Broadband Outdoor Radiometer Calibration

BORCAL
2000-02

Calibration Facility:
Southern Great Plains

Latitude: 36.605°N
Longitude: 97.488°W
Elevation: 317.0 meters AMSL
Avg. Station Pressure: 980.0 mBar
Time Zone: -6.0

Calibration date
08/15/2000 to 08/24/2000

Report Date
December 13, 2002

NOTICE

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Broadband Outdoor Radiometer Calibration Report

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Introduction

This report compiles the calibration results from a Broadband Outdoor Radiometer Calibration (BORCAL). The work was accomplished at the Radiometer Calibration Facility shown on the front of this report. The calibration results reported here are traceable to the World Radiometric Reference and to the National Institute of Standards and Technology.

This report includes these sections:

- Calibration Environment - meteorological conditions and irradiance reference data encountered during the event.
- 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 and suggested methods of applying results for each instrument.

The BORCAL process is described in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002.

Reference Irradiance

0.0° / 0.0° Tilt / Azm

Figure 1. Reference Irradiance

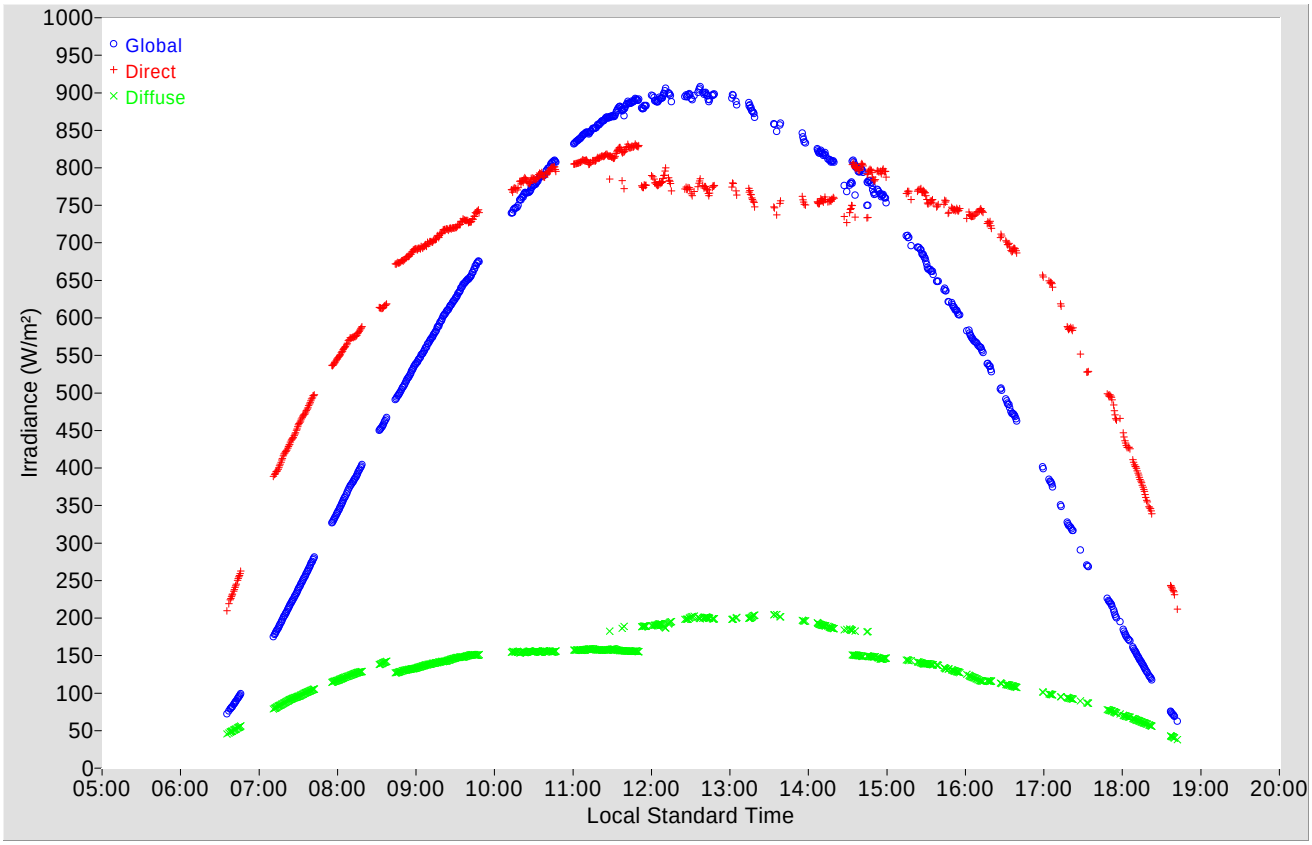
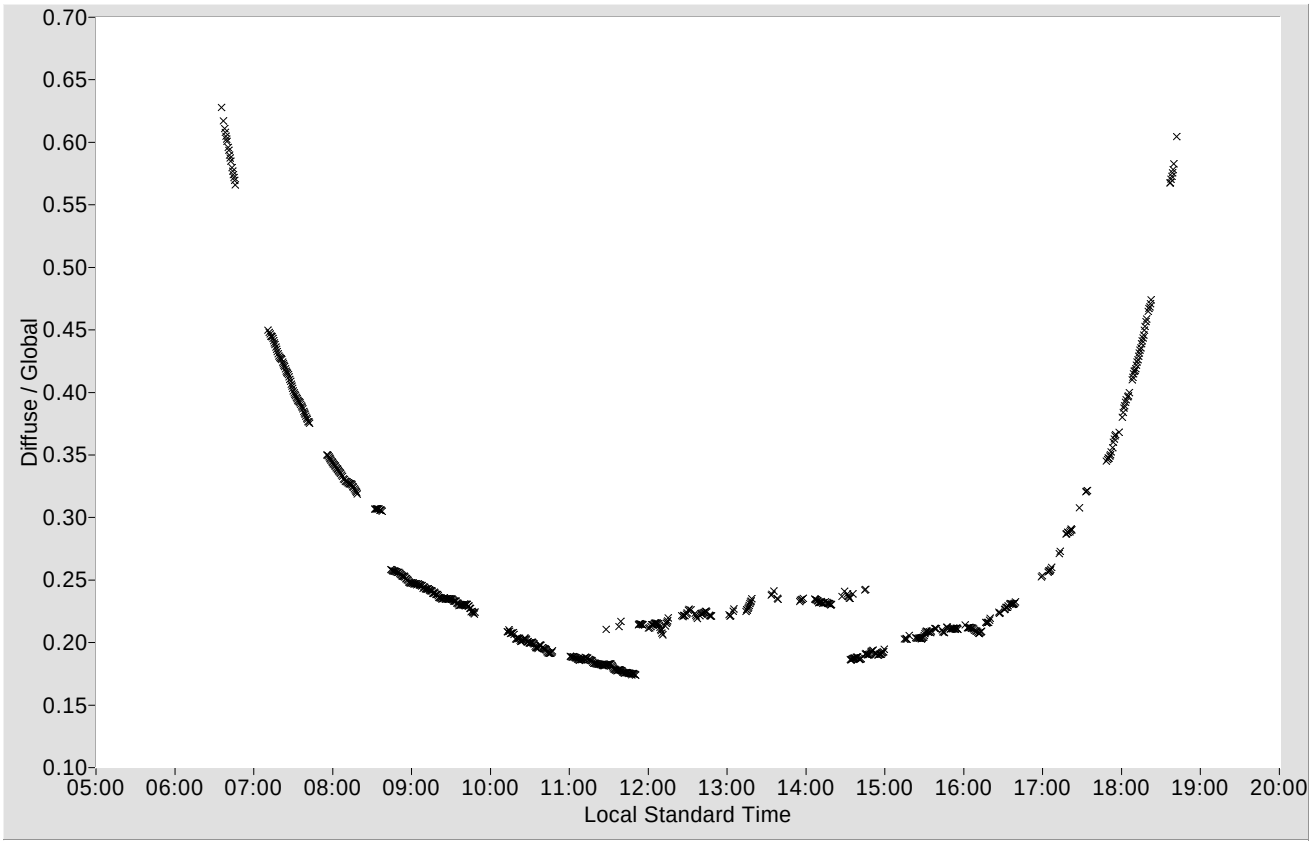


Figure 2. Diffuse / Global



Meteorological Observations

Table 1. Meteorological Observations

Observations	Mean
Temperature (°C)	36.95
Humidity (%)	41.23
Pressure (mBar)	N/A
Est. Aerosol Optical Depth (BB)	0.1919

Figure 3. Temperature

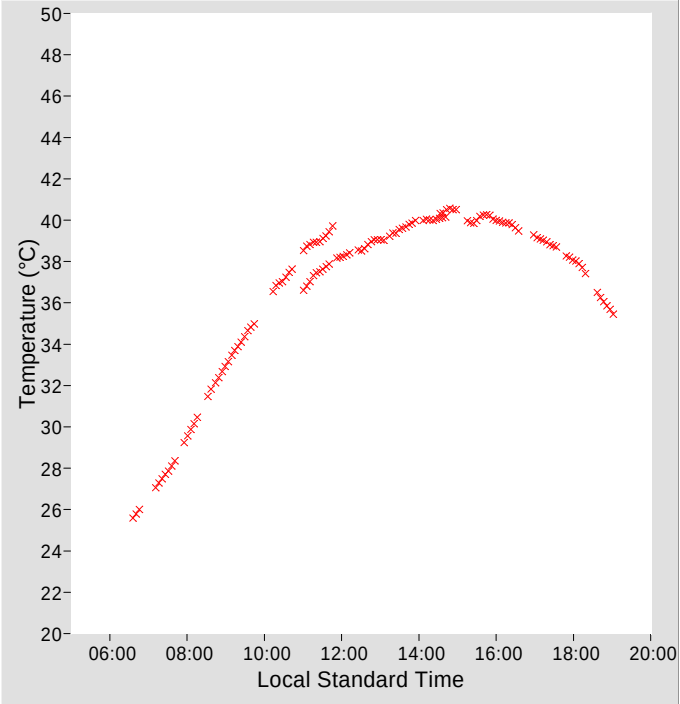


Figure 4. Humidity

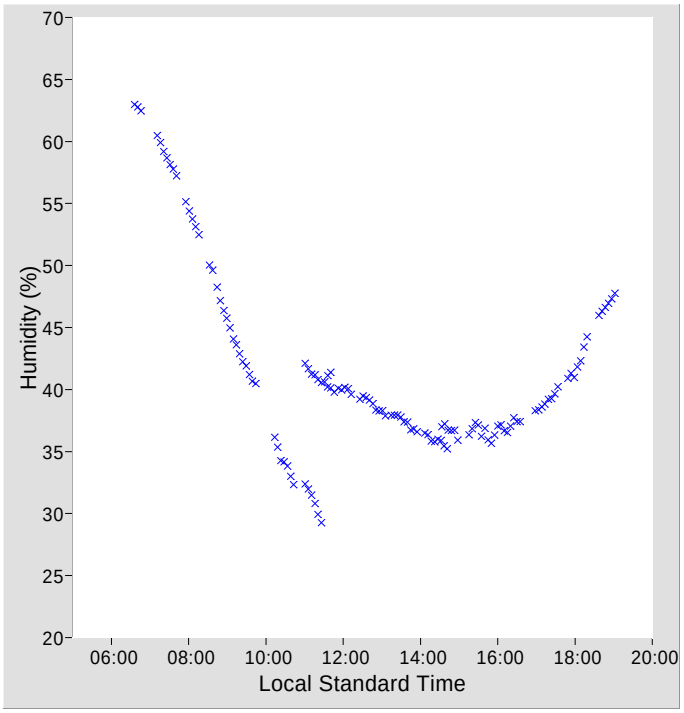


Figure 5. Pressure

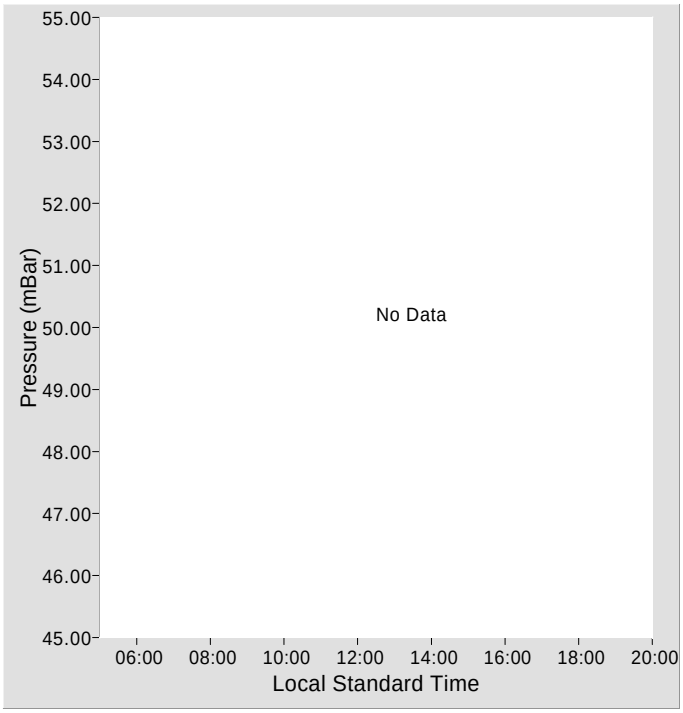
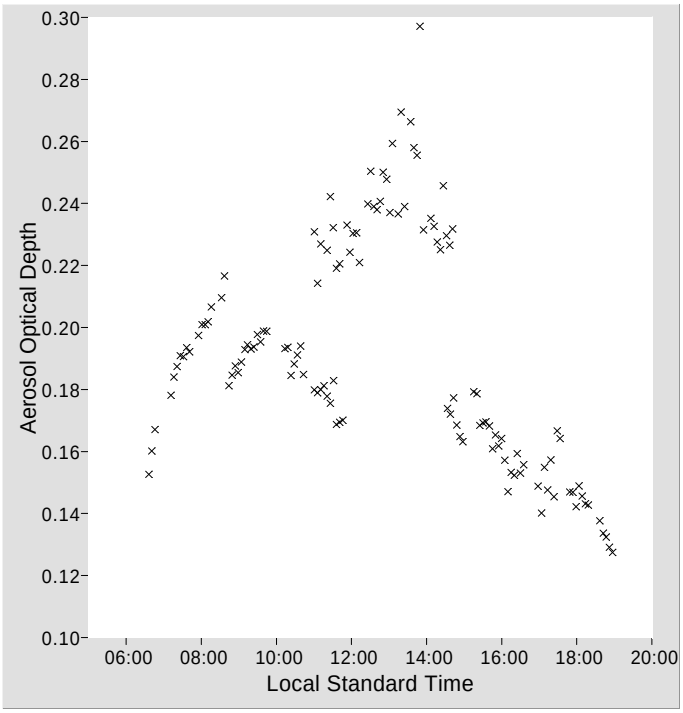


