.53	60	8.6557	0.40	82.78	8.6018	0.36	277.23
16	8.4857	0.32	148.50	8.4927	0.30	211.69	62	8.6494	0.39	81.43	8.6255	0.37	278.61
18	8.4794	0.31	137.26	8.5219	0.32	222.80	64	8.5931	0.43	80.12	8.6443	N/A	279.93
20	8.5015	0.30	129.66	8.5206	0.33	230.42	66	8.5928	0.38	78.78	8.6144	N/A	281.24
22	8.5177	0.32	123.83	8.5267	0.30	236.16	68	8.5965	0.43	77.47	8.5326	N/A	282.62
24	8.5085	0.32	119.30	8.5120	0.32	240.82	70	8.5850	N/A	76.09	8.4732	N/A	283.92
26	8.5247	0.33	115.35	8.5231	0.31	244.59	72	8.6320	N/A	74.72	8.4743	N/A	285.35
28	8.5380	0.34	112.03	8.5387	0.31	248.03	74	8.6417	N/A	73.37	8.4491	N/A	286.50
30	8.5349	0.33	109.10	8.5490	0.30	250.94	76	8.6207	N/A	71.98	N/A	N/A	N/A
32	8.5499	0.29	106.48	8.5298	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5515	0.32	104.16	8.5446	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5730	0.33	101.86	8.5449	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5640	0.30	99.84	8.5796	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5686	0.32	97.97	8.5743	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5894	0.34	96.21	8.5727	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5909	0.32	94.54	8.5854	0.31	265.49	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

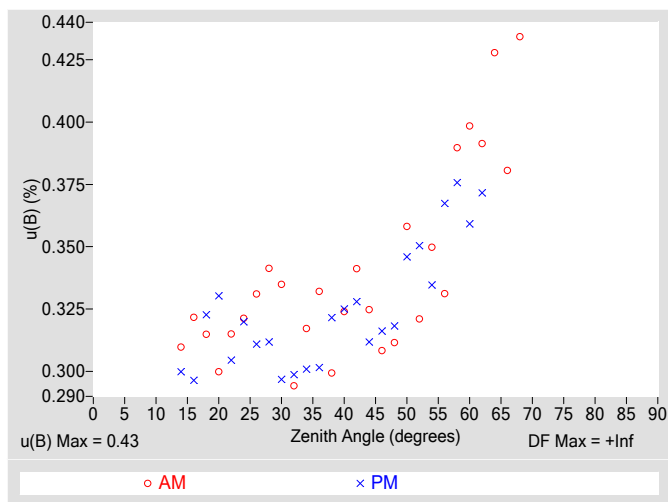


Figure 4. Residuals from Spline Interpolation

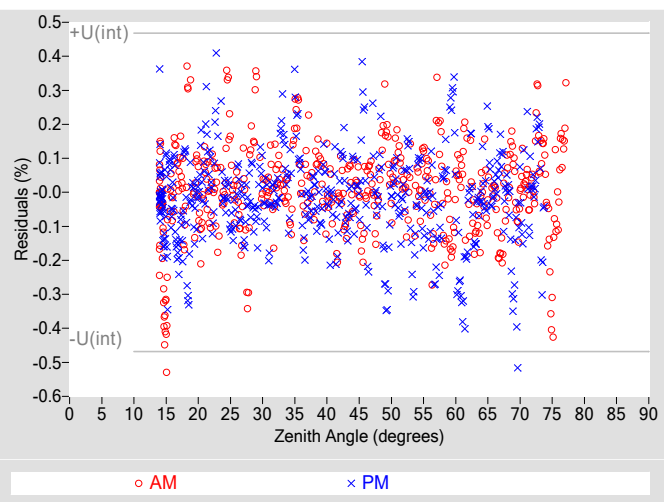


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.49
Effective degrees of freedom, $DF(c)$	17579
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.97
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

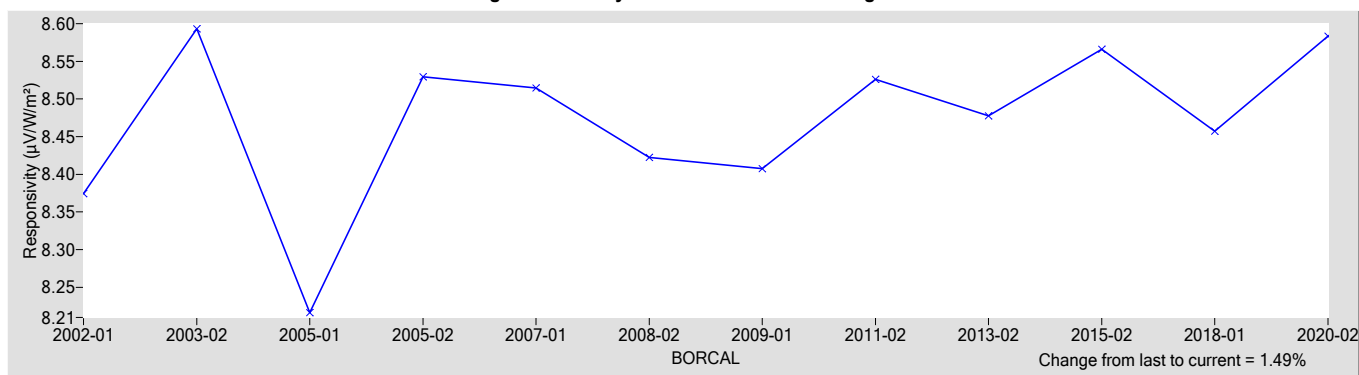
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5835	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+0.84 / -0.63
Expanded Uncertainty, U (%)	+1.6 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33273
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33273 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

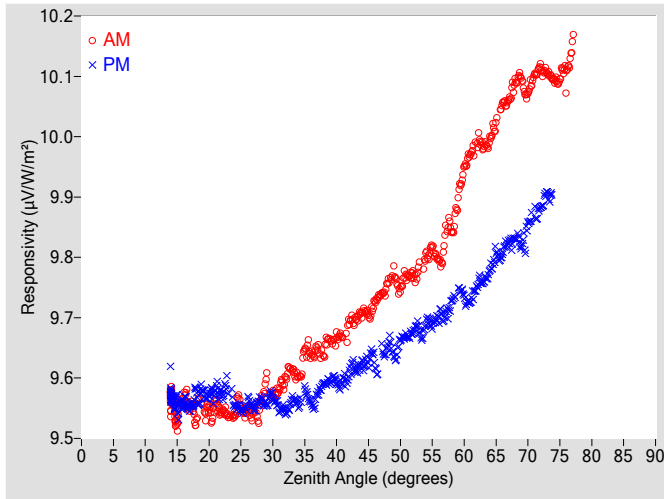


Figure 2. Responsivity vs Local Standard Time

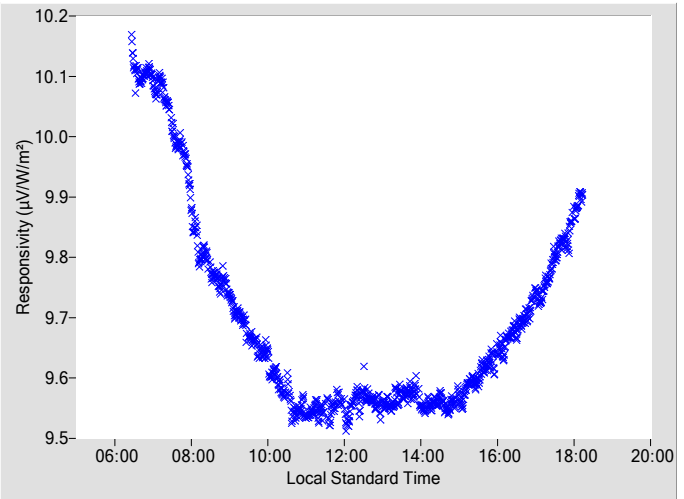


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.7254	0.31	92.91	9.6211	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7564	0.31	91.37	9.6506	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7468	0.36	89.87	9.6622	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7708	0.32	88.40	9.6759	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8012	0.35	86.95	9.6904	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7963	0.33	85.57	9.7036	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8470	0.39	84.20	9.7256	0.38	275.89
14	9.5671	0.31	173.30	9.5689	0.30	187.30	60	9.9488	0.40	82.78	9.7328	0.36	277.23
16	9.5631	0.33	148.39	9.5572	0.30	211.69	62	9.9921	0.39	81.43	9.7537	0.37	278.61
18	9.5333	0.31	137.26	9.5760	0.32	222.80	64	9.9934	0.43	80.12	9.7799	N/A	279.93
20	9.5495	0.30	129.66	9.5730	0.33	230.42	66	10.053	0.38	78.78	9.8060	N/A	281.24
22	9.5443	0.32	123.83	9.5733	0.30	236.16	68	10.087	0.43	77.47	9.8306	N/A	282.62
24	9.5369	0.32	119.30	9.5531	0.32	240.82	70	10.072	N/A	76.09	9.8541	N/A	283.92
26	9.5475	0.33	115.35	9.5582	0.31	244.59	72	10.112	N/A	74.72	9.8836	N/A	285.35
28	9.5537	0.34	112.03	9.5637	0.31	248.03	74	10.094	N/A	73.37	9.9034	N/A	286.50
30	9.5716	0.33	109.10	9.5678	0.30	250.94	76	10.106	N/A	71.98	N/A	N/A	N/A
32	9.5964	0.29	106.48	9.5440	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.6044	0.32	104.16	9.5587	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.6389	0.33	101.86	9.5563	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.6410	0.30	99.84	9.5911	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.6652	0.32	97.97	9.5933	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.6929	0.34	96.21	9.6074	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7077	0.32	94.54	9.6228	0.31	265.49	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

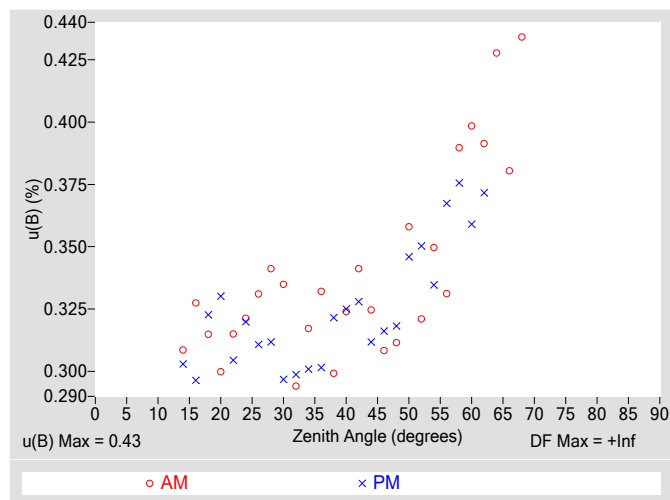


Figure 4. Residuals from Spline Interpolation

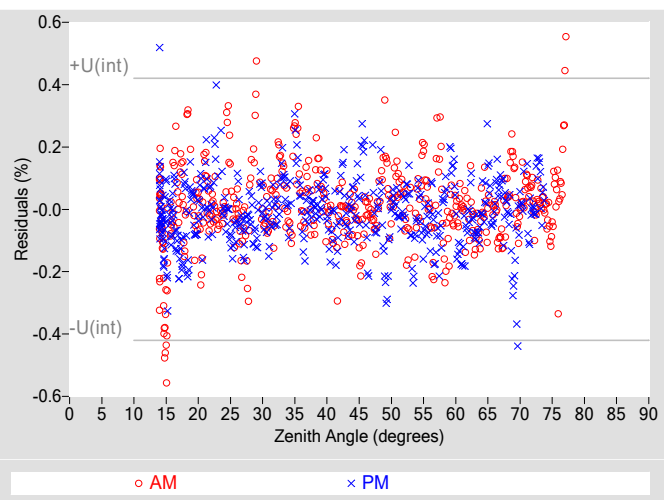


Table 3. Uncertainty using Spline Interpolation ‡

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, $DF(c)$	24718
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.95
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

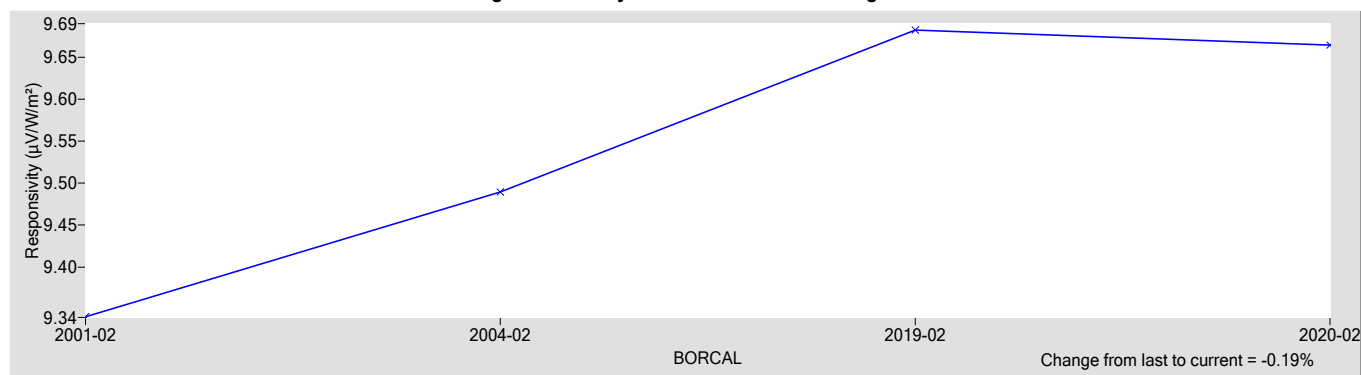
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.6646	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+2.9 / -1.2
Expanded Uncertainty, U (%)	+3.7 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33275
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33275 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

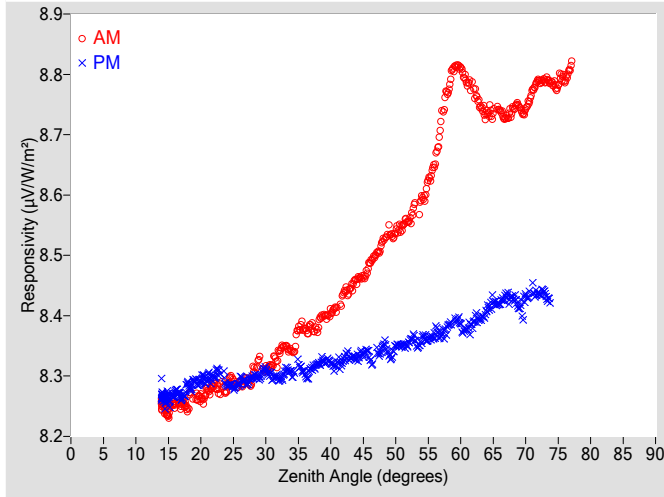


Figure 2. Responsivity vs Local Standard Time

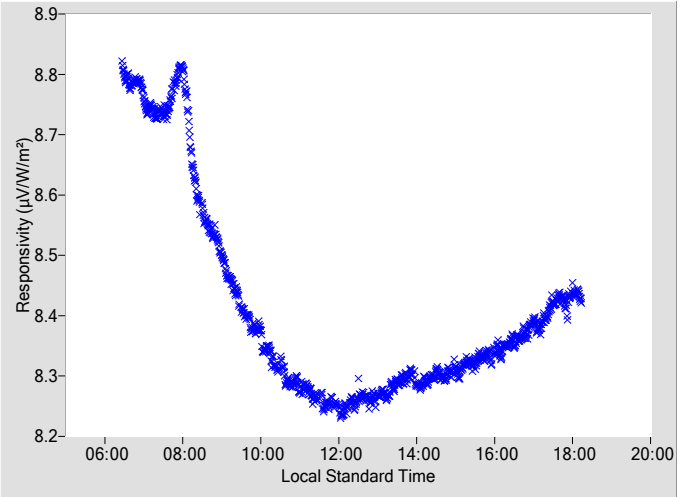


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4865	0.31	92.91	8.3287	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5226	0.31	91.37	8.3478	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5388	0.36	89.87	8.3484	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5571	0.32	88.40	8.3542	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5932	0.35	86.95	8.3594	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6526	0.33	85.57	8.3718	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7709	0.39	84.20	8.3809	0.38	275.89
14	8.2563	0.31	173.58	8.2658	0.30	187.53	60	8.8089	0.40	82.78	8.3839	0.36	277.23
16	8.2545	0.32	148.50	8.2706	0.30	211.69	62	8.7748	0.39	81.43	8.3902	0.37	278.61
18	8.2505	0.31	137.26	8.2859	0.32	222.80	64	8.7340	0.43	80.12	8.4099	N/A	279.93
20	8.2643	0.30	129.66	8.2927	0.33	230.42	66	8.7398	0.38	78.78	8.4206	N/A	281.24
22	8.2843	0.32	123.83	8.2988	0.30	236.16	68	8.7389	0.43	77.47	8.4282	N/A	282.62
24	8.2783	0.32	119.30	8.2850	0.32	240.82	70	8.7415	N/A	76.09	8.4307	N/A	283.92
26	8.2874	0.33	115.35	8.2914	0.31	244.59	72	8.7892	N/A	74.72	8.4361	N/A	285.35
28	8.3045	0.34	112.03	8.2985	0.31	248.03	74	8.7848	N/A	73.37	8.4212	N/A	286.50
30	8.3110	0.33	109.10	8.3106	0.30	250.94	76	8.7926	N/A	71.98	N/A	N/A	N/A
32	8.3338	0.29	106.48	8.2947	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3421	0.32	104.16	8.3042	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3777	0.33	101.86	8.3028	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3807	0.30	99.84	8.3204	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4049	0.32	97.97	8.3224	0.33	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4374	0.34	96.21	8.3265	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4593	0.32	94.54	8.3301	0.31	265.49	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

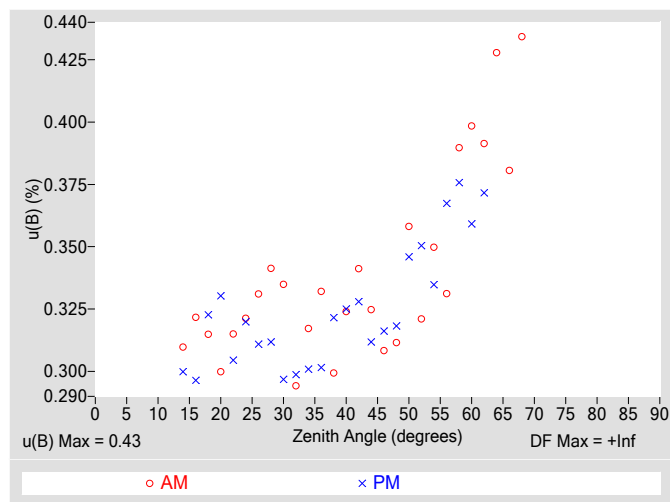


Figure 4. Residuals from Spline Interpolation

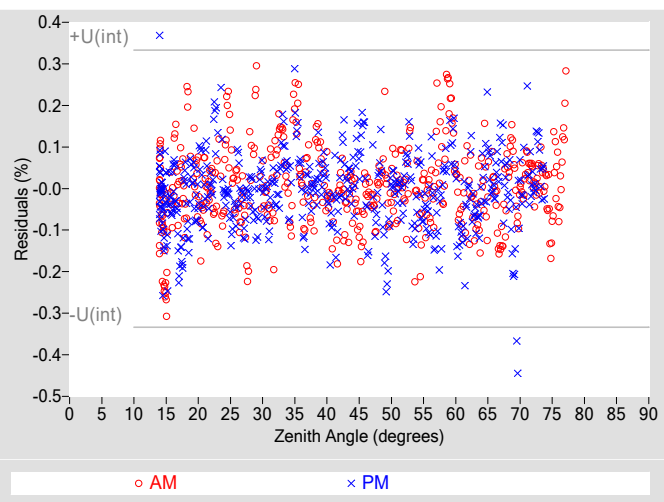


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	54003
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.91
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

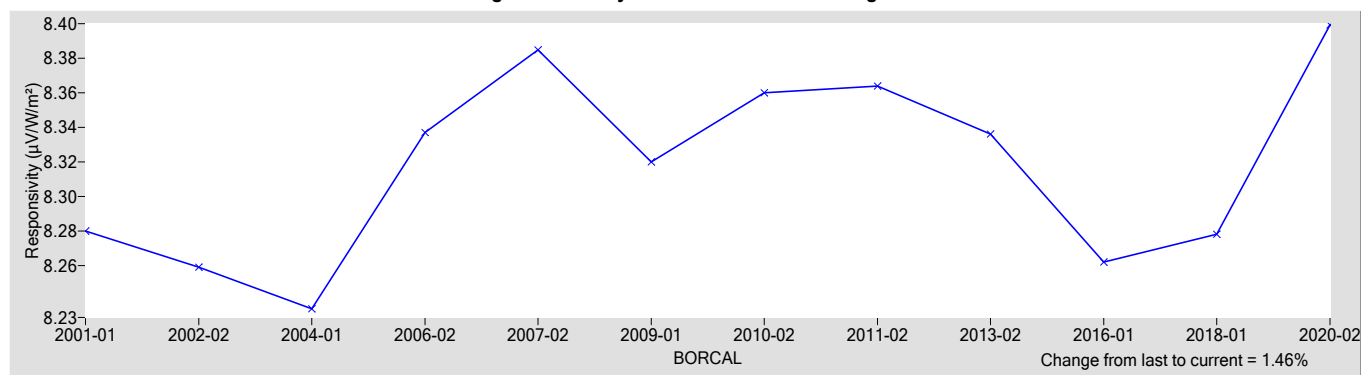
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.3993	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+4.9 / -1.2
Expanded Uncertainty, U (%)	+5.7 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33278
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33278 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

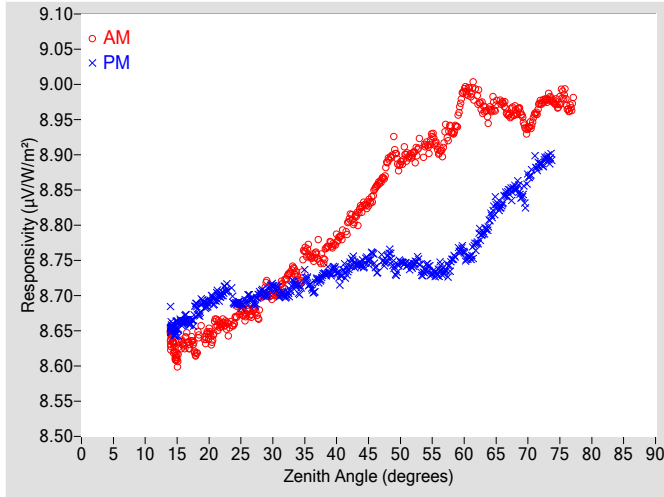


Figure 2. Responsivity vs Local Standard Time

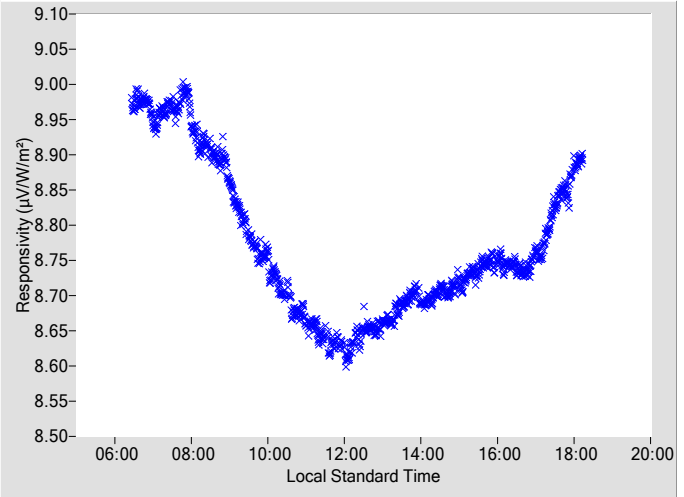


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8501	0.31	92.91	8.7435	0.32	267.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8897	0.31	91.37	8.7543	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8860	0.36	89.87	8.7472	0.35	270.17
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9009	0.32	88.40	8.7428	0.35	271.63
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9144	0.35	86.95	8.7393	0.33	273.07
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9057	0.33	85.57	8.7368	0.37	274.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9354	0.39	84.20	8.7475	0.38	275.89
14	8.6430	0.31	173.58	8.6534	0.30	187.53	60	8.9916	0.40	82.78	8.7595	0.36	277.23
16	8.6326	0.32	148.50	8.6636	0.30	211.69	62	8.9854	0.39	81.43	8.7755	0.37	278.61
18	8.6223	0.31	137.26	8.6838	0.32	222.80	64	8.9609	0.43	80.12	8.8087	N/A	279.93
20	8.6463	0.30	129.66	8.6905	0.33	230.42	66	8.9727	0.38	78.78	8.8314	N/A	281.24
22	8.6601	0.32	123.83	8.7016	0.30	236.16	68	8.9609	0.43	77.47	8.8523	N/A	282.62
24	8.6634	0.32	119.30	8.6886	0.32	240.82	70	8.9364	N/A	76.09	8.8669	N/A	283.96
26	8.6776	0.33	115.35	8.6951	0.31	244.59	72	8.9739	N/A	74.72	8.8868	N/A	285.35
28	8.6882	0.34	112.03	8.7037	0.31	248.03	74	8.9749	N/A	73.37	8.8921	N/A	286.50
30	8.7009	0.33	109.10	8.7144	0.30	250.94	76	8.9763	N/A	71.98	N/A	N/A	N/A
32	8.7185	0.29	106.48	8.6991	0.30	253.55	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7253	0.32	104.16	8.7098	0.30	255.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7555	0.33	101.86	8.7106	0.30	258.18	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7540	0.30	99.84	8.7309	0.32	260.17	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7786	0.32	97.97	8.7346	0.32	262.03	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8080	0.34	96.21	8.7404	0.33	263.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8261	0.32	94.54	8.7449	0.31	265.49	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

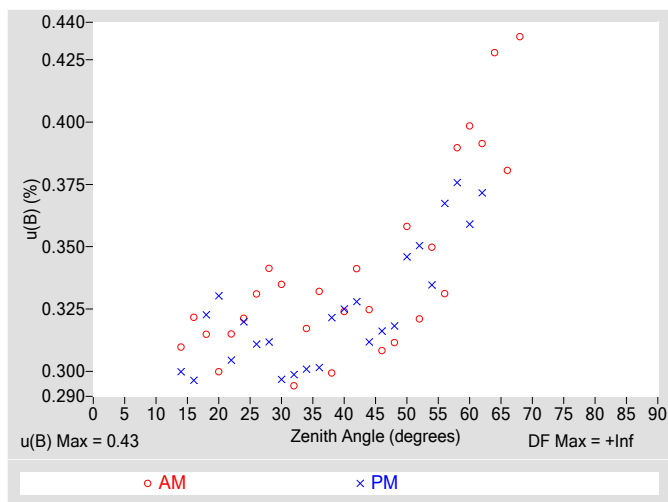


Figure 4. Residuals from Spline Interpolation

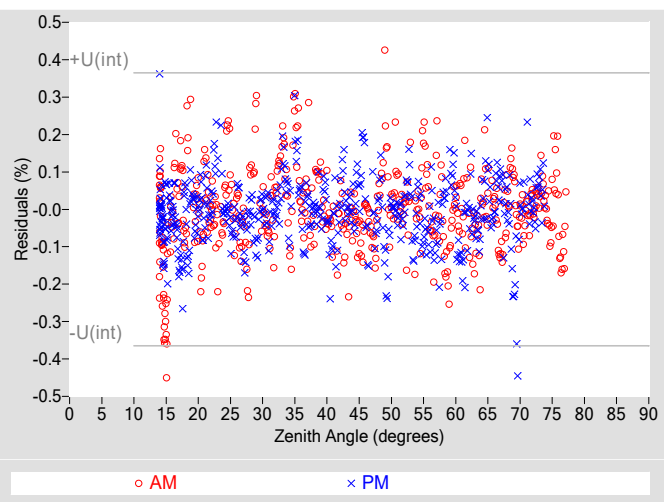


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.18
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	39499
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.92
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

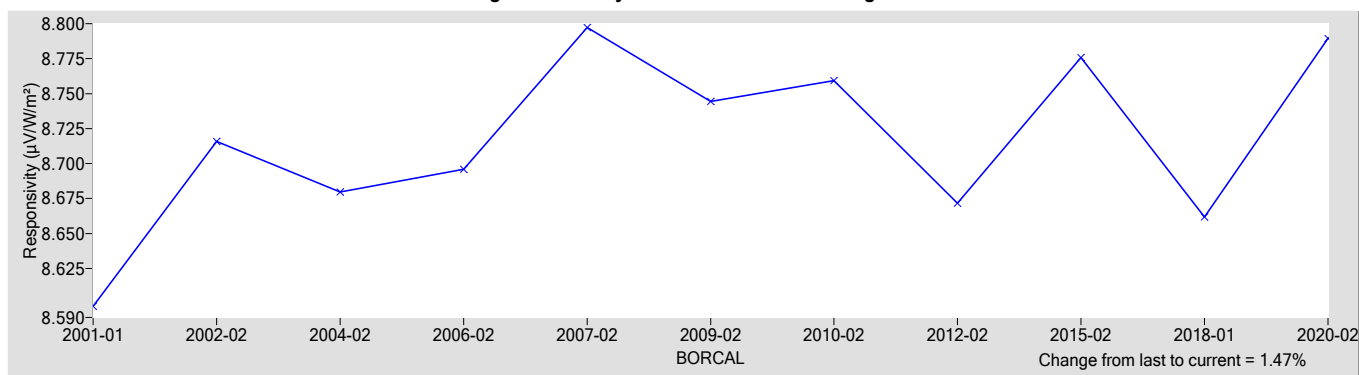
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.7896	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+2.3 / -1.0
Expanded Uncertainty, U (%)	+3.1 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference*. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33283
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33283 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

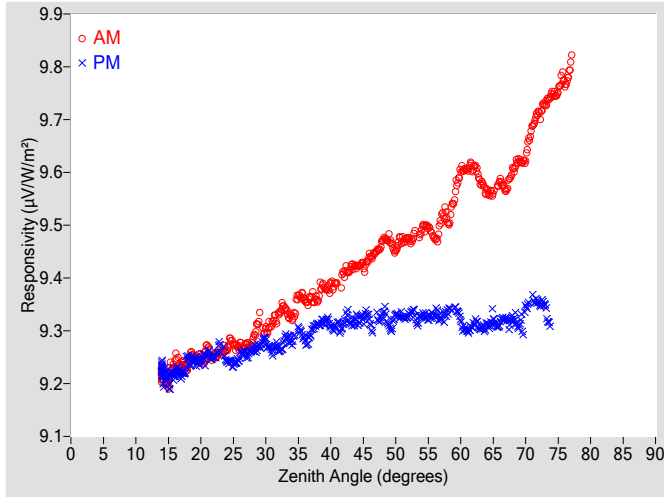


Figure 2. Responsivity vs Local Standard Time

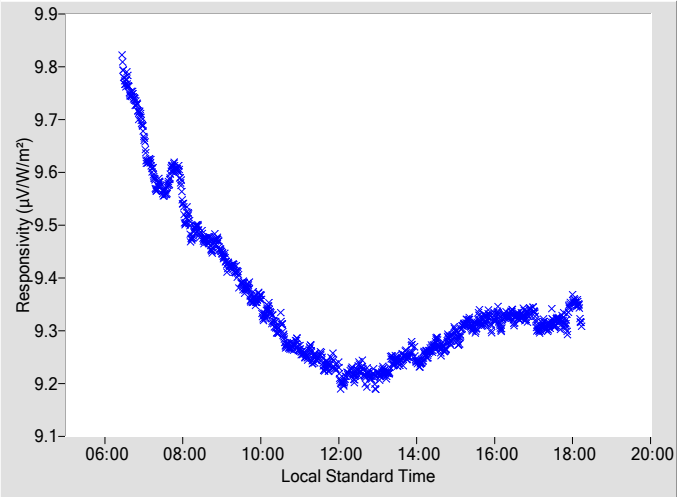


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.4389	0.35	92.92	9.3154	0.32	267.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4696	0.31	91.37	9.3299	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.4515	0.34	89.87	9.3294	0.32	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.4741	0.39	88.41	9.3281	0.35	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4912	0.35	86.96	9.3289	0.33	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4757	0.35	85.57	9.3301	0.34	274.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5096	0.36	84.20	9.3369	0.35	275.90
14	9.2190	0.31	174.07	9.2239	0.32	186.14	60	9.6019	0.37	82.79	9.3209	0.36	277.19
16	9.2394	0.33	148.00	9.2186	0.30	211.72	62	9.6086	0.41	81.46	9.3135	0.37	278.62
18	9.2326	0.30	137.33	9.2478	0.30	222.95	64	9.5630	0.37	80.13	9.3107	N/A	279.94
20	9.2504	0.29	129.57	9.2441	0.30	230.44	66	9.5815	0.41	78.79	9.3132	N/A	281.25
22	9.2518	0.30	123.85	9.2507	0.29	236.18	68	9.6007	0.40	77.48	9.3222	N/A	282.63
24	9.2654	0.32	119.20	9.2418	0.29	240.84	70	9.6284	N/A	76.10	9.3429	N/A	283.97
26	9.2717	0.30	115.37	9.2509	0.29	244.61	72	9.7102	N/A	74.72	9.3519	N/A	285.31
28	9.2830	0.31	112.04	9.2655	0.30	248.04	74	9.7460	N/A	73.37	9.3084	N/A	286.50
30	9.2989	0.32	109.11	9.2799	0.33	250.95	76	9.7690	N/A	71.95	N/A	N/A	N/A
32	9.3335	0.32	106.35	9.2651	0.32	253.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.3268	0.31	104.14	9.2830	0.30	255.98	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.3575	0.30	101.87	9.2805	0.30	258.19	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.3606	0.32	99.91	9.3127	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.3843	0.32	98.04	9.3084	0.31	262.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.4085	0.32	96.22	9.3140	0.35	263.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.4225	0.31	94.55	9.3212	0.35	265.49	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

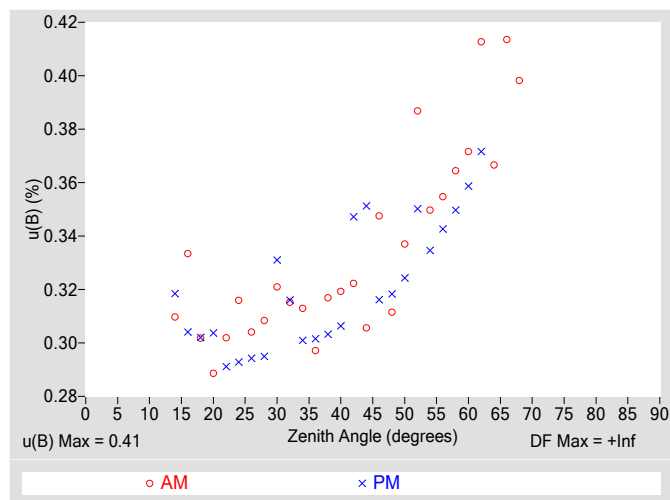


Figure 4. Residuals from Spline Interpolation

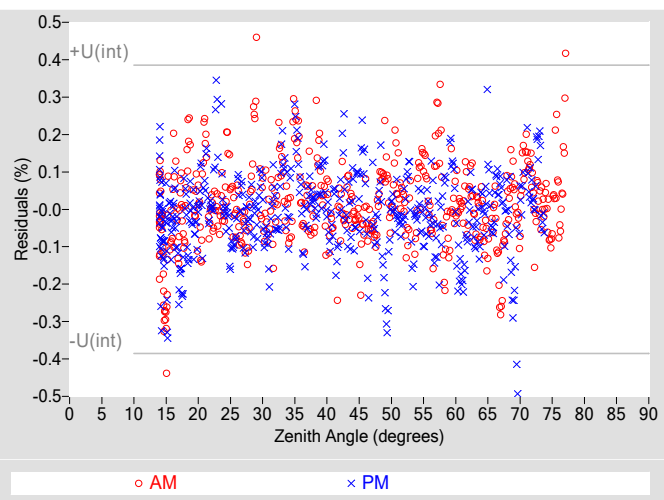


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	28115
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.89
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

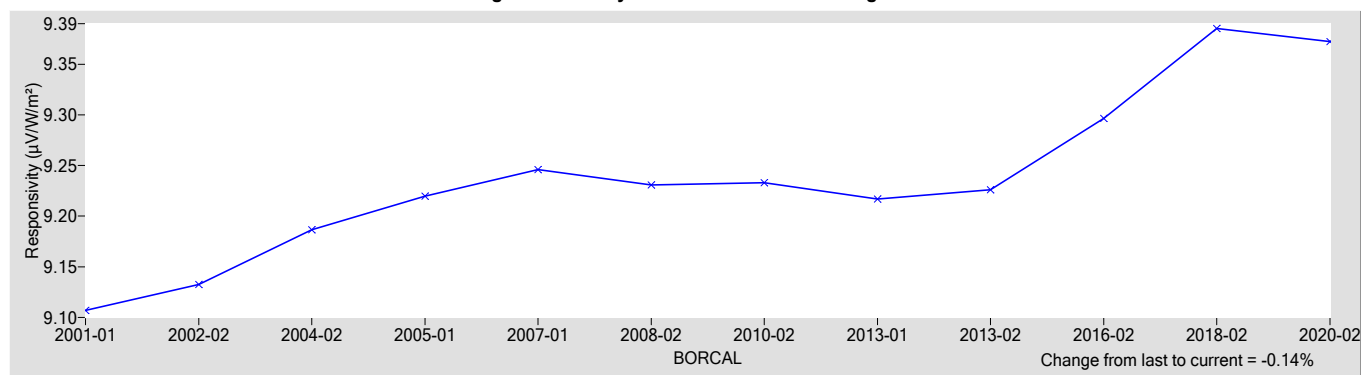
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.3723	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+2.4 / -1.1
Expanded Uncertainty, U (%)	+3.2 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33288
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33288 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

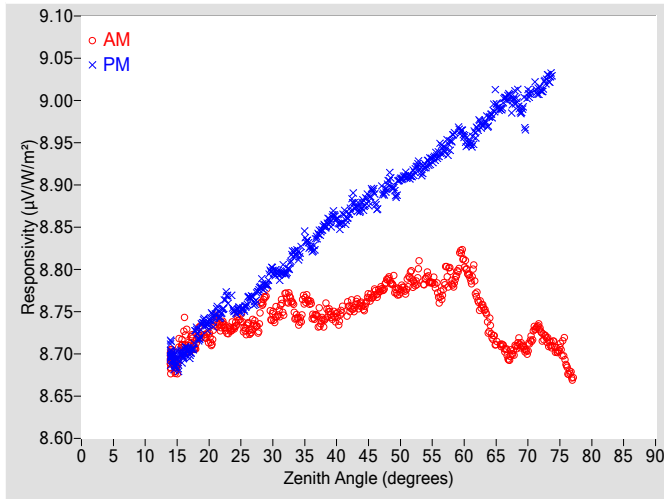


Figure 2. Responsivity vs Local Standard Time

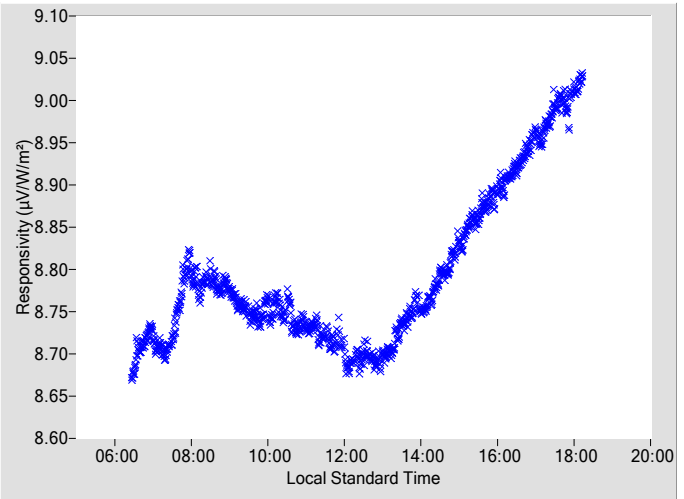


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7718	0.35	92.92	8.8822	0.32	267.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7881	0.31	91.37	8.8997	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7755	0.34	89.87	8.9066	0.32	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7872	0.39	88.41	8.9129	0.35	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7895	0.35	86.96	8.9236	0.33	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7702	0.35	85.57	8.9382	0.34	274.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7902	0.36	84.20	8.9526	0.35	275.90
14	8.6940	0.31	174.07	8.6994	0.32	186.48	60	8.8074	0.37	82.79	8.9579	0.36	277.19
16	8.7199	0.33	148.00	8.6986	0.30	211.72	62	8.7672	0.41	81.46	8.9667	0.37	278.62
18	8.7126	0.30	137.33	8.7262	0.30	222.95	64	8.7302	0.37	80.13	8.9798	N/A	279.94
20	8.7216	0.29	129.57	8.7370	0.30	230.44	66	8.7097	0.41	78.79	8.9939	N/A	281.25
22	8.7338	0.30	123.85	8.7498	0.29	236.18	68	8.7056	0.40	77.48	9.0023	N/A	282.63
24	8.7325	0.32	119.20	8.7498	0.29	240.84	70	8.7062	N/A	76.10	9.0068	N/A	283.97
26	8.7313	0.30	115.37	8.7613	0.29	244.61	72	8.7252	N/A	74.72	9.0112	N/A	285.31
28	8.7464	0.31	112.04	8.7804	0.30	248.04	74	8.7095	N/A	73.37	9.0293	N/A	286.50
30	8.7425	0.32	109.11	8.7988	0.33	250.95	76	8.6853	N/A	71.95	N/A	N/A	N/A
32	8.7677	0.32	106.35	8.7954	0.32	253.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7407	0.31	104.14	8.8179	0.30	255.98	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7538	0.30	101.87	8.8242	0.30	258.19	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7393	0.32	99.91	8.8504	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7443	0.32	98.04	8.8592	0.31	262.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7557	0.32	96.22	8.8667	0.35	263.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7575	0.31	94.55	8.8750	0.35	265.49	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

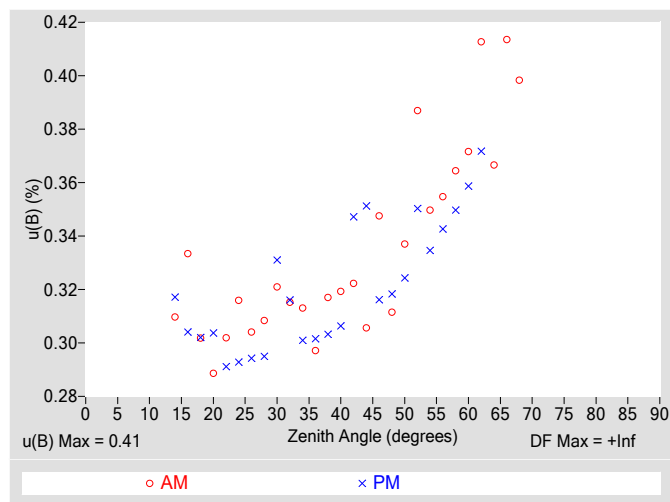


Figure 4. Residuals from Spline Interpolation

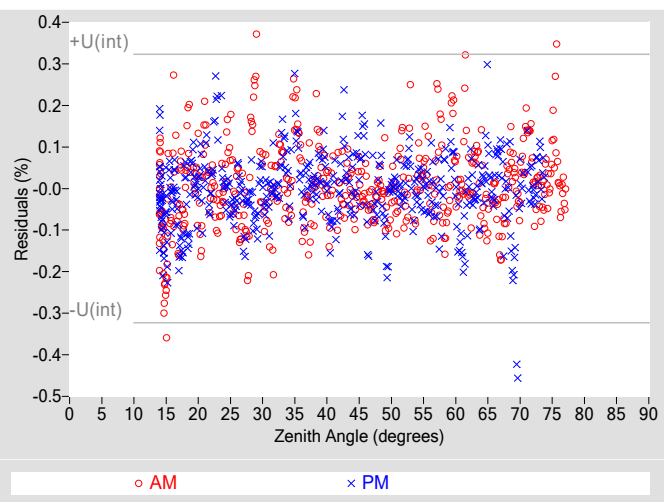


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.16
Combined Standard Uncertainty, $u(c)$ (%)	± 0.44
Effective degrees of freedom, $DF(c)$	51455
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.87
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

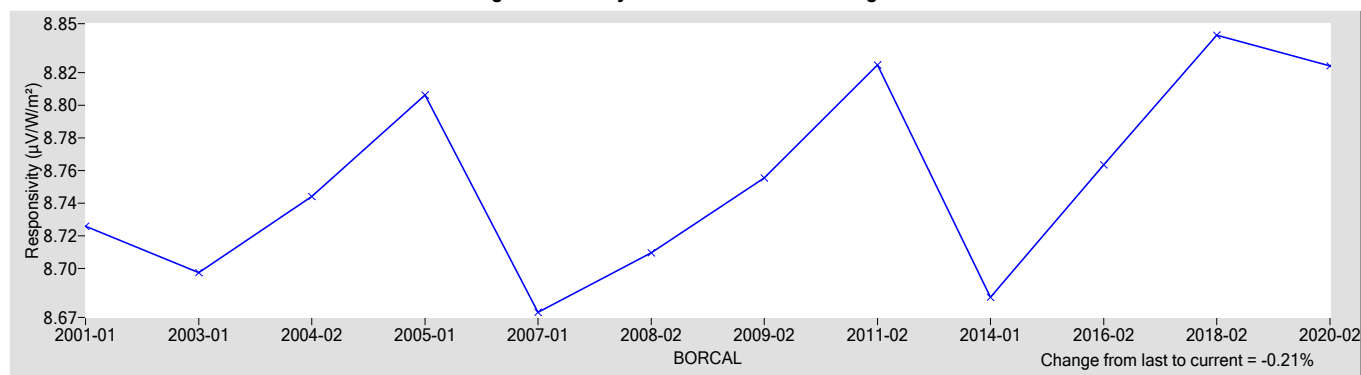
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.8241	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+1.5 / -0.96
Expanded Uncertainty, U (%)	+2.3 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33289
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33289 Eppey 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

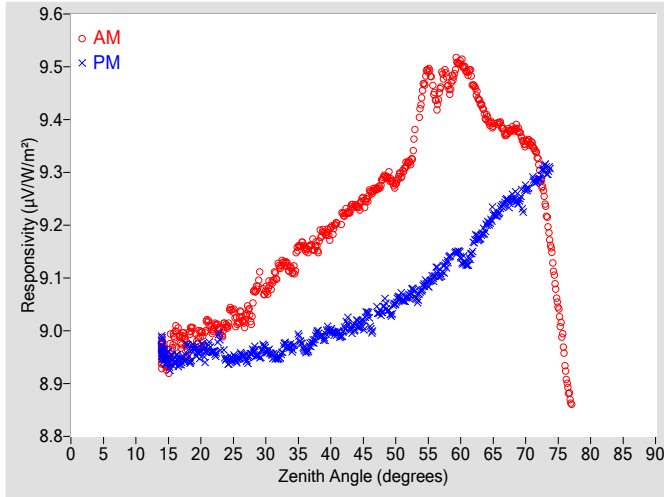


Figure 2. Responsivity vs Local Standard Time

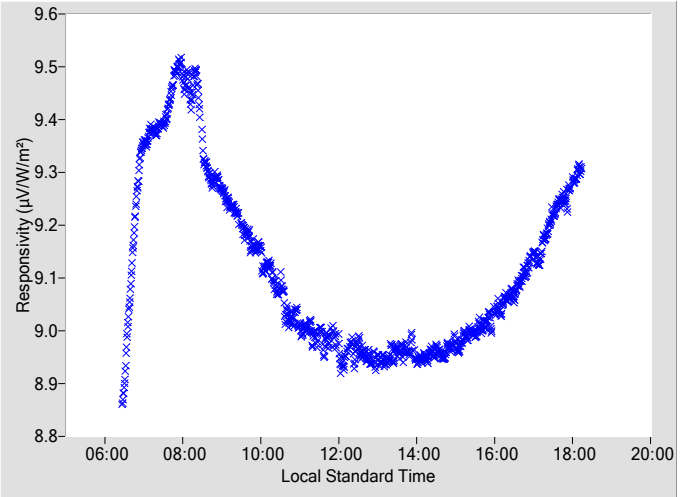


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2588	0.35	92.92	9.0134	0.32	267.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2864	0.31	91.37	9.0383	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2772	0.34	89.87	9.0537	0.32	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3180	0.39	88.41	9.0654	0.35	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4425	0.35	86.96	9.0779	0.33	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4473	0.35	85.57	9.1066	0.34	274.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4708	0.36	84.20	9.1327	0.35	275.90
14	8.9644	0.31	174.07	8.9613	0.32	186.48	60	9.5076	0.37	82.79	9.1412	0.36	277.19
16	8.9925	0.33	148.00	8.9427	0.30	211.72	62	9.4635	0.41	81.46	9.1682	0.37	278.62
18	8.9651	0.30	137.33	8.9632	0.30	222.95	64	9.4027	0.37	80.13	9.2006	N/A	279.94
20	8.9952	0.29	129.57	8.9639	0.30	230.44	66	9.3923	0.41	78.79	9.2270	N/A	281.25
22	9.0047	0.30	123.85	8.9577	0.29	236.18	68	9.3811	0.40	77.48	9.2515	N/A	282.63
24	9.0091	0.32	119.20	8.9432	0.29	240.84	70	9.3545	N/A	76.10	9.2695	N/A	283.97
26	9.0262	0.30	115.37	8.9520	0.29	244.61	72	9.3111	N/A	74.72	9.2867	N/A	285.31
28	9.0487	0.31	112.04	8.9632	0.30	248.04	74	9.1467	N/A	73.37	9.3072	N/A	286.50
30	9.0730	0.32	109.11	8.9638	0.33	250.95	76	8.9384	N/A	71.95	N/A	N/A	N/A
32	9.1227	0.32	106.35	8.9479	0.32	253.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.1158	0.31	104.14	8.9680	0.30	255.98	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1560	0.30	101.87	8.9617	0.30	258.19	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1598	0.32	99.91	8.9960	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1883	0.32	98.04	8.9996	0.31	262.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2207	0.32	96.22	8.9995	0.35	263.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2363	0.31	94.55	9.0120	0.35	265.49	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

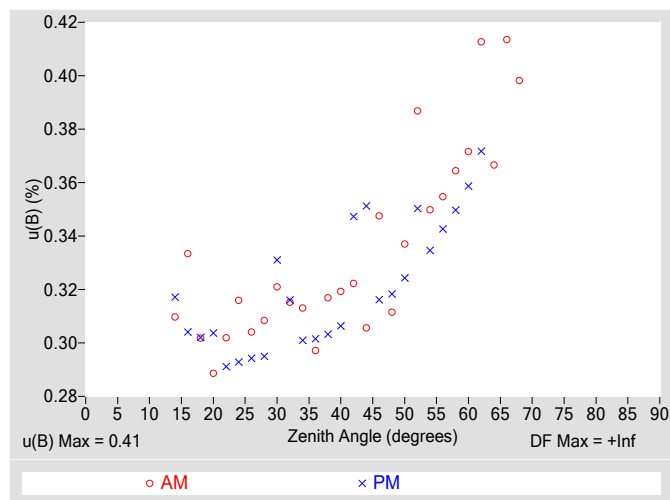


Figure 4. Residuals from Spline Interpolation

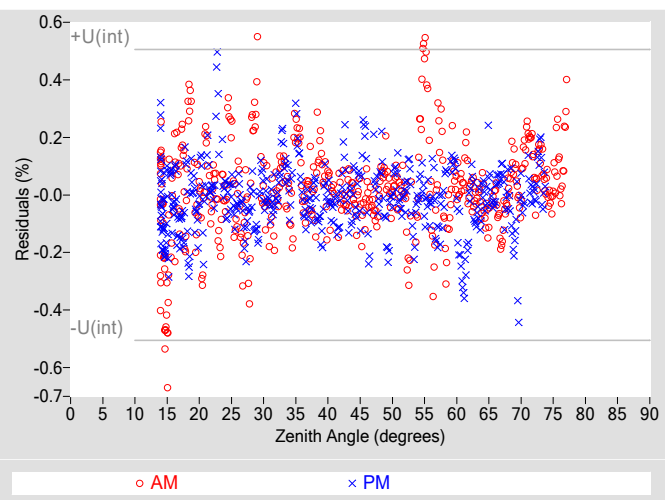


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.25
Combined Standard Uncertainty, $u(c)$ (%)	± 0.48
Effective degrees of freedom, $DF(c)$	12116
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.95
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

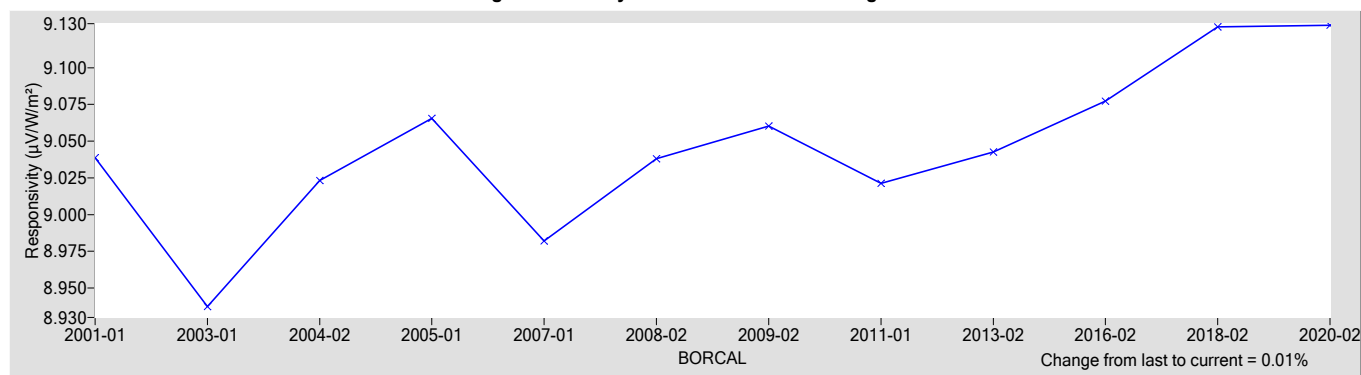
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.1289	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+4.1 / -2.0
Expanded Uncertainty, U (%)	+4.9 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33363
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: SGP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33363 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

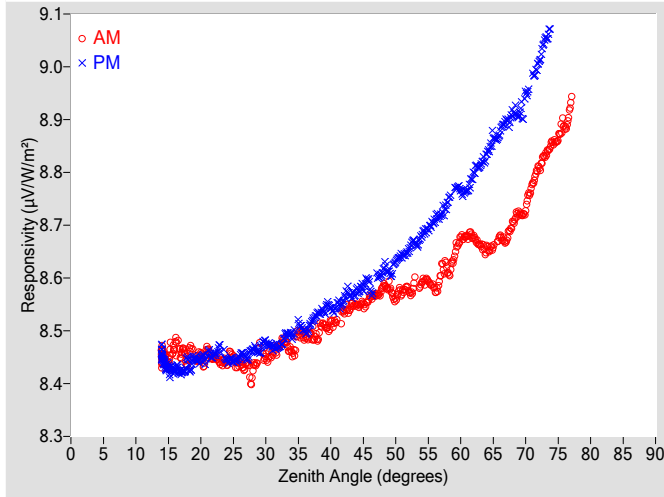


Figure 2. Responsivity vs Local Standard Time

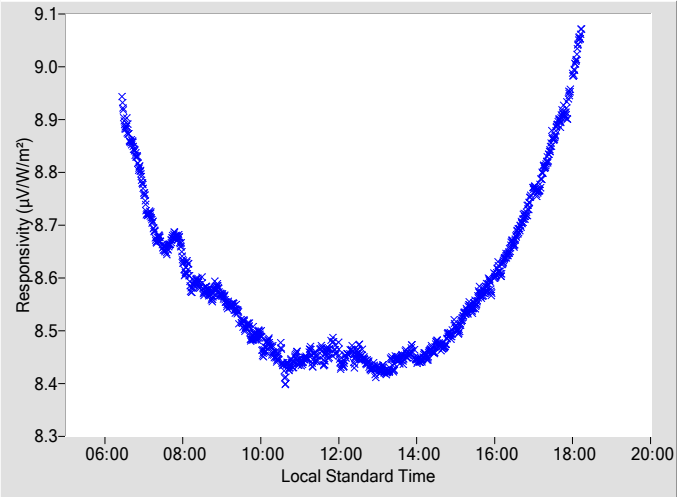


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5616	0.35	92.92	8.5821	0.32	267.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5819	0.31	91.37	8.6110	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5604	0.34	89.87	8.6309	0.32	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5773	0.39	88.41	8.6523	0.35	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5908	0.35	86.96	8.6805	0.33	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5796	0.35	85.57	8.7105	0.34	274.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6152	0.36	84.20	8.7446	0.35	275.90
14	8.4550	0.31	174.07	8.4514	0.32	186.48	60	8.6751	0.37	82.79	8.7668	0.36	277.19
16	8.4713	0.33	148.00	8.4253	0.30	211.72	62	8.6762	0.41	81.46	8.7995	0.37	278.62
18	8.4450	0.30	137.33	8.4419	0.30	222.95	64	8.6531	0.37	80.13	8.8347	N/A	279.94
20	8.4530	0.29	129.57	8.4473	0.30	230.44	66	8.6767	0.41	78.79	8.8739	N/A	281.25
22	8.4484	0.30	123.85	8.4543	0.29	236.18	68	8.7010	0.40	77.48	8.9117	N/A	282.63
24	8.4395	0.32	119.20	8.4438	0.29	240.84	70	8.7306	N/A	76.10	8.9470	N/A	283.97
26	8.4396	0.30	115.37	8.4520	0.29	244.61	72	8.8073	N/A	74.72	9.0070	N/A	285.31
28	8.4216	0.31	112.04	8.4659	0.30	248.04	74	8.8530	N/A	73.37	9.0713	N/A	286.50
30	8.4474	0.32	109.11	8.4773	0.33	250.95	76	8.8850	N/A	71.95	N/A	N/A	N/A
32	8.4709	0.32	106.35	8.4691	0.32	253.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4605	0.31	104.14	8.4917	0.30	255.98	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4875	0.30	101.87	8.4986	0.30	258.19	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4879	0.32	99.91	8.5328	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5117	0.32	98.04	8.5431	0.31	262.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5366	0.32	96.22	8.5586	0.35	263.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5495	0.31	94.55	8.5742	0.35	265.49	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

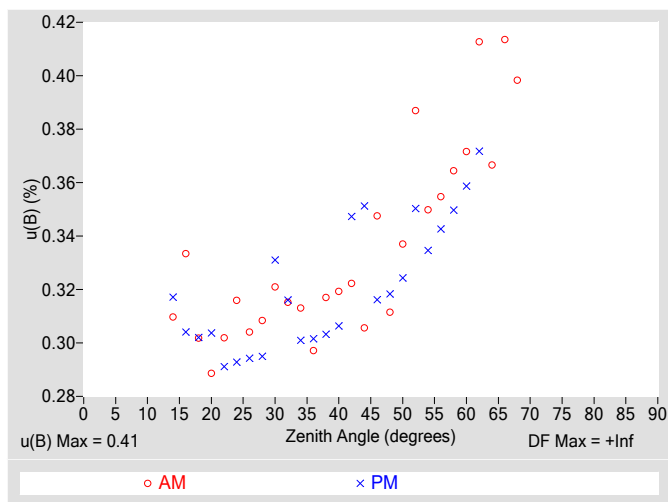


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	27629
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.90
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

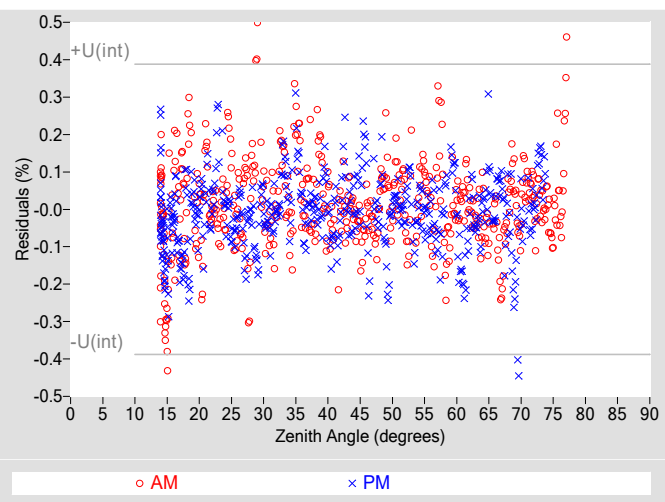


Table 4. Calibration Label Values

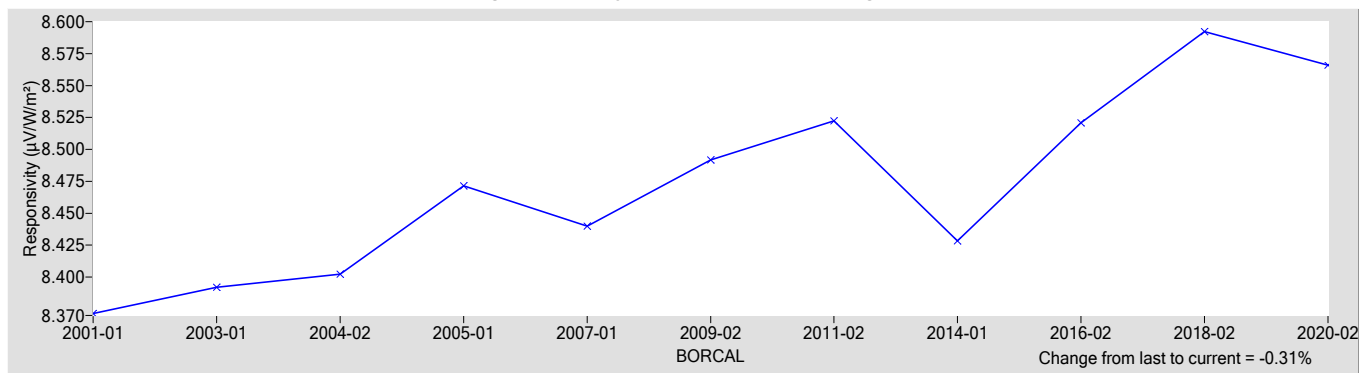
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5659	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+2.3 / -1.4
Expanded Uncertainty, U (%)	+3.1 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33377
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33377 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \text{COS}(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

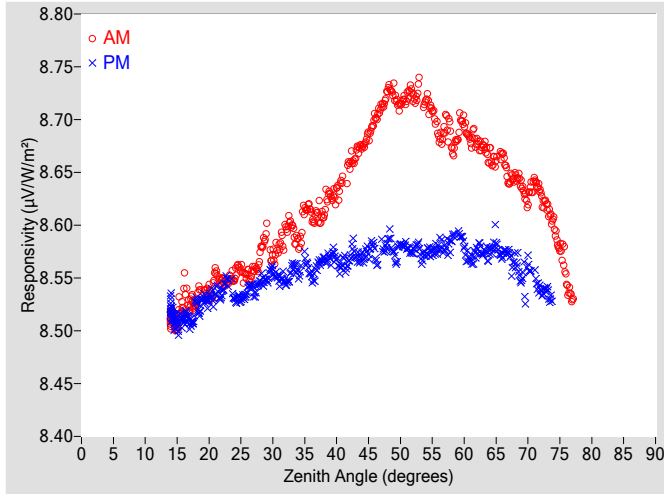


Figure 2. Responsivity vs Local Standard Time

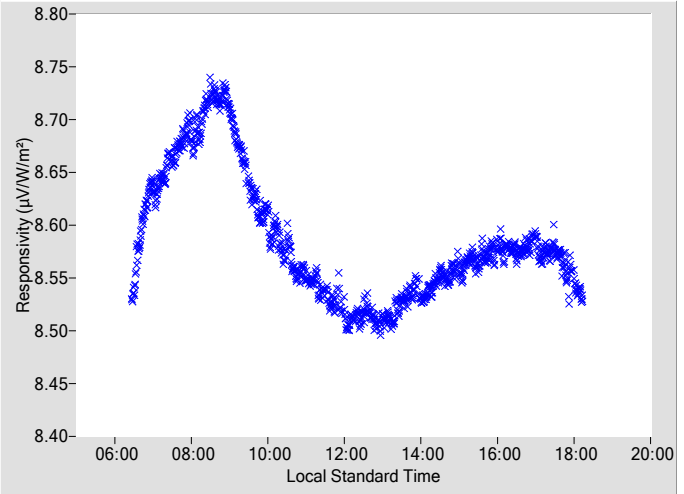


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7004	0.35	92.92	8.5717	0.32	267.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7273	0.31	91.37	8.5822	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7134	0.34	89.87	8.5813	0.32	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7231	0.39	88.41	8.5751	0.35	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7186	0.35	86.96	8.5737	0.33	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6859	0.35	85.57	8.5793	0.34	274.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6803	0.36	84.20	8.5851	0.35	275.90
14	8.5129	0.31	174.07	8.5190	0.32	186.48	60	8.6954	0.37	82.79	8.5808	0.36	277.19
16	8.5314	0.33	148.00	8.5105	0.30	211.72	62	8.6778	0.41	81.46	8.5764	0.37	278.62
18	8.5263	0.30	137.33	8.5269	0.30	222.95	64	8.6649	0.37	80.13	8.5747	N/A	279.94
20	8.5375	0.29	129.57	8.5294	0.30	230.44	66	8.6658	0.41	78.79	8.5717	N/A	281.25
22	8.5470	0.30	123.85	8.5350	0.29	236.18	68	8.6449	0.40	77.48	8.5647	N/A	282.63
24	8.5506	0.32	119.20	8.5292	0.29	240.84	70	8.6243	N/A	76.10	8.5628	N/A	283.97
26	8.5535	0.30	115.37	8.5373	0.29	244.61	72	8.6283	N/A	74.72	8.5371	N/A	285.31
28	8.5724	0.31	112.04	8.5478	0.30	248.04	74	8.6007	N/A	73.37	8.5278	N/A	286.50
30	8.5687	0.32	109.11	8.5569	0.33	250.95	76	8.5460	N/A	71.95	N/A	N/A	N/A
32	8.5970	0.32	106.35	8.5452	0.32	253.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5842	0.31	104.14	8.5555	0.30	255.98	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6102	0.30	101.87	8.5507	0.30	258.19	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6104	0.32	99.91	8.5676	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6308	0.32	98.04	8.5672	0.31	262.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6578	0.32	96.22	8.5670	0.35	263.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6749	0.31	94.55	8.5695	0.35	265.49	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