Figure 6. Estimated Broadband Aerosol Optical Depth



Control Instrument History

Figure 7. Eppley NIP Control Instrument History

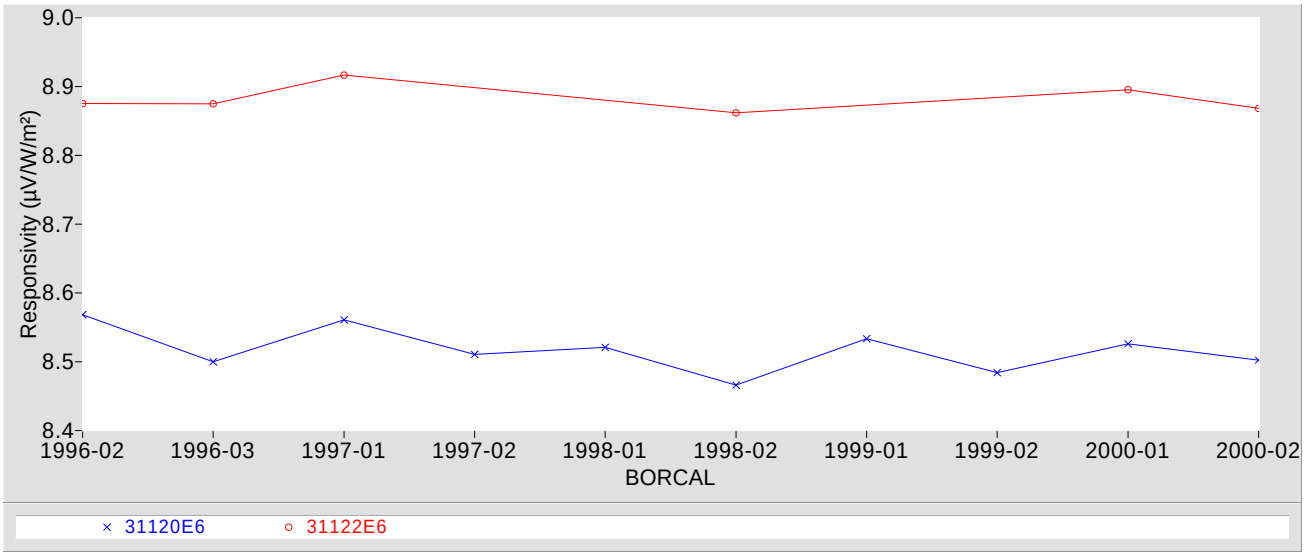


Figure 8. Eppley PSP Control Instrument History

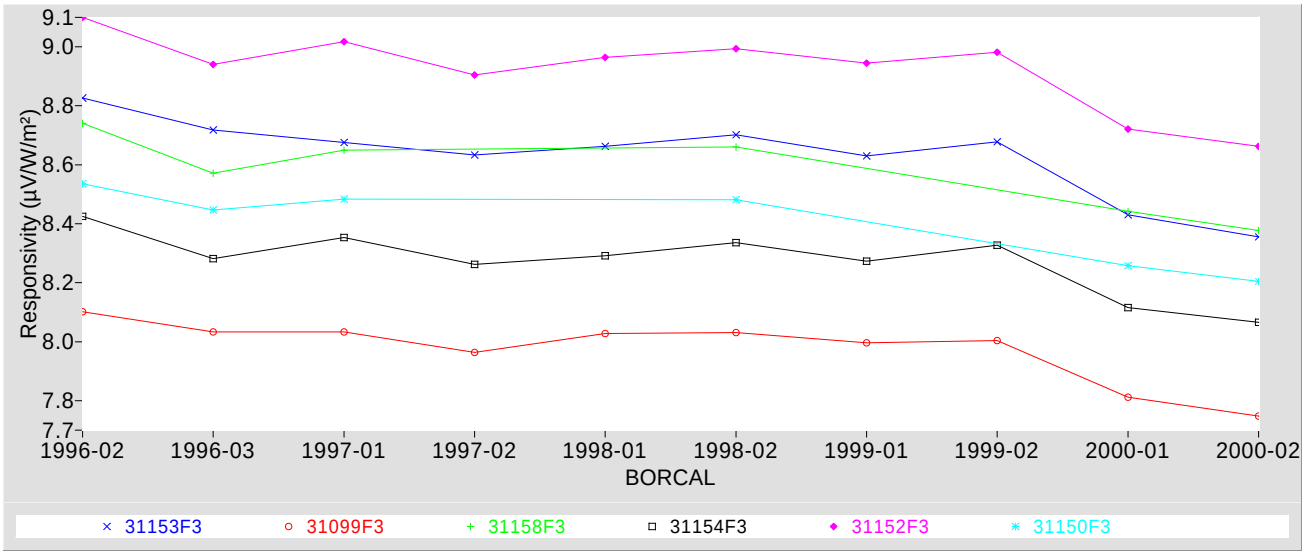
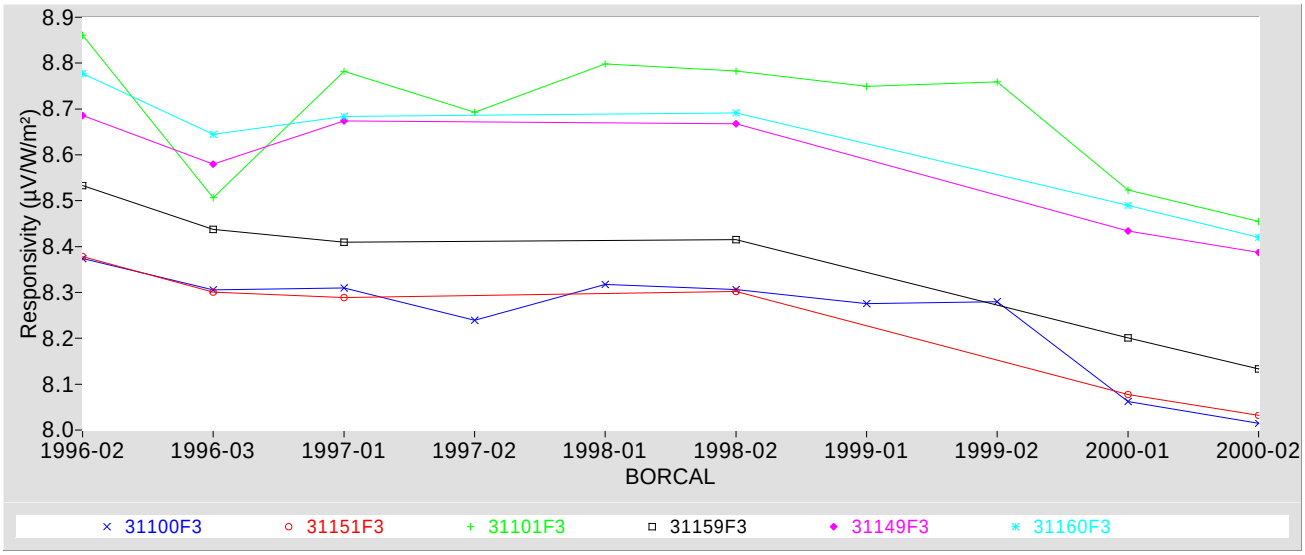


Figure 9. Eppley PSP Control Instrument History



Results Summary

Table 2. Results Summary

Instrument	Customer	Rs@45 (µV/W/m²)	U95 (%)	Page
20386F3	Dan Nelson	9.8503	+2.46 / -4.36	A1-2
29554E6	Dan Nelson	8.0959	+1.40 / -1.45	A1-6
29555E6	Dan Nelson	8.3816	+1.65 / -1.33	A1-9
29738E6	Dan Nelson	7.6990	+1.05 / -1.49	A1-12
29740E6	Dan Nelson	8.1564	+1.02 / -1.33	A1-15
29741E6	Dan Nelson	8.3280	+1.06 / -1.43	A1-18
29847E6	Dan Nelson	7.8917	+1.09 / -1.35	A1-21
29851E6	Dan Nelson	8.5505	+1.08 / -1.42	A1-24
29856E6	Dan Nelson	7.8402	+1.46 / -1.36	A1-27
29935E6	Dan Nelson	8.3276	+1.25 / -1.37	A1-30
29936E6	Dan Nelson	8.1996	+1.23 / -1.23	A1-33
30615F3	Dan Nelson	8.9963	+2.13 / -3.96	A1-36
30617F3	Dan Nelson	8.5116	+2.27 / -3.12	A1-40
30618F3	Dan Nelson	8.7558	+2.45 / -3.31	A1-44
30619F3	Dan Nelson	8.8558	+1.84 / -3.40	A1-48
30620F3	Dan Nelson	8.9975	+2.44 / -3.83	A1-52
30652F3	Dan Nelson	9.0169	+2.33 / -3.59	A1-56
30655F3	Dan Nelson	8.8484	+1.72 / -3.16	A1-60
30663F3	Dan Nelson	8.9364	+1.95 / -2.92	A1-64
30666F3	Dan Nelson	8.4432	+2.77 / -4.61	A1-68
30667F3	Dan Nelson	8.4130	+1.98 / -3.02	A1-72
30668F3	Dan Nelson	8.0322	+1.68 / -2.34	A1-76
30670F3	Dan Nelson	8.4814	+2.24 / -3.06	A1-80
30674F3	Dan Nelson	9.1727	+1.68 / -3.35	A1-84
30677F3	Dan Nelson	8.4110	+1.97 / -3.03	A1-88
30709F3	Dan Nelson	8.2325	+2.27 / -3.43	A1-92
30719E6	Dan Nelson	8.5989	+1.28 / -1.27	A1-96
30720E6	Dan Nelson	8.0593	+1.84 / -1.40	A1-99
30775F3	Dan Nelson	8.6023	+1.92 / -3.18	A1-102
30777F3	Dan Nelson	8.3169	+2.11 / -4.02	A1-106
30791F3	Dan Nelson	8.3430	+2.23 / -3.09	A1-110
30793F3	Dan Nelson	8.5658	+1.87 / -3.24	A1-114
30796F3	Dan Nelson	8.6786	+2.16 / -3.21	A1-118
30799F3	Dan Nelson	8.0764	+2.39 / -3.31	A1-122
30811F3	Dan Nelson	8.6263	+1.69 / -2.62	A1-126
30812F3	Dan Nelson	8.2450	+2.02 / -2.89	A1-130
30813F3	Dan Nelson	8.3120	+2.14 / -3.70	A1-134
30818F3	Dan Nelson	8.2663	+2.12 / -3.00	A1-138
30820F3	Dan Nelson	8.2610	+2.18 / -3.18	A1-142
30823F3	Dan Nelson	8.3592	+1.77 / -3.05	A1-146
30890F3	Dan Nelson	8.0303	+1.97 / -3.57	A1-150
30891F3	Dan Nelson	7.6743	+2.23 / -3.30	A1-154
30894F3	Dan Nelson	8.2566	+2.13 / -3.32	A1-158
30901F3	Dan Nelson	8.1519	+1.69 / -2.86	A1-162
30948F3	Dan Nelson	8.4594	+1.66 / -2.86	A1-166
30952F3	Dan Nelson	8.8956	+1.71 / -2.67	A1-170
30957F3	Dan Nelson	8.8867	+1.72 / -3.21	A1-174
30958F3	Dan Nelson	9.1027	+1.67 / -2.65	A1-178
30961F3	Dan Nelson	8.9543	+1.71 / -3.18	A1-182
31099F3	Calibration System	7.7475	+2.14 / -2.97	A1-186

Results Summary

Table 2. Results Summary

Instrument	Customer	Rs@45 (µV/W/m²)	U95 (%)	Page
31100F3	Calibration System	8.0146	+2.10 / -3.42	A1-190
31101F3	Calibration System	8.4546	+2.18 / -3.31	A1-194
31120E6	Calibration System	8.5025	+0.87 / -1.15	A1-198
31121E6	Dan Nelson	8.4807	+1.41 / -1.37	A1-201
31122E6	Calibration System	8.8682	+0.87 / -0.98	A1-204
31146F3	Dan Nelson	7.9699	+2.00 / -2.88	A1-207
31147F3	Dan Nelson	7.9224	+2.08 / -3.17	A1-211
31148F3	Dan Nelson	7.9643	+1.95 / -2.73	A1-215
31149F3	Calibration System	8.3869	+1.91 / -2.87	A1-219
31150F3	Calibration System	8.2043	+1.93 / -2.92	A1-223
31151F3	Calibration System	8.0323	+2.01 / -2.89	A1-227
31152F3	Calibration System	8.6624	+1.75 / -3.06	A1-231
31153F3	Calibration System	8.3560	+2.00 / -3.05	A1-235
31154F3	Calibration System	8.0660	+1.87 / -3.33	A1-239
31155F3	Dan Nelson	8.2021	+1.47 / -2.72	A1-243
31156F3	Dan Nelson	8.0906	+1.61 / -2.81	A1-247
31157F3	Dan Nelson	8.1870	+1.65 / -2.84	A1-251
31158F3	Calibration System	8.3774	+1.56 / -2.17	A1-255
31159F3	Calibration System	8.1333	+1.66 / -2.57	A1-259
31160F3	Calibration System	8.4203	+1.69 / -2.63	A1-263
31387E6	Dan Nelson	8.3931	+1.66 / -1.37	A1-267
31388E6	Dan Nelson	8.9226	+1.02 / -1.16	A1-270
31629F3	Dan Nelson	8.7392	+2.39 / -2.80	A1-273
31630F3	Dan Nelson	8.5896	+1.78 / -2.50	A1-277
31631F3	Dan Nelson	8.9270	+2.47 / -4.21	A1-281
31632F3	Dan Nelson	8.0067	+2.47 / -3.26	A1-285
31633F3	Dan Nelson	8.9875	+2.23 / -3.50	A1-289
31634F3	Dan Nelson	8.7478	+1.84 / -3.04	A1-293
31635F3	Dan Nelson	8.8881	+1.65 / -3.06	A1-297
31636F3	Dan Nelson	8.7533	+2.06 / -2.89	A1-301
31747E6	Dan Nelson	8.3441	+1.14 / -1.19	A1-305
5034	Calibration System	8.4049	+1.84 / -2.33	A1-308
PY22692	Dan Nelson	8.9950	+2.29 / -1.86	A1-311

Note: Ancillary Data for BORCAL starts on page A1-315.

Appendix 1
Instrument Details

Calibration Certificates: Page 1 and 2 for each instrument
Suggested Methods: 1 Page for each Pyrheliometer/Shaded Pyranometer and 2 Pages for each Unshaded Pyranometer
Ancillary Data for BORCAL: Page 3 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 **Manufacturer:** Eppley

Model: PSP **Serial Number:** 20386F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____
Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____
Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

20386F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

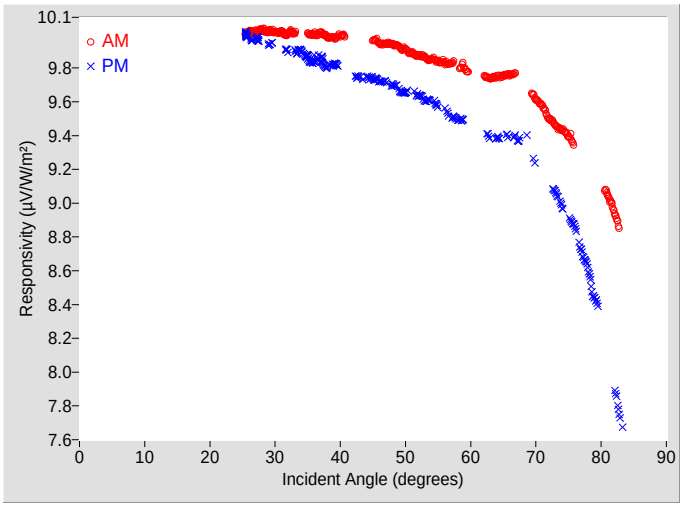


Figure 2. Responsivity vs Local Standard Time

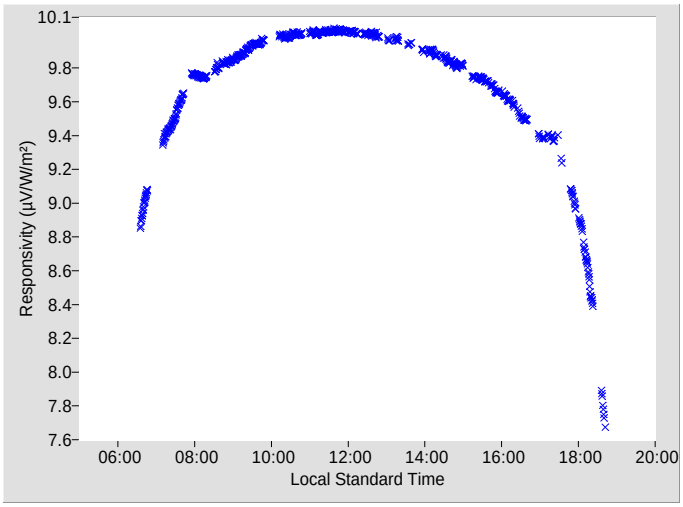


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
9.8503	+2.46 / -4.36	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.9461	0.72	113.07	9.7219	0.69	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.9411	0.72	110.68	9.6980	0.71	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.9147	0.76	108.48	9.6559	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8753	0.77	106.40	9.6378	0.78	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8532	0.78	104.43	9.6061	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8352	0.81	102.59	9.5615	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	9.4922	0.82	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7499	0.96	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7500	1.01	95.29	9.3869	0.94	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7611	1.08	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.6151	1.32	90.69	9.2382	N/A	272.44
26	10.012	0.63	166.50	9.9814	0.67	192.61	72	9.5011	1.54	89.19	N/A	N/A	N/A
28	10.025	0.60	153.79	N/A	N/A	N/A	74	9.4361	1.61	87.73	8.9814	1.62	275.41
30	10.013	0.60	144.99	N/A	N/A	N/A	76	9.3439	N/A	86.42	8.8596	2.04	276.84
32	10.006	0.62	138.24	9.9024	0.65	222.18	78	N/A	N/A	N/A	8.6080	2.62	278.31
34	N/A	N/A	N/A	9.9030	0.71	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	10.001	0.63	128.67	9.8429	0.67	237.64	82	8.9486	3.56	81.85	7.8824	3.69	281.35
38	9.9853	0.66	124.75	9.8029	0.72	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.9928	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	9.7523	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	9.7466	0.67	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

20386F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

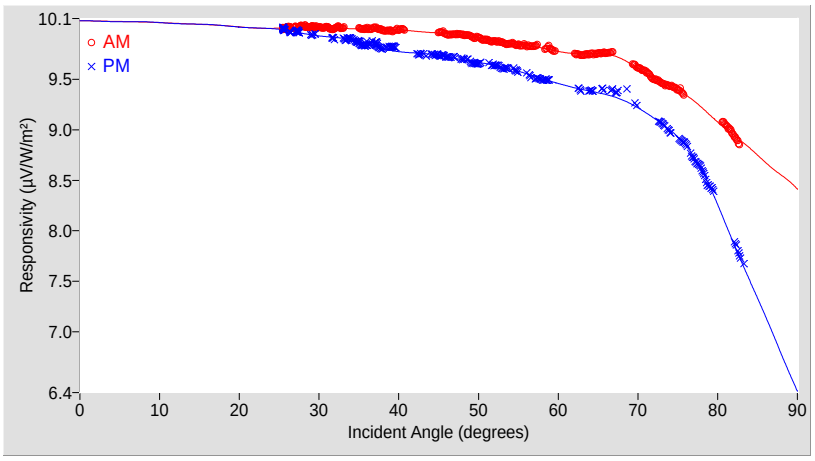


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.88	±1.88
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R^2	0.9999998	0.9999994

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	10.072	*	10.072	*	10.072	*
9-18	10.048	*	10.048	*	10.048	*
18-27	10.012	*	10.006	*	10.009	*
27-36	10.010	±1.89	9.9178	±1.96	9.9640	±2.22
36-45	9.9831	±1.89	9.7809	±1.96	9.8820	±2.63
45-54	9.9160	±1.95	9.6750	±1.99	9.7955	±3.13
54-63	9.8021	±1.95	9.5009	±2.14	9.6515	±3.79
63-72	9.6894	±2.21	9.2992	±2.33	9.4943	±4.99
72-81	9.3052	±3.14	8.7486	±5.75	9.0269	±11.10
81-90	8.7154	*	7.2391	*	7.9772	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