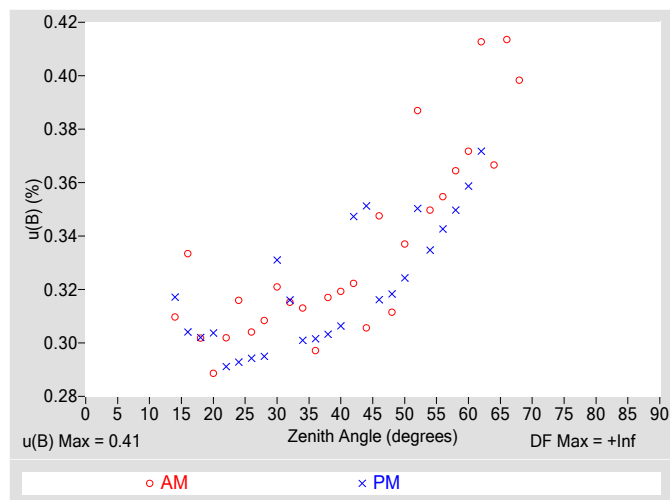


Figure 4. Residuals from Spline Interpolation

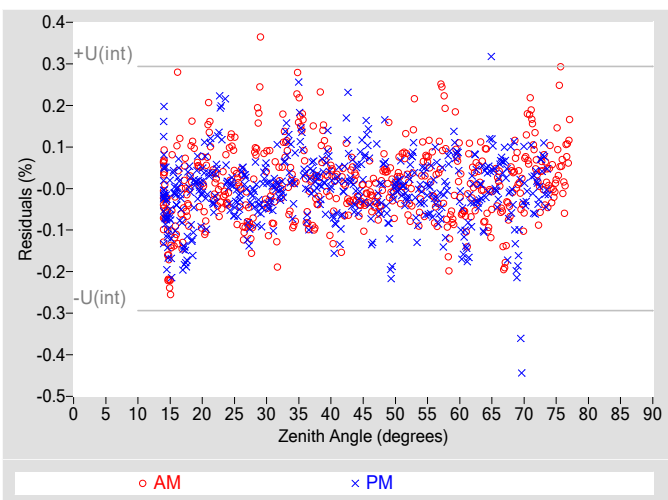


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.15
Combined Standard Uncertainty, $u(c)$ (%)	± 0.44
Effective degrees of freedom, $DF(c)$	71423
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (%)	± 0.86
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

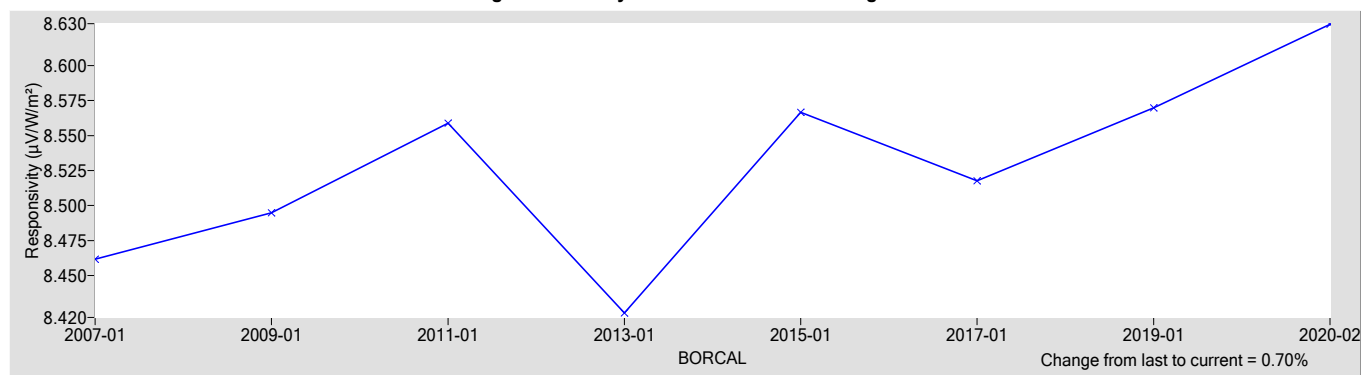
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.6295	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+1.1 / -0.98
Expanded Uncertainty, U (%)	+1.9 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33383
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33383 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

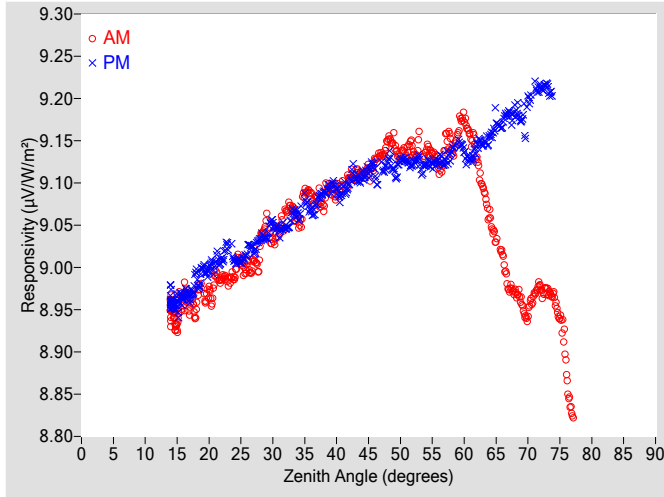


Figure 2. Responsivity vs Local Standard Time

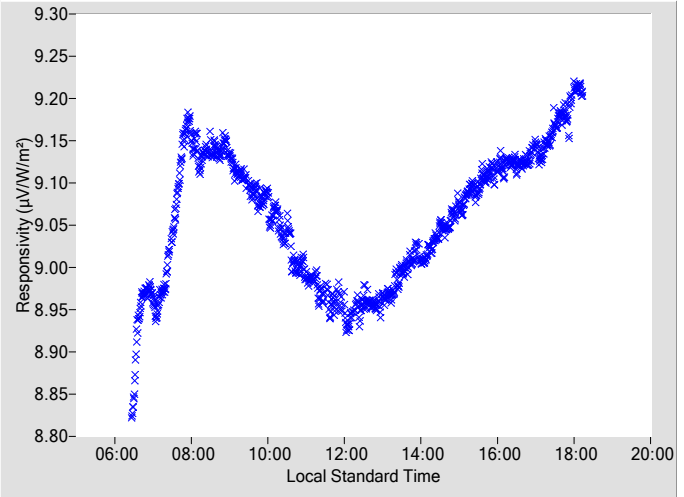


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1247	0.35	92.92	9.1101	0.32	267.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1495	0.31	91.37	9.1236	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1319	0.34	89.87	9.1266	0.32	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1397	0.39	88.41	9.1228	0.35	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1380	0.35	86.96	9.1227	0.33	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1195	0.35	85.57	9.1259	0.34	274.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1451	0.36	84.20	9.1366	0.35	275.90
14	8.9526	0.31	174.07	8.9584	0.32	186.89	60	9.1748	0.37	82.79	9.1374	0.36	277.19
16	8.9643	0.33	148.00	8.9647	0.30	211.72	62	9.1266	0.41	81.46	9.1446	0.37	278.62
18	8.9507	0.30	137.33	8.9902	0.30	222.95	64	9.0580	0.37	80.13	9.1546	N/A	279.94
20	8.9707	0.29	129.57	8.9990	0.30	230.44	66	9.0142	0.41	78.79	9.1688	N/A	281.25
22	8.9864	0.30	123.85	9.0085	0.29	236.18	68	8.9697	0.40	77.48	9.1844	N/A	282.63
24	8.9908	0.32	119.20	9.0072	0.29	240.84	70	8.9450	N/A	76.10	9.1971	N/A	283.97
26	9.0011	0.30	115.37	9.0194	0.29	244.61	72	8.9734	N/A	74.72	9.2122	N/A	285.31
28	9.0219	0.31	112.04	9.0345	0.30	248.04	74	8.9651	N/A	73.37	9.2032	N/A	286.50
30	9.0317	0.32	109.11	9.0522	0.33	250.95	76	8.8754	N/A	71.95	N/A	N/A	N/A
32	9.0669	0.32	106.35	9.0463	0.32	253.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.0546	0.31	104.14	9.0618	0.30	255.98	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0827	0.30	101.87	9.0653	0.30	258.19	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0759	0.32	99.91	9.0885	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0905	0.32	98.04	9.0920	0.31	262.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1065	0.32	96.22	9.0998	0.35	263.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1113	0.31	94.55	9.1072	0.35	265.49	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

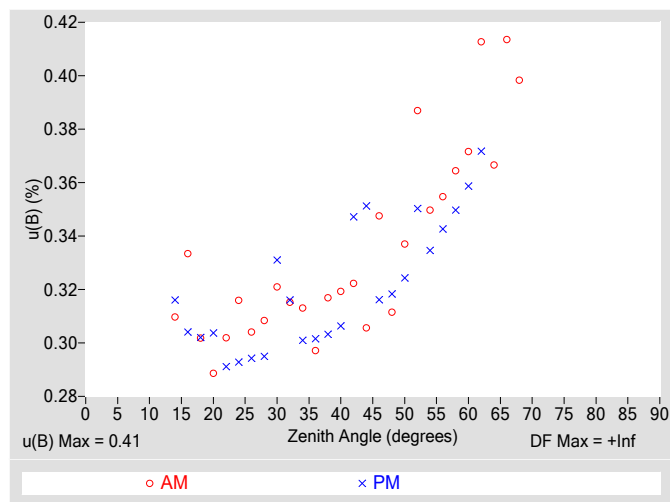


Figure 4. Residuals from Spline Interpolation

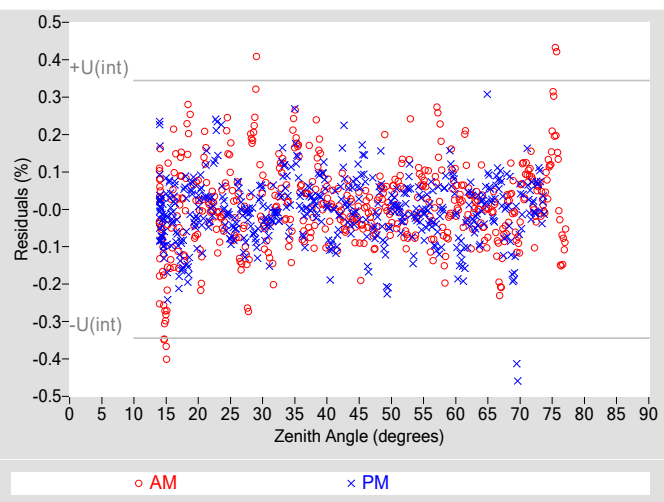


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.45
Effective degrees of freedom, $DF(c)$	41199
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.88
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

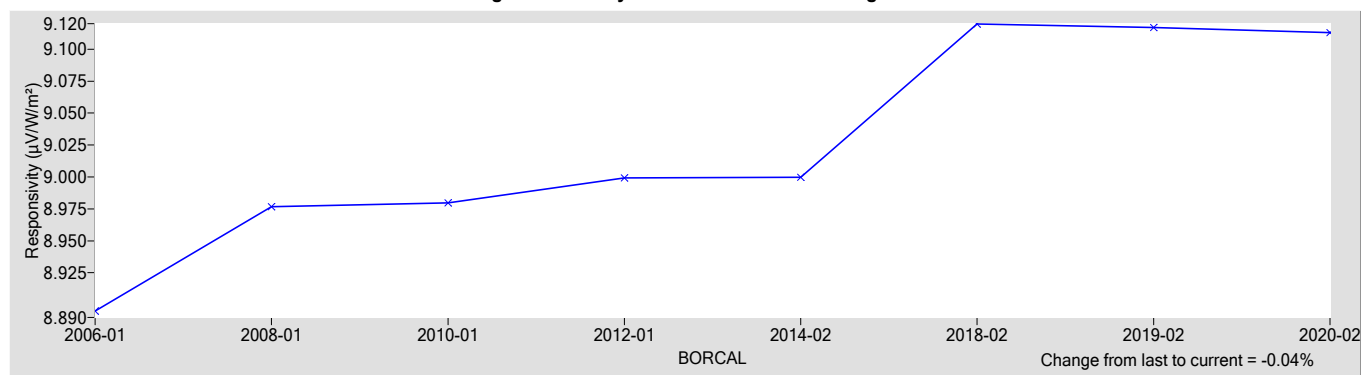
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.1130	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+0.68 / -0.89
Expanded Uncertainty, U (%)	+1.4 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 33575
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33575 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

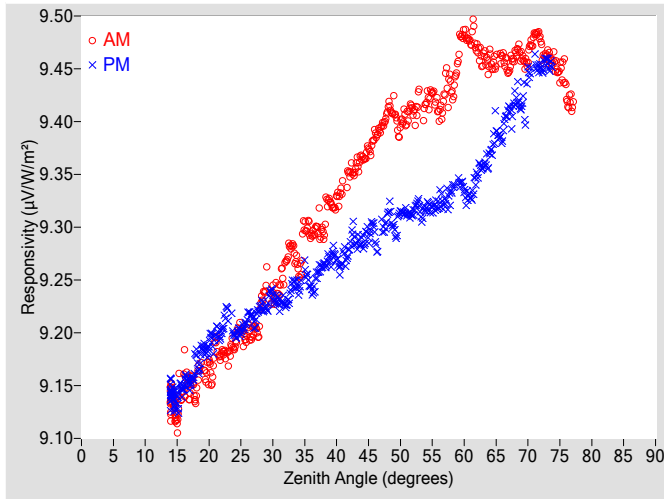


Figure 2. Responsivity vs Local Standard Time

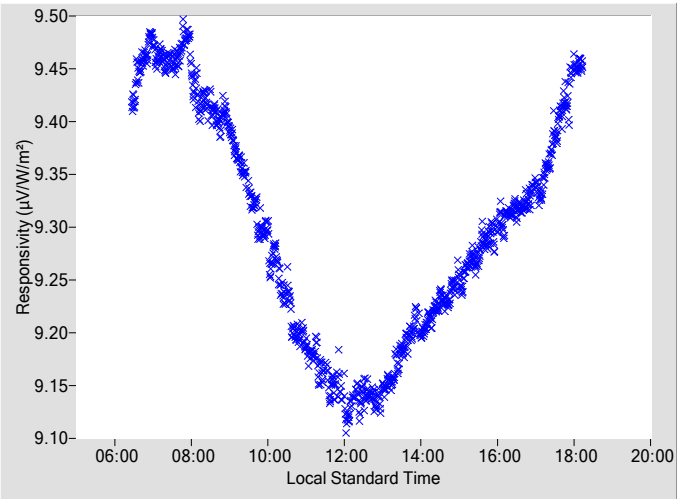


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith			AM			PM			Zenith			AM			PM		
Angle	R		$u(B)$	Azimuth		R	$u(B)$	Azimuth	Angle	R		$u(B)$	Azimuth		R	$u(B)$	Azimuth
(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)		\pm (%)	Angle		($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)		\pm (%)	Angle		($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle
0	N/A		N/A	N/A		N/A	N/A	N/A	46	9.3863		0.35	92.92		9.2891	0.32	267.19
2	N/A		N/A	N/A		N/A	N/A	N/A	48	9.4104		0.31	91.37		9.3088	0.32	268.67
4	N/A		N/A	N/A		N/A	N/A	N/A	50	9.3939		0.34	89.87		9.3139	0.32	270.18
6	N/A		N/A	N/A		N/A	N/A	N/A	52	9.4113		0.39	88.41		9.3135	0.35	271.64
8	N/A		N/A	N/A		N/A	N/A	N/A	54	9.4185		0.35	86.96		9.3187	0.33	273.08
10	N/A		N/A	N/A		N/A	N/A	N/A	56	9.4107		0.35	85.57		9.3228	0.34	274.54
12	N/A		N/A	N/A		N/A	N/A	N/A	58	9.4320		0.36	84.20		9.3331	0.35	275.90
14	9.1390		0.31	174.07		9.1427	0.32	186.48	60	9.4827		0.37	82.79		9.3355	0.36	277.19
16	9.1543		0.33	148.00		9.1489	0.30	211.72	62	9.4691		0.41	81.46		9.3499	0.37	278.62
18	9.1428		0.30	137.33		9.1763	0.30	222.95	64	9.4567		0.37	80.13		9.3685	N/A	279.94
20	9.1671		0.29	129.57		9.1898	0.30	230.44	66	9.4601		0.41	78.79		9.3874	N/A	281.25
22	9.1796		0.30	123.85		9.2016	0.29	236.18	68	9.4622		0.40	77.48		9.4206	N/A	282.63
24	9.1873		0.32	119.20		9.1972	0.29	240.84	70	9.4607		N/A	76.10		9.4439	N/A	283.97
26	9.1993		0.30	115.37		9.2137	0.29	244.61	72	9.4733		N/A	74.72		9.4494	N/A	285.31
28	9.2174		0.31	112.04		9.2248	0.30	248.04	74	9.4561		N/A	73.37		9.4516	N/A	286.50
30	9.2332		0.32	109.11		9.2358	0.33	250.95	76	9.4252		N/A	71.95		N/A	N/A	N/A
32	9.2679		0.32	106.35		9.2262	0.32	253.56	78	N/A		N/A	N/A		N/A	N/A	N/A
34	9.2609		0.31	104.14		9.2426	0.30	255.98	80	N/A		N/A	N/A		N/A	N/A	N/A
36	9.2927		0.30	101.87		9.2405	0.30	258.19	82	N/A		N/A	N/A		N/A	N/A	N/A
38	9.2959		0.32	99.91		9.2643	0.30	260.18	84	N/A		N/A	N/A		N/A	N/A	N/A
40	9.3253		0.32	98.04		9.2690	0.31	262.04	86	N/A		N/A	N/A		N/A	N/A	N/A
42	9.3514		0.32	96.22		9.2797	0.35	263.83	88	N/A		N/A	N/A		N/A	N/A	N/A
44	9.3660		0.31	94.55		9.2859	0.35	265.49	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

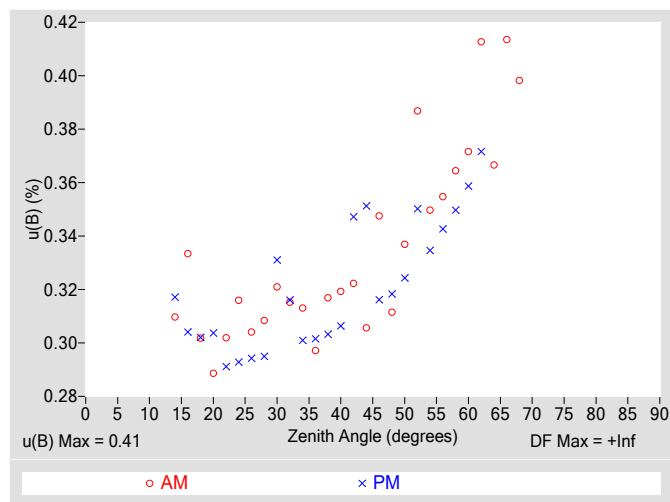


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.45
Effective degrees of freedom, $DF(c)$	38899
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.88
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

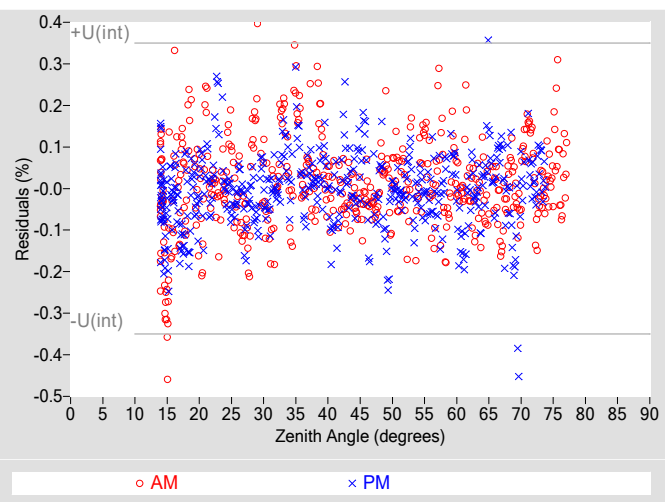


Table 4. Calibration Label Values

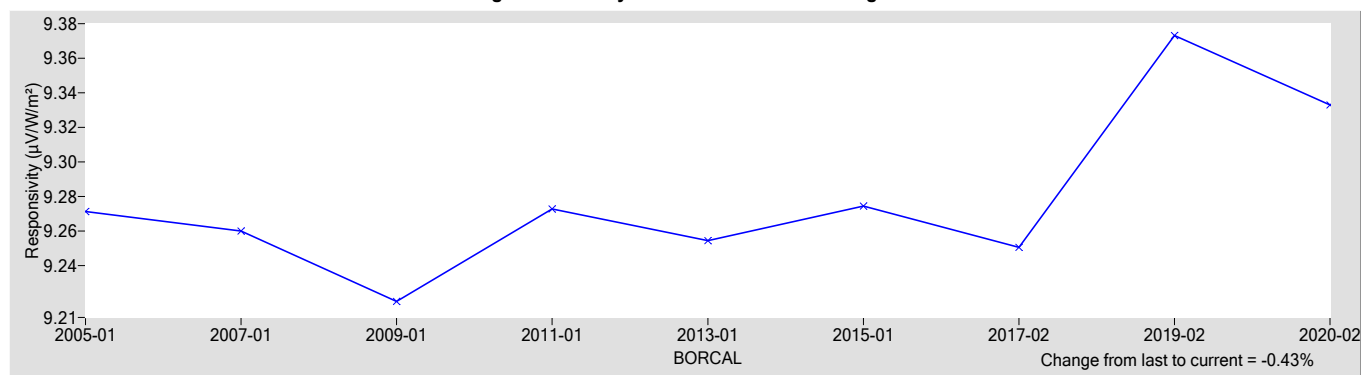
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.3330	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+1.6 / -1.1
Expanded Uncertainty, U (%)	+2.4 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 33703F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: TWP **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33703F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

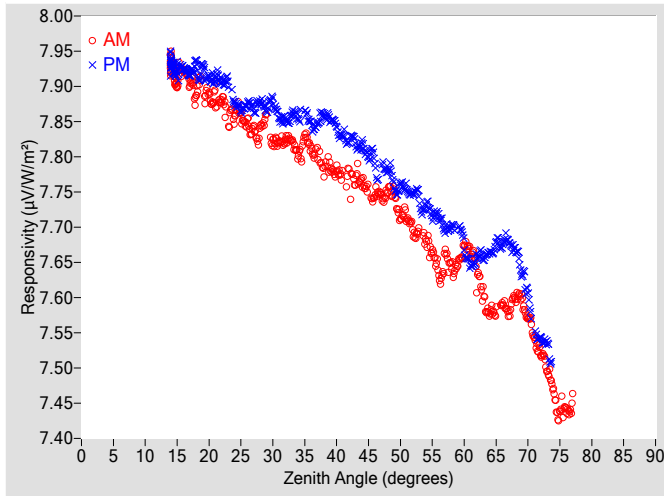


Figure 2. Responsivity vs Local Standard Time

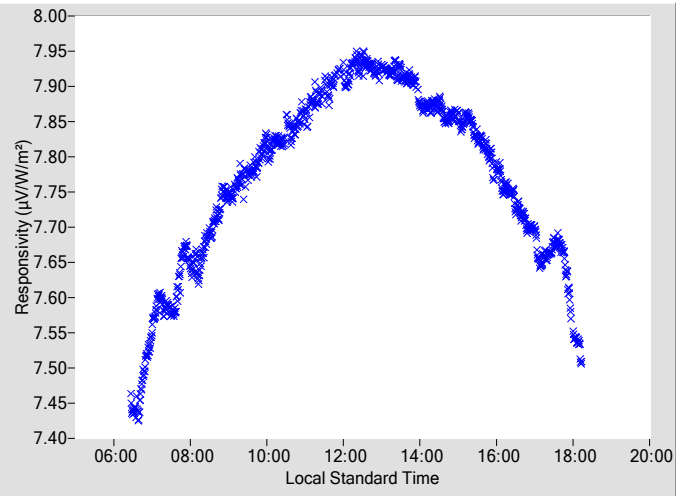


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith		AM		PM			Zenith		AM		PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)	± (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	± (%)	Angle	(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)	± (%)	Angle	($\mu\text{V}/\text{W}/\text{m}^2$)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7460	0.35	92.87	7.7898	0.35	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7531	0.36	91.32	7.7802	0.36	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7151	0.40	89.82	7.7601	0.37	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6937	0.37	88.36	7.7486	0.39	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6776	0.38	86.96	7.7322	0.39	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6337	0.40	85.53	7.7150	0.40	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6437	0.41	84.16	7.7006	0.41	275.86
14	7.9337	0.32	173.78	7.9328	0.33	187.33	60	7.6713	0.40	82.83	7.6714	0.43	277.23
16	7.9230	0.35	148.12	7.9247	0.33	211.71	62	7.6350	0.43	81.50	7.6568	0.48	278.57
18	7.8900	0.33	137.21	7.9298	0.32	222.82	64	7.5795	0.45	80.17	7.6642	N/A	279.89
20	7.8872	0.33	129.44	7.9125	0.34	230.38	66	7.5900	0.44	78.83	7.6759	N/A	281.29
22	7.8812	0.32	123.98	7.9072	0.34	236.04	68	7.6003	0.50	77.44	7.6673	N/A	282.59
24	7.8564	0.33	119.20	7.8771	0.33	240.72	70	7.5715	N/A	76.14	7.6032	N/A	283.97
26	7.8488	0.33	115.36	7.8757	0.33	244.70	72	7.5226	N/A	74.76	7.5418	N/A	285.31
28	7.8361	0.34	112.03	7.8764	0.32	247.94	74	7.4670	N/A	73.37	N/A	N/A	N/A
30	7.8200	0.32	109.11	7.8767	0.32	250.95	76	7.4420	N/A	71.99	N/A	N/A	N/A
32	7.8224	0.35	106.49	7.8529	0.36	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.8052	0.36	104.07	7.8540	0.33	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8119	0.33	101.93	7.8461	0.33	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7838	0.35	99.85	7.8593	0.35	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7783	0.37	97.98	7.8395	0.34	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7705	0.38	96.16	7.8251	0.36	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7645	0.36	94.49	7.8167	0.38	265.54	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

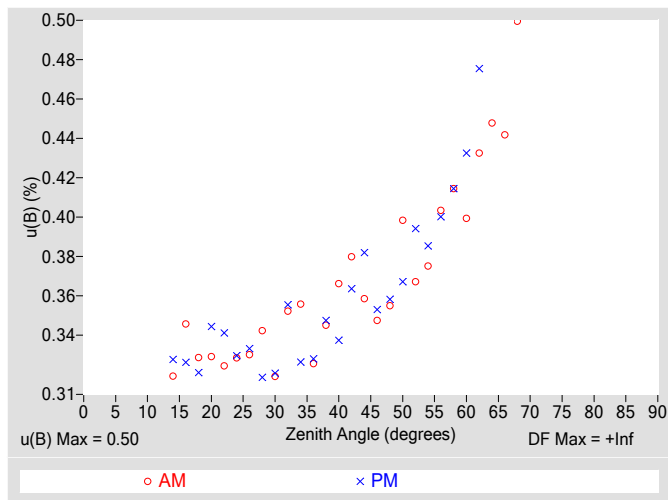


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.50
Type-A Interpolating Function, $u(int)$ (%)	± 0.22
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	35473
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

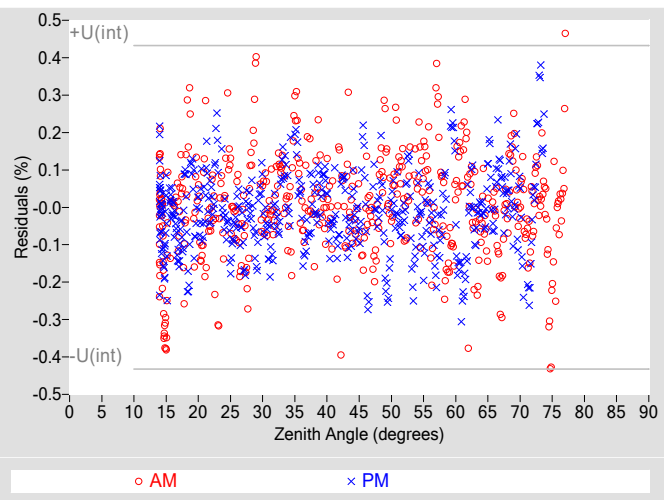


Table 4. Calibration Label Values

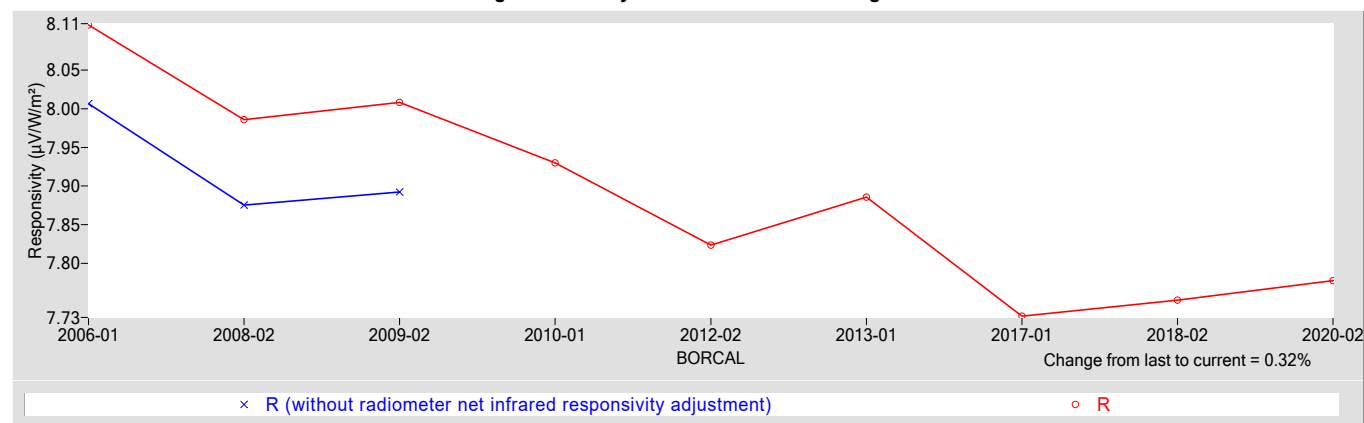
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
7.7774	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.85
Offset Uncertainty, $U(off)$ (%)	+1.3 / -1.8
Expanded Uncertainty, U (%)	+2.1 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 34293F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: AMF **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

34293F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

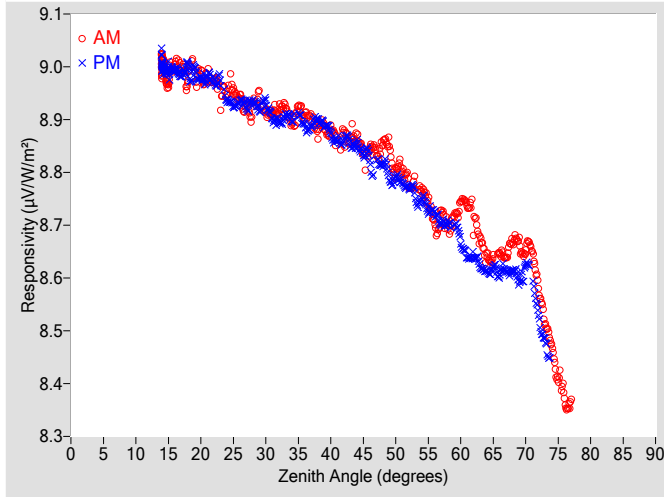


Figure 2. Responsivity vs Local Standard Time

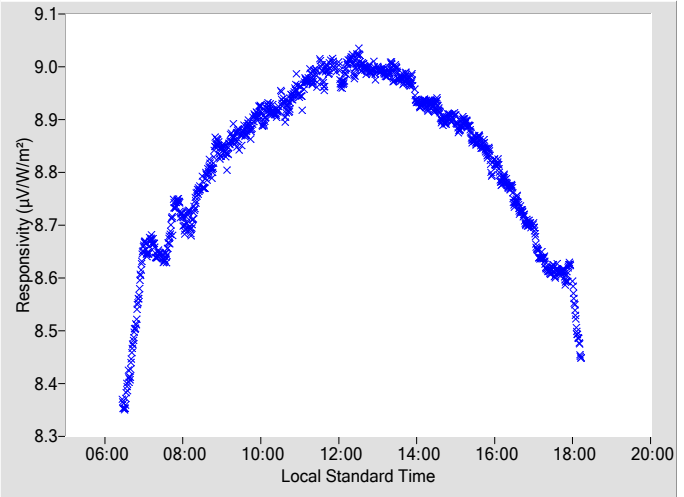


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8447	0.32	92.87	8.8219	0.32	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8565	0.32	91.32	8.8151	0.33	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8035	0.37	89.82	8.7921	0.33	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7799	0.33	88.36	8.7710	0.36	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7653	0.34	86.96	8.7505	0.34	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6993	0.36	85.53	8.7229	0.35	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6992	0.37	84.16	8.7036	0.36	275.86
14	9.0070	0.30	173.53	9.0026	0.31	187.56	60	8.7417	0.35	82.83	8.6678	0.37	277.23
16	9.0053	0.32	147.99	8.9928	0.31	211.71	62	8.7148	0.40	81.48	8.6400	0.42	278.57
18	8.9765	0.31	137.21	8.9985	0.30	222.82	64	8.6412	0.41	80.17	8.6129	N/A	279.89
20	8.9876	0.31	129.44	8.9775	0.33	230.38	66	8.6455	0.39	78.83	8.6083	N/A	281.29
22	8.9744	0.31	123.98	8.9724	0.32	236.04	68	8.6680	0.45	77.44	8.6129	N/A	282.59
24	8.9500	0.31	119.20	8.9376	0.31	240.72	70	8.6501	N/A	76.14	8.6244	N/A	283.97
26	8.9430	0.31	115.36	8.9349	0.31	244.70	72	8.5821	N/A	74.76	8.5293	N/A	285.31
28	8.9233	0.32	112.03	8.9332	0.30	247.94	74	8.4712	N/A	73.37	N/A	N/A	N/A
30	8.9150	0.30	109.11	8.9292	0.30	250.95	76	8.3739	N/A	71.99	N/A	N/A	N/A
32	8.9158	0.33	106.49	8.8969	0.34	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8956	0.33	104.07	8.8992	0.31	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9076	0.30	101.93	8.8872	0.31	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8784	0.32	99.85	8.8984	0.33	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8790	0.34	97.98	8.8714	0.31	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8724	0.35	96.16	8.8618	0.34	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8646	0.33	94.49	8.8533	0.36	265.54	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

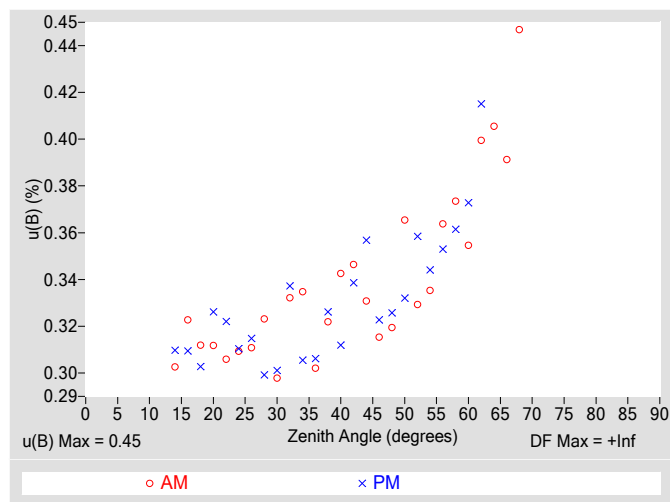


Figure 4. Residuals from Spline Interpolation

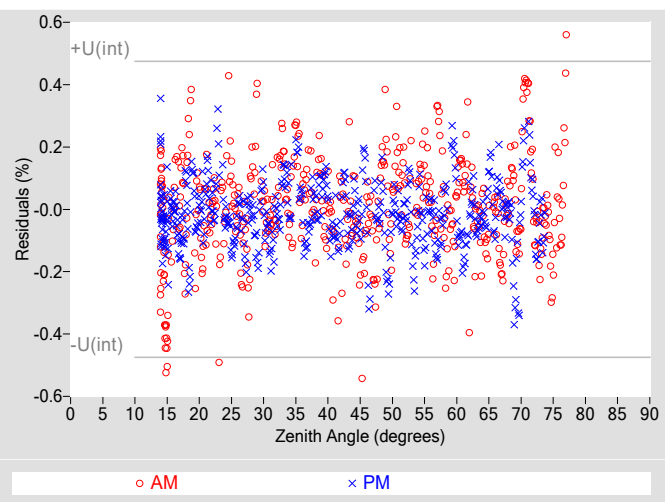


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.45
Type-A Interpolating Function, $u(int)$ (%)	± 0.24
Combined Standard Uncertainty, $u(c)$ (%)	± 0.51
Effective degrees of freedom, $DF(c)$	18395
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.99
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

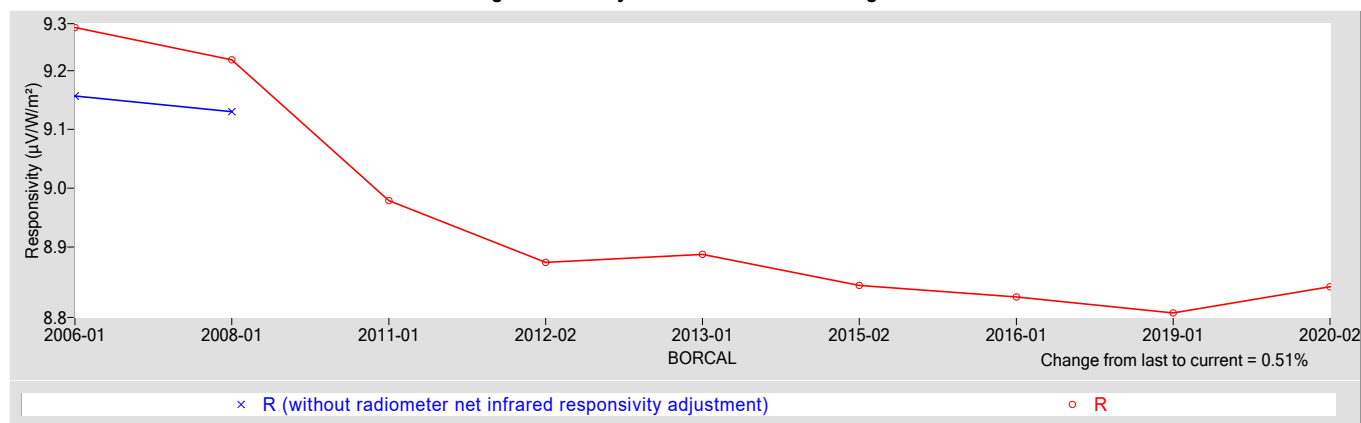
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.8323	0.54700

† R_{net} determination date: 04/03/2006

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.73
Offset Uncertainty, $U(off)$ (%)	+1.1 / -1.9
Expanded Uncertainty, U (%)	+1.8 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer
Model: PSP
Calibration Date: 6/5/2020
Customer: AMF#2
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 35831F3
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

35831F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

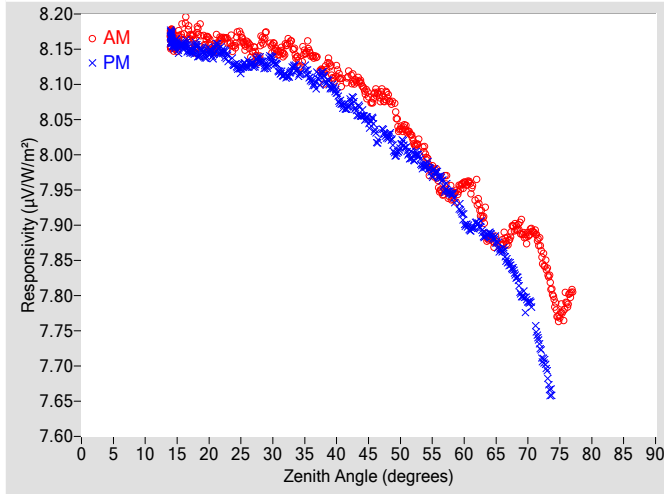


Figure 2. Responsivity vs Local Standard Time

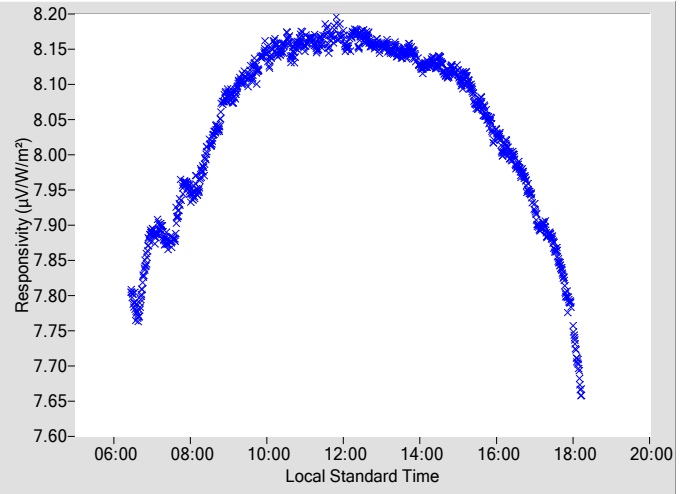


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ \pm (%)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ \pm (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0864	0.36	92.89	8.0322	0.32	267.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0839	0.32	91.34	8.0259	0.33	268.74
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0366	0.33	89.84	8.0138	0.33	270.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0201	0.35	88.38	7.9963	0.34	271.70
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9993	0.34	86.93	7.9849	0.35	273.14
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9561	0.37	85.55	7.9701	0.36	274.51
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9438	0.36	84.18	7.9451	0.37	275.87
14	8.1691	0.30	173.34	8.1655	0.32	187.72	60	7.9587	0.41	82.85	7.9047	0.38	277.25
16	8.1716	0.36	148.27	8.1549	0.29	211.82	62	7.9438	0.42	81.43	7.9030	0.39	278.59
18	8.1629	0.29	137.12	8.1530	0.33	222.71	64	7.8801	0.39	80.10	7.8883	N/A	279.91
20	8.1621	0.32	129.74	8.1472	0.30	230.36	66	7.8762	0.43	78.76	7.8647	N/A	281.22
22	8.1654	0.32	124.11	8.1472	0.30	236.10	68	7.8970	0.42	77.45	7.8296	N/A	282.61
24	8.1550	0.33	119.19	8.1275	0.30	240.77	70	7.8840	N/A	76.07	7.7913	N/A	283.99
26	8.1581	0.31	115.41	8.1277	0.31	244.65	72	7.8645	N/A	74.74	7.7192	N/A	285.33
28	8.1487	0.35	112.07	8.1336	0.30	247.98	74	7.7977	N/A	73.39	7.6583	N/A	286.48
30	8.1544	0.33	109.15	8.1347	0.30	250.91	76	7.7897	N/A	72.01	N/A	N/A	N/A
32	8.1509	0.35	106.52	8.1127	0.30	253.52	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1322	0.34	104.10	8.1166	0.32	255.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1431	0.30	101.99	8.1049	0.31	258.16	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1166	0.31	99.87	8.1125	0.33	260.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1172	0.31	97.95	8.0881	0.31	262.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1144	0.31	96.23	8.0724	0.33	263.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0992	0.33	94.52	8.0566	0.36	265.57	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

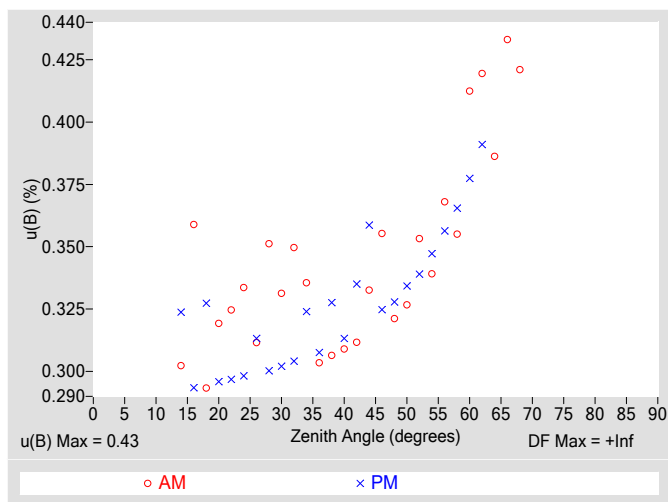


Figure 4. Residuals from Spline Interpolation

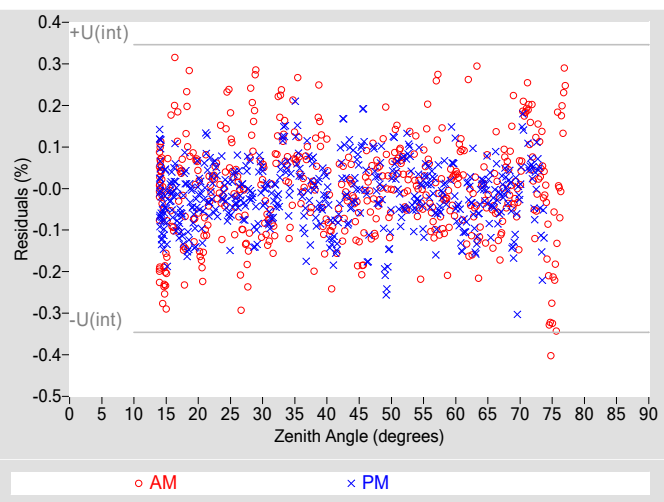


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.43
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.47
Effective degrees of freedom, $DF(c)$	46134
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.91
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

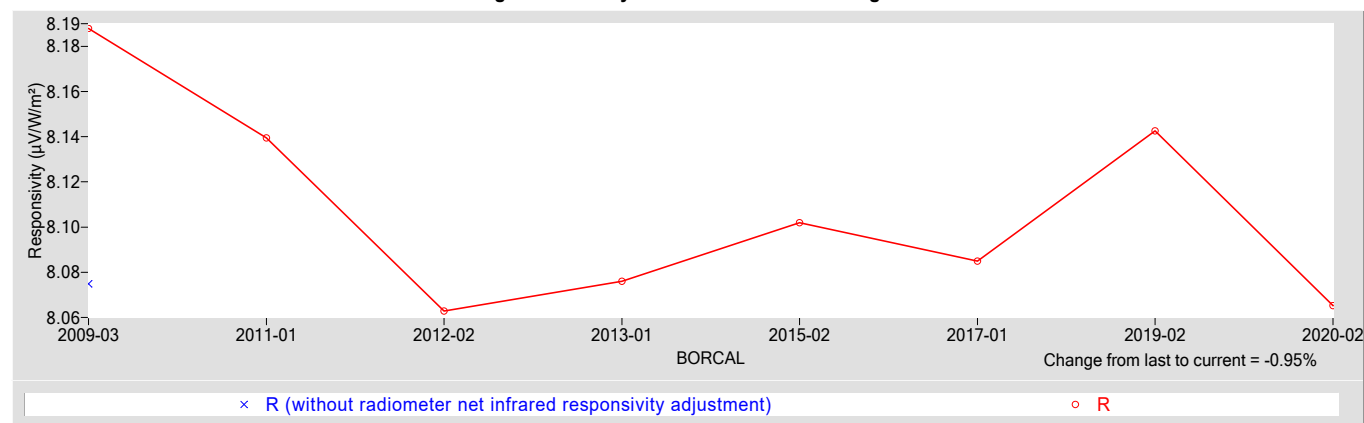
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0652	0.54390

† R_{net} determination date: 08/05/2009

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.81
Offset Uncertainty, $U(off)$ (%)	+1.1 / -2.0
Expanded Uncertainty, U (%)	+1.9 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 36313E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

36313E6 Eppley NIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

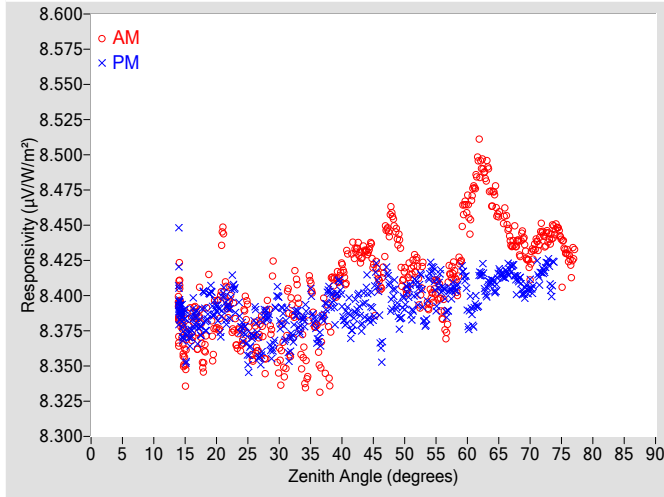


Figure 2. Responsivity vs Local Standard Time

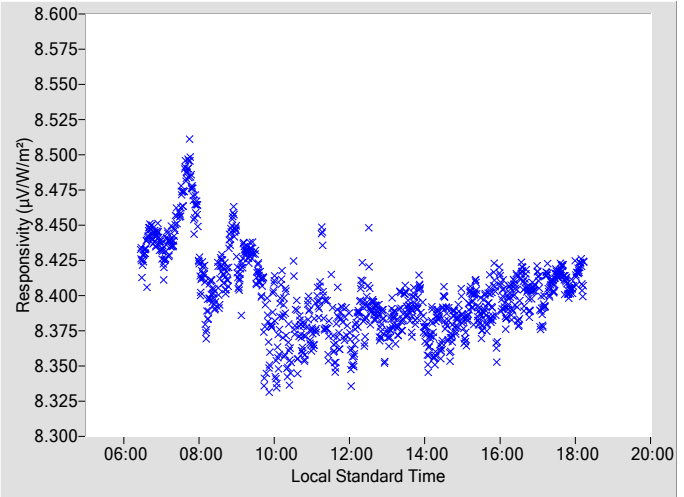


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4097	0.30	92.94	8.3849	0.29	267.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4582	0.29	91.34	8.3961	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4131	0.34	89.84	8.3977	0.30	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4213	0.29	88.38	8.4035	0.30	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3955	0.29	86.97	8.4161	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3903	0.34	85.59	8.4072	0.30	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4162	0.30	84.22	8.4056	0.30	275.83
14	8.3922	0.29	173.41	8.3931	0.30	187.43	60	8.4629	0.30	82.80	8.3926	0.30	277.21
16	8.3787	0.33	148.10	8.3792	0.33	211.94	62	8.4953	0.31	81.47	8.4109	0.30	278.55
18	8.3550	0.30	137.29	8.3927	0.30	223.09	64	8.4698	0.32	80.14	8.4089	N/A	279.95
20	8.3867	0.29	129.35	8.3908	0.30	230.35	66	8.4566	0.30	78.82	8.4152	N/A	281.26
22	8.3947	0.29	123.89	8.3914	0.31	236.22	68	8.4362	0.30	77.41	8.4099	N/A	282.60
24	8.3672	0.32	119.13	8.3755	0.30	240.77	70	8.4221	N/A	76.11	8.4060	N/A	283.94
26	8.3664	0.31	115.40	8.3815	0.29	244.64	72	8.4453	N/A	74.74	8.4172	N/A	285.29
28	8.3715	0.32	112.15	8.3859	0.30	247.98	74	8.4477	N/A	73.34	8.4239	N/A	286.52
30	8.3496	0.30	108.98	8.3873	0.30	250.98	76	8.4290	N/A	71.96	N/A	N/A	N/A
32	8.3810	0.29	106.45	8.3686	0.29	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3529	0.31	104.10	8.3856	0.29	256.01	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3740	0.34	101.92	8.3727	0.29	258.09	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3646	0.31	99.93	8.4013	0.29	260.20	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4192	0.29	97.95	8.3929	0.29	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4321	0.31	96.21	8.3873	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4309	0.31	94.52	8.4000	0.29	265.51	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

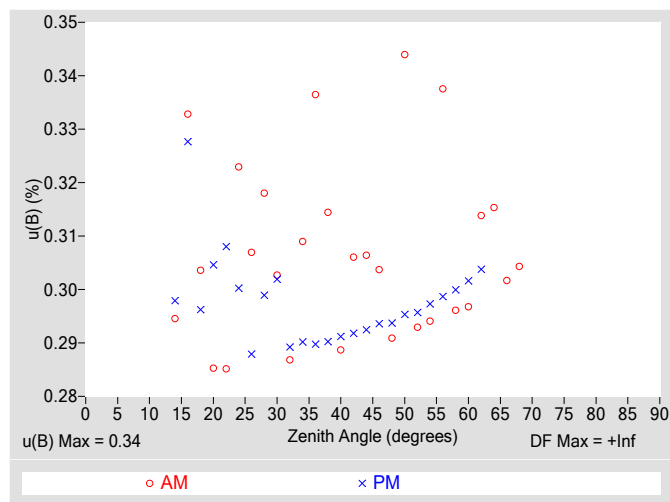


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.30
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	4727
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.89
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

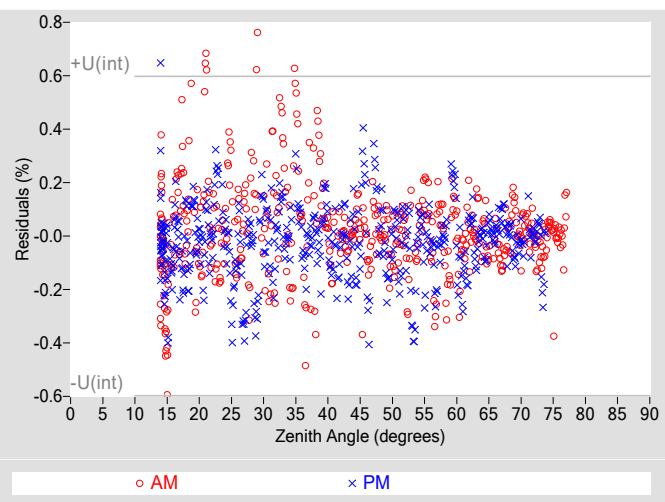


Table 4. Calibration Label Values

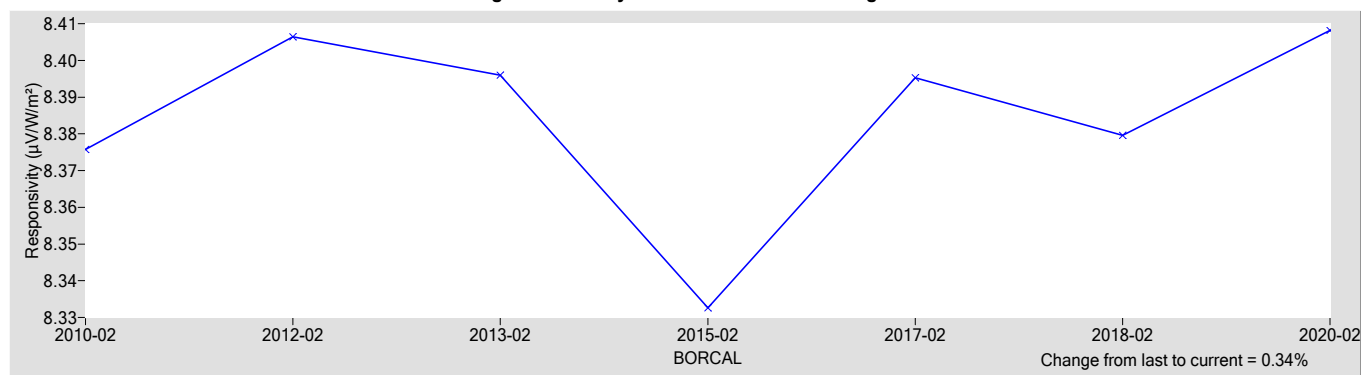
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.4082	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+0.65 / -0.70
Expanded Uncertainty, U (%)	+1.3 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 36314E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

36314E6 Eppley NIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

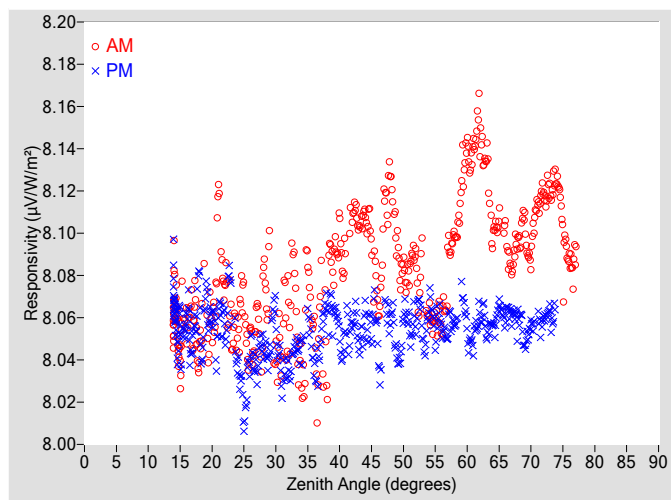


Figure 2. Responsivity vs Local Standard Time

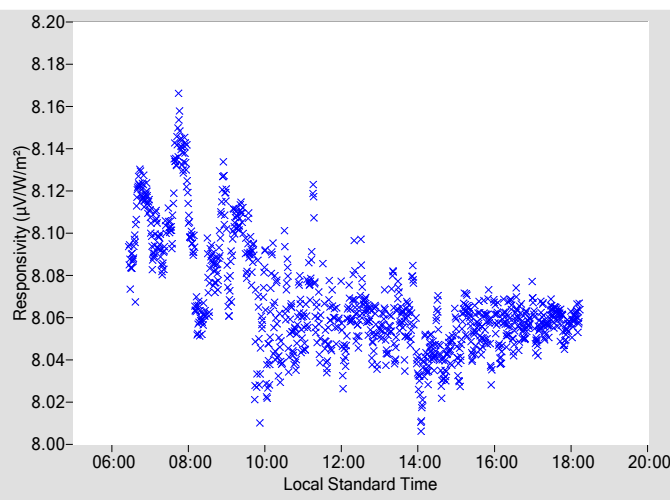


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0685	0.30	92.94	8.0476	0.29	267.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1270	0.29	91.34	8.0589	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0843	0.34	89.84	8.0588	0.30	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0853	0.29	88.38	8.0593	0.30	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0615	0.29	86.97	8.0649	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0586	0.34	85.59	8.0569	0.30	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0982	0.30	84.22	8.0573	0.30	275.83
14	8.0613	0.29	173.49	8.0660	0.30	187.43	60	8.1402	0.30	82.80	8.0539	0.30	277.21
16	8.0558	0.33	148.10	8.0598	0.33	211.94	62	8.1496	0.31	81.47	8.0609	0.30	278.55
18	8.0423	0.30	137.29	8.0657	0.30	223.09	64	8.1001	0.32	80.14	8.0556	N/A	279.95
20	8.0601	0.29	129.35	8.0612	0.30	230.35	66	8.1008	0.30	78.82	8.0605	N/A	281.26
22	8.0766	0.29	123.89	8.0563	0.31	236.22	68	8.0960	0.30	77.41	8.0587	N/A	282.60
24	8.0506	0.32	119.13	8.0372	0.30	240.77	70	8.0906	N/A	76.11	8.0566	N/A	283.94
26	8.0460	0.31	115.40	8.0432	0.29	244.64	72	8.1190	N/A	74.74	8.0591	N/A	285.29
28	8.0662	0.31	112.07	8.0454	0.30	247.98	74	8.1252	N/A	73.34	8.0637	N/A	286.52
30	8.0388	0.30	108.98	8.0549	0.30	250.98	76	8.0876	N/A	71.96	N/A	N/A	N/A
32	8.0579	0.29	106.45	8.0337	0.29	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0369	0.31	104.10	8.0472	0.29	256.01	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0545	0.34	101.92	8.0366	0.29	258.09	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0427	0.32	99.99	8.0634	0.29	260.20	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0981	0.29	97.95	8.0491	0.29	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1091	0.31	96.21	8.0578	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1085	0.31	94.52	8.0582	0.29	265.51	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

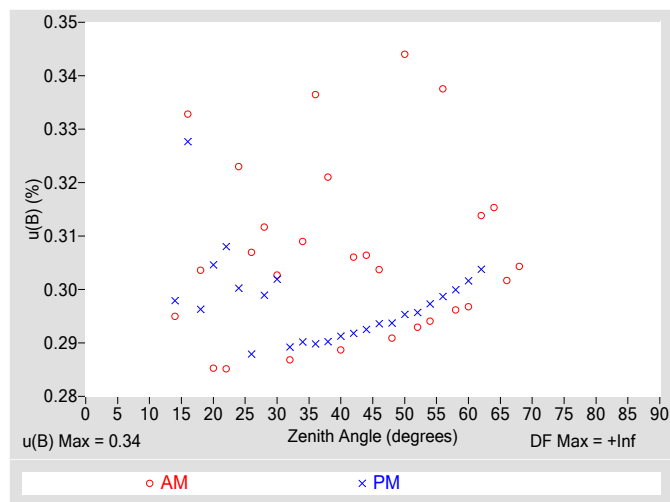


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.26
Combined Standard Uncertainty, $u(c)$ (%)	± 0.43
Effective degrees of freedom, $DF(c)$	6380
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.85
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

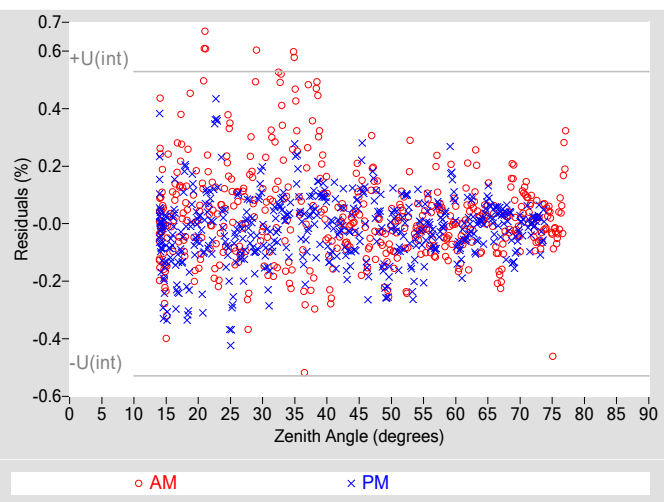


Table 4. Calibration Label Values

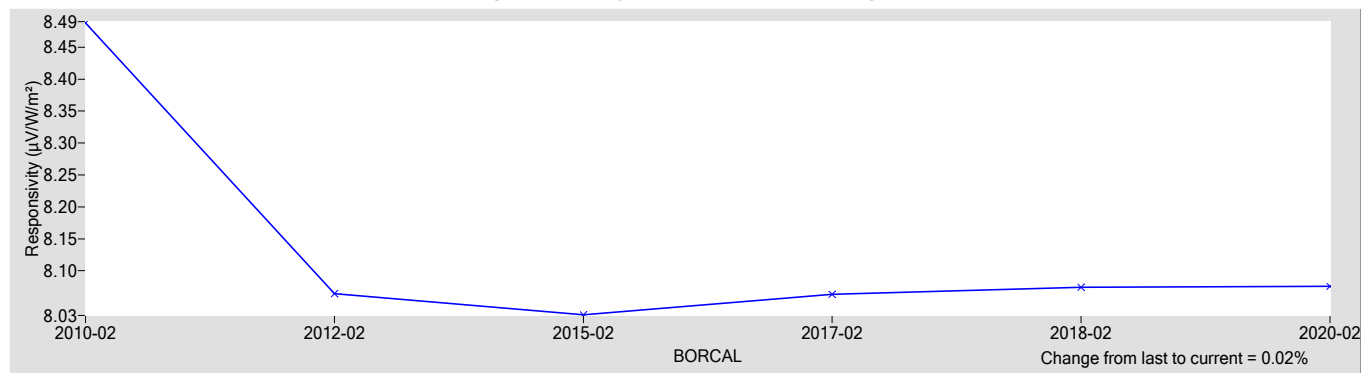
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.0758	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+0.80 / -0.52
Expanded Uncertainty, U (%)	+1.5 / -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).



Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 37167
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: AMF **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37167 Eppley 8-48

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

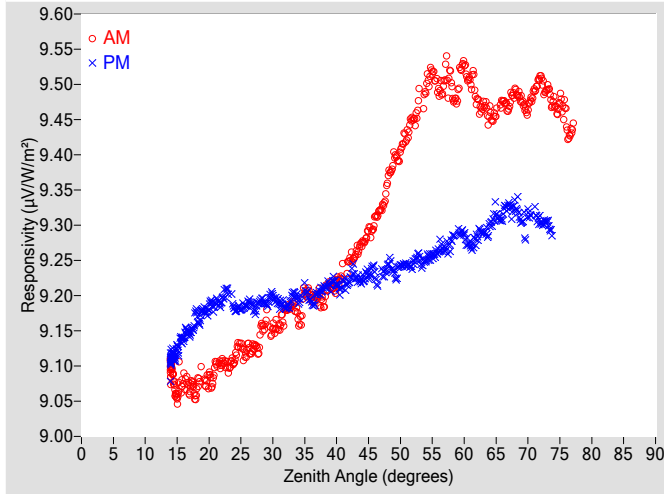


Figure 2. Responsivity vs Local Standard Time

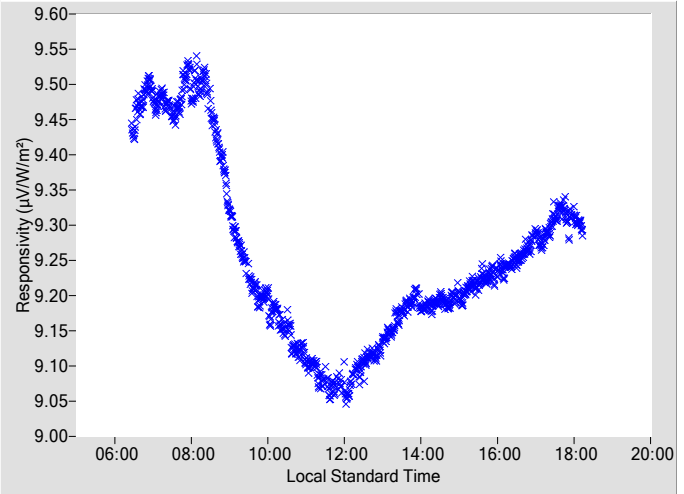


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith			AM			PM			Zenith			AM			PM		
Angle	R		$u(B)$	Azimuth		R	$u(B)$	Azimuth	Angle	R		$u(B)$	Azimuth		R	$u(B)$	Azimuth
(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)		\pm (%)	Angle		($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle	(deg.)	($\mu\text{V}/\text{W}/\text{m}^2$)		\pm (%)	Angle		($\mu\text{V}/\text{W}/\text{m}^2$)	\pm (%)	Angle
0	N/A		N/A	N/A		N/A	N/A	N/A	46	9.3063		0.35	92.92		9.2282	0.32	267.19
2	N/A		N/A	N/A		N/A	N/A	N/A	48	9.3619		0.31	91.37		9.2405	0.32	268.67
4	N/A		N/A	N/A		N/A	N/A	N/A	50	9.4009		0.34	89.87		9.2423	0.32	270.18
6	N/A		N/A	N/A		N/A	N/A	N/A	52	9.4507		0.39	88.41		9.2444	0.35	271.64
8	N/A		N/A	N/A		N/A	N/A	N/A	54	9.4957		0.35	86.96		9.2510	0.33	273.08
10	N/A		N/A	N/A		N/A	N/A	N/A	56	9.4930		0.35	85.57		9.2661	0.34	274.54
12	N/A		N/A	N/A		N/A	N/A	N/A	58	9.5037		0.36	84.20		9.2781	0.35	275.90
14	9.0964		0.31	174.07		9.1114	0.31	186.67	60	9.5263		0.37	82.79		9.2871	0.36	277.19
16	9.0775		0.33	148.13		9.1410	0.30	211.72	62	9.4782		0.41	81.46		9.2834	0.37	278.62
18	9.0619		0.30	137.33		9.1740	0.30	222.95	64	9.4550		0.37	80.13		9.2989	N/A	279.94
20	9.0842		0.29	129.57		9.1835	0.30	230.44	66	9.4747		0.41	78.79		9.3122	N/A	281.25
22	9.1036		0.30	123.85		9.1925	0.29	236.18	68	9.4882		0.40	77.48		9.3256	N/A	282.63
24	9.1089		0.32	119.20		9.1806	0.29	240.84	70	9.4653		N/A	76.10		9.3157	N/A	283.97
26	9.1239		0.30	115.37		9.1878	0.29	244.61	72	9.5076		N/A	74.72		9.3039	N/A	285.31
28	9.1410		0.31	112.04		9.1921	0.30	248.04	74	9.4719		N/A	73.37		9.2851	N/A	286.50
30	9.1499		0.32	109.11		9.1998	0.33	250.95	76	9.4457		N/A	71.95		N/A	N/A	N/A
32	9.1801		0.32	106.35		9.1828	0.32	253.56	78	N/A		N/A	N/A		N/A	N/A	N/A
34	9.1682		0.31	104.14		9.1946	0.30	255.98	80	N/A		N/A	N/A		N/A	N/A	N/A
36	9.1975		0.30	101.87		9.1902	0.30	258.19	82	N/A		N/A	N/A		N/A	N/A	N/A
38	9.1914		0.32	99.91		9.2109	0.30	260.18	84	N/A		N/A	N/A		N/A	N/A	N/A
40	9.2155		0.32	98.04		9.2167	0.31	262.04	86	N/A		N/A	N/A		N/A	N/A	N/A
42	9.2498		0.32	96.22		9.2213	0.35	263.83	88	N/A		N/A	N/A		N/A	N/A	N/A
44	9.2742		0.31	94.55		9.2218	0.35	265.49	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

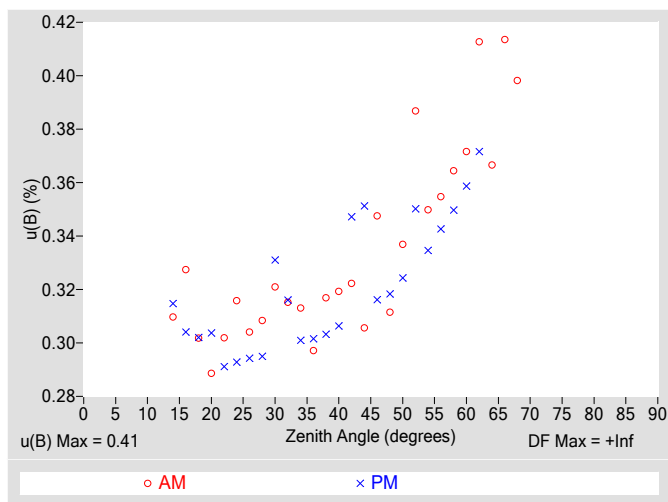


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.19
Combined Standard Uncertainty, $u(c)$ (%)	± 0.46
Effective degrees of freedom, $DF(c)$	28596
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.89
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

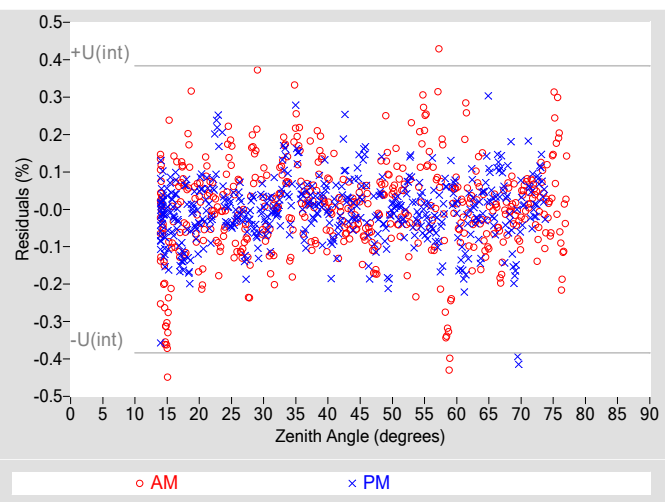


Table 4. Calibration Label Values

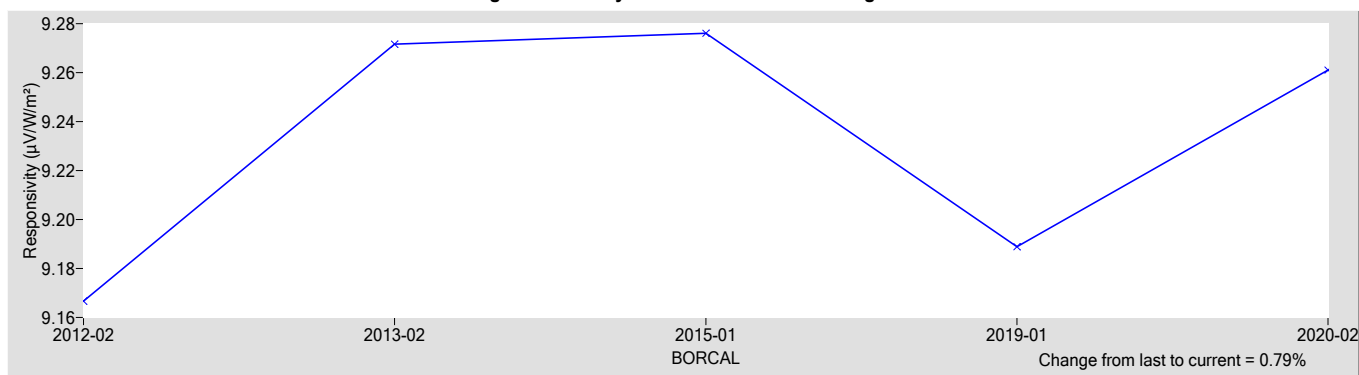
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.2610	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+2.9 / -1.2
Expanded Uncertainty, U (%)	+3.6 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: NSA
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 37288E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37288E6 Eppley NIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

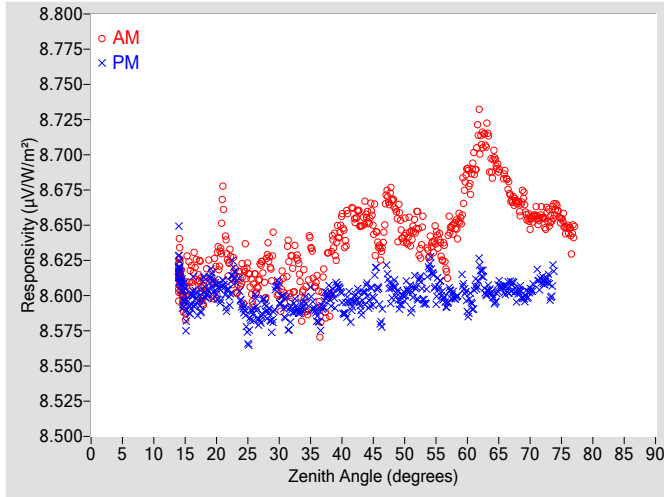


Figure 2. Responsivity vs Local Standard Time

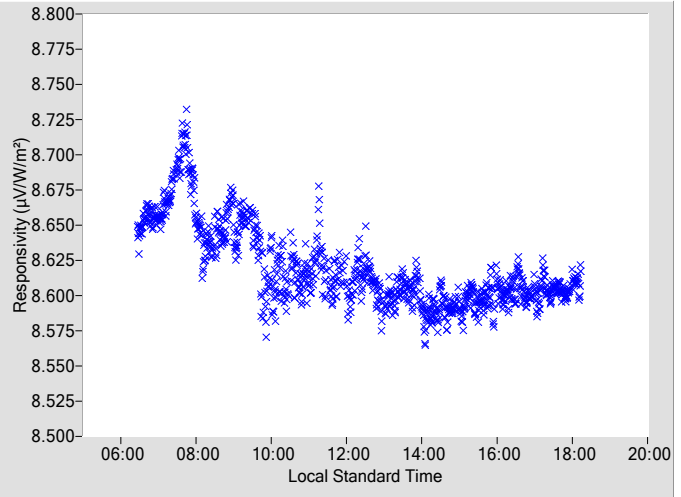


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6333	0.30	92.94	8.5934	0.29	267.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6703	0.29	91.34	8.6024	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6449	0.34	89.84	8.6019	0.30	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6537	0.29	88.38	8.6034	0.30	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6328	0.29	86.97	8.6216	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6306	0.34	85.59	8.6017	0.30	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6494	0.30	84.22	8.5992	0.30	275.83
14	8.6171	0.29	173.41	8.6157	0.30	187.43	60	8.6866	0.30	82.80	8.5921	0.30	277.21
16	8.6138	0.33	148.10	8.5980	0.33	211.94	62	8.7135	0.31	81.47	8.6188	0.30	278.55
18	8.6010	0.30	137.29	8.6060	0.30	223.09	64	8.6936	0.32	80.14	8.5989	N/A	279.95
20	8.6217	0.29	129.35	8.6057	0.30	230.35	66	8.6853	0.30	78.82	8.6046	N/A	281.26
22	8.6244	0.29	123.89	8.6019	0.31	236.22	68	8.6648	0.30	77.41	8.6016	N/A	282.60
24	8.6091	0.32	119.13	8.5939	0.30	240.77	70	8.6535	N/A	76.11	8.6036	N/A	283.94
26	8.6050	0.31	115.40	8.5919	0.29	244.64	72	8.6568	N/A	74.74	8.6105	N/A	285.29
28	8.6179	0.31	112.07	8.5894	0.30	247.98	74	8.6625	N/A	73.34	8.6174	N/A	286.52
30	8.5992	0.30	108.98	8.5999	0.30	250.98	76	8.6479	N/A	71.96	N/A	N/A	N/A
32	8.6149	0.29	106.45	8.5879	0.29	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.6030	0.31	104.10	8.5943	0.29	256.01	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6083	0.34	101.92	8.5851	0.29	258.09	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6092	0.31	99.93	8.5999	0.29	260.20	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6516	0.29	97.95	8.5947	0.29	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6559	0.31	96.21	8.5976	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6563	0.31	94.52	8.6020	0.29	265.51	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

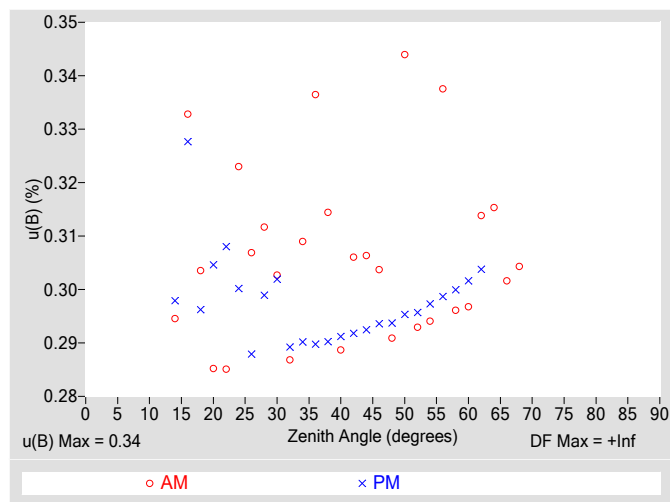


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.21
Combined Standard Uncertainty, $u(c)$ (%)	± 0.40
Effective degrees of freedom, $DF(c)$	11846
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.79
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

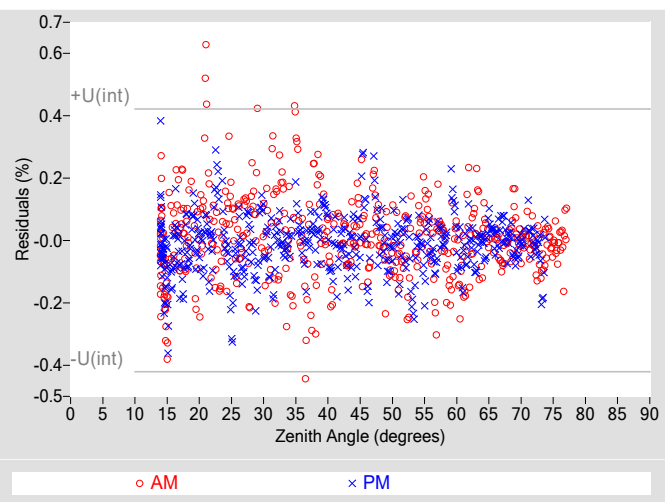


Table 4. Calibration Label Values

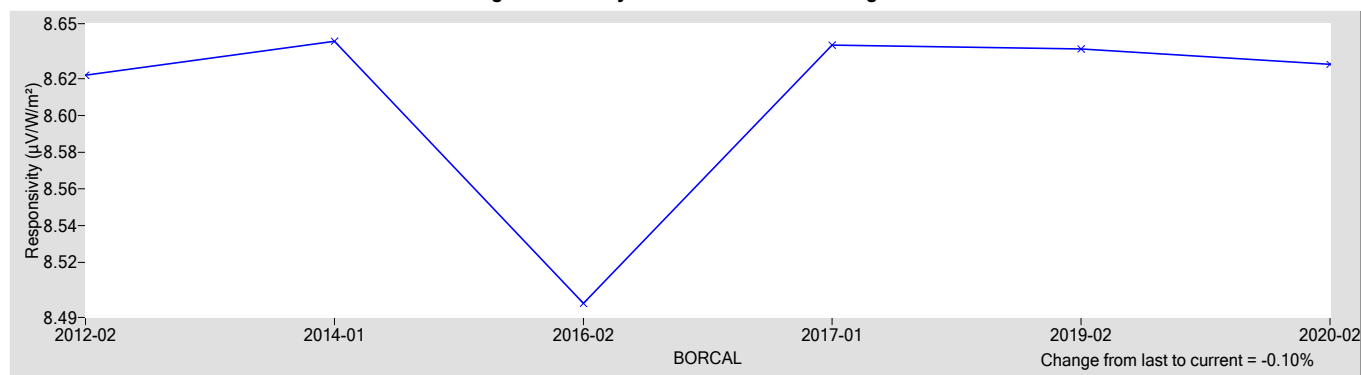
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.6279	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+0.68 / -0.50
Expanded Uncertainty, U (%)	+1.4 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 37301F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: AMF **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37301F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

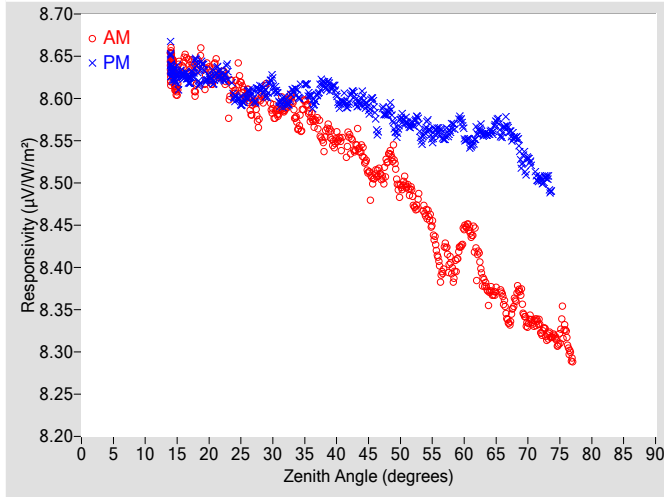


Figure 2. Responsivity vs Local Standard Time

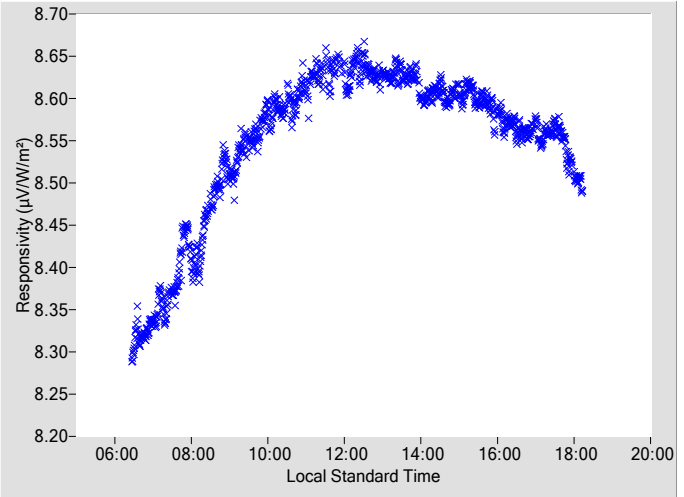


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5086	0.34	92.87	8.5818	0.35	267.14
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5291	0.35	91.32	8.5840	0.35	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4930	0.39	89.82	8.5756	0.36	270.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4786	0.36	88.36	8.5707	0.39	271.68
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4627	0.37	86.96	8.5672	0.38	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4036	0.40	85.53	8.5615	0.39	274.49
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3986	0.41	84.16	8.5654	0.40	275.86
14	8.6413	0.32	173.53	8.6350	0.32	187.56	60	8.4434	0.39	82.83	8.5569	0.42	277.23
16	8.6440	0.34	147.99	8.6269	0.32	211.71	62	8.4177	0.42	81.50	8.5594	0.46	278.57
18	8.6209	0.33	137.21	8.6378	0.32	222.82	64	8.3693	0.44	80.17	8.5596	N/A	279.89
20	8.6330	0.33	129.44	8.6248	0.34	230.38	66	8.3669	0.43	78.83	8.5605	N/A	281.29
22	8.6287	0.32	123.98	8.6263	0.34	236.04	68	8.3617	0.49	77.44	8.5537	N/A	282.59
24	8.6105	0.32	119.20	8.6015	0.33	240.72	70	8.3334	N/A	76.14	8.5282	N/A	283.97
26	8.6050	0.33	115.36	8.6062	0.33	244.70	72	8.3272	N/A	74.76	8.5044	N/A	285.31
28	8.5907	0.34	112.03	8.6116	0.31	247.94	74	8.3184	N/A	73.37	N/A	N/A	N/A
30	8.5852	0.31	109.11	8.6175	0.32	250.95	76	8.3216	N/A	71.99	N/A	N/A	N/A
32	8.5891	0.35	106.49	8.5956	0.35	253.63	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5694	0.35	104.07	8.6031	0.32	255.91	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5784	0.32	101.93	8.5990	0.32	258.12	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5504	0.34	99.85	8.6172	0.34	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5519	0.36	97.98	8.6009	0.33	262.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5518	0.37	96.16	8.5996	0.36	263.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5370	0.35	94.49	8.6001	0.38	265.54	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

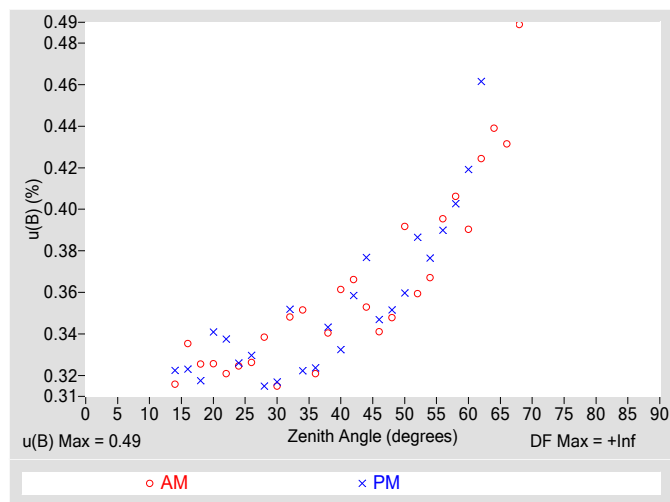


Figure 4. Residuals from Spline Interpolation

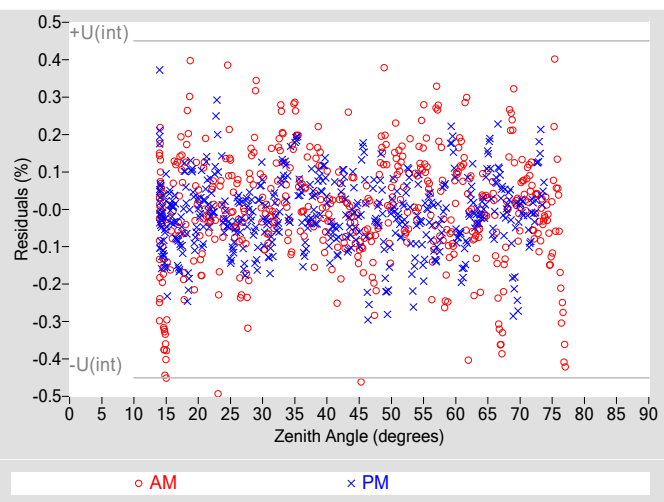


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.49
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	29181
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

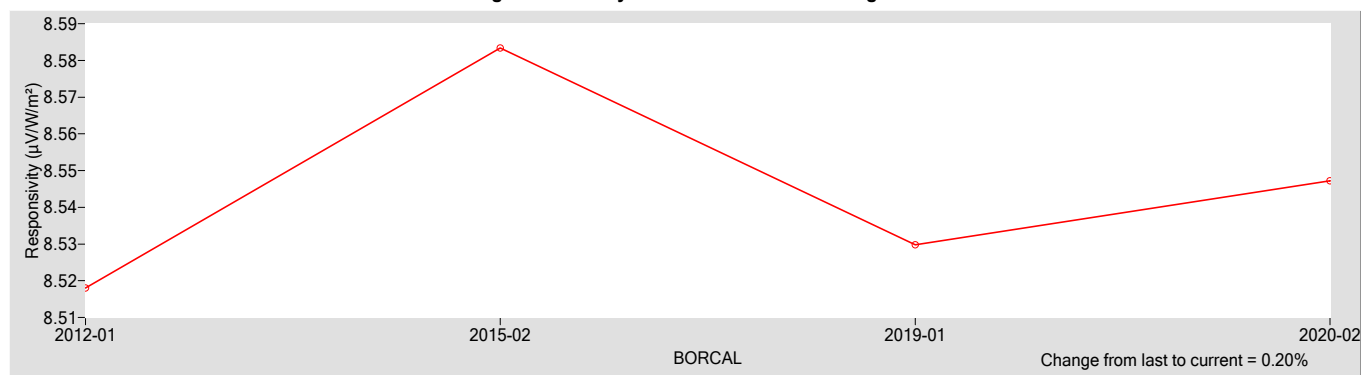
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.5472	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.82
Offset Uncertainty, $U(off)$ (%)	$+0.82 / -1.7$
Expanded Uncertainty, U (%)	$+1.6 / -2.6$
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 37315F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: NSA **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37315F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

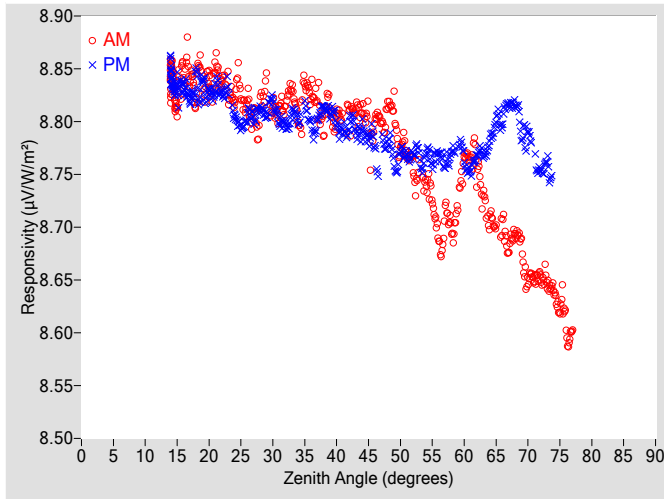


Figure 2. Responsivity vs Local Standard Time

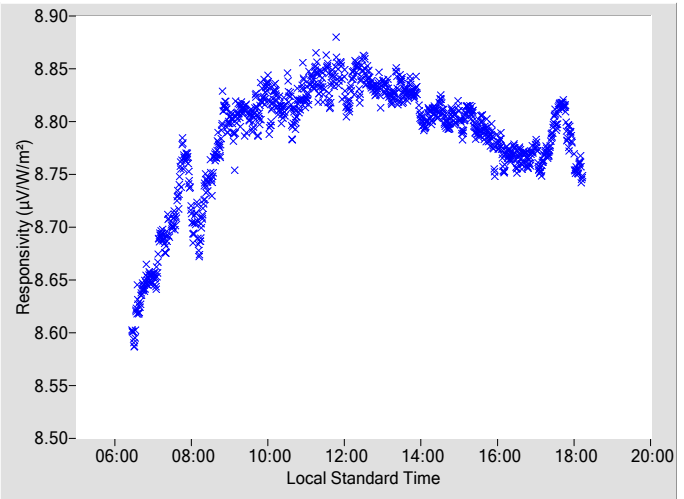


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7999	0.38	92.88	8.7736	0.36	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8149	0.35	91.33	8.7800	0.35	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7729	0.39	89.83	8.7725	0.36	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7552	0.40	88.37	8.7683	0.36	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7409	0.41	86.91	8.7707	0.37	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6881	0.44	85.54	8.7686	0.39	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6977	0.40	84.16	8.7710	0.40	275.86
14	8.8439	0.33	173.24	8.8437	0.33	187.33	60	8.7606	0.41	82.83	8.7634	0.42	277.24
16	8.8470	0.34	148.32	8.8318	0.31	211.51	62	8.7592	0.45	81.50	8.7679	0.43	278.58
18	8.8264	0.32	137.24	8.8394	0.32	223.22	64	8.7078	0.45	80.13	8.7814	N/A	279.90
20	8.8402	0.33	129.69	8.8290	0.31	230.31	66	8.7020	0.49	78.83	8.8021	N/A	281.29
22	8.8383	0.31	123.99	8.8268	0.32	236.06	68	8.6943	0.45	77.44	8.8160	N/A	282.59
24	8.8208	0.33	119.32	8.8054	0.33	240.73	70	8.6485	N/A	76.10	8.7904	N/A	283.97
26	8.8203	0.36	115.37	8.8059	0.31	244.61	72	8.6525	N/A	74.77	8.7540	N/A	285.32
28	8.8097	0.34	112.04	8.8113	0.33	247.96	74	8.6411	N/A	73.37	N/A	N/A	N/A
30	8.8119	0.35	109.12	8.8175	0.32	250.96	76	8.6052	N/A	71.99	N/A	N/A	N/A
32	8.8138	0.34	106.53	8.7963	0.32	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8045	0.32	104.07	8.8006	0.32	255.92	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8256	0.34	101.94	8.7968	0.32	258.13	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7997	0.36	99.85	8.8136	0.34	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8050	0.33	97.99	8.7975	0.33	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8074	0.37	96.17	8.7974	0.33	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8112	0.33	94.50	8.7921	0.34	265.55	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

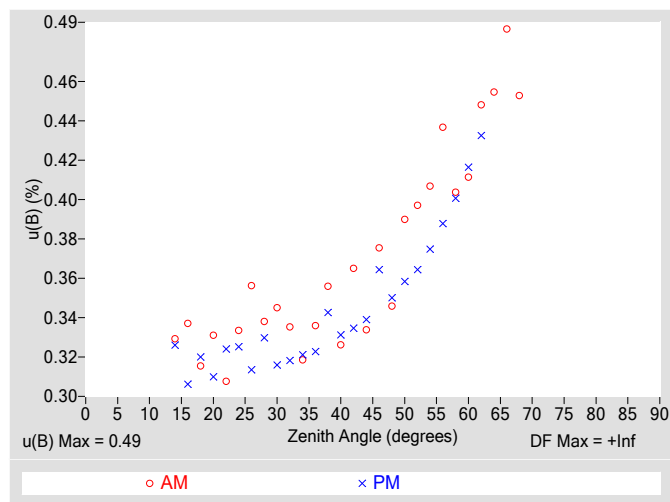


Figure 4. Residuals from Spline Interpolation

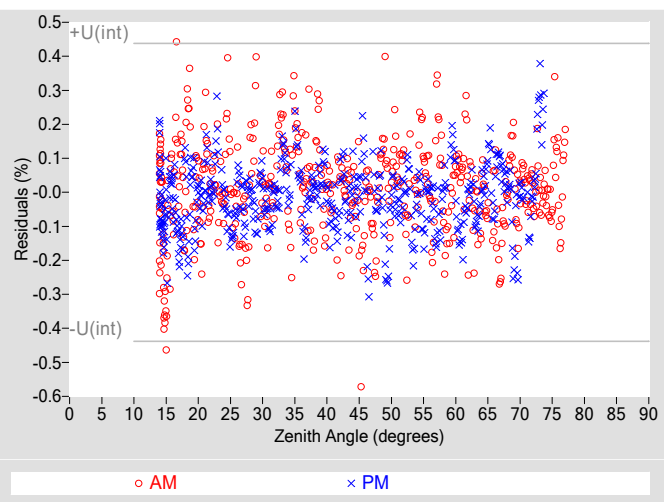


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.49
Type-A Interpolating Function, $u(int)$ (%)	± 0.22
Combined Standard Uncertainty, $u(c)$ (%)	± 0.53
Effective degrees of freedom, $DF(c)$	31590
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.0
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