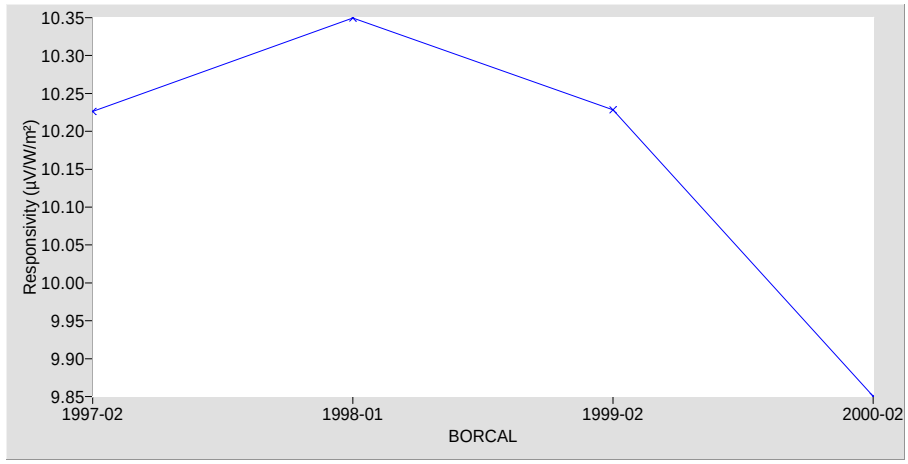
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	9.8503	+2.46 / -4.36 [1]
45° - 55°	9.7847	±2.70 [2]
Composite	9.8638	+2.46 / -22.11 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



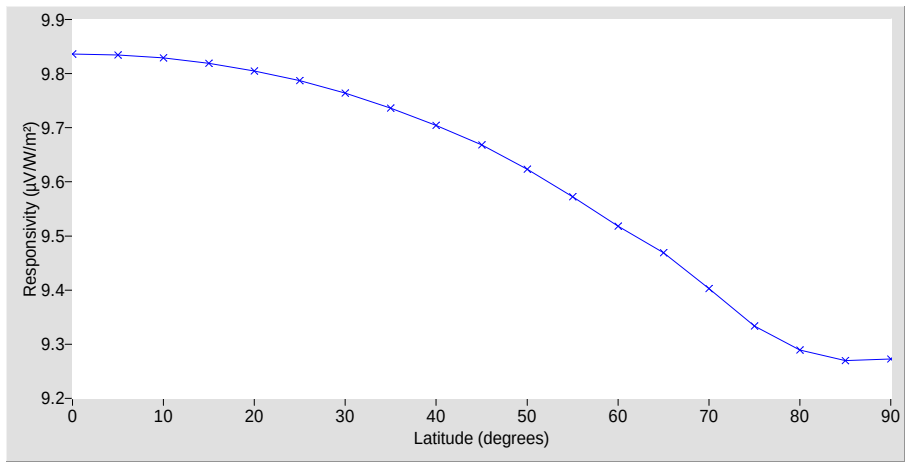
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	9.8359	+3.11 / -33.04
5	9.8345	+3.12 / -33.03
10	9.8289	+3.17 / -32.99
15	9.8189	+3.25 / -32.93
20	9.8051	+3.37 / -32.83
25	9.7870	+3.52 / -32.71
30	9.7640	+3.65 / -32.55
35	9.7362	+3.79 / -32.36
40	9.7045	+3.95 / -32.14
45	9.6680	+4.10 / -31.88
50	9.6235	+4.53 / -31.57
55	9.5723	+4.99 / -31.20
60	9.5182	+5.37 / -30.81
65	9.4691	+5.74 / -30.45
70	9.4027	+6.14 / -29.96
75	9.3335	+6.30 / -29.44
80	9.2894	+6.16 / -29.11
85	9.2698	+5.63 / -28.96
90	9.2725	+5.47 / -28.98

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 29554E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29554E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

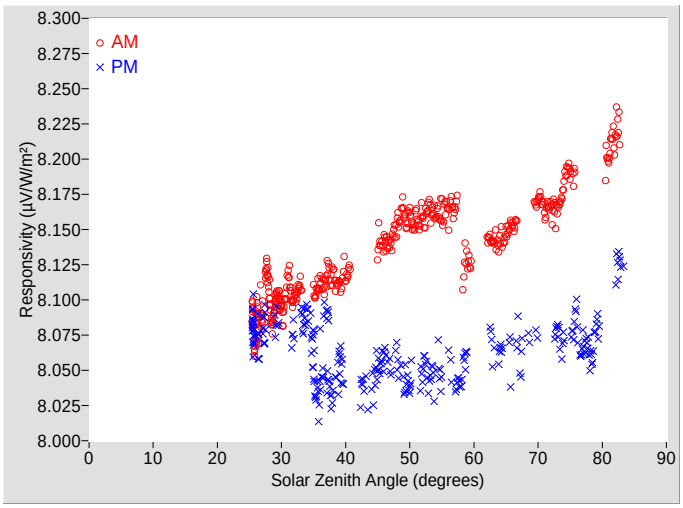


Figure 2. Responsivity vs Local Standard Time

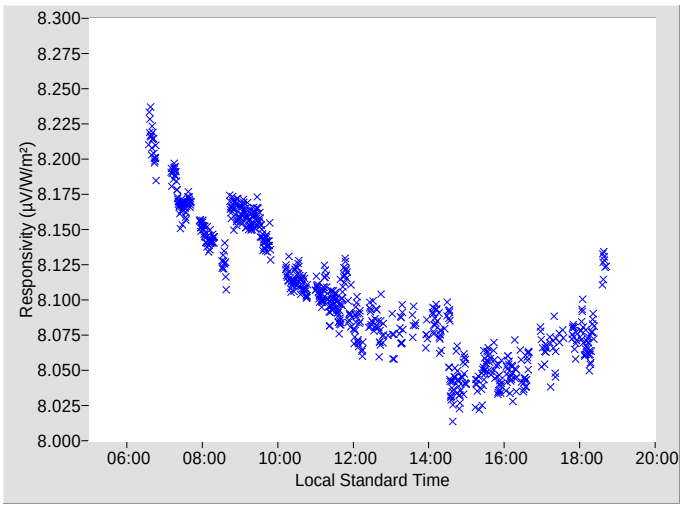


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0959	+1.40 / -1.45	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1410	0.45	113.03	8.0605	0.45	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1524	0.49	110.71	8.0572	0.46	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1608	0.45	108.45	8.0415	0.46	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1593	0.45	106.43	8.0522	0.47	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1615	0.45	104.45	8.0280	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1629	0.46	102.62	8.0643	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1073	N/A	100.02	8.0399	0.47	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1434	0.45	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1420	0.46	95.31	8.0631	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1527	0.46	93.72	8.0381	N/A	269.38
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1717	0.47	90.67	8.0730	N/A	272.45
26	8.0807	0.53	166.54	8.0800	0.52	192.77	72	8.1642	0.49	89.17	N/A	N/A	N/A
28	8.1096	0.54	153.68	N/A	N/A	N/A	74	8.1807	0.51	87.75	8.0689	0.49	275.34
30	8.0919	0.48	145.04	N/A	N/A	N/A	76	8.1908	N/A	86.43	8.0872	0.54	276.86
32	8.1010	0.47	138.29	8.0780	0.45	222.23	78	N/A	N/A	N/A	8.0625	0.52	278.32
34	N/A	N/A	N/A	8.0905	0.51	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1104	0.44	128.71	8.0396	0.68	237.75	82	8.2173	0.65	81.86	8.1217	0.60	281.35
38	8.1182	0.45	124.78	8.0295	0.61	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1184	0.46	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.0237	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0366	0.51	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29554E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

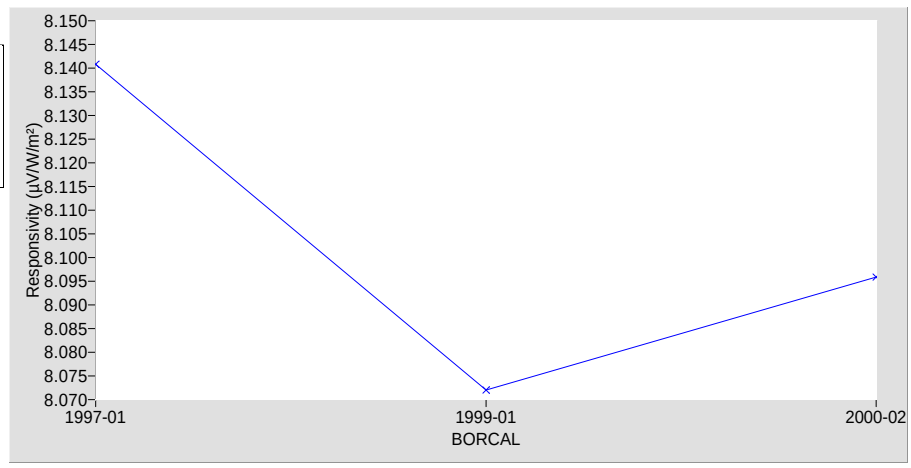
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0959	+1.40 / -1.45 †
Average	8.1039	+2.05 / -1.53 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 29555E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29555E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

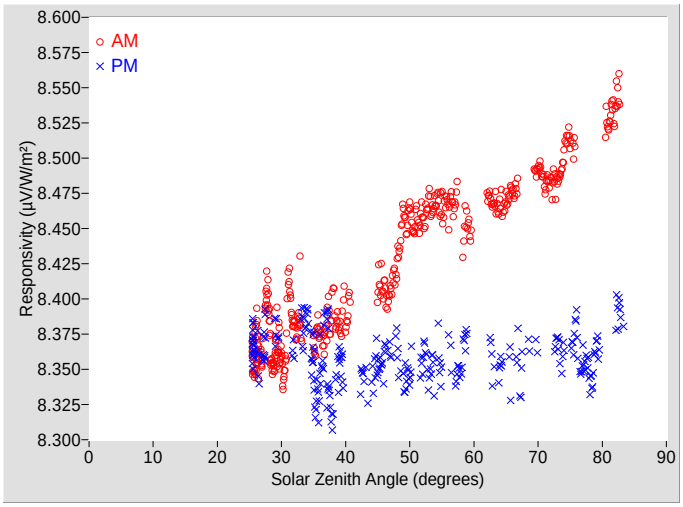

Figure 2. Responsivity vs Local Standard Time

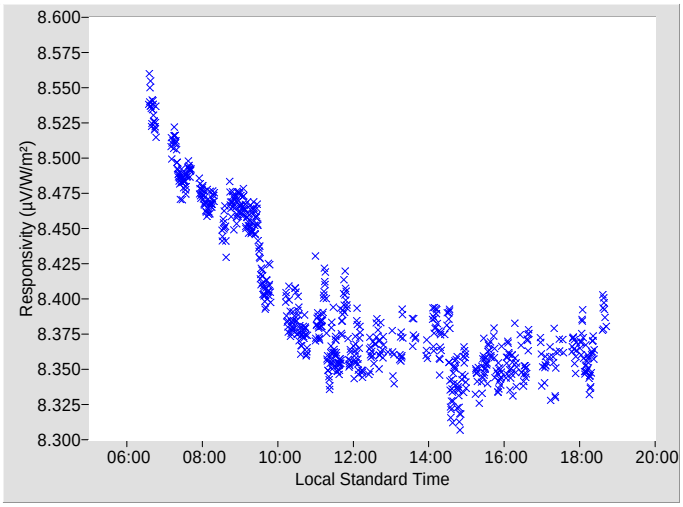

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3816	+1.65 / -1.33	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4080	0.47	113.03	8.3585	0.47	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4229	0.58	110.71	8.3640	0.48	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4624	0.45	108.45	8.3483	0.48	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4589	0.46	106.43	8.3595	0.48	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4684	0.45	104.45	8.3311	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4649	0.47	102.62	8.3746	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4295	N/A	100.02	8.3475	0.50	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4727	0.45	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4670	0.46	95.31	8.3513	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4761	0.46	93.72	8.3280	N/A	269.38
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4928	0.47	90.67	8.3618	N/A	272.45
26	8.3636	0.52	166.54	8.3690	0.51	192.77	72	8.4815	0.48	89.17	N/A	N/A	N/A
28	8.3911	0.61	153.68	N/A	N/A	N/A	74	8.5009	0.52	87.75	8.3597	0.49	275.34
30	8.3531	0.58	145.04	N/A	N/A	N/A	76	8.5081	N/A	86.43	8.3784	0.54	276.86
32	8.3795	0.56	138.29	8.3640	0.44	222.23	78	N/A	N/A	N/A	8.3460	0.52	278.32
34	N/A	N/A	N/A	8.3875	0.52	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3760	0.46	128.71	8.3411	0.64	237.75	82	8.5359	0.63	81.86	8.3903	0.59	281.35
38	8.3962	0.49	124.78	8.3140	0.67	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3867	0.48	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.3323	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3421	0.51	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29555E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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where,

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1. The Single Responsivities:

Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3816	+1.65 / -1.33 †
Average	8.4015	+2.24 / -1.71 ‡

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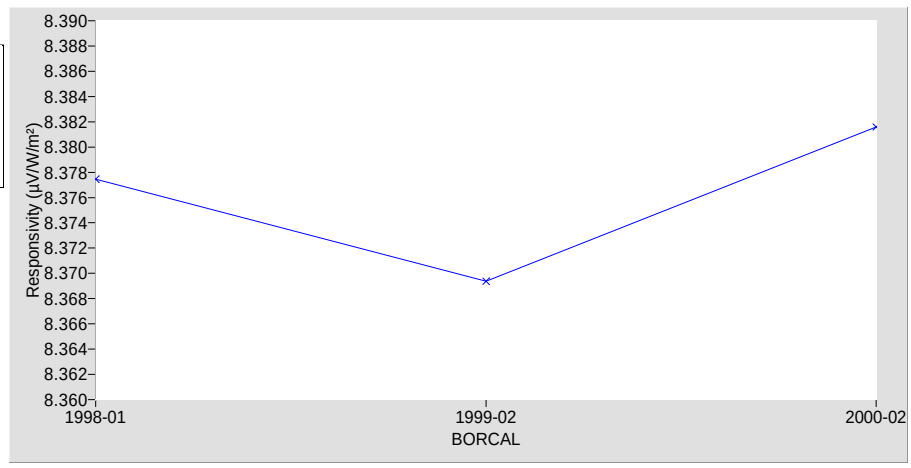
Figure 1. History of instrument at Z = 45°



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The responsivities above are applied according to equation [1]:

Example

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Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 29738E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29738E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

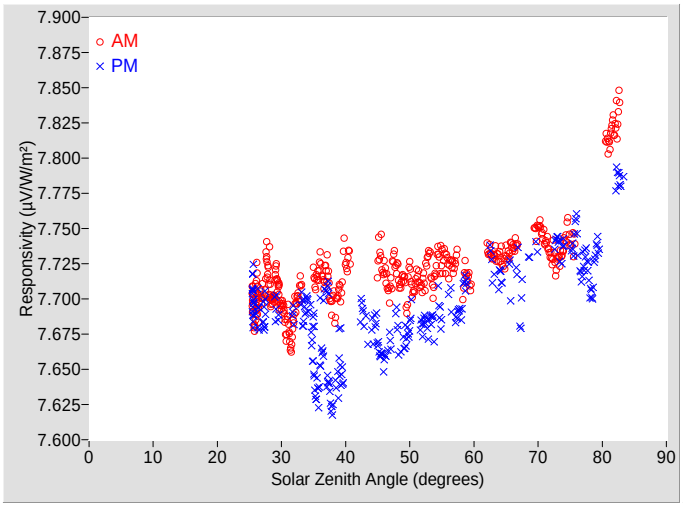


Figure 2. Responsivity vs Local Standard Time

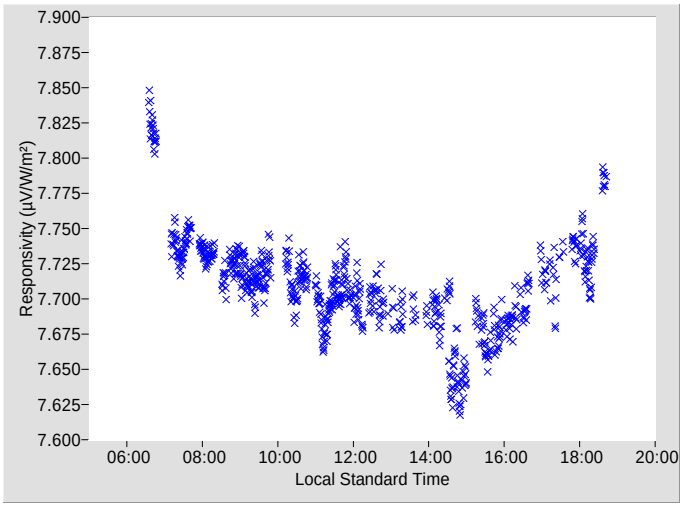


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.6990	+1.05 / -1.49	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7207	0.54	113.03	7.6571	0.47	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7213	0.47	110.71	7.6806	0.49	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7181	0.50	108.45	7.6827	0.49	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7112	0.48	106.43	7.6828	0.45	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7191	0.50	104.45	7.6696	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7248	0.46	102.62	7.7032	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6995	N/A	100.02	7.6904	0.49	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7349	0.46	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7312	0.46	95.31	7.7157	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7370	0.47	93.72	7.6987	N/A	269.38
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7506	0.48	90.67	7.7334	N/A	272.45
26	7.6977	0.54	166.54	7.6982	0.53	192.77	72	7.7295	0.51	89.17	N/A	N/A	N/A
28	7.7159	0.53	153.68	N/A	N/A	N/A	74	7.7368	0.53	87.75	7.7357	0.49	275.34
30	7.6952	0.56	145.04	N/A	N/A	N/A	76	7.7390	N/A	86.43	7.7499	0.57	276.86
32	7.6902	0.56	138.29	7.6893	0.44	222.23	78	N/A	N/A	N/A	7.7123	0.55	278.32
34	N/A	N/A	N/A	7.6965	0.54	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7235	0.47	128.71	7.6525	0.70	237.75	82	7.8249	0.67	81.86	7.7853	0.60	281.35
38	7.6960	0.54	124.78	7.6216	0.76	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7269	0.52	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	7.6837	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.6774	0.46	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29738E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

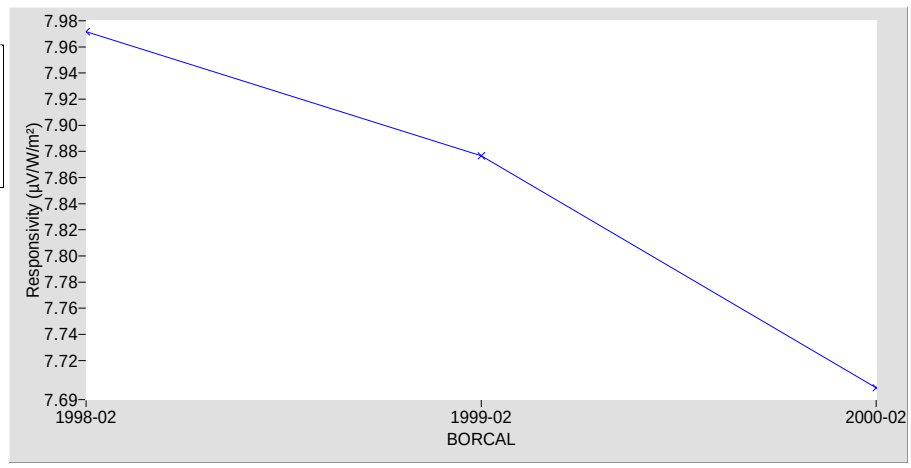
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.6990	+1.05 / -1.49 †
Average	7.7114	+2.15 / -1.92 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 29740E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29740E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

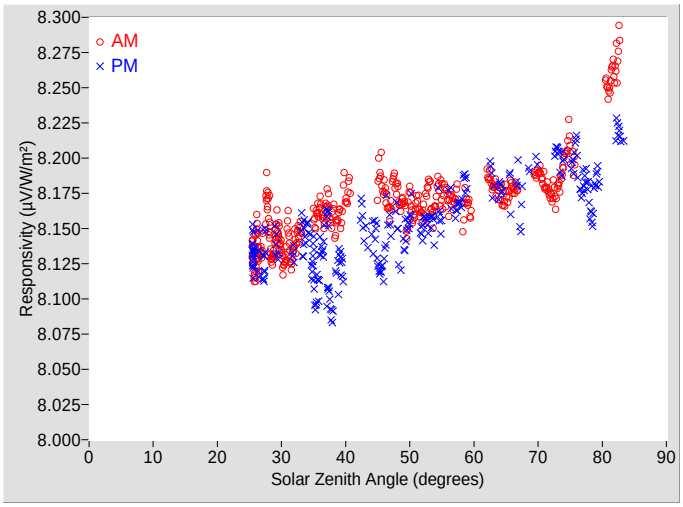


Figure 2. Responsivity vs Local Standard Time

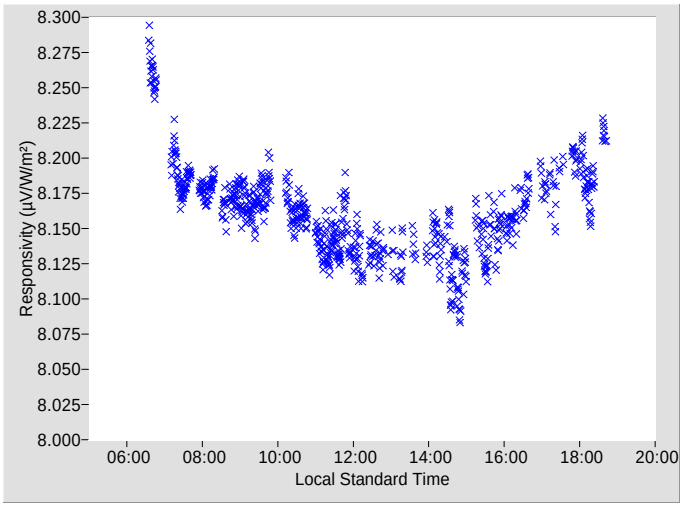


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.1564	+1.02 / -1.33	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1780	0.53	113.03	8.1279	0.57	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1776	0.47	110.71	8.1509	0.52	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1716	0.49	108.45	8.1585	0.50	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1612	0.48	106.43	8.1513	0.45	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1681	0.49	104.45	8.1382	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1702	0.46	102.62	8.1770	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1477	N/A	100.02	8.1679	0.48	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1877	0.46	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1758	0.46	95.31	8.1783	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1787	0.46	93.72	8.1601	N/A	269.38
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1903	0.47	90.67	8.1954	N/A	272.45
26	8.1325	0.52	166.54	8.1385	0.49	192.77	72	8.1724	0.49	89.17	N/A	N/A	N/A
28	8.1598	0.59	153.68	N/A	N/A	N/A	74	8.1957	0.57	87.75	8.1973	0.48	275.34
30	8.1325	0.52	145.04	N/A	N/A	N/A	76	8.1952	N/A	86.43	8.2057	0.55	276.86
32	8.1381	0.50	138.29	8.1324	0.44	222.23	78	N/A	N/A	N/A	8.1684	0.55	278.32
34	N/A	N/A	N/A	8.1496	0.52	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1649	0.45	128.71	8.1241	0.62	237.75	82	8.2651	0.66	81.86	8.2203	0.59	281.35
38	8.1572	0.48	124.78	8.0879	0.65	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1733	0.50	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.1559	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.1444	0.48	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29740E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

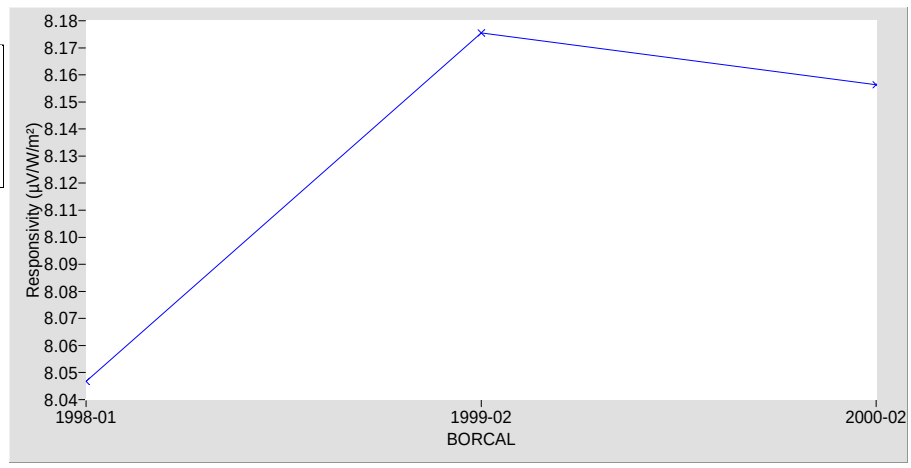
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1564	+1.02 / -1.33 †
Average	8.1671	+1.87 / -1.62 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 29741E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29741E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

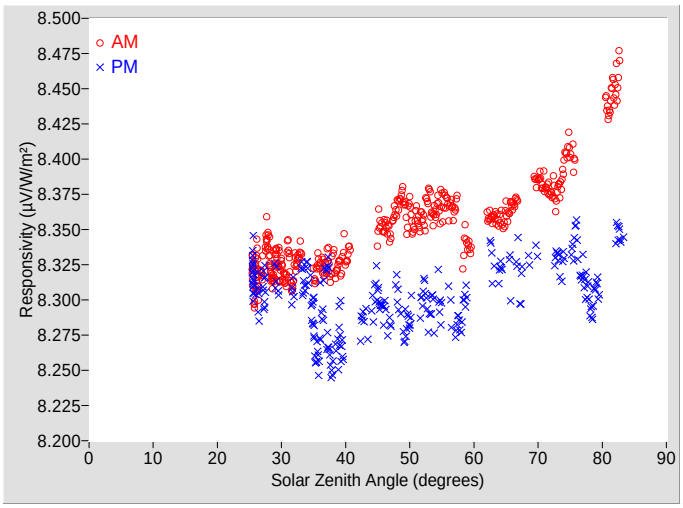


Figure 2. Responsivity vs Local Standard Time

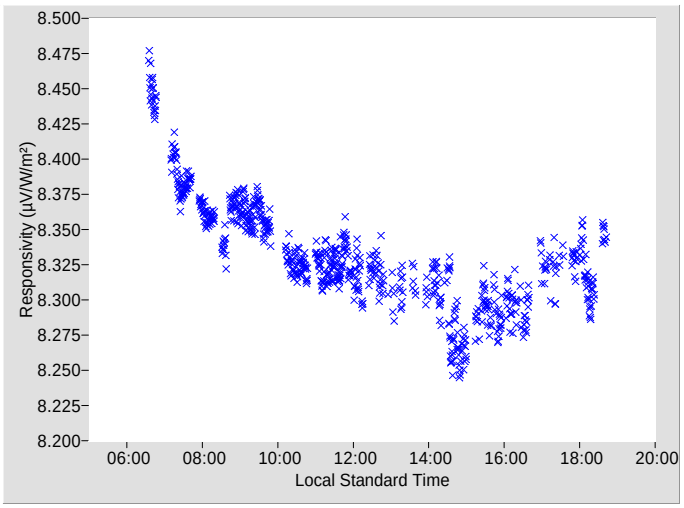


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3280	+1.06 / -1.43	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3515	0.46	113.03	8.2933	0.48	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3650	0.49	110.71	8.3055	0.50	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3652	0.46	108.45	8.2873	0.48	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3586	0.47	106.43	8.3058	0.49	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3631	0.46	104.45	8.2764	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3672	0.45	102.62	8.3098	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3221	N/A	100.02	8.2799	0.49	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3588	0.45	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3577	0.45	95.31	8.3212	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3674	0.46	93.72	8.2993	N/A	269.38
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3857	0.47	90.67	8.3309	N/A	272.45
26	8.3163	0.52	166.54	8.3123	0.57	192.77	72	8.3749	0.49	89.17	N/A	N/A	N/A
28	8.3362	0.53	153.68	N/A	N/A	N/A	74	8.3944	0.55	87.75	8.3260	0.48	275.34
30	8.3202	0.47	145.04	N/A	N/A	N/A	76	8.3993	N/A	86.43	8.3467	0.54	276.86
32	8.3212	0.48	138.29	8.3081	0.45	222.23	78	N/A	N/A	N/A	8.3000	0.53	278.32
34	N/A	N/A	N/A	8.3198	0.51	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3256	0.45	128.71	8.2730	0.63	237.75	82	8.4509	0.65	81.86	8.3475	0.58	281.35
38	8.3260	0.46	124.78	8.2496	0.67	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3308	0.47	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.2707	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2933	0.53	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29741E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

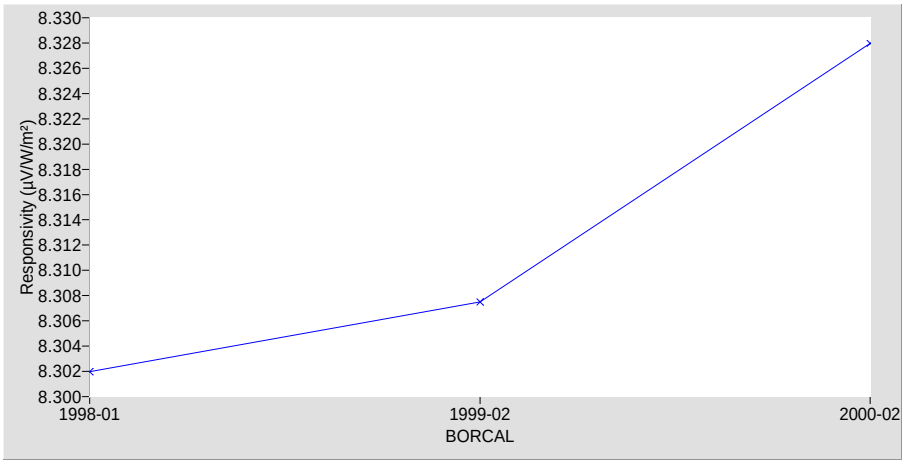
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3280	+1.06 / -1.43 †
Average	8.3326	+2.08 / -1.67 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
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Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer **Manufacturer:** Eppley

Model: NIP **Serial Number:** 29847E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29847E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

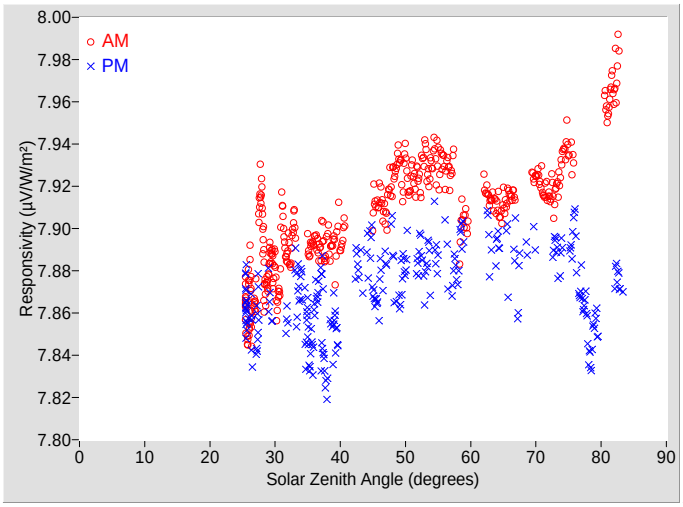


Figure 2. Responsivity vs Local Standard Time

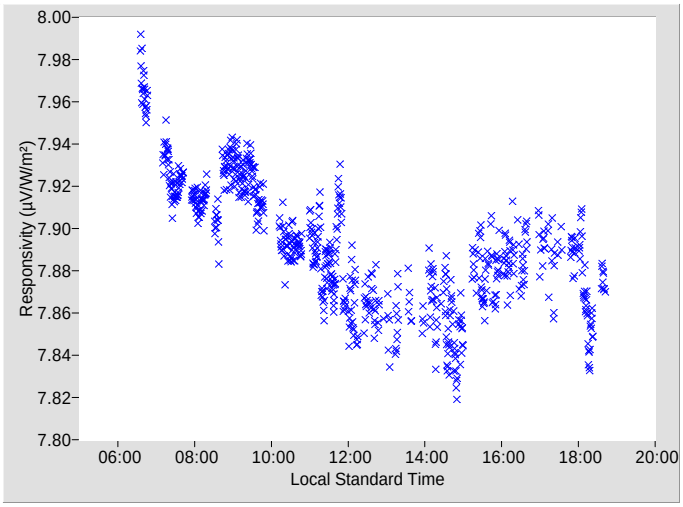


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.8917	+1.09 / -1.35	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9147	0.45	113.03	7.8727	0.48	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9220	0.51	110.71	7.8894	0.51	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9318	0.47	108.45	7.8846	0.49	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9246	0.47	106.43	7.8885	0.49	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9305	0.46	104.45	7.8684	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9289	0.46	102.62	7.9040	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8832	N/A	100.02	7.8764	0.49	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9203	0.46	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9120	0.46	95.31	7.8924	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9158	0.46	93.72	7.8674	N/A	269.38
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9251	0.47	90.67	7.8899	N/A	272.45
26	7.8636	0.53	166.54	7.8634	0.53	192.77	72	7.9147	0.49	89.17	N/A	N/A	N/A
28	7.9052	0.62	153.68	N/A	N/A	N/A	74	7.9321	0.53	87.75	7.8881	0.48	275.34
30	7.8767	0.51	145.04	N/A	N/A	N/A	76	7.9310	N/A	86.43	7.8995	0.55	276.86
32	7.8879	0.49	138.29	7.8586	0.44	222.23	78	N/A	N/A	N/A	7.8471	0.55	278.32
34	N/A	N/A	N/A	7.8741	0.57	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8943	0.44	128.71	7.8543	0.54	237.75	82	7.9692	0.66	81.86	7.8768	0.60	281.35
38	7.8925	0.45	124.78	7.8252	0.61	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8951	0.50	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	7.8761	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.8877	0.48	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29847E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

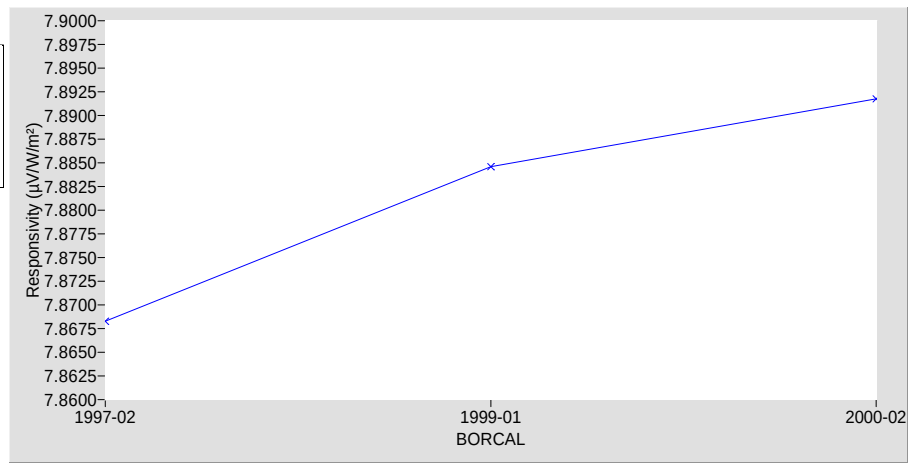
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.8917	+1.09 / -1.35 †
Average	7.8959	+1.59 / -1.50 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 29851E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

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Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29851E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