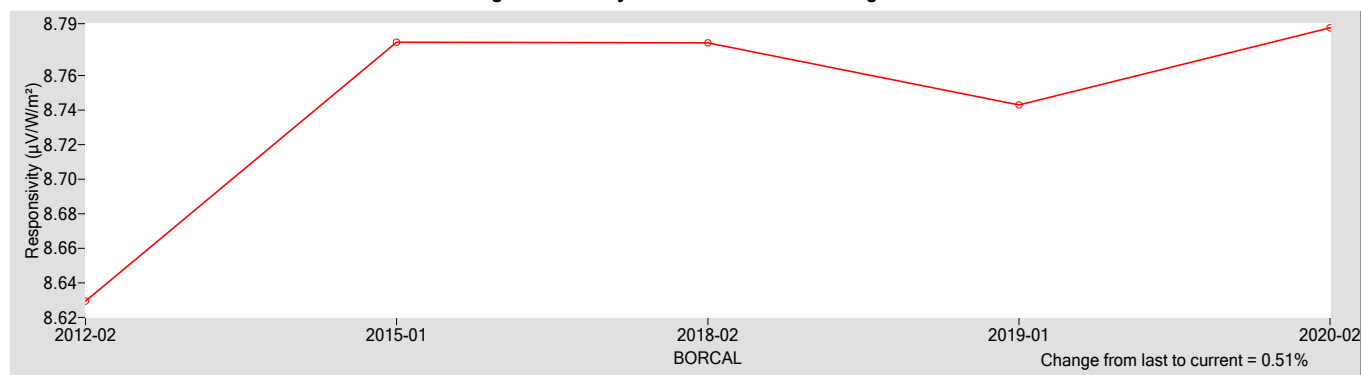
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.7876	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.86
Offset Uncertainty, $U(off)$ (%)	+0.43 / -1.1
Expanded Uncertainty, U (%)	+1.3 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure*. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: PSP **Serial Number:** 37319F3
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: AMF **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37319F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I \quad [1]$$

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

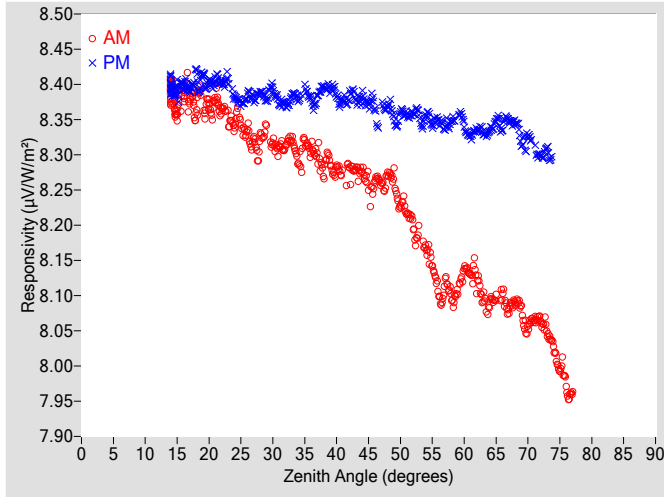


Figure 2. Responsivity vs Local Standard Time

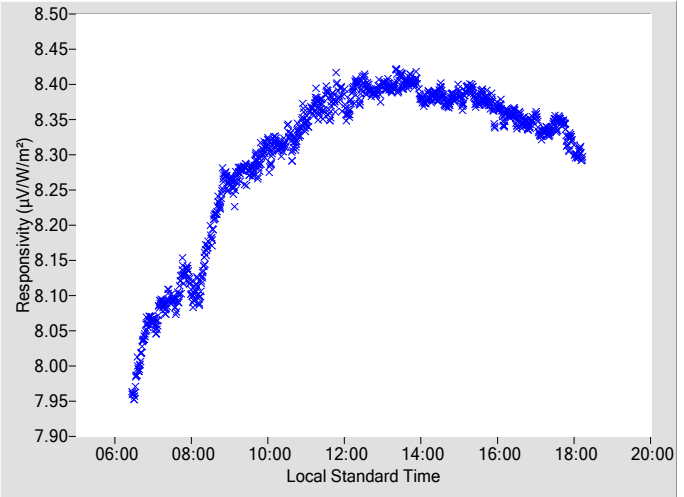


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2621	0.38	92.88	8.3622	0.37	267.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2721	0.35	91.33	8.3691	0.35	268.72
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2270	0.39	89.83	8.3613	0.36	270.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1977	0.40	88.37	8.3578	0.37	271.69
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1653	0.41	86.91	8.3568	0.38	273.12
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1025	0.44	85.54	8.3481	0.39	274.50
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0970	0.41	84.16	8.3484	0.41	275.86
14	8.3937	0.33	173.24	8.3963	0.33	187.33	60	8.1346	0.42	82.83	8.3403	0.42	277.24
16	8.3879	0.34	148.32	8.3979	0.31	211.51	62	8.1237	0.45	81.50	8.3347	0.44	278.58
18	8.3628	0.32	137.24	8.4116	0.32	223.22	64	8.0882	0.46	80.13	8.3346	N/A	279.90
20	8.3722	0.33	129.69	8.4037	0.31	230.31	66	8.1015	0.49	78.83	8.3407	N/A	281.29
22	8.3633	0.31	123.99	8.4030	0.33	236.06	68	8.0912	0.46	77.44	8.3456	N/A	282.59
24	8.3422	0.34	119.32	8.3821	0.33	240.73	70	8.0539	N/A	76.10	8.3269	N/A	283.97
26	8.3351	0.36	115.37	8.3844	0.32	244.61	72	8.0642	N/A	74.77	8.2988	N/A	285.32
28	8.3166	0.34	112.04	8.3873	0.33	247.96	74	8.0275	N/A	73.37	N/A	N/A	N/A
30	8.3157	0.35	109.12	8.3924	0.32	250.96	76	7.9723	N/A	71.99	N/A	N/A	N/A
32	8.3101	0.34	106.53	8.3712	0.32	253.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.2926	0.32	104.07	8.3790	0.32	255.92	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3069	0.34	101.94	8.3775	0.32	258.13	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2790	0.36	99.85	8.3960	0.34	260.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2796	0.33	97.99	8.3830	0.33	262.05	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2786	0.37	96.17	8.3833	0.34	263.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2773	0.34	94.50	8.3813	0.34	265.55	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

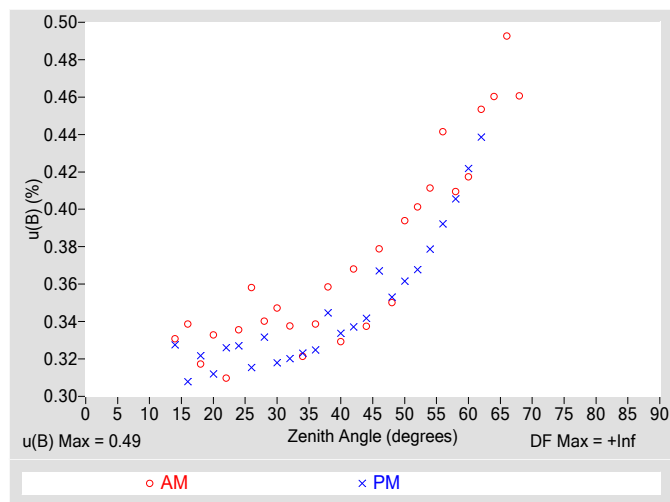


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.49
Type-A Interpolating Function, $u(int)$ (%)	± 0.23
Combined Standard Uncertainty, $u(c)$ (%)	± 0.54
Effective degrees of freedom, $DF(c)$	28694
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.1
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

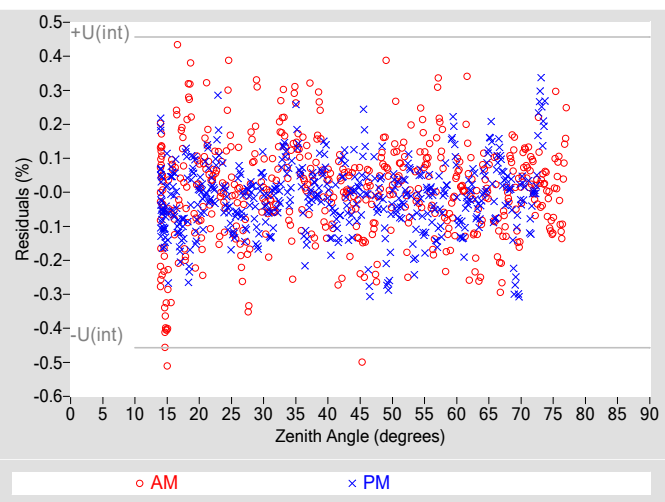


Table 4. Calibration Label Values

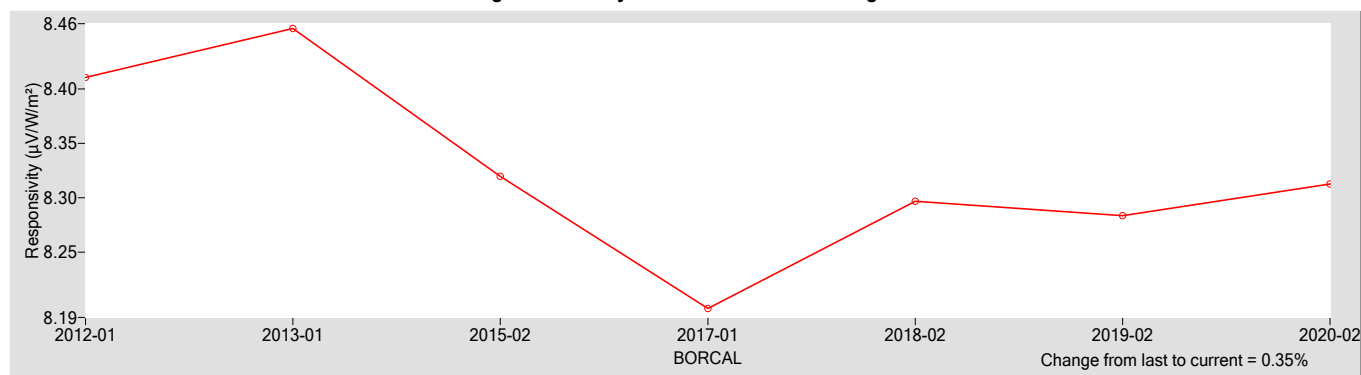
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.3126	0.60000

† R_{net} determination date: Estimated

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.87
Offset Uncertainty, $U(off)$ (%)	+1.0 / -2.6
Expanded Uncertainty, U (%)	+1.9 / -3.5
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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: NIP
Calibration Date: 6/5/2020
Customer: AMF
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 37362E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37362E6 Eppley NIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

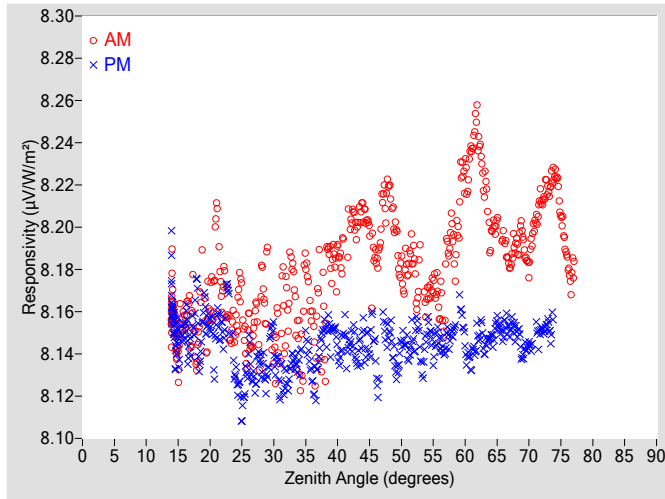


Figure 2. Responsivity vs Local Standard Time

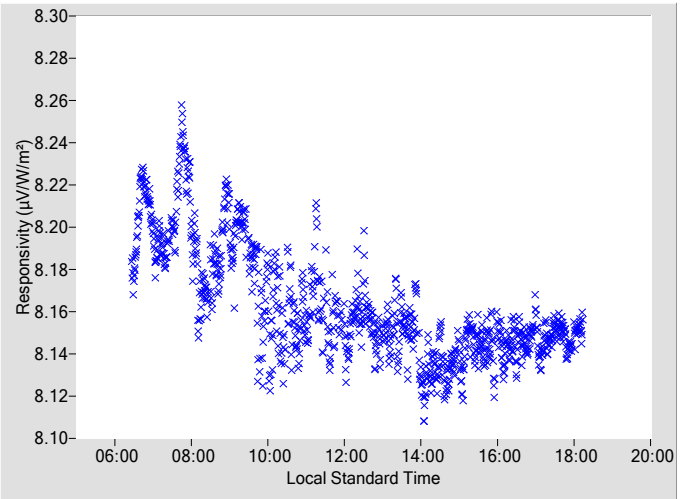


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1855	0.30	92.94	8.1367	0.29	267.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2204	0.29	91.34	8.1490	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1797	0.34	89.84	8.1454	0.30	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1842	0.29	88.38	8.1453	0.30	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1651	0.29	86.97	8.1512	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1638	0.34	85.59	8.1457	0.30	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1991	0.30	84.22	8.1500	0.30	275.83
14	8.1594	0.29	173.49	8.1617	0.30	187.43	60	8.2238	0.30	82.80	8.1442	0.30	277.21
16	8.1549	0.33	148.10	8.1539	0.33	211.94	62	8.2450	0.31	81.47	8.1479	0.30	278.55
18	8.1403	0.30	137.29	8.1579	0.30	223.09	64	8.1951	0.32	80.14	8.1472	N/A	279.95
20	8.1680	0.29	129.35	8.1553	0.30	230.35	66	8.1945	0.30	78.82	8.1513	N/A	281.26
22	8.1716	0.29	123.89	8.1503	0.31	236.22	68	8.1908	0.30	77.41	8.1507	N/A	282.60
24	8.1514	0.32	119.13	8.1294	0.30	240.77	70	8.1833	N/A	76.11	8.1442	N/A	283.94
26	8.1468	0.31	115.40	8.1386	0.29	244.64	72	8.2131	N/A	74.74	8.1514	N/A	285.29
28	8.1604	0.31	112.07	8.1345	0.30	247.98	74	8.2250	N/A	73.34	8.1562	N/A	286.52
30	8.1384	0.30	108.98	8.1418	0.30	250.98	76	8.1843	N/A	71.96	N/A	N/A	N/A
32	8.1607	0.29	106.45	8.1260	0.29	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1435	0.31	104.10	8.1383	0.29	256.01	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1573	0.34	101.92	8.1280	0.29	258.09	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1520	0.31	99.93	8.1512	0.29	260.20	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1848	0.29	97.95	8.1407	0.29	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2033	0.31	96.21	8.1458	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2085	0.31	94.52	8.1475	0.29	265.51	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

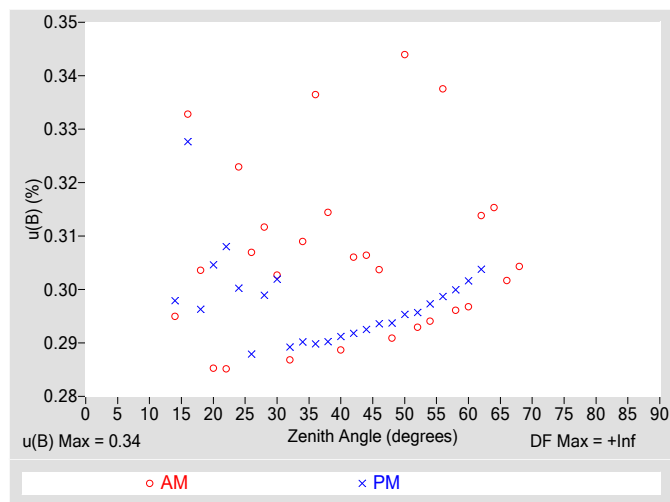


Figure 4. Residuals from Spline Interpolation

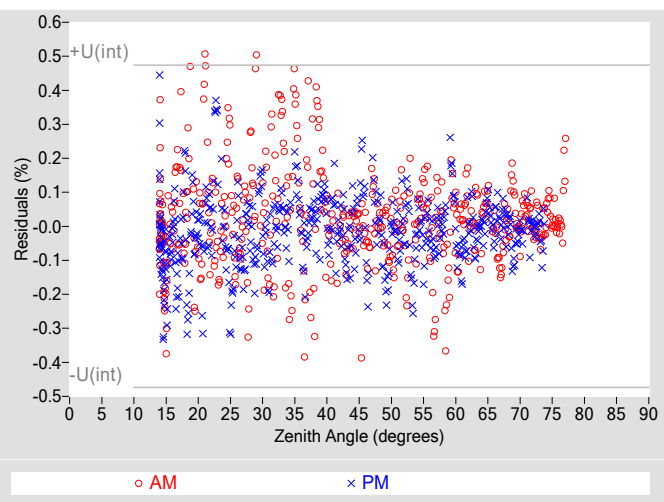


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.24
Combined Standard Uncertainty, $u(c)$ (%)	± 0.42
Effective degrees of freedom, $DF(c)$	8506
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.82
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

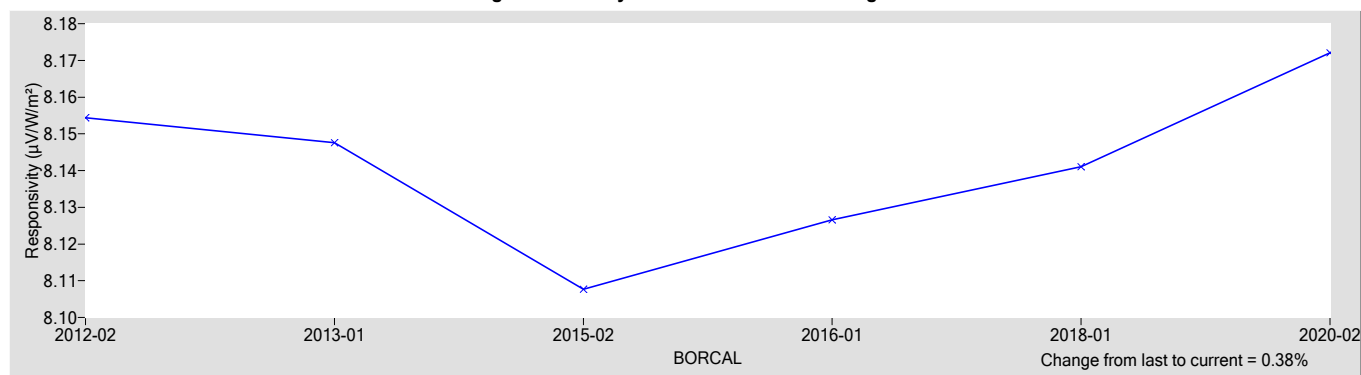
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.1720	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+0.63 / -0.56
Expanded Uncertainty, U (%)	+1.3 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated) **Manufacturer:** Eppley
Model: 8-48 **Serial Number:** 37394
Calibration Date: 6/5/2020 **Due Date:** 6/5/2021
Customer: AMF **Environmental Conditions:** see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37394 Eppley 8-48

The responsivity (R , $\mu\text{V/W/m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V/W/m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_c^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,

T_c = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

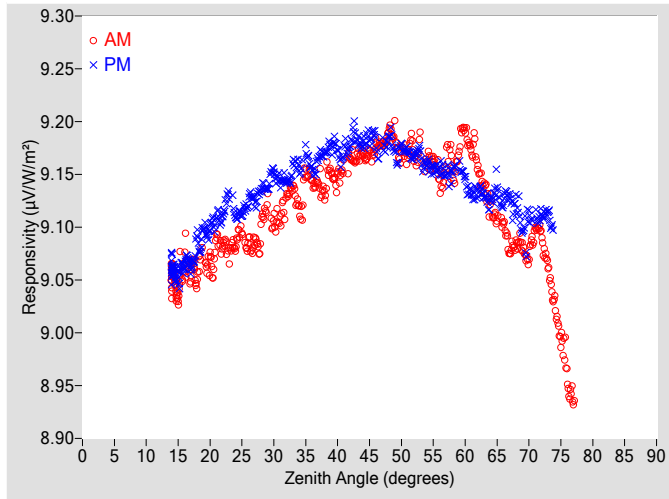


Figure 2. Responsivity vs Local Standard Time

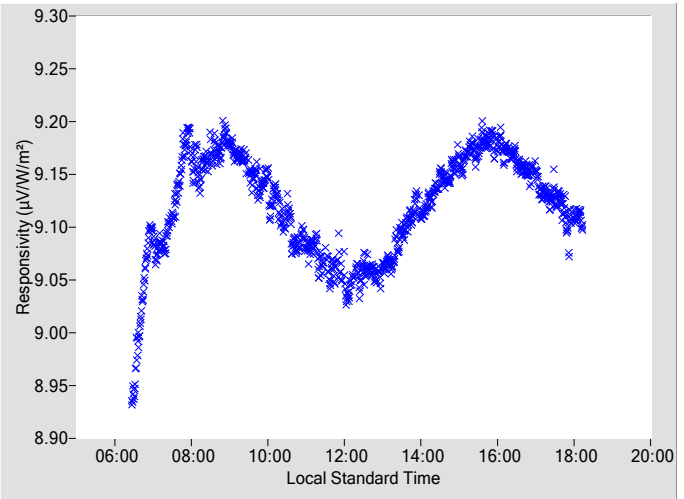


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V/W/m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V/W/m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V/W/m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V/W/m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1765	0.35	92.92	9.1775	0.32	267.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1900	0.31	91.37	9.1829	0.32	268.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1687	0.34	89.87	9.1767	0.32	270.18
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1703	0.39	88.41	9.1674	0.35	271.64
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1641	0.35	86.96	9.1605	0.33	273.08
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1450	0.35	85.57	9.1543	0.34	274.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1597	0.36	84.20	9.1518	0.35	275.90
14	9.0544	0.31	174.07	9.0611	0.32	186.48	60	9.1904	0.37	82.79	9.1463	0.36	277.19
16	9.0675	0.33	148.00	9.0643	0.30	211.72	62	9.1556	0.41	81.46	9.1323	0.37	278.62
18	9.0522	0.30	137.33	9.0885	0.30	222.95	64	9.1196	0.37	80.13	9.1246	N/A	279.94
20	9.0683	0.29	129.57	9.0987	0.30	230.44	66	9.1020	0.41	78.79	9.1234	N/A	281.25
22	9.0818	0.30	123.85	9.1116	0.29	236.18	68	9.0823	0.40	77.48	9.1196	N/A	282.63
24	9.0828	0.32	119.20	9.1097	0.29	240.84	70	9.0737	N/A	76.10	9.1107	N/A	283.93
26	9.0846	0.30	115.37	9.1234	0.29	244.61	72	9.0881	N/A	74.72	9.1108	N/A	285.31
28	9.0969	0.31	112.04	9.1361	0.30	248.04	74	9.0269	N/A	73.37	9.0972	N/A	286.50
30	9.1021	0.32	109.11	9.1519	0.33	250.95	76	8.9542	N/A	71.95	N/A	N/A	N/A
32	9.1299	0.32	106.35	9.1432	0.32	253.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.1170	0.31	104.14	9.1561	0.30	255.98	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1424	0.30	101.87	9.1540	0.30	258.19	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1330	0.32	99.91	9.1701	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1463	0.32	98.04	9.1727	0.31	262.04	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1658	0.32	96.22	9.1789	0.35	263.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1689	0.31	94.55	9.1788	0.35	265.49	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

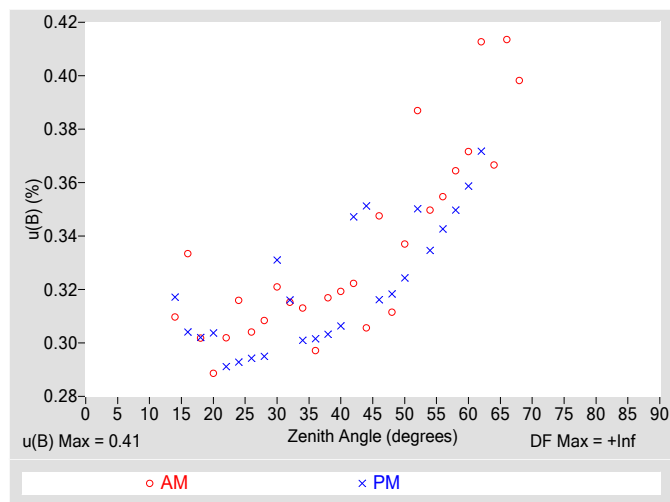


Figure 4. Residuals from Spline Interpolation

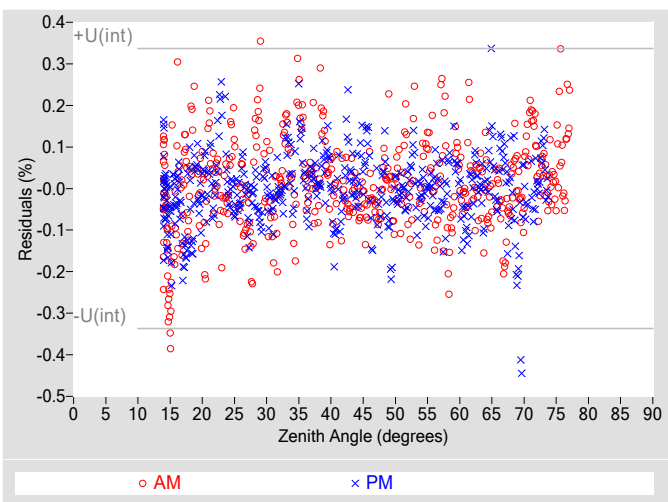


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.41
Type-A Interpolating Function, $u(int)$ (%)	± 0.17
Combined Standard Uncertainty, $u(c)$ (%)	± 0.45
Effective degrees of freedom, $DF(c)$	44224
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.88
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

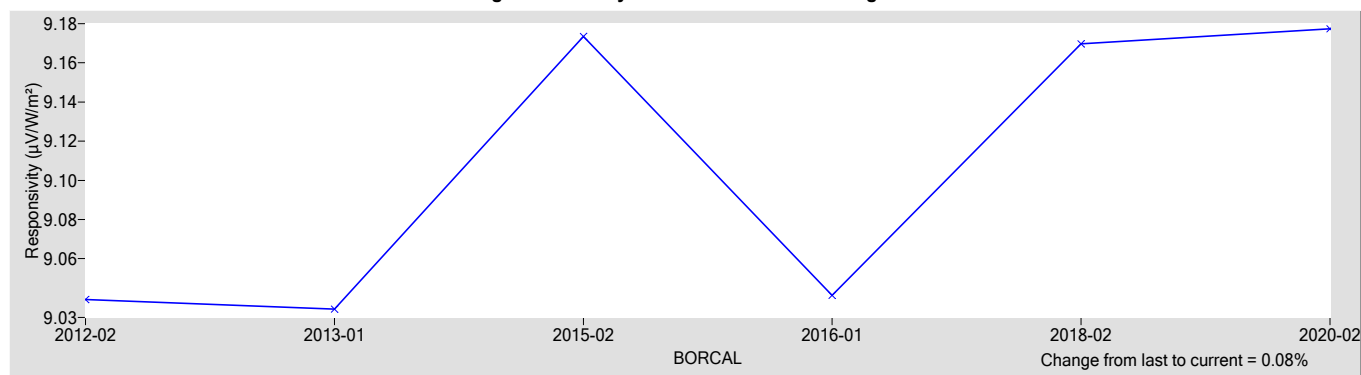
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.1773	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.76
Offset Uncertainty, $U(off)$ (%)	+0.14 / -0.82
Expanded Uncertainty, U (%)	+0.90 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." *Journal of Atmospheric and Oceanic Technology*. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1
- [2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." *Measure.* (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137
- [3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." *Solar Energy*. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003
- [4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.
- [5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." *Solar Energy*. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5
- [6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.
- [7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: sNIP
Serial Number: 37945E6
Calibration Date: 6/5/2020
Due Date: 6/5/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 6/5

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37945E6 Eppley sNIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I \quad [1]$$

where,

V = radiometer output voltage (microvolts),
 R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,
 W_{net} = effective net infrared measured by pyrgeometer (W/m^2),
 $= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$
 where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,
 T_{c} = case temperature of pyrgeometer (K).
 I = reference irradiance (W/m^2), beam (B) or global (G)
 where, $G = B * \text{COS}(Z) + D$,
 Z = zenith angle (degrees),
 D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

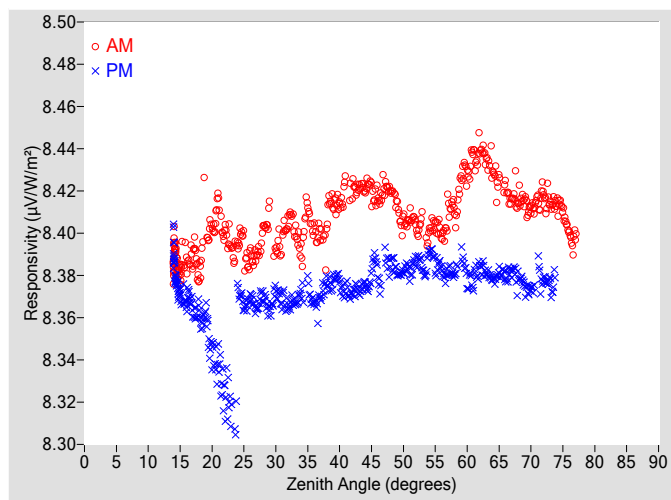


Figure 2. Responsivity vs Local Standard Time

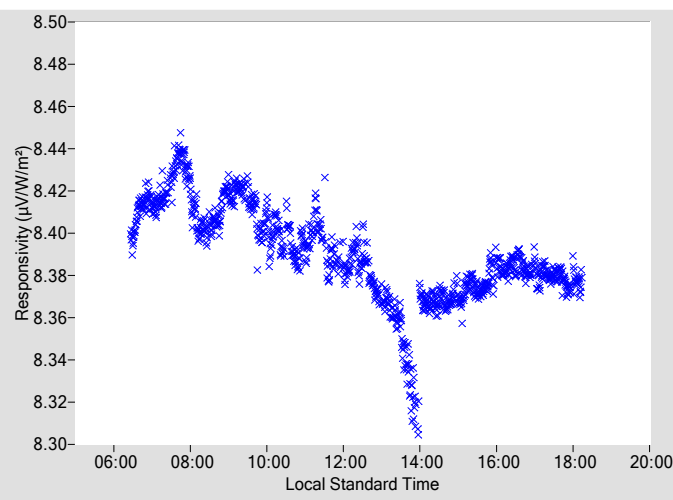


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM u(B) \pm (%)	Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM u(B) \pm (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4165	0.30	92.94	8.3809	0.29	267.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4202	0.29	91.34	8.3841	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4049	0.34	89.84	8.3821	0.30	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4029	0.29	88.38	8.3864	0.30	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3986	0.29	86.97	8.3903	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3995	0.34	85.59	8.3833	0.30	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4106	0.30	84.22	8.3804	0.30	275.83
14	8.3893	0.29	173.41	8.3869	0.30	186.97	60	8.4279	0.30	82.80	8.3771	0.30	277.21
16	8.3879	0.33	148.10	8.3686	0.33	211.94	62	8.4404	0.31	81.47	8.3836	0.30	278.55
18	8.3803	0.30	137.29	8.3618	0.30	223.09	64	8.4307	0.32	80.14	8.3778	N/A	279.95
20	8.4029	0.29	129.35	8.3439	0.30	230.35	66	8.4215	0.30	78.82	8.3795	N/A	281.26
22	8.4002	0.29	123.89	8.3235	0.31	236.22	68	8.4151	0.30	77.41	8.3773	N/A	282.60
24	8.3944	0.32	119.13	8.3599	0.30	240.82	70	8.4124	N/A	76.11	8.3743	N/A	283.94
26	8.3880	0.31	115.40	8.3692	0.29	244.64	72	8.4191	N/A	74.74	8.3777	N/A	285.29
28	8.4012	0.31	112.07	8.3697	0.30	247.98	74	8.4131	N/A	73.34	8.3789	N/A	286.52
30	8.3921	0.30	108.98	8.3712	0.30	250.98	76	8.4000	N/A	71.96	N/A	N/A	N/A
32	8.4065	0.29	106.45	8.3646	0.29	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3913	0.31	104.10	8.3716	0.29	256.01	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4013	0.34	101.92	8.3677	0.29	258.09	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4003	0.31	99.93	8.3758	0.29	260.20	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4138	0.29	97.95	8.3764	0.29	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4219	0.31	96.21	8.3722	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4200	0.31	94.52	8.3757	0.29	265.51	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