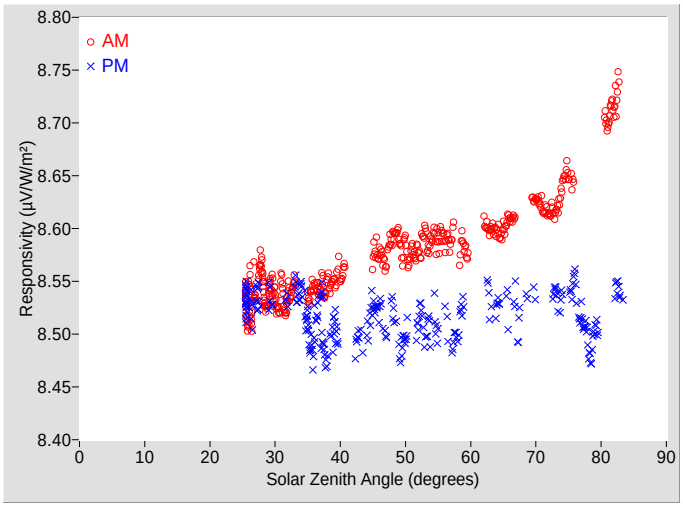

Figure 2. Responsivity vs Local Standard Time

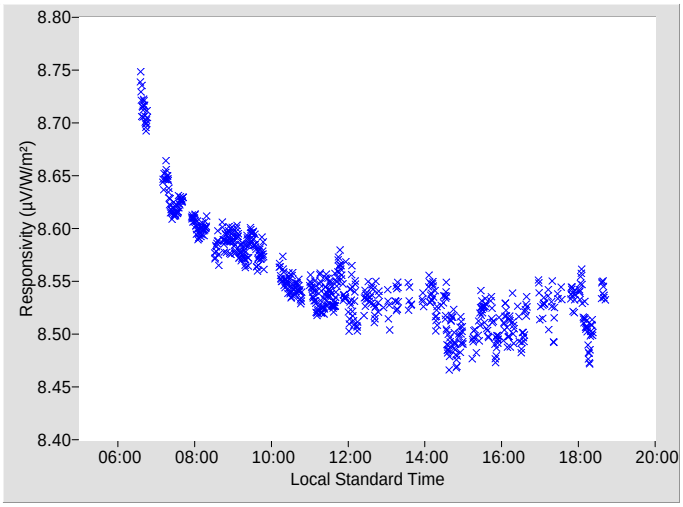

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.5505	+1.08 / -1.42	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5759	0.47	113.03	8.5254	0.48	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5904	0.48	110.71	8.5234	0.51	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5845	0.47	108.45	8.4991	0.50	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5791	0.48	106.43	8.5167	0.50	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5898	0.46	104.45	8.4877	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5889	0.46	102.62	8.5263	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5652	N/A	100.02	8.4963	0.54	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6050	0.46	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5984	0.45	95.31	8.5271	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6096	0.46	93.72	8.5043	N/A	269.38
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6276	0.46	90.67	8.5327	N/A	272.45
26	8.5300	0.58	166.54	8.5346	0.51	192.77	72	8.6129	0.47	89.17	N/A	N/A	N/A
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44	N/A	N/A	N/A	8.5016	0.55	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

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29851E6 Eppley NIP

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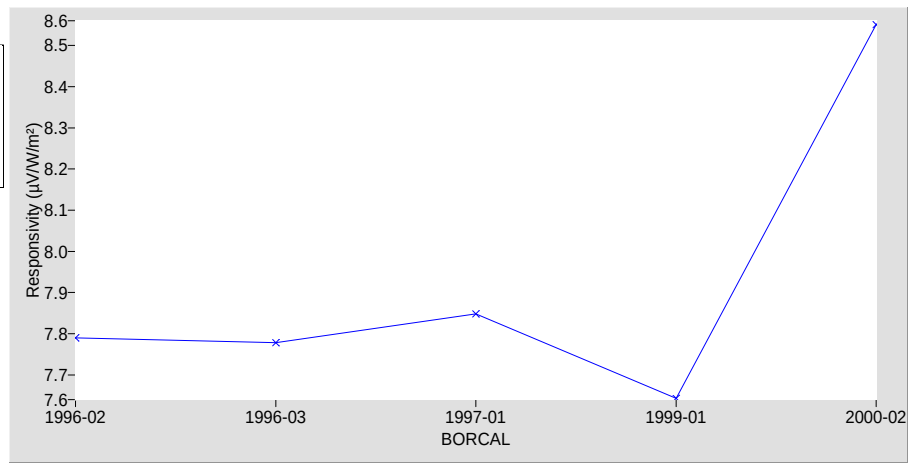

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National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer **Manufacturer:** Eppley

Model: NIP **Serial Number:** 29856E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

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Certified by:

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Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29856E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

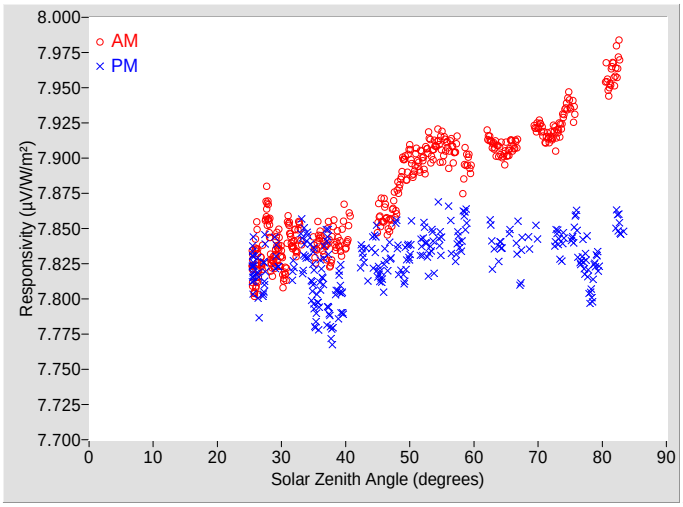

Figure 2. Responsivity vs Local Standard Time

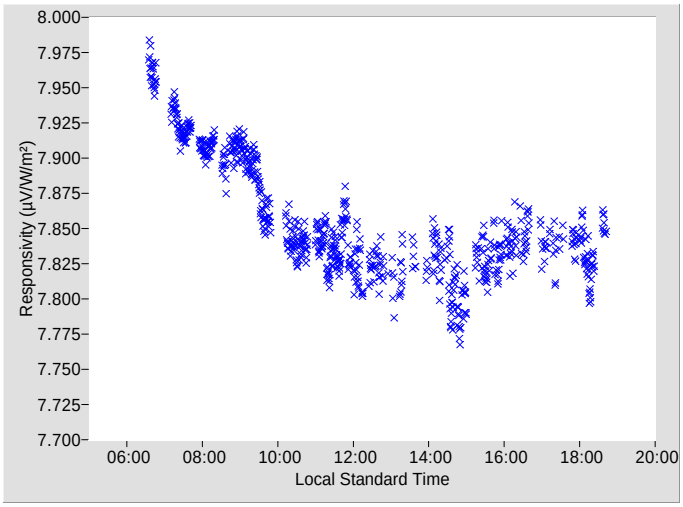

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.8402	+1.46 / -1.36	N/A

† Valid zenith angle range: 30.0° to 60.0°

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	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8627	0.47	113.03	7.8213	0.49	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8694	0.54	110.71	7.8402	0.50	254.33
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10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9056	0.47	102.62	7.8660	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8747	N/A	100.02	7.8371	0.50	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9164	0.46	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9063	0.46	95.31	7.8361	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9091	0.46	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9231	0.47	90.67	7.8426	N/A	272.45
26	7.8226	0.55	166.54	7.8235	0.57	192.77	72	7.9144	0.49	89.17	N/A	N/A	N/A
28	7.8556	0.59	153.68	N/A	N/A	N/A	74	7.9301	0.52	87.75	7.8391	0.49	275.34
30	7.8259	0.53	145.04	N/A	N/A	N/A	76	7.9310	N/A	86.43	7.8520	0.54	276.86
32	7.8396	0.47	138.29	7.8230	0.44	222.23	78	N/A	N/A	N/A	7.8081	0.58	278.32
34	N/A	N/A	N/A	7.8383	0.57	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8445	0.47	128.71	7.8053	0.63	237.75	82	7.9630	0.66	81.86	7.8567	0.60	281.35
38	7.8406	0.48	124.78	7.7743	0.68	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8438	0.49	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	7.8221	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.8339	0.50	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29856E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

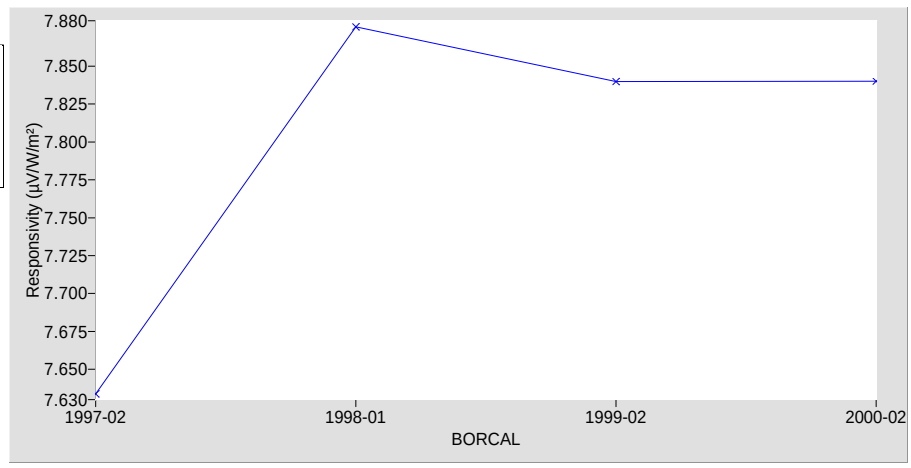
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.8402	+1.46 / -1.36 †
Average	7.8607	+1.97 / -1.77 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 29935E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29935E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

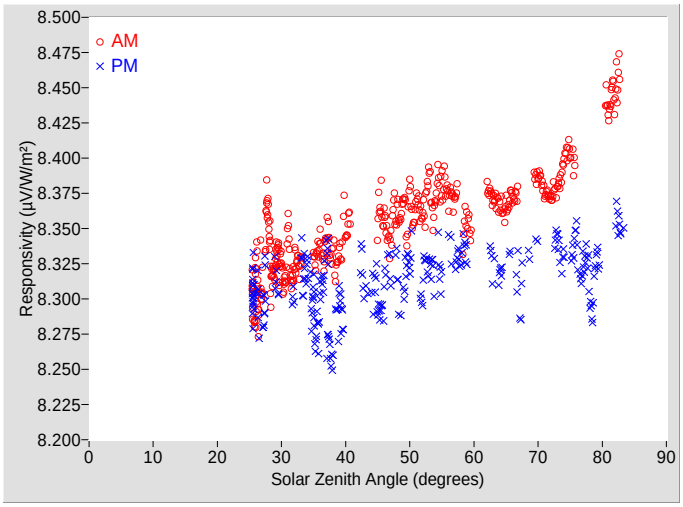


Figure 2. Responsivity vs Local Standard Time

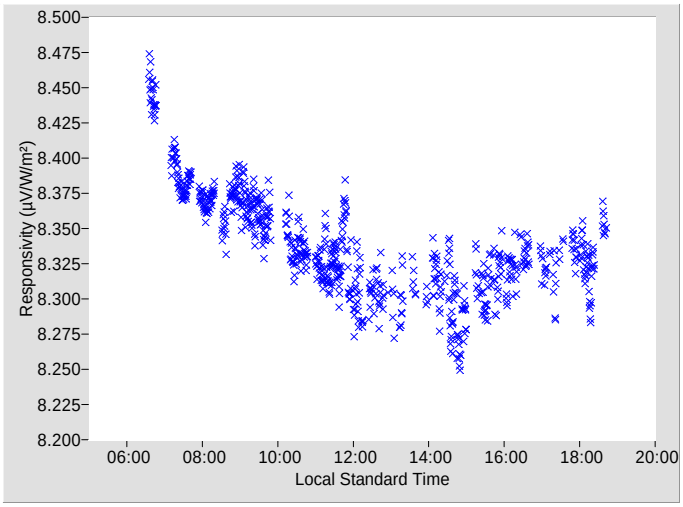


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3276	+1.25 / -1.37	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3570	0.55	113.03	8.3055	0.52	252.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3591	0.49	110.71	8.3166	0.52	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3727	0.52	108.45	8.3292	0.52	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3618	0.51	106.43	8.3112	0.48	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3700	0.52	104.45	8.3018	N/A	259.77
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3744	0.48	102.62	8.3456	N/A	261.76
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3316	N/A	100.02	8.3267	0.46	263.37
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3784	0.46	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3676	0.46	95.31	8.3176	0.45	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3729	0.46	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3869	0.47	90.67	8.3408	N/A	272.45
26	8.3041	0.60	166.54	8.3091	0.57	192.77	72	8.3717	0.47	89.17	N/A	N/A	N/A
28	8.3525	0.69	153.68	N/A	N/A	N/A	74	8.3969	0.52	87.75	8.3282	0.49	275.34
30	8.3223	0.51	145.04	N/A	N/A	N/A	76	8.3949	N/A	86.43	8.3424	0.54	276.86
32	8.3232	0.54	138.29	8.3028	0.44	222.23	78	N/A	N/A	N/A	8.3075	0.59	278.32
34	N/A	N/A	N/A	8.3215	0.59	227.80	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3386	0.47	128.71	8.2942	0.65	237.75	82	8.4479	0.65	81.86	8.3606	0.59	281.35
38	8.3311	0.51	124.78	8.2556	0.71	241.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3505	0.51	121.30	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.3186	N/A	247.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3039	0.48	250.15	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29935E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

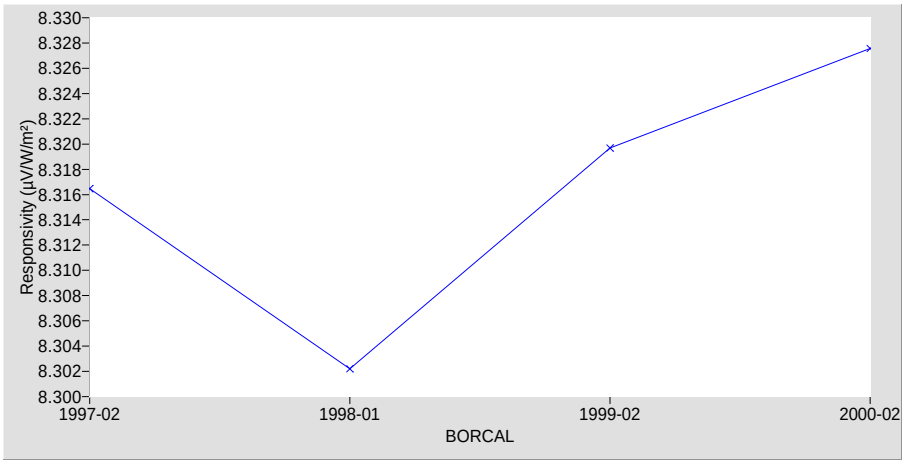
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3276	+1.25 / -1.37 †
Average	8.3408	+1.95 / -1.73 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 29936E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

29936E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

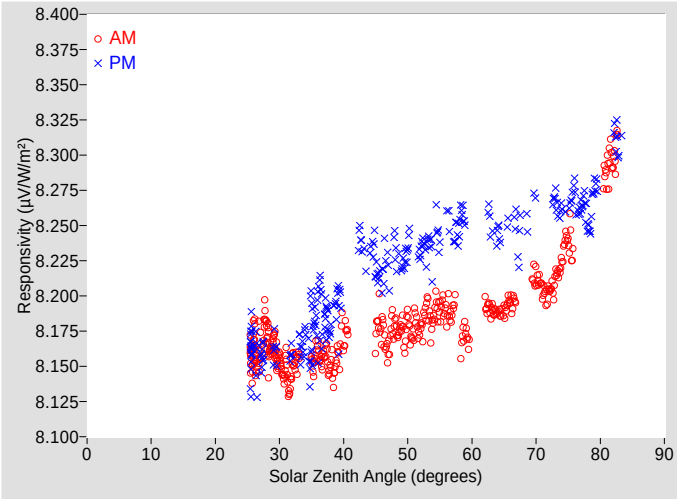


Figure 2. Responsivity vs Local Standard Time

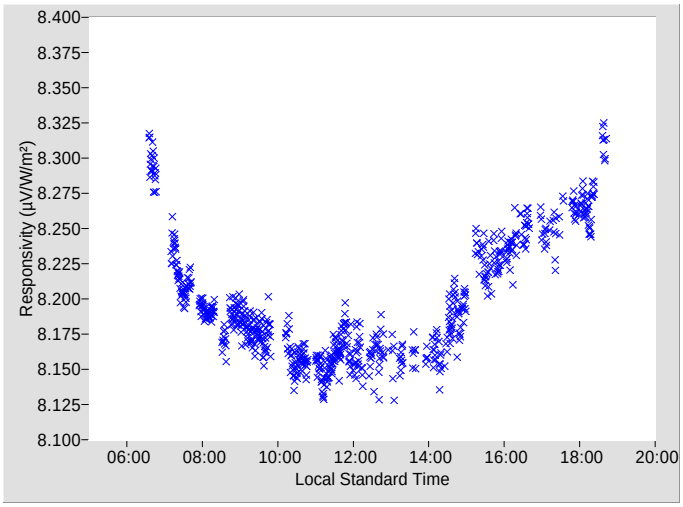


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.1996	+1.23 / -1.23	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1756	0.53	112.98	8.2122	0.49	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1778	0.48	110.72	8.2330	0.50	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1825	0.48	108.46	8.2355	0.47	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1774	0.47	106.43	8.2324	0.45	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1836	0.49	104.46	8.2101	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1873	0.46	102.63	8.2604	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1554	N/A	100.03	8.2486	0.47	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1937	0.46	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1889	0.45	95.32	8.2444	0.45	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1951	0.46	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2117	0.48	90.67	8.2695	N/A	272.46
26	8.1609	0.51	166.57	8.1656	0.57	192.79	72	8.2029	0.48	89.17	N/A	N/A	N/A
28	8.1762	0.55	153.70	N/A	N/A	N/A	74	8.2246	0.52	87.71	8.2608	0.48	275.35
30	8.1539	0.49	144.94	N/A	N/A	N/A	76	8.2336	N/A	86.44	8.2733	0.50	276.91
32	8.1495	0.48	138.30	8.1610	0.44	222.24	78	N/A	N/A	N/A	8.2518	0.52	278.33
34	N/A	N/A	N/A	8.1709	0.60	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1607	0.46	128.63	8.1870	0.58	237.13	82	8.2961	0.65	81.83	8.3193	0.60	281.36
38	8.1500	0.47	124.80	8.1746	0.49	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1722	0.50	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2329	0.48	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

29936E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

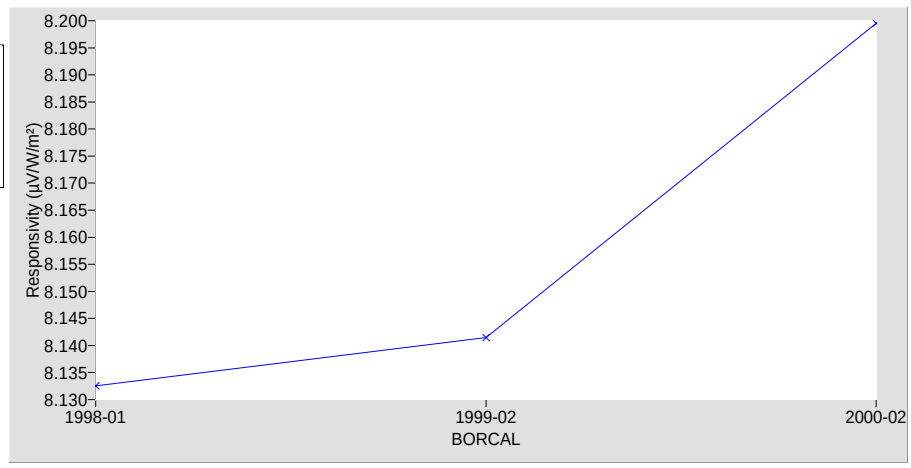
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1996	+1.23 / -1.23 †
Average	8.2095	+1.94 / -1.21 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 30615F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30615F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

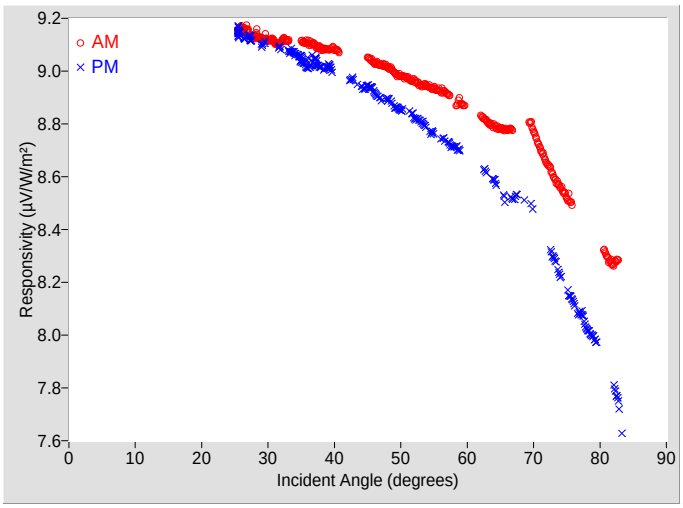


Figure 2. Responsivity vs Local Standard Time

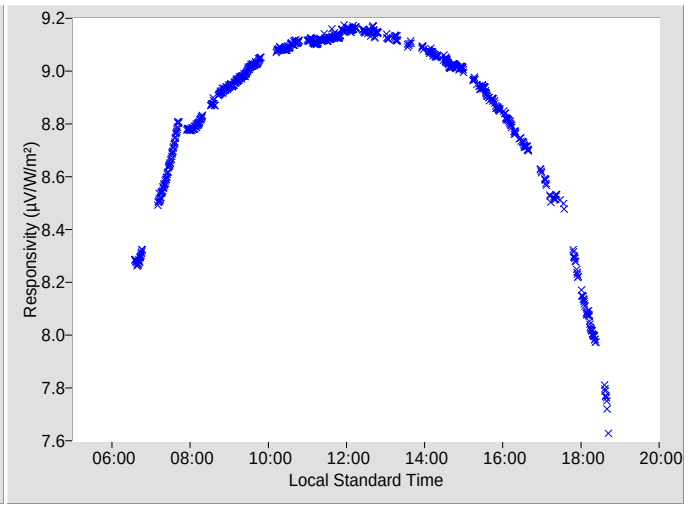


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9963	+2.13 / -3.96	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0308	0.72	113.07	8.9212	0.73	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0161	0.73	110.68	8.8936	0.71	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9829	0.74	108.48	8.8530	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9642	0.77	106.40	8.8260	0.75	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9444	0.78	104.43	8.7866	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9277	0.82	102.59	8.7435	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.7136	0.84	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8287	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7930	1.03	95.29	8.5868	0.96	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7787	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.7738	1.39	90.69	8.4782	N/A	272.44
26	9.1598	0.63	166.50	9.1432	0.68	192.61	72	8.6519	1.55	89.19	N/A	N/A	N/A
28	9.1324	0.63	153.79	N/A	N/A	N/A	74	8.5642	1.65	87.73	8.2269	1.60	275.41
30	9.1174	0.62	144.99	N/A	N/A	N/A	76	8.4926	N/A	86.42	8.1250	1.86	276.84
32	9.1133	0.62	138.24	9.0891	0.64	222.18	78	N/A	N/A	N/A	8.0254	2.19	278.31
34	N/A	N/A	N/A	9.0672	0.71	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1091	0.63	128.67	9.0194	0.69	237.64	82	8.2701	3.44	81.85	7.8033	3.59	281.35
38	9.0850	0.65	124.75	9.0156	0.68	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0848	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.9638	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.9383	0.67	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30615F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

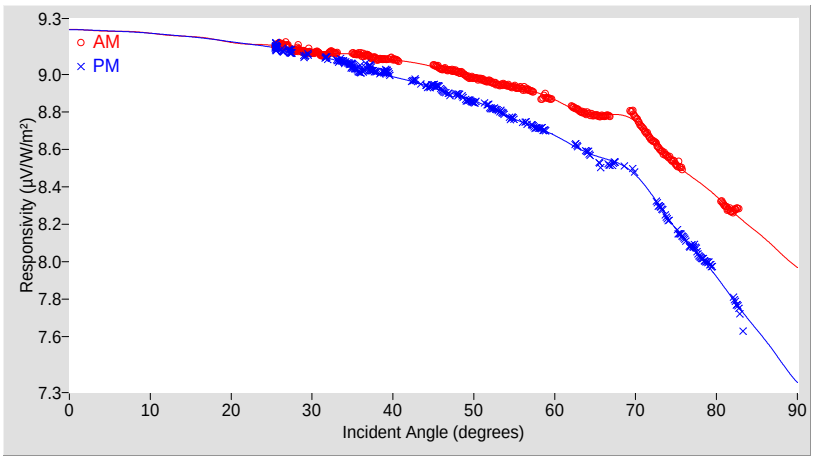


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.80	±1.80
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R²	0.9999996	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.2347	*	9.2346	*	9.2346	*
9-18	9.2089	*	9.2086	*	9.2088	*
18-27	9.1656	*	9.1629	*	9.1643	*
27-36	9.1193	±1.81	9.0928	±1.87	9.1061	±1.99
36-45	9.0777	±1.82	8.9846	±1.87	9.0312	±2.24
45-54	8.9958	±1.87	8.8678	±1.95	8.9318	±2.68
54-63	8.8883	±1.94	8.7045	±2.04	8.7964	±3.19
63-72	8.7713	±1.90	8.5213	±2.20	8.6463	±3.92
72-81	8.4860	±2.68	8.1159	±3.39	8.3009	±6.86
81-90	8.1377	*	7.6062	*	7.8720	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

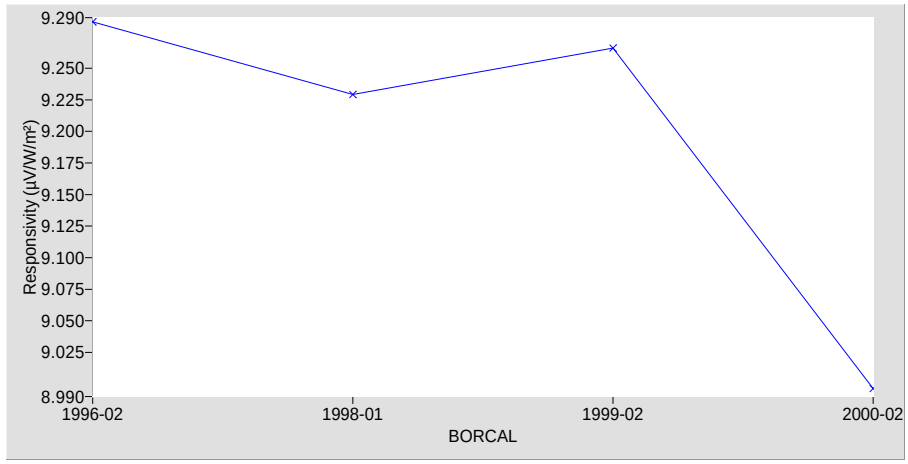
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9963	+2.13 / -3.96 [1]
45° - 55°	8.9208	±2.38 [2]
Composite	9.0271	+2.29 / -14.33 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



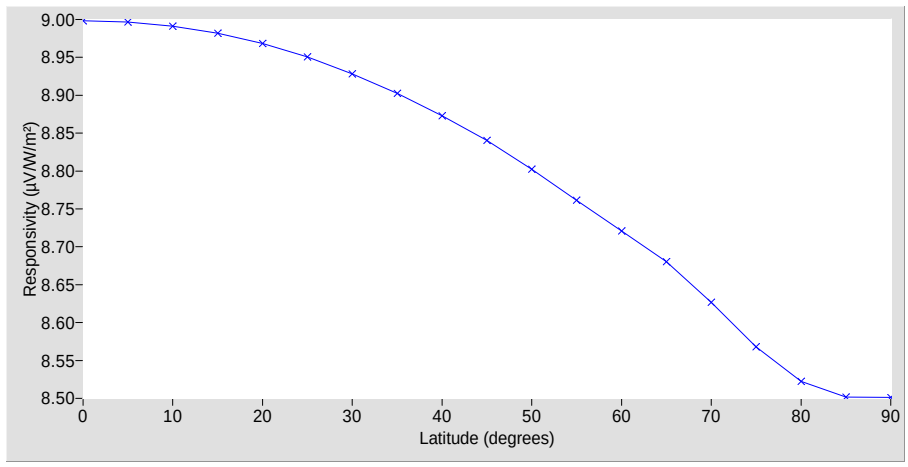
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.9982	+3.25 / -17.79
5	8.9966	+3.27 / -17.78
10	8.9912	+3.32 / -17.73
15	8.9817	+3.41 / -17.64
20	8.9683	+3.54 / -17.52
25	8.9504	+3.71 / -17.35
30	8.9284	+3.84 / -17.15
35	8.9025	+3.97 / -16.91
40	8.8728	+4.11 / -16.63
45	8.8405	+4.14 / -16.33
50	8.8025	+4.36 / -15.97
55	8.7615	+4.41 / -15.58
60	8.7211	+4.75 / -15.19
65	8.6803	+4.88 / -14.80
70	8.6266	+5.02 / -14.27
75	8.5680	+5.10 / -13.69
80	8.5225	+5.03 / -13.23
85	8.5015	+4.41 / -13.02
90	8.5012	+3.81 / -13.01

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30617F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30617F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

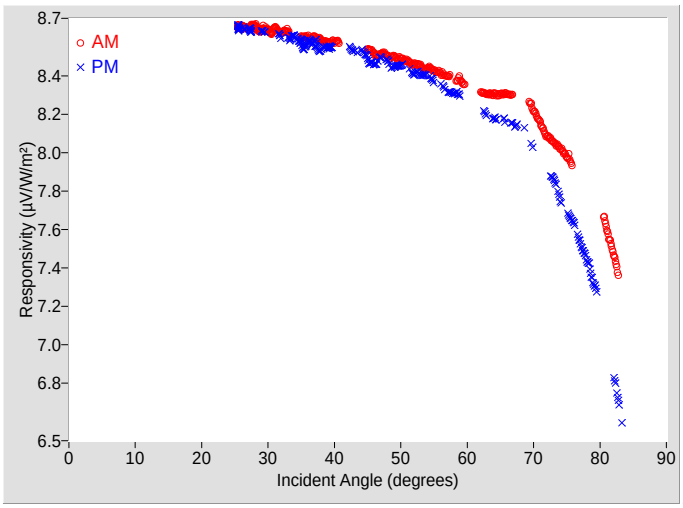


Figure 2. Responsivity vs Local Standard Time

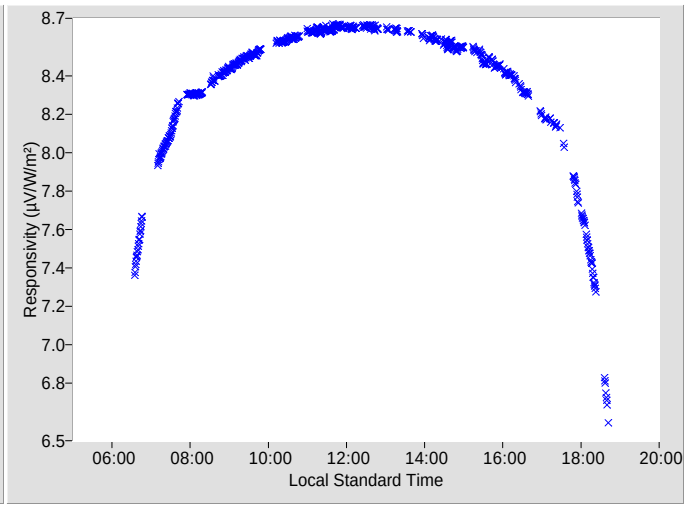


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.5116	+2.27 / -3.12	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5174	0.73	113.07	8.4631	0.73	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5043	0.74	110.68	8.4768	0.76	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4933	0.75	108.48	8.4553	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4619	0.77	106.40	8.4118	0.75	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4418	0.79	104.43	8.4040	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4178	0.83	102.59	8.3582	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.3080	0.83	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3141	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3059	1.02	95.29	8.1781	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3063	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2195	1.42	90.69	8.0288	N/A	272.44
26	8.6526	0.63	166.50	8.6496	0.64	192.61	72	8.0876	1.57	89.19	N/A	N/A	N/A
28	8.6600	0.64	153.62	N/A	N/A	N/A	74	8.0248	1.67	87.73	7.7586	1.74	275.41
30	8.6392	0.65	144.99	N/A	N/A	N/A	76	7.9338	N/A	86.42	7.6373	2.01	276.84
32	8.6257	0.63	138.24	8.6058	0.66	222.18	78	N/A	N/A	N/A	7.4443	2.52	278.31
34	N/A	N/A	N/A	8.6068	0.69	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6012	0.64	128.67	8.5791	0.70	237.64	82	7.4796	3.81	81.85	6.8202	3.77	281.35
38	8.5879	0.66	124.75	8.5333	0.73	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5801	0.65	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.5527	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.5317	0.72	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30617F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

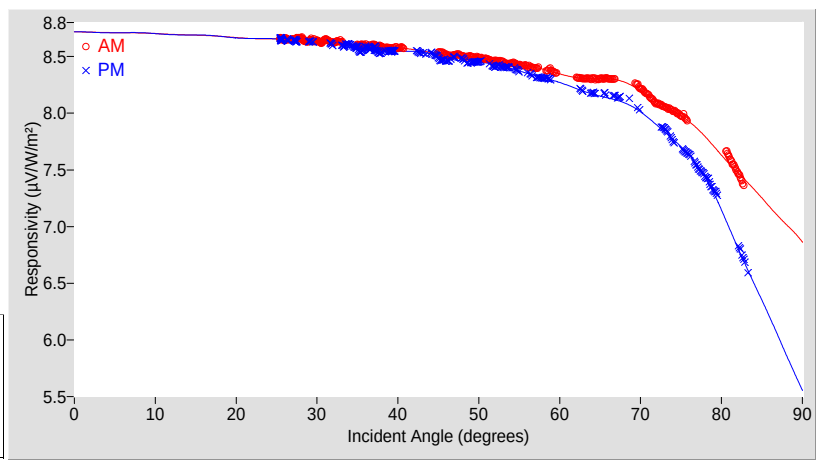


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.94	±1.94
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R^2	0.9999996	0.9999990

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.7121	*	8.7123	*	8.7122	*
9-18	8.6931	*	8.6934	*	8.6933	*
18-27	8.6615	*	8.6605	*	8.6610	*
27-36	8.6316	±1.97	8.6145	±1.98	8.6231	±2.05
36-45	8.5721	±1.98	8.5439	±1.97	8.5580	±2.06
45-54	8.4918	±2.00	8.4540	±2.03	8.4729	±2.19
54-63	8.3778	±2.09	8.3049	±2.25	8.3413	±2.80
63-72	8.2597	±2.22	8.0899	±2.55	8.1748	±3.95
72-81	7.8837	±3.81	7.5600	±5.83	7.7218	±10.05
81-90	7.2111	*	6.2673	*	6.7392	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