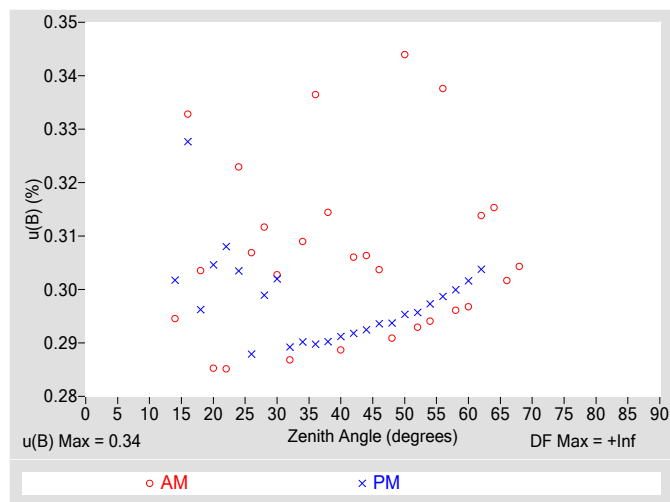


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.13
Combined Standard Uncertainty, $u(c)$ (%)	± 0.37
Effective degrees of freedom, $DF(c)$	62216
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.72
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Figure 4. Residuals from Spline Interpolation

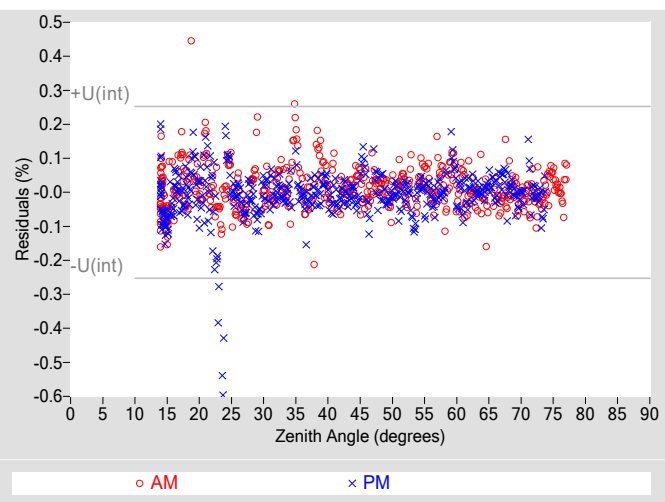


Table 4. Calibration Label Values

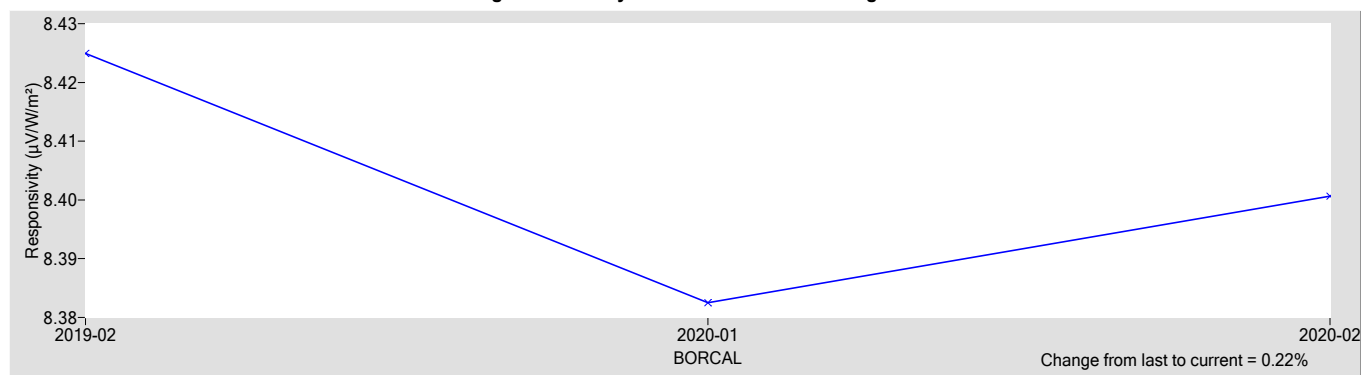
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.4007	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+0.32 / -0.43
Expanded Uncertainty, U (%)	+1.00 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory



Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Model: sNIP
Calibration Date: 6/5/2020
Customer: SGP
Test Dates: 6/5

Manufacturer: Eppley
Serial Number: 37947E6
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37947E6 Eppley sNIP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \cos(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

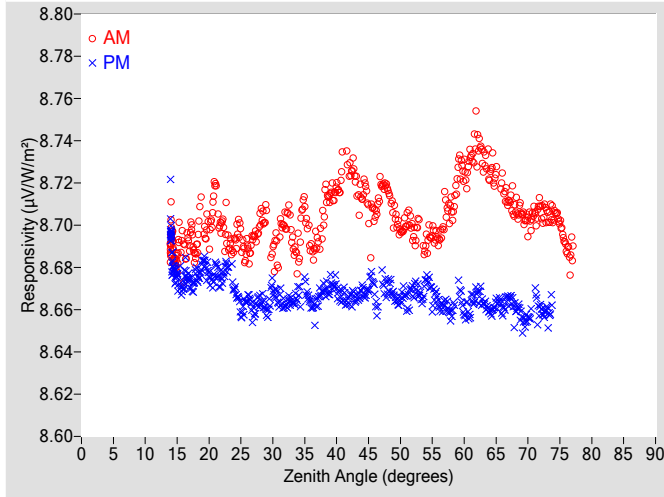


Figure 2. Responsivity vs Local Standard Time

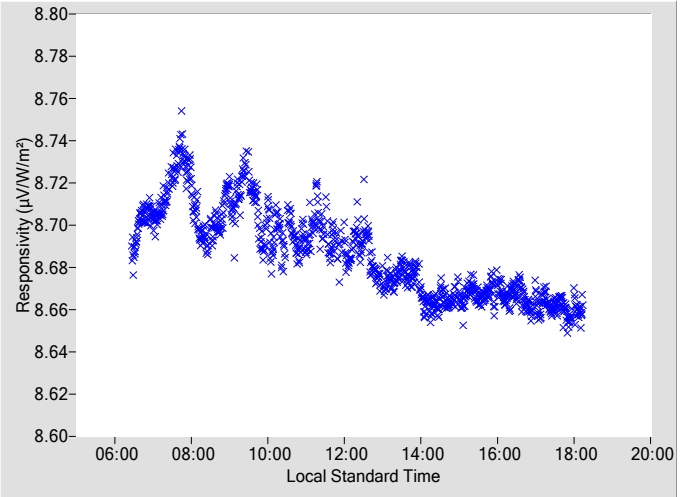


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7057	0.30	92.94	8.6674	0.29	267.11
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7171	0.29	91.34	8.6698	0.29	268.69
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6968	0.34	89.84	8.6649	0.30	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6968	0.29	88.38	8.6690	0.30	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6893	0.29	86.97	8.6740	0.30	273.09
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6931	0.34	85.59	8.6626	0.30	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7064	0.30	84.22	8.6579	0.30	275.83
14	8.6924	0.29	173.49	8.6913	0.30	187.43	60	8.7248	0.30	82.80	8.6581	0.30	277.21
16	8.6880	0.33	148.10	8.6723	0.32	211.70	62	8.7392	0.31	81.47	8.6679	0.30	278.55
18	8.6869	0.30	137.29	8.6765	0.30	223.09	64	8.7262	0.32	80.14	8.6586	N/A	279.95
20	8.6975	0.29	129.35	8.6770	0.30	230.35	66	8.7192	0.30	78.82	8.6601	N/A	281.26
22	8.7004	0.29	123.89	8.6748	0.31	236.22	68	8.7077	0.30	77.41	8.6592	N/A	282.60
24	8.6913	0.32	119.13	8.6692	0.30	240.77	70	8.7024	N/A	76.11	8.6562	N/A	283.94
26	8.6873	0.31	115.40	8.6651	0.29	244.64	72	8.7086	N/A	74.74	8.6602	N/A	285.29
28	8.7018	0.31	112.07	8.6639	0.30	247.98	74	8.7052	N/A	73.34	8.6621	N/A	286.52
30	8.6862	0.30	108.98	8.6697	0.30	250.98	76	8.6894	N/A	71.96	N/A	N/A	N/A
32	8.7017	0.29	106.45	8.6616	0.29	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.6865	0.31	104.10	8.6669	0.29	256.01	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6892	0.34	101.92	8.6629	0.29	258.09	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7042	0.31	99.93	8.6692	0.29	260.20	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7174	0.29	97.95	8.6703	0.29	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7262	0.31	96.21	8.6657	0.29	263.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7131	0.31	94.52	8.6693	0.29	265.51	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

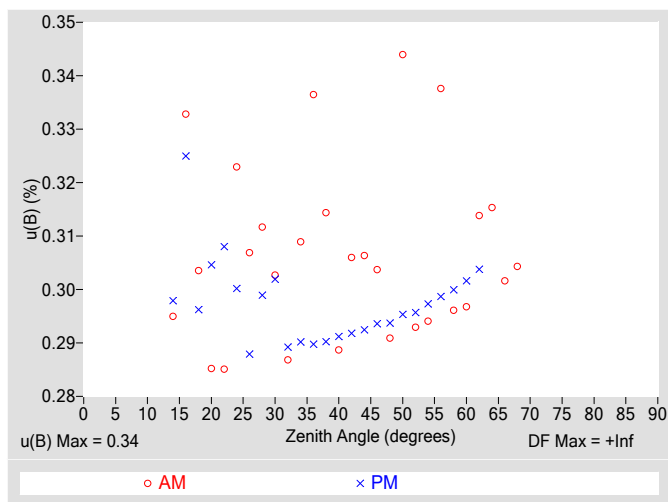


Figure 4. Residuals from Spline Interpolation

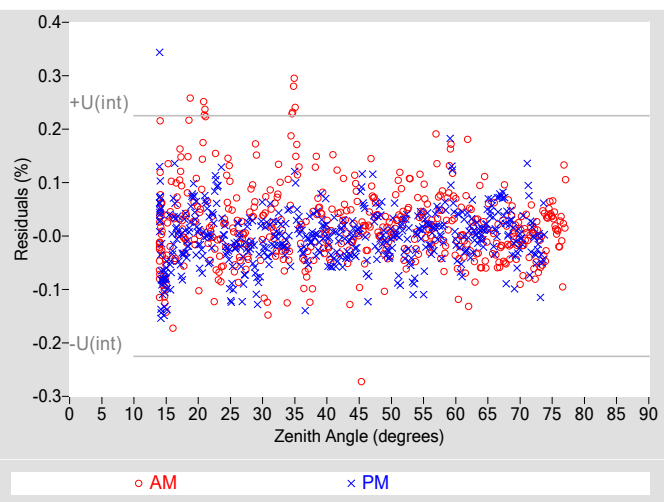


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, $u(B)$ (%)	± 0.34
Type-A Interpolating Function, $u(int)$ (%)	± 0.11
Combined Standard Uncertainty, $u(c)$ (%)	± 0.36
Effective degrees of freedom, $DF(c)$	94172
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.71
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

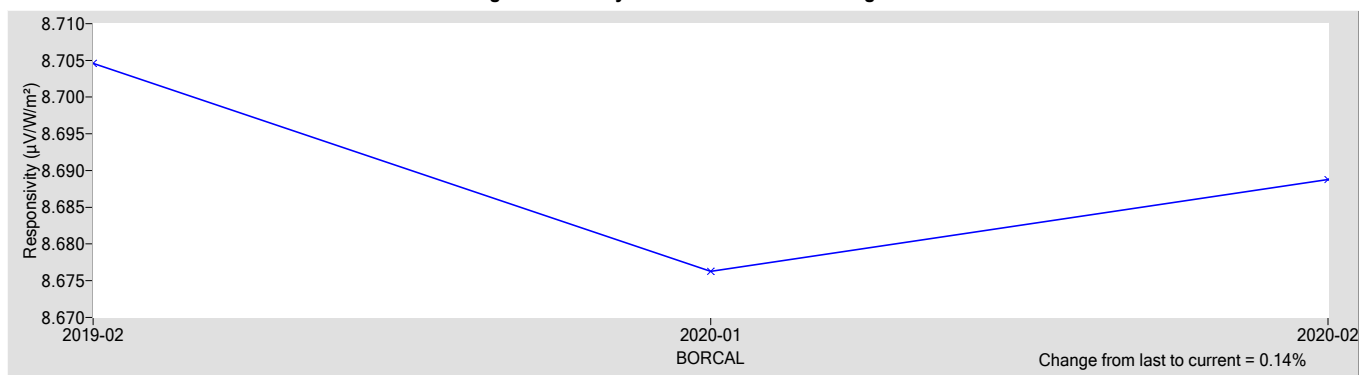
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
8.6888	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.67
Offset Uncertainty, $U(off)$ (%)	+0.43 / -0.36
Expanded Uncertainty, U (%)	+1.1 / -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).

Southern Great Plains Radiometer Calibration Facility



National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Silicon Pyranometer
Model: LI200
Calibration Date: 6/5/2020
Customer: Calibration System
Test Dates: 6/5

Manufacturer: Licor
Serial Number: PY22693
Due Date: 6/5/2021
Environmental Conditions: see page 4

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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°. Pyrhemometers are installed on solar trackers.

Calibrated by: Craig Webb

Peter Gotseff, Technical Manager

Date

For questions or comments, please contact the technical manager at:

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

PY22693 Licor LI200

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - R_{\text{net}} * W_{\text{net}}) / I$$

[1]

where,

V = radiometer output voltage (microvolts),

R_{net} = radiometer net infrared responsivity ($\mu\text{V}/\text{W}/\text{m}^2$), see Table 4,

W_{net} = effective net infrared measured by pyrgeometer (W/m^2),

$$= W_{\text{in}} - W_{\text{out}} = W_{\text{in}} - \sigma * T_{\text{c}}^4$$

where, W_{in} = incoming infrared (W/m^2), $\sigma = 5.6704\text{e-}8 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$,

T_{c} = case temperature of pyrgeometer (K).

I = reference irradiance (W/m^2), beam (B) or global (G)

where, $G = B * \text{COS}(Z) + D$,

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m^2).

Figure 1. Responsivity vs Zenith Angle

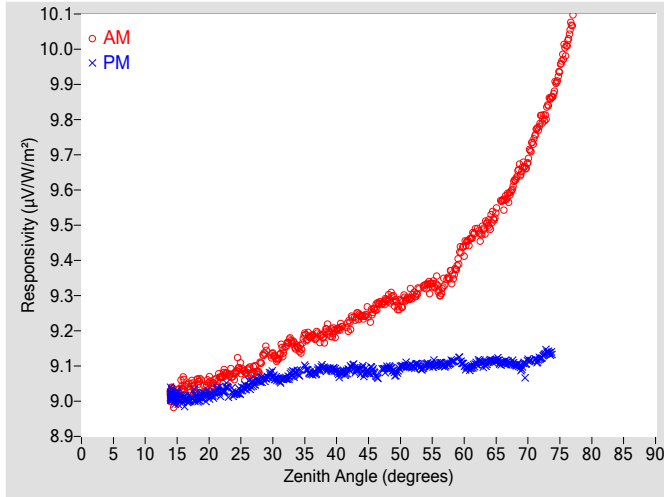


Figure 2. Responsivity vs Local Standard Time

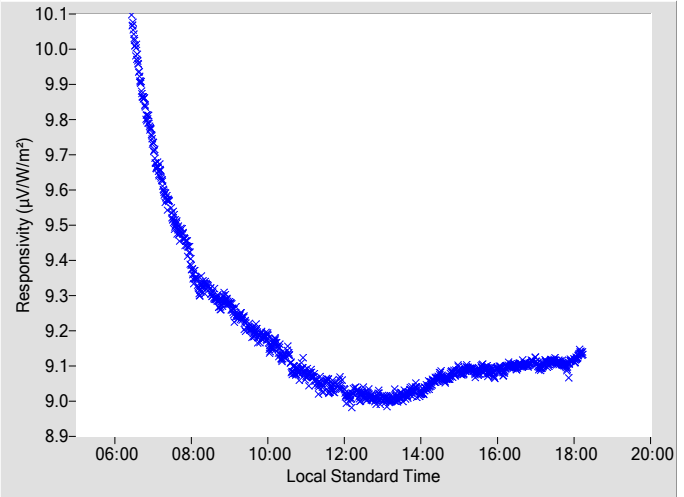


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, $u(B)$

Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle	Zenith Angle (deg.)	R ($\mu\text{V}/\text{W}/\text{m}^2$)	AM $u(B)$ (\pm %)	AM Azimuth Angle	R ($\mu\text{V}/\text{W}/\text{m}^2$)	PM $u(B)$ (\pm %)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2628	0.33	92.95	9.0792	0.32	267.12
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2904	0.31	91.35	9.0957	0.32	268.70
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2735	0.34	89.80	9.0971	0.32	270.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3004	0.35	88.34	9.0977	0.35	271.66
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3273	0.33	86.98	9.1042	0.33	273.10
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3134	0.33	85.55	9.1062	0.34	274.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3570	0.36	84.14	9.1112	0.35	275.84
14	9.0224	0.30	173.82	9.0162	0.30	187.37	60	9.4368	0.40	82.81	9.1004	0.36	277.22
16	9.0476	0.34	148.25	9.0083	0.31	211.43	62	9.4882	0.40	81.45	9.1085	0.37	278.55
18	9.0371	0.35	137.31	9.0094	0.30	222.92	64	9.5055	0.43	80.15	9.1154	N/A	279.96
20	9.0576	0.32	129.57	9.0182	0.29	230.37	66	9.5647	0.41	78.81	9.1082	N/A	281.27
22	9.0704	0.30	123.91	9.0256	0.31	236.31	68	9.6306	0.40	77.42	9.1032	N/A	282.57
24	9.0759	0.30	119.26	9.0198	0.31	240.78	70	9.6838	N/A	76.12	9.1141	N/A	283.95
26	9.0858	0.32	115.42	9.0430	0.29	244.66	72	9.7967	N/A	74.74	9.1223	N/A	285.29
28	9.0985	0.29	112.08	9.0585	0.29	247.99	74	9.8783	N/A	73.35	9.1326	N/A	286.53
30	9.1302	0.33	109.07	9.0711	0.33	250.99	76	10.006	N/A	71.97	N/A	N/A	N/A
32	9.1555	0.34	106.46	9.0648	0.30	253.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.1512	0.31	104.03	9.0800	0.30	256.02	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1835	0.33	101.90	9.0778	0.32	258.10	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1825	0.33	99.93	9.0948	0.30	260.18	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1997	0.30	97.95	9.0838	0.31	262.07	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2156	0.32	96.25	9.0933	0.33	263.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2400	0.31	94.52	9.0870	0.31	265.52	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

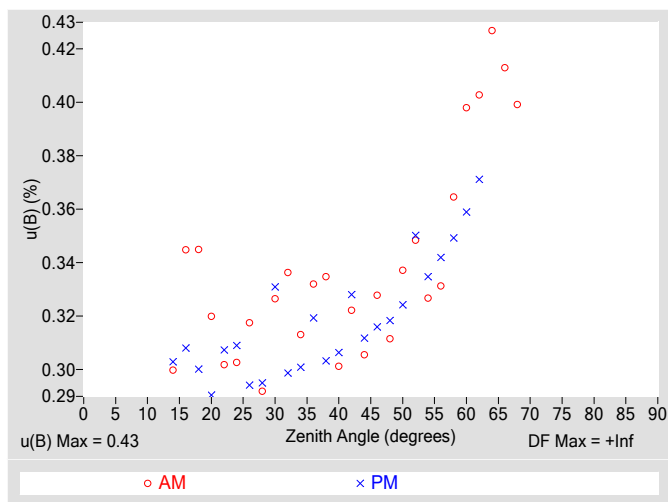


Figure 4. Residuals from Spline Interpolation

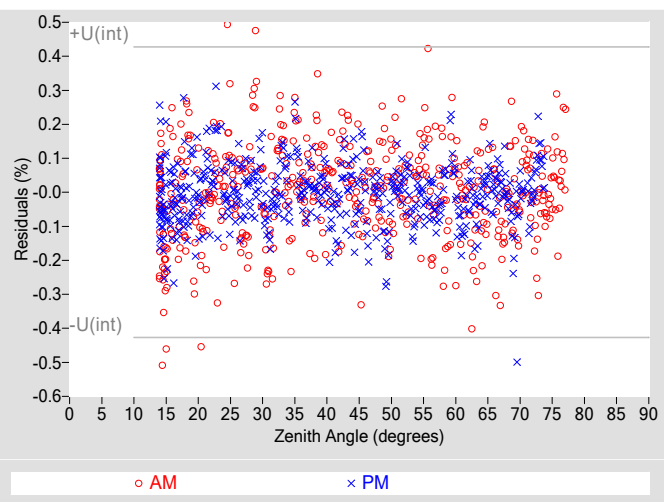


Table 3. Uncertainty using Spline Interpolation ‡

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, $DF(c)$	22022
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 0.94
AM Valid zenith angle range	14° to 68°
PM Valid zenith angle range	14° to 62°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than $R@45^\circ$.

Table 4. Calibration Label Values

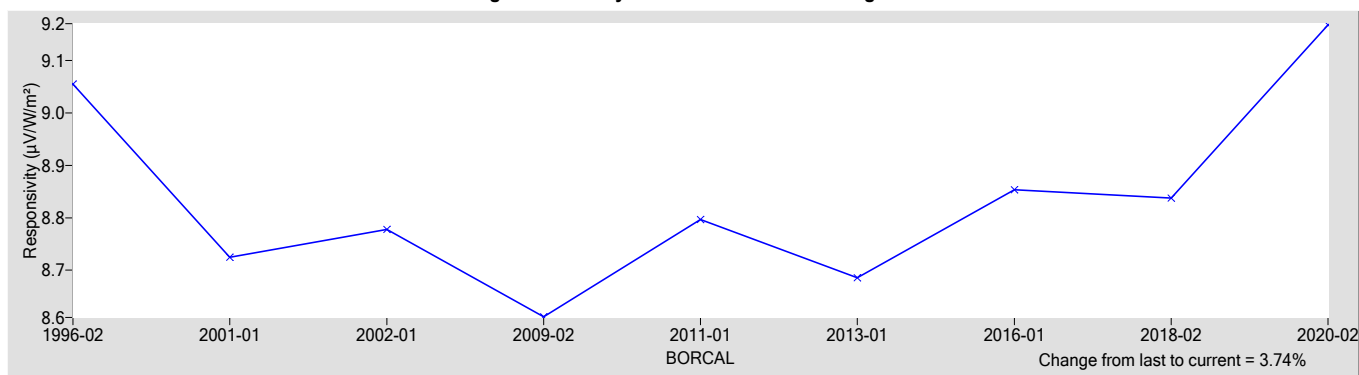
$R @ 45^\circ$ ($\mu V/W/m^2$)	R_{net} ($\mu V/W/m^2$) †
9.1677	0

† R_{net} determination date: N/A

Table 5. Uncertainty using $R @ 45^\circ$

Type-B Expanded Uncertainty, $U(B)$ (%)	± 0.78
Offset Uncertainty, $U(off)$ (%)	+2.9 / -1.1
Expanded Uncertainty, U (%)	+3.7 / -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).

Environmental and Sky Conditions for BORCAL-SW 2020-02

Calibration Facility: Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Reference Irradiance:

Figure 6. Reference Irradiance

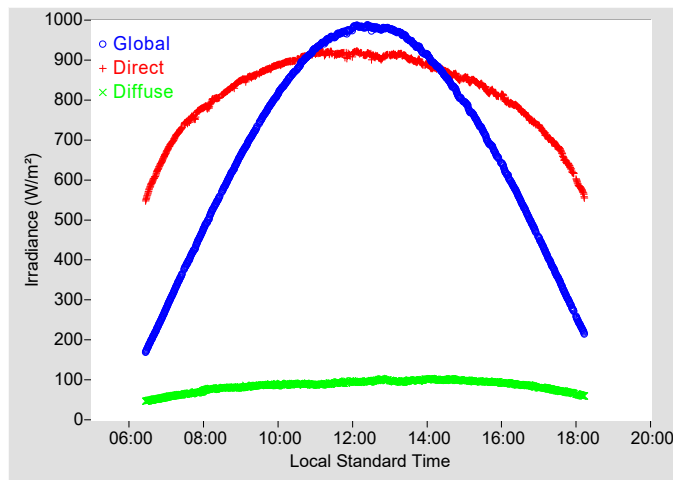
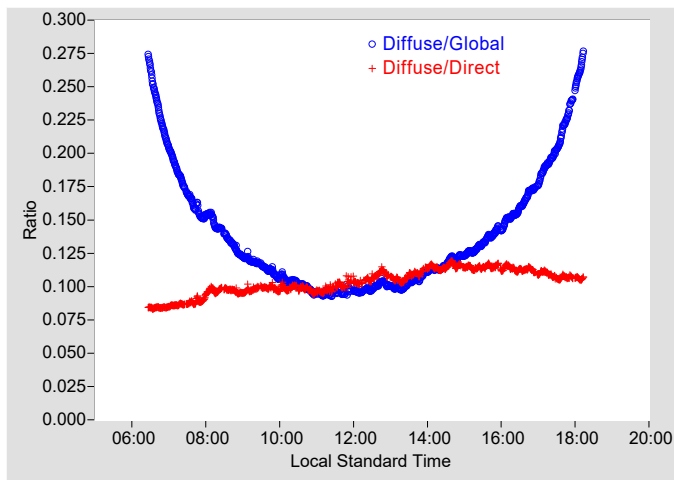


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

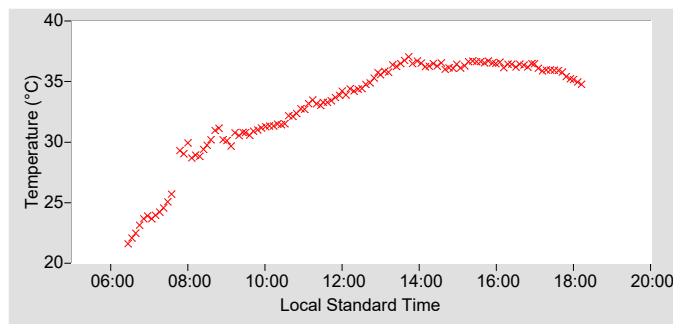


Figure 9. Humidity

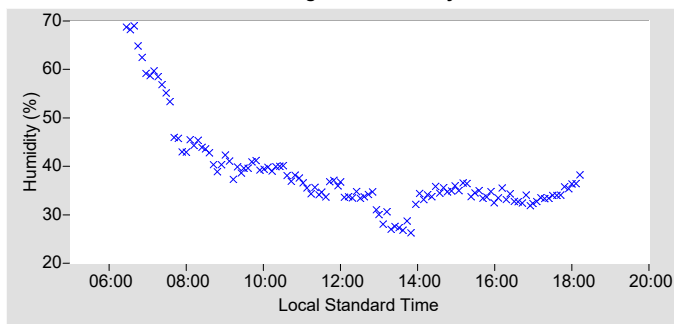


Figure 10. Pressure

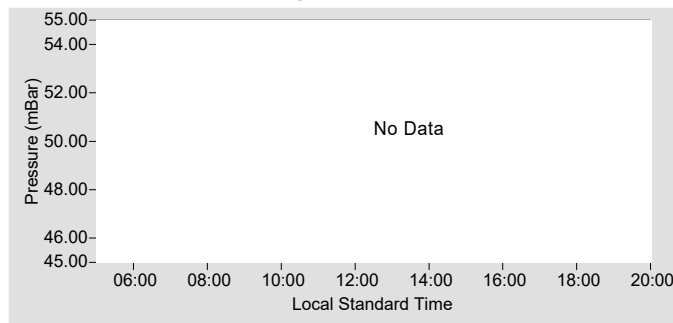


Figure 11. Effective Net Infrared

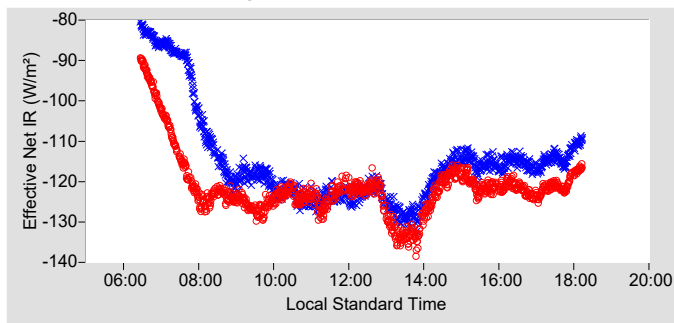


Figure 12. Estimated Broadband Aerosol Optical Depth

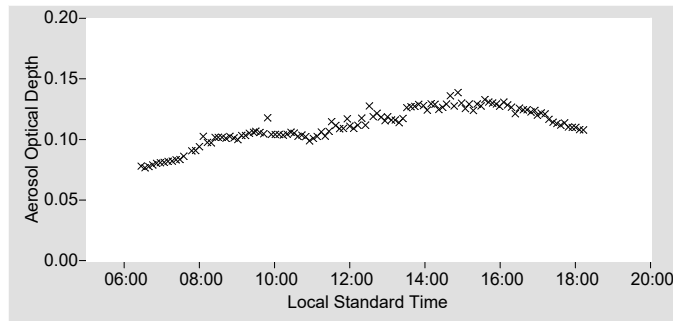


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	32.99	21.62	37.05
Humidity (%)	38.52	26.28	69.04
Pressure (mBar)	N/A	N/A	N/A
Est. Aerosol Optical Depth (BB)	0.111	0.077	0.139

For other information about the calibration facility visit: <https://www.arm.gov/capabilities/observatories/sqp>

Appendix 2

BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Southern Great Plains

Comments:

Avg. Station Pressure and Temperature is for Tulsa, OK, which is used for the Solar Position Algorithm (SPA).

29011E6 Eppley NIP

Comments:

Instrument repaired 6/1/09 and new factory cal of 8.33 uV/W/m² applied. Replaces old cal of 9.25.

29935E6 Eppley NIP

Comments:

Instrument repaired 6/30/09. New factory cal of 8.04 uV/W/m². Replaces old cal of 8.580

31746E6 Eppley NIP

Comments:

Instrument repaired June 2011. New factory cal of 8.515 assigned. Old cal 7.98

33289 Eppley 8-48

Comments:

Factory Cal was recorded as 9.160 instead of 9.190 as per cal report dated Mar 8,2001.

36314E6 Eppley NIP

Comments:

NEW FACTORY CAL DATE AUG 23,2011

Appendix 3

Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL 2020-02 Session Configuration Audit Report

LOCATION

Facility	Facility Abbrev.	Contact	Latitude	Longitude	Elevation (m)	Avg press (mbr)	Avg temp (C)	Time zone	ISO
Southern Great Plains	SGP	Craig Webb	36.605	-97.488	317.0	992.0	15.0	-6.0	

SYSTEM

% Error Thresholds

Cav1 / Cav2	2.0
Dif1 / Dif2	5.0
Global Ctrl / Ref	5.0
Direct Ctrl / Ref	5.0
Test(x) / Test(x-1)	0.5

Delta Thresholds

Temp(x) - Temp(x-1)	2.0
Hum(x) - Hum(x-1)	10.0
Bar(x) - Bar(x-1)	2.0
Thrm(x) - Thrm(x-1)	1.0
Thm (Dome-Case)	3.0
Case Thm (Inst-Pyrg)	5.0

Shade/Unshade

<input type="checkbox"/> Enabled	Port	1
Shaded Wait (s)		85
Unshaded Wait (s)		15

Scan Rate (sec)

Radiometers	30
Meteorological	300

ASR Setup

Scan Rate (s)	1
ASR Readings	2
Threshold 1 (Blue)	1.000
Threshold 2 (Green)	2.000
Threshold 3 (Brown)	3.000
Diffuse scaling factor	1.00

Clock

Reset Interval (m)	30
Warning Threshold (s)	3
Delta UT1	-0.200

Uncertainty

Zenith Angle (deg)	0.003	
Significant Figures	2	
45° Offsets: -	-15.00	+ 15.00
Min. Legal Direct	700	
Max. Legal Diffuse	200	
Max. Diffuse/Direct (%)	45.0	

Miscellaneous

PW: Slope	1.23	Intercept	1.00
Tilt: Zenith	0.00	Azimuth	0.00
W in: Min	150	Max	500
Zenith Angle (Auto Mode): Startup	90	Shutdown	90
Intervals (m): Cavity Calibration	60	Oper. Log	20
SPA: Atmos. Refraction	0.5667	Delta T	69.384

ASR RADIOMETERS

Channel Junction Box Cable Location

ASR 1: PY22692 Licor LI200

60 2 2

ASR 2: None

METEOROLOGICAL INSTRUMENTS

Channel Junction Box Cable Location

Temperature: E0710025T Vaisala HMP155 T

239 AT AT
Scale 100 Offset -40

Humidity: E0710025H Vaisala HMP155 H

255 RH RH
Scale 100 Offset 0

Pressure: None

Scale 0 Offset 0

GPS TIME RECIEVER

SGP Symmetricom NTP

Type	Port	Baud	Parity	Stop bits	Data bits
RS232	1	9600	0	1	8

DATALOGGER

Logger/Relay

Unit	Logger/Relay	DMM
Unit 1	2009-1207 NREL RAP-DAQ	MY42002864 Agilent 34420A
Unit 2	2009-1208 NREL RAP-DAQ	MY42002866 Agilent 34420A
Unit 3	2014-1302 NREL RAP-DAQ	SG42000596 Agilent 34420A
Unit 0	2009-1206 NREL RAP-DAQ	MY42002863 Agilent 34420A

Unit 1 Unit 2 Unit 3 Unit 0

Cal Date 05/14/2020 05/14/2020 05/14/2020 05/14/2020

Cal Due Date 05/14/2021 05/14/2021 05/14/2021 05/14/2021

System Offsets: Volts DC (µV) 0.34 0.34 0.34 0.34

2-Wire Res. (mOhms) 2672.00 2672.00 2672.00 2672.00

4-Wire Res. (mOhms) 0.00 0.00 0.00 0.00

Communications

	Unit	Type	Addr.	Board	Parity	Stop	Data
DMM	1	GPIO	22	0	0	0	0
Relay	1	GPIO	25	1	0	0	0
DMM	2	GPIO	23	0	0	0	0
Relay	2	GPIO	26	1	0	0	0
DMM	3	GPIO	1	0	0	0	0
Relay	3	GPIO	4	1	0	0	0
DMM	0	GPIO	21	0	0	0	0
Relay	0	GPIO	24	1	0	0	0

CAVITIES, CONTROL UNITS, AND DIGITAL MULTI METERS

Cavity 1

Cavity 2

Unwindowed WRR	1.000000	1.000000
Windowed WRR	1.057560	1.057970
Unwindowed Uncert (%)	0.00	0.00
Windowed Uncert (%)	0.38	0.39
Heater Resistance	153.90	154.40
Heater Lead Resistance	0.0660	0.0660
Mfg Calibration Factor	1.99980	1.99990
Default Sensitivity	0.01041	0.01050
Cal Date	09/23/2019	09/23/2019
Cal Due Date	09/23/2020	09/23/2020

Calibration Waits
(Seconds)

TP-solar	0	0
TP-heated	45	45
TP-zero	60	60
Dwell	15	15

Active ☒ ☒Window in Use ☒ ☒

Unit 1

Unit 2

Cavity Head	29222 Eppley HF	30495 Eppley HF
Control Unit	US37037985 NREL Reda	US37037994 NREL Reda
Digital Multi Meter	US37037985 Hewlett Packard 34970A	US37037994 Hewlett Packard 34970A
Cavity Location	T2-A	T5

Control Unit 1

Control Unit 2

Current Shunt	1.000	1.000
Circuit Resist	3.700	2.600
Cal Date	09/04/2019	09/04/2019
Cal Due Date	09/04/2020	09/04/2020

Communications

	Type	Port	Bd.	Parity	Stop bits	Data bits
Control Unit 1	GPIO	10	0	0	0	0
DMM 1		0	0	0	0	0
Control Unit 2	GPIO	9	0	0	0	0
DMM 2		0	0	0	0	0

BORCAL 2020-02 Session Configuration Audit Report

DIFFUSE REFERENCE INSTRUMENTS

Responsivity	Cal Date	Cal Due Date	Shading Disk			Uncertainty		Max Out (mV)	Channel	J Box	Cable	Location	Tilt	Active
			Diameter (cm)	Arm Length (cm)	Subtended Angle	Percent	Offset (W/m^2)							
Diffuse 1: 2550 Hukseflux SR25-T2														
8.722	05/03/2019	05/03/2021	6.2	70.0	5.1	1.20	0.0	50	177		T4	T4	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Diffuse 1: Case NONE Temperature									n/a	n/a	n/a			
Diffuse 1: Dome NONE Temperature									n/a	n/a	n/a			
Diffuse 2: 2549 Hukseflux SR25-T2														
9.094	05/03/2019	05/03/2021	6.2	70.0	5.1	1.30	0.0	50	176		T3	T3	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Diffuse 2: Case NONE Temperature									n/a	n/a	n/a			
Diffuse 2: Dome NONE Temperature									n/a	n/a	n/a			

PYRGEOMETER INSTRUMENTS

Cal Date	Cal Due Date	K0	Calibration Coefficients				Uncert. (W/m^2)	Max Out (mV)	Channel	J Box	Cable	Location	Active
			K1	K2	K3	Kr							
Pyrgometer 1: 30170F3 Eppley PIR													
04/02/2019	04/02/2021	-5.30000	0.23381	0.99290	-3.79000	7.04400E-4	2.70	9	208		30	30	<input checked="" type="checkbox"/>
Pyrgometer 1: Case 10K Temperature									216		30		
Pyrgometer 1: Dome 10K Temperature									224		30		
Pyrgometer 2: 30020F3 Eppley PIR-V (Ventilated)													
04/02/2019	04/02/2021	-1.90000	0.24287	1.00440	-3.99000	7.04400E-4	2.80	9	146		74	83	<input checked="" type="checkbox"/>
Pyrgometer 2: Case 10K Temperature									154		74		
Pyrgometer 2: Dome 10K Temperature									34		54		

BORCAL 2020-02 Session Configuration Audit Report**INSTRUMENT GROUPS**

Group	Calib. Type	Out (mV)	Instrument Type	Instrument Grouping Type	Correcting Pyrgometer	Count
1	Global	50	Eppley 8-48	Eppley 8-48	none	10
2	Global	50	Eppley 8-48	Eppley 8-48	none	9
3	Direct	50	Eppley NIP	Eppley NIP	none	10
4	Direct	50	Eppley NIP	Eppley NIP	none	10
5	Direct	50	Eppley NIP	Eppley NIP	none	5
			Eppley sNIP			2
6	Global	50	Licor LI200	Licor LI200	none	1
7	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
8	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
9	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
10	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	2
11	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	10
12	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	9
Total						98

BORCAL 2020-02 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
13011F3 ©	PSP	TWP	11	1	66		14	No	Yes	No	TOT	14	12
16152E6	NIP	TWP	-	-	192		T13	No	Yes	No	DIR	T13	12
17494	8-48	TWP	1	1	38		81	No	Yes	Yes	TOT	81	12
17607E6	NIP	TWP	3	1	214		T11	No	No	No	DIR	T11	12
18070E6	NIP	TWP	3	2	249		T30	No	Yes	No	DIR	T30	12
18637E6	NIP	TWP	3	3	209		T28	No	No	No	DIR	T28	12
18648E6	NIP	TWP	3	4	212		T9	No	No	No	DIR	T9	12
20186E6	NIP	TWP	-	-	210		T32	No	Yes	No	DIR	T32	12
27974F3 ©	PSP	TWP	11	2	93		21	No	Yes	No	TOT	21	12
28019E6	NIP	TWP	3	5	213		T10	No	No	No	DIR	T10	12
29008E6	NIP	SGP	3	6	241		T21	No	Yes	No	DIR	T21	12
29010E6	NIP	SGP	3	7	242		T29	No	Yes	No	DIR	T29	12
29011E6	NIP	SGP	3	8	229		T8	No	Yes	No	DIR	T8	12
29281F3 ©	PSP	TWP	-	-	92		20	No	Yes	No	TOT	20	12
29541E6	NIP	SGP	3	9	226		T15	No	Yes	No	DIR	T15	12
29609F3 ©	PSP	SGP	7	1	110		38	No	Yes	Yes	TOT	38	12
29741E6	NIP	SGP	3	10	250		T31	No	Yes	No	DIR	T31	12
29850E6	NIP	SGP	4	1	237		T24	No	Yes	No	DIR	T24	12
29911F3 ©	PSP	SGP	7	2	108		39	No	Yes	Yes	TOT	39	12
29935E6	NIP	SGP	4	2	244		T18	No	Yes	No	DIR	T18	12
29936E6	NIP	SGP	4	3	205		T23	No	Yes	No	DIR	T23	12
29938E6	NIP	SGP	4	4	204		T14	No	Yes	No	DIR	T14	12
30569E6	NIP	TWP	4	5	246		T34	No	Yes	No	DIR	T34	12
30584E6	NIP	SGP	4	6	234		T20	No	Yes	No	DIR	T20	12
30621F3 ©	PSP	SGP	11	3	78		15	No	Yes	Yes	TOT	15	12
30654F3 ©	PSP	SGP	7	3	133		51	No	Yes	Yes	TOT	51	12
30662F3 ©	PSP	SGP	7	4	126		49	No	Yes	Yes	TOT	49	12
30671F3 ©	PSP	SGP	11	4	6		24	No	Yes	No	TOT	24	12
30708F3 ©	PSP	SGP	11	5	65		13	No	Yes	No	TOT	13	12
30718E6	NIP	SGP	4	7	230		T16	No	Yes	No	DIR	T16	12
30778F3 ©	PSP	SGP	11	6	64		12	No	Yes	No	TOT	12	12
30802F3 ©	PSP	SGP	11	7	1		5	No	Yes	No	TOT	5	12
30894F3 ©	PSP	SGP	7	5	124		47	No	Yes	Yes	TOT	47	12
30900F3 ©	PSP	SGP	11	8	2		6	No	Yes	No	TOT	6	12
30903F3 ©	PSP	SGP	7	6	157		69	No	Yes	Yes	TOT	69	12
30934F3 ©	PSP	SGP	7	7	125		48	No	Yes	Yes	TOT	48	12
30940F3 ©	PSP	SGP	7	8	114		56	No	Yes	Yes	TOT	56	12
30942F3 ©	PSP	SGP	7	9	165		77	No	Yes	Yes	TOT	77	12
30944F3 ©	PSP	SGP	7	10	150		68	No	Yes	Yes	TOT	68	12
30955F3 ©	PSP	SGP	11	9	5		23	No	Yes	No	TOT	23	12
30956F3 ©	PSP	SGP	11	10	61		3	No	Yes	No	TOT	3	12
31099F3 ‡©	PSP	Calibration System	8	1	130		64	No	Yes	Yes	TOT	64	12
		(Case 10K Temperature)			138		64						
31100F3 ‡©	PSP	Calibration System	8	2	145		73	No	Yes	Yes	TOT	73	12
		(Case 10K Temperature)			153		73						
31101F3 ‡©	PSP	Calibration System	8	3	160		82	No	Yes	Yes	TOT	82	12
		(Case 10K Temperature)			168		82						
31120E6 ‡	NIP	Calibration System	4	8	225		T7	No	Yes	No	DIR	T7	12
31121E6	NIP	Calibration System	4	9	245		T26	No	Yes	No	DIR	T26	12

‡ Control Instrument

© Effective Net IR Corrected Instrument

BORCAL 2020-02 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
31146F3 ‡©	PSP	Calibration System (Case 10K Temperature)	8	4	98 106		37 37	No	Yes	Yes	TOT	37	12
31147F3 ‡©	PSP	Calibration System (Case 10K Temperature)	8	5	112 120		46 46	No	Yes	Yes	TOT	46	12
31148F3 ‡©	PSP	Calibration System (Case 10K Temperature)	8	6	113 121		55 55	No	Yes	Yes	TOT	55	12
31152F3 ‡©	PSP	Calibration System (Case 10K Temperature)	12	1	80 88		19 19	No	Yes	No	TOT	19	12
31153F3 ‡©	PSP	Calibration System (Case 10K Temperature)	12	2	81 89		28 28	No	Yes	No	TOT	28	12
31154F3 ‡©	PSP	Calibration System (Case 10K Temperature)	12	3	82 90		29 29	No	Yes	No	TOT	29	12
31155F3 ‡©	PSP	Calibration System (Case 10K Temperature)	12	4	48 56		1 1	No	Yes	No	TOT	1	12
31156F3 ‡©	PSP	Calibration System (Case 10K Temperature)	12	5	49 57		10 10	No	Yes	No	TOT	10	12
31157F3 ‡©	PSP	Calibration System (Case 10K Temperature)	12	6	50 58		11 11	No	Yes	No	TOT	11	12
31275F3 ©	PSP	TWP	12	7	96		31	No	Yes	No	TOT	31	12
31276F3 ©	PSP	TWP	8	7	117		41	No	Yes	Yes	TOT	41	12
31280F3 ©	PSP	TWP	12	8	109		33	No	Yes	No	TOT	33	12
31295F3 ©	PSP	TWP	8	8	149		67	No	Yes	Yes	TOT	67	12
31627F3 ©	PSP	SGP	8	9	158		75	No	Yes	Yes	TOT	75	12
31628F3 ©	PSP	SGP	8	10	166		78	No	Yes	Yes	TOT	78	12
31632F3 ©	PSP	SGP	9	1	144		65	No	Yes	Yes	TOT	65	12
31635F3 ©	PSP	SGP	9	2	118		42	No	Yes	Yes	TOT	42	12
31746E6	NIP	SGP	4	10	222		T33	No	Yes	No	DIR	T33	12
31762E6	NIP	NSA	5	1	254		T36	No	Yes	No	DIR	T36	12
32015F3 ©	PSP	NSA	9	3	141		59	No	Yes	Yes	TOT	59	12
32023F3 ©	PSP	NSA	9	4	156		66	No	Yes	Yes	TOT	66	12
32039F3 ©	PSP	NSA	9	5	128		57	No	Yes	Yes	TOT	57	12
32330	8-48	SGP	1	2	26		45	No	Yes	Yes	TOT	45	12
32815F3 ©	PSP	TWP	9	6	116		40	No	Yes	Yes	TOT	40	12
32872	8-48	Calibration System	1	3	24		43	No	Yes	Yes	TOT	43	12
32991F3 ©	PSP	TWP	9	7	132		50	No	Yes	Yes	TOT	50	12
33237	8-48	SGP	1	4	36		79	No	Yes	Yes	TOT	79	12
33243	8-48	TWP	1	5	40		61	No	Yes	Yes	TOT	61	12
33267	8-48	SGP	1	6	29		71	No	Yes	Yes	TOT	71	12
33269	8-48	SGP	1	7	30		72	No	Yes	Yes	TOT	72	12
33273	8-48	SGP	1	8	44		88	No	Yes	Yes	TOT	88	12
33275	8-48	SGP	1	9	37		80	No	Yes	Yes	TOT	80	12
33278	8-48	SGP	1	10	25		44	No	Yes	Yes	TOT	44	12
33283	8-48	SGP	2	1	42		63	No	Yes	Yes	TOT	63	12
33288	8-48	SGP	2	2	45		89	No	Yes	Yes	TOT	89	12
33289	8-48	SGP	2	3	46		90	No	Yes	Yes	TOT	90	12
33363	8-48	SGP	2	4	173		87	No	Yes	Yes	TOT	87	12
33377	8-48	TWP	2	5	142		60	No	Yes	Yes	TOT	60	12
33383	8-48	TWP	2	6	41		62	No	Yes	Yes	TOT	62	12
33575	8-48	TWP	2	7	32		52	No	Yes	Yes	TOT	52	12
33703F3 ©	PSP	TWP	9	8	164		76	No	Yes	Yes	TOT	76	12

‡ Control Instrument

© Effective Net IR Corrected Instrument

BORCAL 2020-02 Session Configuration Audit Report**INSTRUMENTS**

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
34293F3 ©	PSP	AMF	9	9	161		84	No	Yes	Yes	TOT	84	12
35831F3 ©	PSP	AMF#2	12	9	0		4	No	Yes	No	TOT	4	12
36313E6	NIP	SGP	5	2	238		T25	No	Yes	No	DIR	T25	12
36314E6	NIP	SGP	5	3	194		T27	No	Yes	No	DIR	T27	12
37167	8-48	AMF	2	8	28		70	No	Yes	Yes	TOT	70	12
37288E6	NIP	NSA	5	4	253		T35	No	Yes	No	DIR	T35	12
37301F3 ©	PSP	AMF	9	10	162		85	No	Yes	Yes	TOT	85	12
37315F3 ©	PSP	NSA	10	1	129		58	No	Yes	Yes	TOT	58	12
37319F3 ©	PSP	AMF	10	2	174		86	No	Yes	Yes	TOT	86	12
37362E6	NIP	AMF	5	5	236		T17	No	Yes	No	DIR	T17	12
37394	8-48	AMF	2	9	33		53	No	Yes	Yes	TOT	53	12
37945E6 ‡	sNIP	SGP	5	6	178		T12	No	Yes	No	DIR	T12	12
37947E6 ‡	sNIP	SGP	5	7	193		T22	No	Yes	No	DIR	T22	12
PY22693	LI200	Calibration System	6	1	8		7	No	Yes	No	TOT	7	12

‡ Control Instrument

© Effective Net IR Corrected Instrument

BORCAL 2020-02 Session Configuration Audit Report**Effective Net IR Corrected Instruments**

Instrument	Vent	Correcting Pyrgometer	Inst. RSnet	RSnet uncert.	RSnet Date
13011F3 Eppey PSP	No	30170F3 Eppey PIR	0.6000	20.0000	Estimated
27974F3 Eppey PSP	No	30170F3 Eppey PIR	0.6000	20.0000	Estimated
29281F3 Eppey PSP	No	30170F3 Eppey PIR	0.6000	20.0000	Estimated
29609F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6360	10.0000	04/20/2006
29911F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5975	10.0000	04/24/2007
30621F3 Eppey PSP	Yes	30170F3 Eppey PIR	0.6603	10.0000	07/18/2007
30654F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6710	10.0000	07/18/2007
30662F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6463	10.0000	05/10/2007
30671F3 Eppey PSP	No	30170F3 Eppey PIR	0.5870	10.0000	04/05/2006
30708F3 Eppey PSP	No	30170F3 Eppey PIR	0.5860	10.0000	04/04/2006
30778F3 Eppey PSP	No	30170F3 Eppey PIR	0.6431	10.0000	06/06/2006
30802F3 Eppey PSP	No	30170F3 Eppey PIR	0.6870	10.0000	04/25/2007
30894F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6467	10.0000	06/07/2006
30900F3 Eppey PSP	No	30170F3 Eppey PIR	0.6338	10.0000	05/08/2007
30903F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5865	10.0000	04/18/2006
30934F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5300	10.0000	04/18/2006
30940F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6187	10.0000	06/07/2006
30942F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6091	10.0000	07/05/2007
30944F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5669	10.0000	04/18/2006
30955F3 Eppey PSP	No	30170F3 Eppey PIR	0.6150	10.0000	07/06/2006
30956F3 Eppey PSP	No	30170F3 Eppey PIR	0.5739	10.0000	04/26/2007
31099F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5787	10.0000	05/08/2006
31100F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6473	10.0000	05/09/2006
31101F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6483	10.0000	05/09/2006
31146F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5490	10.0000	03/30/2006
31147F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5510	10.0000	03/30/2006
31148F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5330	10.0000	03/30/2006
31152F3 Eppey PSP	No	30170F3 Eppey PIR	0.6339	10.0000	05/09/2006
31153F3 Eppey PSP	No	30170F3 Eppey PIR	0.6429	10.0000	05/09/2006
31154F3 Eppey PSP	No	30170F3 Eppey PIR	0.5616	10.0000	05/09/2006
31155F3 Eppey PSP	No	30170F3 Eppey PIR	0.5240	10.0000	03/30/2006
31156F3 Eppey PSP	No	30170F3 Eppey PIR	0.5320	10.0000	03/30/2006
31157F3 Eppey PSP	No	30170F3 Eppey PIR	0.4900	10.0000	03/30/2006
31275F3 Eppey PSP	No	30170F3 Eppey PIR	0.5915	10.0000	07/03/2008
31276F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5694	10.0000	06/09/2006
31280F3 Eppey PSP	No	30170F3 Eppey PIR	0.4970	10.0000	03/30/2006
31295F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5465	10.0000	06/13/2006
31627F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6180	10.0000	06/29/2005
31628F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6080	10.0000	04/18/2006
31632F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6000	20.0000	06/24/2013
31635F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6137	10.0000	06/06/2006
32015F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.4221	10.0000	03/25/2009
32023F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.7060	10.0000	04/04/2006
32039F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6577	10.0000	06/13/2006
32815F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6000	20.0000	Estimated
32991F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6000	20.0000	Estimated
33703F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6000	20.0000	Estimated
34293F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.5470	10.0000	04/03/2006
35831F3 Eppey PSP	No	30170F3 Eppey PIR	0.5439	10.0000	08/05/2009
37301F3 Eppey PSP	Yes	30020F3 Eppey PIR-V	0.6000	20.0000	Estimated

BORCAL 2020-02 Session Configuration Audit Report**Effective Net IR Corrected Instruments**

Instrument	Vent	Correcting Pyrgometer	Inst. RSnet	RSnet uncert.	RSnet Date
37315F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
37319F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated

Appendix 4

Operator Session Logs

Operator session logs for the BORCAL

BORCAL 2020-02 Operator Session Log

=====
Session: 1

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-04-2020	11:43:19	11:47:11	29222	11:15	968.0	968.0
			30495	11:15	954.6	954.6

Observations: [None]
=====

Session: 2

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-04-2020	11:50:31	12:50:36	29222	11:15	967.7	966.4
			30495	11:15	954.6	953.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:10:58	14.56	Green	888.1	11.3	Craig Webb

Comments:

THIS IS A TEST RUN FOR BORCAL 2020-02. HAZE ON THE HORIZON, TEMP 36c, HUM 38%. HPA 971, WND DIR 100 @ 3 MPH.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:31:50	14.07	Blue	890.9	11.5	Craig Webb

Comments:

lighjt haze around sun, otherwise clear, temp 40 C hum 65%, hpa 971, wnd dir 125 @ 2 mph.
=====

Session: 3

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-04-2020	12:50:36	13:50:39	29222	11:15	966.4	965.6
			30495	11:15	953.4	952.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:51:58	14.94	Blue	886.0	11.6	Craig Webb

Comments:

clear, temp 37C, hum 36%, hpa -971, wnd dir 224 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:12:13	16.94	Blue	889.1	11.8	Craig Webb

Comments:

no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:32:27	19.72	Blue	874.1	12.0	Craig Webb

Comments:

some light haze thru out the sky, temp 37C, hum 35%, hpa 970, wnd dir 100 @ 3 mph,
=====

Session: 4

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-04-2020	13:50:39	14:48:41	29222	11:15	965.6	965.3
			30495	11:15	952.7	952.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:56:35	23.65	Blue	861.8	12.6	Craig Webb

Comments:

high humidity and haze through out sky, temp 37C, hum 36%, hpa 970, wnd dir 120 @ 2 mph.

BORCAL 2020-02 Operator Session Log

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:16:43	27.24	Blue	851.4	13.5	Craig Webb

Comments:
no change in conditions.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:36:47	31.02	Blue	842.2	14.7	Craig Webb

Comments:
small cirrus forming in area, temp 37C, hum 38%, hpa 970, wnd dir 175 @ 3 mph

Session: 5

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-04-2020	14:48:41	15:56:45	29222	11:15	965.3	965.2
			30495	11:15	952.2	952.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:57:01	34.93	Blue	817.6	15.2	Craig Webb

Comments:
clouds to the west and southwest, temp 37C, hum 40%, hpa 970, wnd dir 150 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:20:48	39.62	Red	439.9	27.0	Craig Webb

Comments:
small cloud passing, temp 36C, hum 38%, hpa 970, wnd dir 152 @ 4 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:40:53	43.61	Blue	802.0	16.9	Craig Webb

Comments:
no change in conditions, temp 37C, hum 37%, hpa 969, wnd dir 145 @ 2 mph.

Session: 6

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-04-2020	15:56:45	16:56:47	29222	11:15	965.2	964.9
			30495	11:15	952.3	951.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:00:59	47.64	Blue	772.4	17.8	Craig Webb

Comments:
clouds getting closer, temp 36C, hum 40%, hpa 969, wnd dir 152 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:21:57	51.84	Blue	747.0	19.0	Craig Webb

Comments:
birds around 37945E6, clouds to s/e temp 36C, hum 41%, hpa 969, wnd dir 250 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:42:20	55.93	Blue	702.5	22.0	Craig Webb

Comments:
temp 36C, hum 41%, hpa 968, wnd dir 110 @ 5 mph.

BORCAL 2020-02 Operator Session Log

=====
Session: 7

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-04-2020	16:56:47	16:57:33	29222	11:15	964.9	964.9
			30495	11:15	951.8	951.8

Observations: [None]
=====

Session: 8

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	06:26:05	07:28:05	29222	06:00	971.4	970.3
			30495	06:00	957.9	956.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:46:21	73.28	Blue	627.4	22.6	Craig Webb

Comments:

clouds to the south-east, temp 23C, hum 65%, hpa 974, wnd dir 200 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:08:04	69.08	Blue	693.2	19.5	Craig Webb

Comments:

sky is clearing temp 24C, hum 59%, hpa 974, wnd dir 200 @ 5 mph
=====

Session: 9

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	07:28:05	08:29:08	29222	06:00	970.3	969.2
			30495	06:00	956.9	955.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:28:14	65.65	Blue	733.0	17.4	Craig Webb

Comments:

birds in area, temp 25C, hum 60%, hpa 975, wnd dir 260 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:49:12	60.97	Blue	770.3	15.5	Craig Webb

Comments:

birds won't leave area, temp 30C, hum 46%, hpa 975, wnd dir 050 @ 1 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:09:24	56.95	Blue	786.1	15.4	Craig Webb

Comments:

some alarms due to birds and bugs, temp 30C, hum 45%, hpa 976, wnd dir 120 @ 2 mph.
=====

Session: 10

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	08:29:08	09:29:08	29222	06:00	969.2	967.8
			30495	06:00	955.4	954.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:29:29	52.93	Green	813.1	14.0	Craig Webb

Comments:

clear, temp 30C, hum 44%, hpa 976, wnd dir 110 @ 2 mph.

BORCAL 2020-02 Operator Session Log

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:50:48	48.66	Blue	838.6	12.6	Craig Webb

Comments:

temp 31C, hum 39%, hpa 976, wnd dir 050 @ 6 m ph

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:11:13	44.57	Blue	858.0	11.9	Craig Webb

Comments:

some light cirrus, temp 30C, hum 41%, hpa 976, wnd dir 080 @ 3 mph

=====

Session: 11

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	09:29:08	10:30:11	29222	06:00	967.8	967.0
			30495	06:00	954.6	953.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:32:17	40.37	Green	869.6	11.5	Craig Webb

Comments:

some light cirrus in area, temp 31C, hum 40%, hpa 976, wnd dir 040 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:52:38	36.34	Blue	885.0	10.9	Craig Webb

Comments:

no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:13:35	32.26	Blue	896.9	10.4	Craig Webb

Comments:

some alarms mainly birds or bugs, temp 31C, hum 40%, hpa 976, wnd dir 210 @ 1 mph.

=====

Session: 12

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	10:30:11	11:30:14	29222	06:00	967.0	966.8
			30495	06:00	953.8	953.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:34:30	28.29	Blue	902.9	10.1	Craig Webb

Comments:

some alarms, temp 31C, hum 40%, hpa 976, wnd dir 190 @ 3 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:55:23	24.49	Green	916.0	9.5	Craig Webb

Comments:

no change

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:16:50	20.86	Blue	918.4	9.4	Craig Webb

Comments:

Farmer starting to cut wheat to the East of the site, may work up some dust. temp 34C, hum 34%, hpa 975, wnd dir 141 @ 2 mph.

=====

BORCAL 2020-02 Operator Session Log

=====
Session: 13

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	11:30:14	11:59:14	29222	06:00	966.8	966.1
			30495	06:00	953.7	953.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:55:33	15.68	Blue	912.2	9.8	Craig Webb

Comments:

calibrating early for solar noon,temp 34C, hum 36%, hpa 976, wnd dir 213 @ 2 mph.

=====
Session: 14

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	11:59:14	12:59:17	29222	06:00	966.1	965.9
			30495	06:00	953.3	953.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:15:54	14.22	Red	901.0	10.2	Craig Webb

Comments:

some light cirrus, temp 34C, hum 34%, hpa 975, wnd dir 080 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:45:14	14.40	Blue	905.4	10.4	Craig Webb

Comments:

clear, some dust in the air, temp 35C, hum 34C, hpa 975, wnd dir 210 @ 1 mph

=====
Session: 15

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	12:59:17	13:56:18	29222	06:00	965.9	965.7
			30495	06:00	953.1	952.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:06:23	16.16	Blue	916.6	9.8	Craig Webb

Comments:

temp 36C, hum 28%, hpa 975, wnd dir 200 @ 3 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:36:02	20.16	Blue	900.7	10.4	Craig Webb

Comments:

no change in conditions.

=====
Session: 16

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	13:56:18	14:57:21	29222	06:00	965.7	965.3
			30495	06:00	952.3	952.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:00:09	24.17	Blue	891.2	11.1	Craig Webb

Comments:

claer, farmer moved to another field, temp 37C, hum 32%, hpa 975, wnd dir 140 @ 7 mph.

BORCAL 2020-02 Operator Session Log

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:26:19	28.93	Green	874.7	11.5	Craig Webb

Comments:
no change

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:47:30	32.99	Green	861.6	11.9	Craig Webb

Comments:
clear temp 36C, hum 35%, hpa 974, wnd dir 155 @ 9 mph

Session: 17

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	14:57:21	15:58:21	29222	06:00	965.3	965.1
			30495	06:00	952.4	952.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:08:02	37.00	Blue	844.8	12.7	Craig Webb

Comments:
temp 36C, hum 35%, hpa 974, wnd dir 132 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:28:21	41.03	Blue	838.2	13.1	Craig Webb

Comments:
no change in conditions,

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:48:41	45.09	Blue	818.5	14.0	Craig Webb

Comments:
no change in conditions.

Session: 18

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	15:58:21	16:58:25	29222	06:00	965.1	965.0
			30495	06:00	952.3	952.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:09:10	49.18	Blue	795.8	15.2	Craig Webb

Comments:
clouds starting to form to the west, temp 37C, hum 33%, hpa 974, wnd dir 150 @ 5 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:29:35	53.29	Blue	776.4	15.9	Craig Webb

Comments:
clear,

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:49:46	57.32	Blue	746.2	17.3	Craig Webb

Comments:
clouds on horzin, temp 36C, hum 34%, hpa 974, wnd dir 190 @ 8 mph

BORCAL 2020-02 Operator Session Log

=====
Session: 19

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	16:58:25	17:59:26	29222	06:00	965.0	964.9
			30495	06:00	952.0	952.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:09:52	61.32	Blue	712.1	19.0	Craig Webb

Comments:

clouds on horzin, temp 36C, hum 32%, hpa 974, wnd dir 130 @ 9 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:32:14	65.73	Blue	681.3	20.5	Craig Webb

Comments:

no changes,

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:52:20	69.67	Blue	624.5	23.9	Craig Webb

Comments:

getting a few aLARMS DUE TO HAZE ON HORIZON,TEMP 35c, HUM 25%, HPA 974, WND DIR 160 @ 2 MPH.

=====
Session: 20

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
06-05-2020	17:59:26	18:16:12	29222	06:00	964.9	965.4
			30495	06:00	952.1	952.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:12:37	73.58	Blue	558.3	27.5	Craig Webb

Comments:

TEMP 35c, HUM 38%, HPA 974 WND DIR 140 @ 6 MPH. CLOSING DOWN FOR THE DAY.