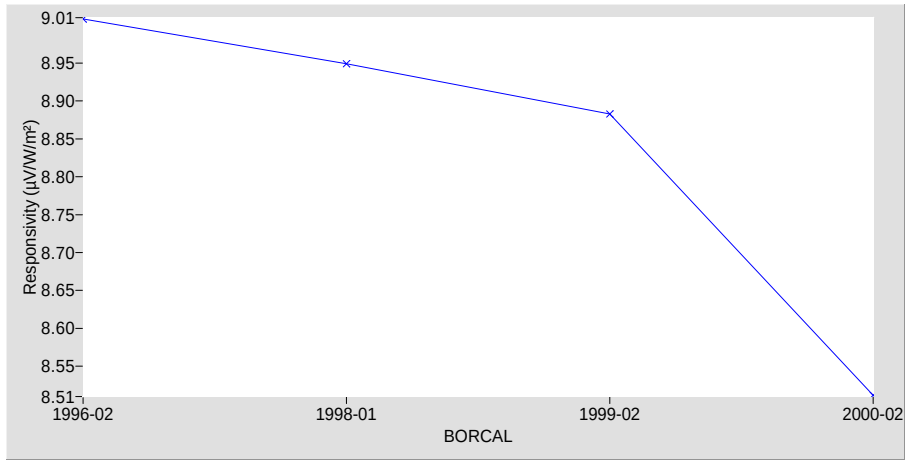
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5116	+2.27 / -3.12 [1]
45° - 55°	8.4638	±2.14 [2]
Composite	8.5269	+2.46 / -22.03 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



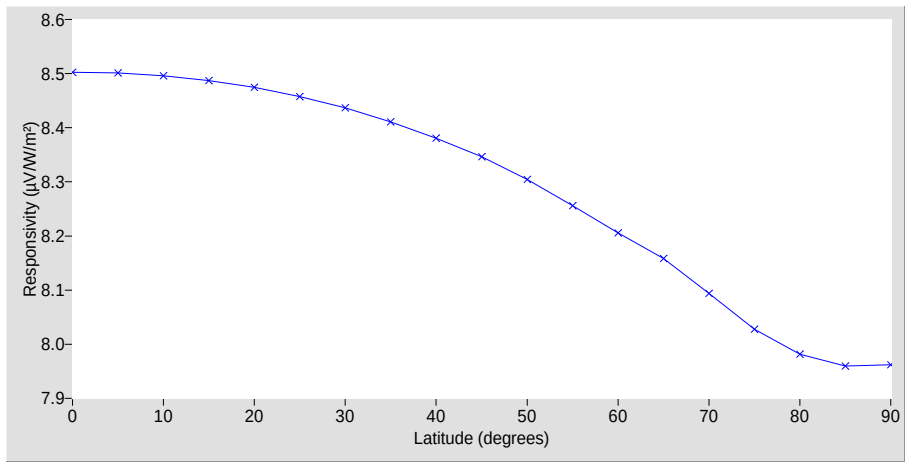
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.5025	+3.20 / -32.88
5	8.5012	+3.22 / -32.87
10	8.4962	+3.26 / -32.83
15	8.4872	+3.35 / -32.76
20	8.4748	+3.48 / -32.66
25	8.4578	+3.64 / -32.53
30	8.4369	+3.79 / -32.36
35	8.4111	+3.94 / -32.15
40	8.3809	+4.16 / -31.91
45	8.3465	+4.25 / -31.63
50	8.3044	+4.64 / -31.28
55	8.2562	+5.00 / -30.88
60	8.2055	+5.17 / -30.46
65	8.1584	+5.42 / -30.06
70	8.0940	+5.60 / -29.50
75	8.0274	+5.94 / -28.92
80	7.9817	+5.79 / -28.51
85	7.9599	+5.02 / -28.31
90	7.9620	+4.72 / -28.33

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30618F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30618F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

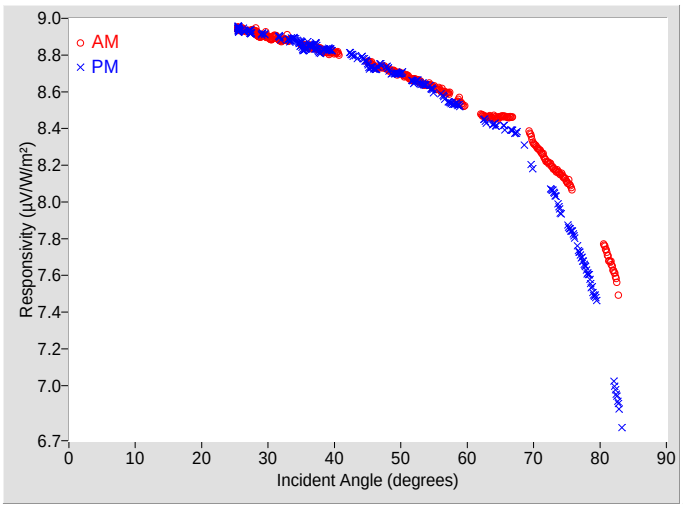


Figure 2. Responsivity vs Local Standard Time

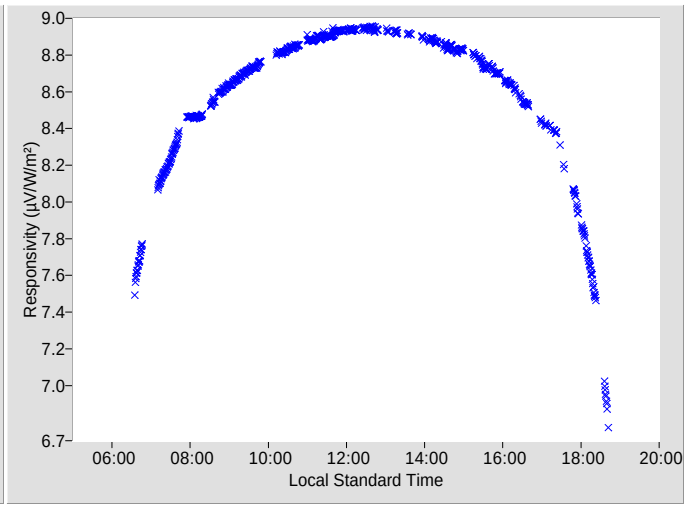


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.7558	+2.45 / -3.31	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7395	0.73	113.07	8.7259	0.70	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7227	0.73	110.68	8.7287	0.74	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7013	0.75	108.48	8.7011	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6670	0.78	106.40	8.6546	0.73	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6393	0.79	104.43	8.6359	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6128	0.84	102.59	8.5883	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.5315	0.83	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4747	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4625	1.02	95.29	8.4217	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4623	1.09	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3224	1.43	90.69	8.1807	N/A	272.44
26	8.9383	0.63	166.50	8.9409	0.65	192.61	72	8.2211	1.56	89.19	N/A	N/A	N/A
28	8.9297	0.66	153.62	N/A	N/A	N/A	74	8.1562	1.65	87.73	7.9526	1.71	275.41
30	8.8978	0.65	144.99	N/A	N/A	N/A	76	8.0656	N/A	86.42	7.8255	2.01	276.84
32	8.8790	0.64	138.24	8.8931	0.65	222.18	78	N/A	N/A	N/A	7.6255	2.50	278.31
34	N/A	N/A	N/A	8.8884	0.70	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8467	0.64	128.67	8.8515	0.68	237.64	82	7.6323	3.79	81.85	7.0093	3.76	281.35
38	8.8280	0.66	124.75	8.8152	0.71	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8141	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.8129	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.7877	0.71	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30618F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

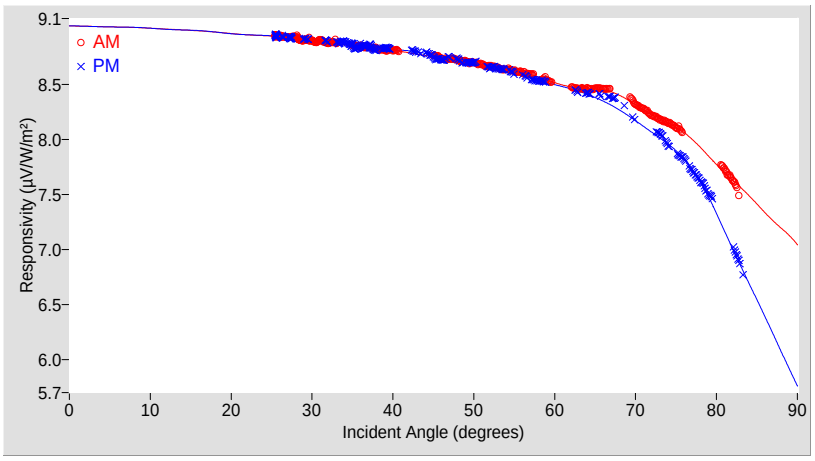


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.93	±1.93
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R^2	0.9999998	0.9999994

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.0256	*	9.0257	*	9.0256	*
9-18	8.9988	*	8.9989	*	8.9989	*
18-27	8.9532	*	8.9533	*	8.9533	*
27-36	8.8894	±1.99	8.9006	±1.97	8.8950	±2.04
36-45	8.8067	±1.99	8.8128	±1.98	8.8098	±2.06
45-54	8.7044	±2.02	8.7029	±2.05	8.7036	±2.17
54-63	8.5592	±2.16	8.5354	±2.20	8.5473	±2.50
63-72	8.3971	±2.34	8.2868	±2.84	8.3420	±3.88
72-81	8.0187	±3.62	7.7448	±5.62	7.8818	±9.36
81-90	7.3765	*	6.4637	*	6.9201	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

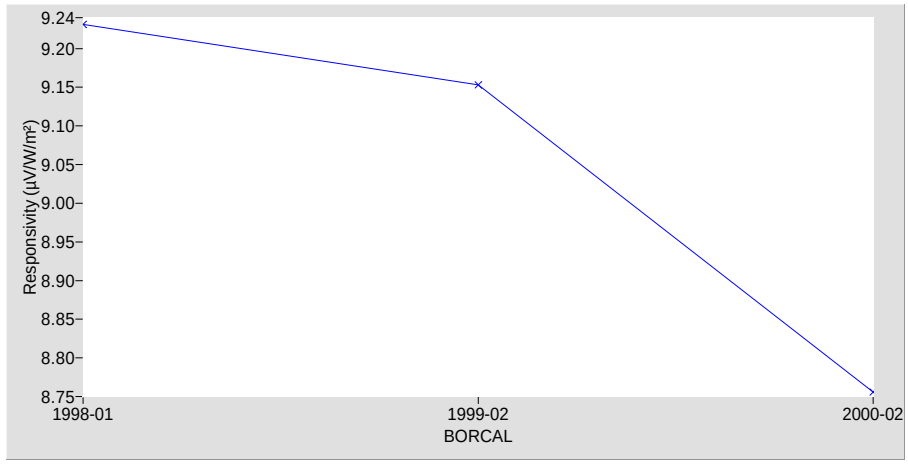
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.7558	+2.45 / -3.31 [1]
45° - 55°	8.6926	±2.13 [2]
Composite	8.7899	+2.58 / -22.16 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



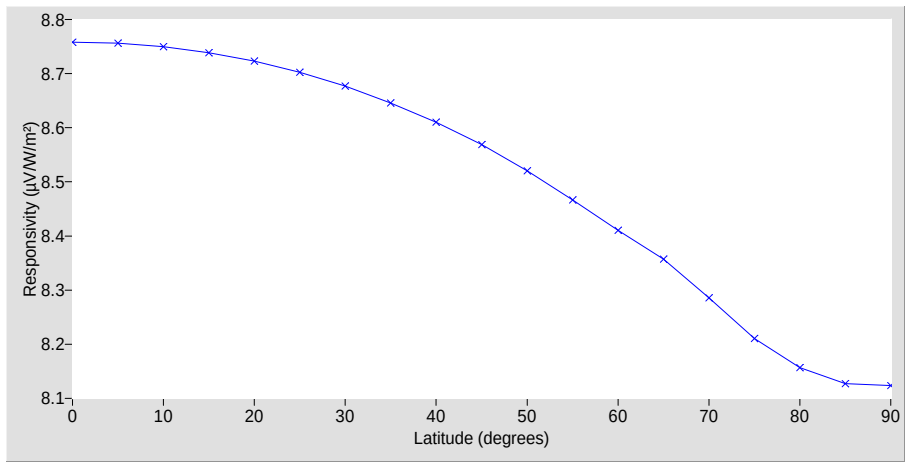
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.7579	+3.69 / -32.51
5	8.7562	+3.71 / -32.49
10	8.7498	+3.77 / -32.44
15	8.7387	+3.88 / -32.36
20	8.7232	+4.04 / -32.24
25	8.7025	+4.25 / -32.08
30	8.6770	+4.43 / -31.88
35	8.6458	+4.61 / -31.63
40	8.6100	+4.82 / -31.35
45	8.5688	+4.93 / -31.02
50	8.5206	+5.25 / -30.63
55	8.4667	+5.54 / -30.19
60	8.4106	+5.55 / -29.72
65	8.3571	+5.77 / -29.27
70	8.2855	+5.88 / -28.66
75	8.2108	+6.09 / -28.01
80	8.1569	+5.90 / -27.54
85	8.1270	+4.92 / -27.27
90	8.1235	+4.48 / -27.24

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30619F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30619F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

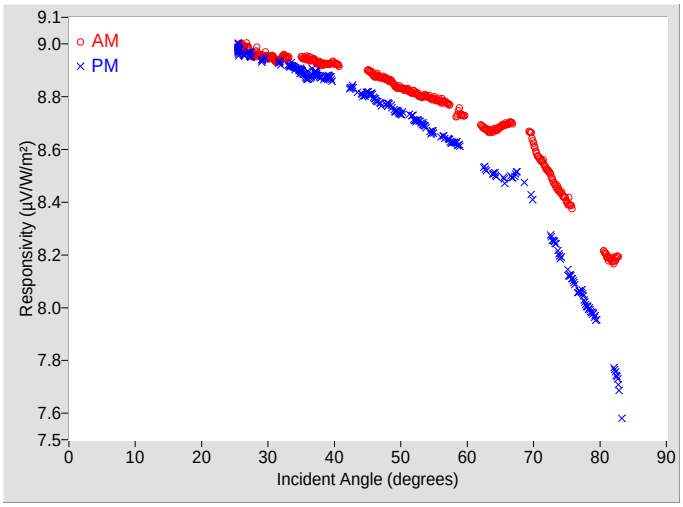


Figure 2. Responsivity vs Local Standard Time

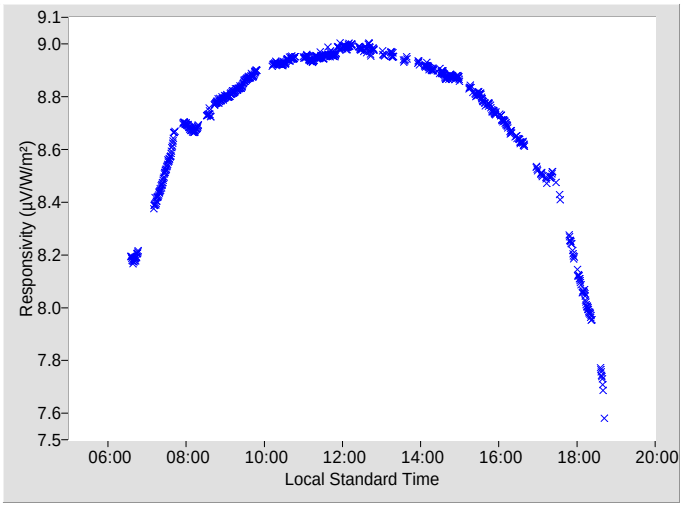


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.8558	+1.84 / -3.40	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8790	0.72	113.07	8.7945	0.72	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8647	0.73	110.68	8.7710	0.71	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8330	0.74	108.48	8.7353	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8167	0.77	106.40	8.7150	0.75	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8006	0.78	104.43	8.6811	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7851	0.82	102.59	8.6469	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.6259	0.83	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6893	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6720	1.02	95.29	8.5071	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6961	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6233	1.42	90.69	8.4086	N/A	272.44
26	8.9905	0.63	166.50	8.9748	0.68	192.61	72	8.5249	1.52	89.19	N/A	N/A	N/A
28	8.9597	0.63	153.79	N/A	N/A	N/A	74	8.4415	1.65	87.73	8.1941	1.59	275.41
30	8.9473	0.62	144.99	N/A	N/A	N/A	76	8.3749	N/A	86.42	8.1006	1.85	276.84
32	8.9454	0.63	138.24	8.9276	0.65	222.18	78	N/A	N/A	N/A	8.0062	2.18	278.31
34	N/A	N/A	N/A	8.9090	0.69	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9449	0.63	128.67	8.8726	0.67	237.64	82	8.1775	3.44	81.85	7.7693	3.59	281.35
38	8.9234	0.65	124.75	8.8733	0.66	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9273	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.8286	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.8062	0.67	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30619F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

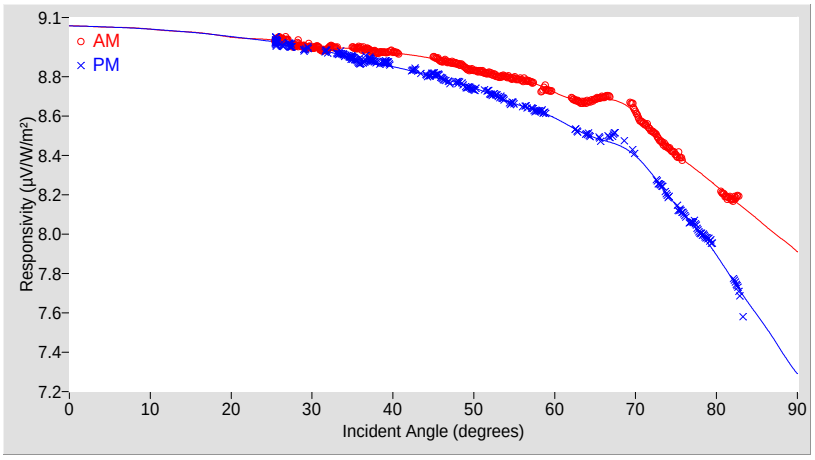


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.79	±1.79
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R²	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.0522	*	9.0521	*	9.0521	*
9-18	9.0306	*	9.0304	*	9.0305	*
18-27	8.9943	*	8.9920	*	8.9932	*
27-36	8.9506	±1.80	8.9315	±1.84	8.9410	±1.92
36-45	8.9196	±1.81	8.8460	±1.84	8.8828	±2.10
45-54	8.8459	±1.85	8.7489	±1.90	8.7974	±2.43
54-63	8.7470	±1.91	8.6142	±1.97	8.6806	±2.82
63-72	8.6536	±1.95	8.4482	±2.12	8.5509	±3.50
72-81	8.3695	±2.54	8.0867	±3.27	8.2281	±6.01
81-90	8.0608	*	7.5591	*	7.8100	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

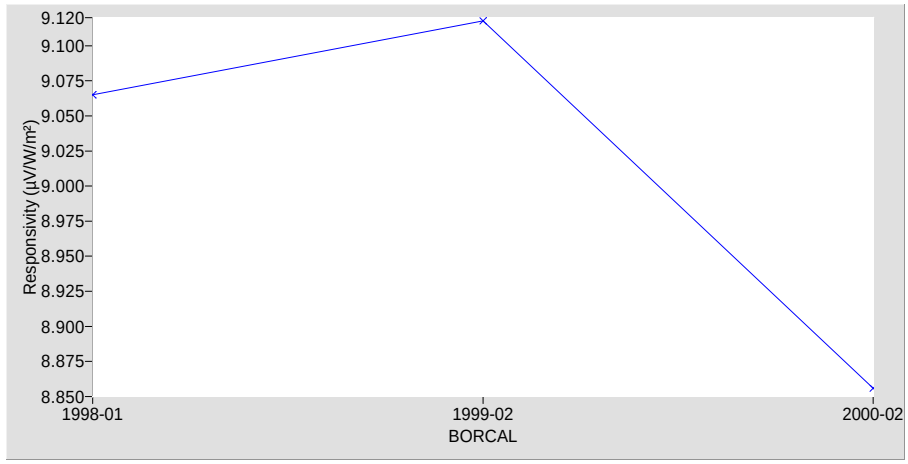
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.8558	+1.84 / -3.40 [1]
45° - 55°	8.7883	±2.21 [2]
Composite	8.8745	+2.17 / -13.29 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



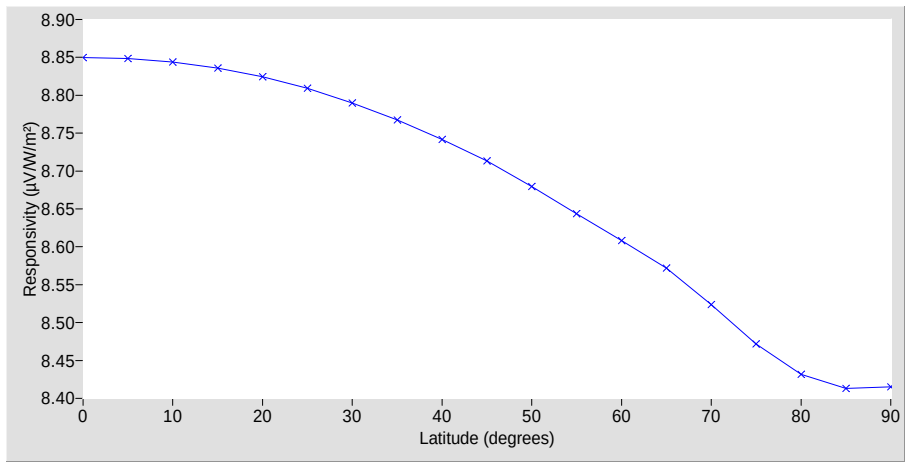
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.8498	+2.95 / -17.09
5	8.8484	+2.97 / -17.08
10	8.8437	+3.01 / -17.03
15	8.8358	+3.09 / -16.96
20	8.8243	+3.19 / -16.85
25	8.8090	+3.34 / -16.71
30	8.7900	+3.46 / -16.53
35	8.7676	+3.57 / -16.32
40	8.7418	+3.68 / -16.07
45	8.7135	+3.73 / -15.80
50	8.6797	+3.90 / -15.47
55	8.6437	+3.92 / -15.12
60	8.6080	+4.26 / -14.77
65	8.5719	+4.40 / -14.42
70	8.5238	+4.56 / -13.94
75	8.4717	+4.55 / -13.41
80	8.4316	+4.54 / -13.00
85	8.4133	+3.87 / -12.81
90	8.4154	+3.66 / -12.84

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30620F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30620F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

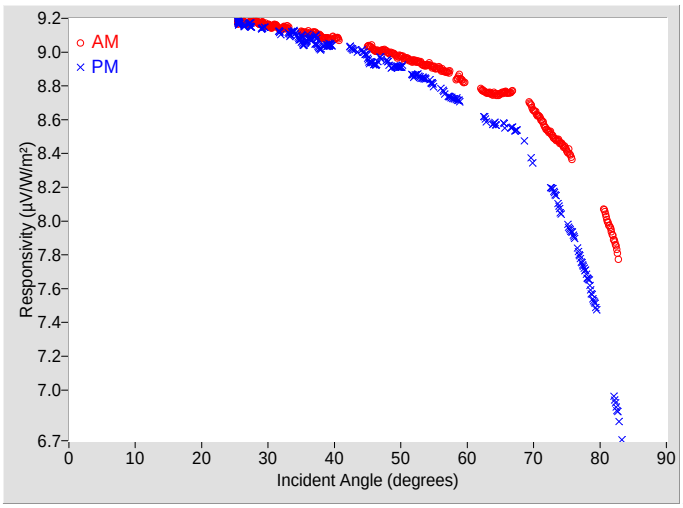


Figure 2. Responsivity vs Local Standard Time

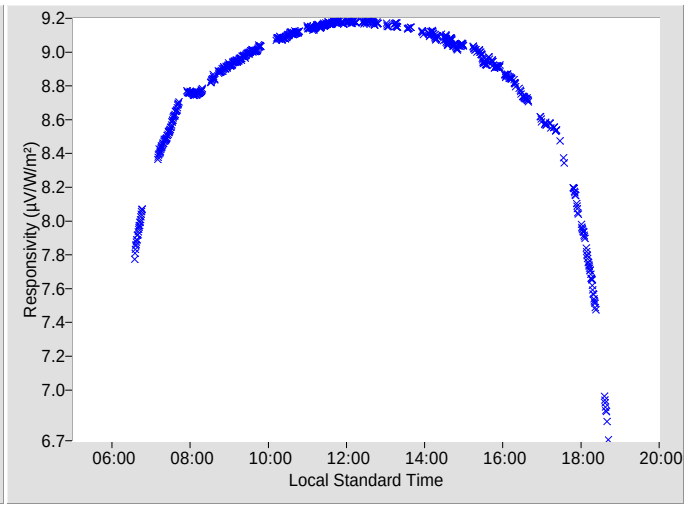


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9975	+2.44 / -3.83	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0137	0.73	113.07	8.9276	0.73	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0003	0.73	110.68	8.9418	0.75	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9777	0.76	108.48	8.9130	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9476	0.77	106.40	8.8608	0.73	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9253	0.79	104.43	8.8404	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9018	0.83	102.59	8.7852	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.7237	0.83	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7782	0.98	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7530	1.02	95.29	8.5760	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7616	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6573	1.38	90.69	8.3435	N/A	272.44
26	9.1798	0.63	166.50	9.1711	0.67	192.61	72	8.5415	1.58	89.19	N/A	N/A	N/A
28	9.1862	0.62	153.62	N/A	N/A	N/A	74	8.4677	1.64	87.73	8.0631	1.75	275.41
30	9.1609	0.63	144.99	N/A	N/A	N/A	76	8.3643	N/A	86.42	7.9180	2.13	276.84
32	9.1387	0.63	138.24	9.1128	0.65	222.18	78	N/A	N/A	N/A	7.6795	2.63	278.31
34	N/A	N/A	N/A	9.1180	0.75	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1142	0.64	128.67	9.0808	0.72	237.64	82	7.9045	3.76	81.85	6.9524	3.77	281.35
38	9.0920	0.67	124.75	9.0176	0.80	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0855	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	9.0324	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	9.0072	0.72	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30620F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

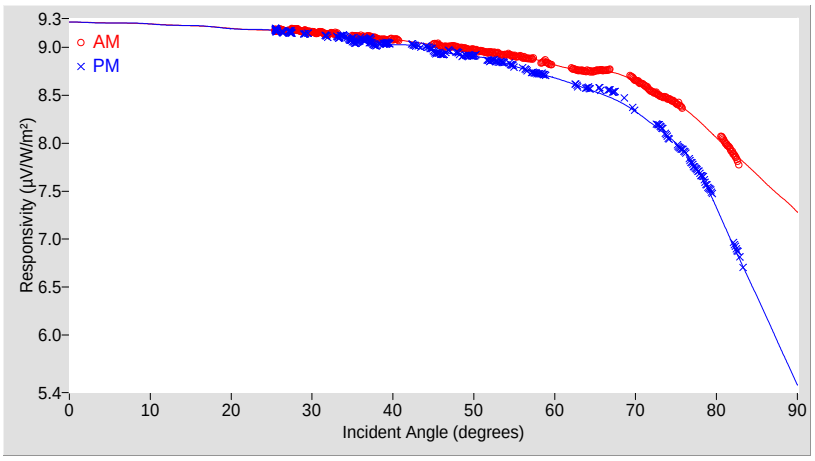


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.95	±1.95
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R^2	0.9999998	0.9999989

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.2559	*	9.2561	*	9.2560	*
9-18	9.2309	*	9.2311	*	9.2310	*
18-27	9.1896	*	9.1874	*	9.1885	*
27-36	9.1497	±1.99	9.1256	±2.00	9.1377	±2.11
36-45	9.0765	±2.00	9.0271	±2.00	9.0518	±2.17
45-54	8.9821	±2.02	8.9123	±2.08	8.9472	±2.42
54-63	8.8531	±2.14	8.7224	±2.33	8.7878	±3.21
63-72	8.7086	±2.23	8.4438	±2.89	8.5762	±4.94
72-81	8.3183	±3.77	7.8210	±6.50	8.0697	±12.12
81-90	7.6328	*	6.3084	*	6.9706	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

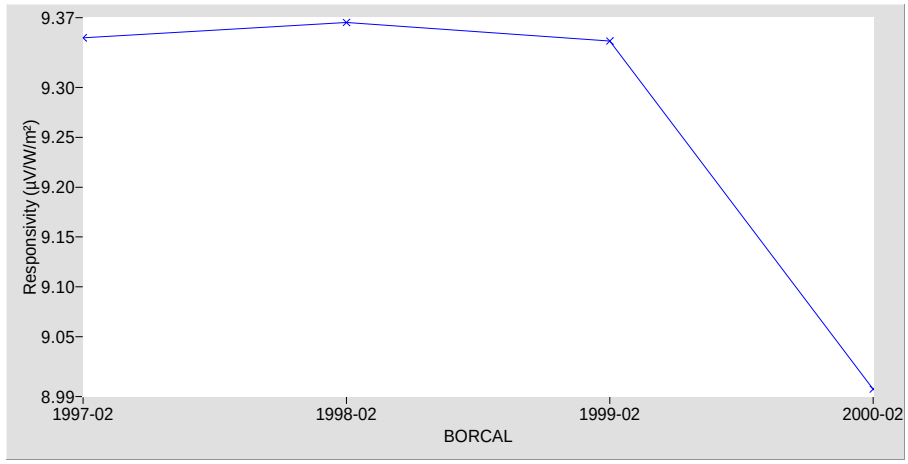
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9975	+2.44 / -3.83 [1]
45° - 55°	8.9361	±2.31 [2]
Composite	9.0232	+2.62 / -25.12 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



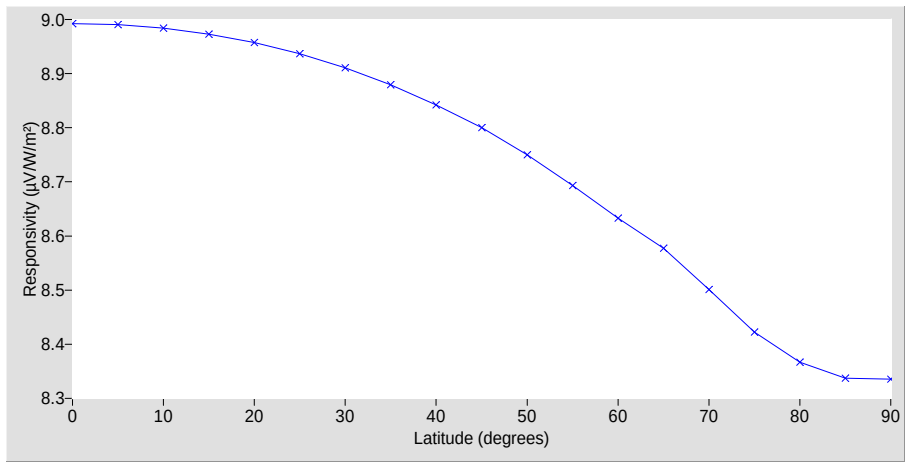
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.9923	+3.60 / -37.07
5	8.9906	+3.62 / -37.06
10	8.9843	+3.68 / -37.01
15	8.9731	+3.79 / -36.93
20	8.9575	+3.94 / -36.82
25	8.9367	+4.14 / -36.68
30	8.9109	+4.32 / -36.49
35	8.8792	+4.50 / -36.27
40	8.8424	+4.75 / -36.00
45	8.8003	+4.84 / -35.70
50	8.7502	+5.30 / -35.33
55	8.6930	+5.66 / -34.90
60	8.6330	+5.85 / -34.45
65	8.5771	+6.10 / -34.02
70	8.5011	+6.38 / -33.44
75	8.4222	+6.71 / -32.81
80	8.3667	+6.67 / -32.37
85	8.3375	+5.82 / -32.13
90	8.3354	+5.38 / -32.11

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30652F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30652F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

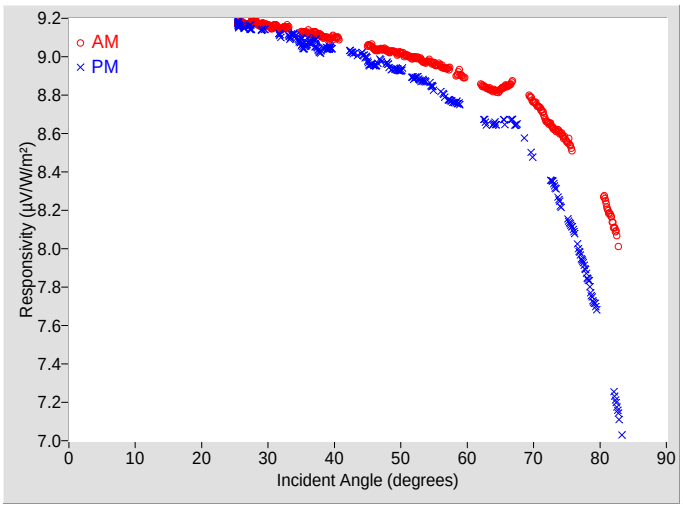


Figure 2. Responsivity vs Local Standard Time

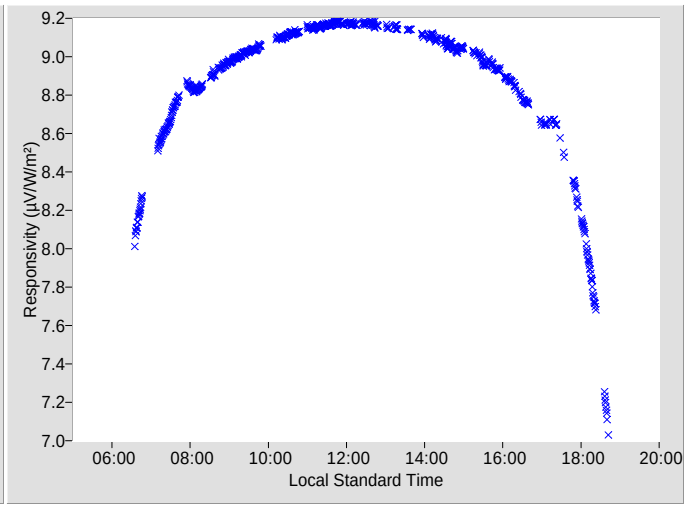


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
9.0169	+2.33 / -3.59	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0411	0.72	113.07	8.9552	0.71	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0301	0.72	110.68	8.9601	0.73	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0208	0.74	108.48	8.9300	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9950	0.76	106.40	8.8898	0.73	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9758	0.79	104.43	8.8678	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9558	0.83	102.59	8.8184	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.7608	0.83	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8530	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8241	1.02	95.29	8.6506	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8488	1.12	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.7650	1.33	90.69	8.4763	N/A	272.44
26	9.1719	0.62	166.50	9.1643	0.66	192.61	72	8.6634	1.56	89.19	N/A	N/A	N/A
28	9.1827	0.62	153.62	N/A	N/A	N/A	74	8.6061	1.63	87.73	8.2349	1.71	275.41
30	9.1619	0.62	144.99	N/A	N/A	N/A	76	8.5095	N/A	86.42	8.0993	2.07	276.84
32	9.1462	0.62	138.24	9.1093	0.65	222.18	78	N/A	N/A	N/A	7.8641	2.60	278.31
34	N/A	N/A	N/A	9.1142	0.74	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1262	0.64	128.67	9.0755	0.70	237.64	82	8.1287	3.66	81.85	7.2437	3.72	281.35
38	9.1100	0.66	124.75	9.0247	0.76	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1014	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	9.0317	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	9.0147	0.71	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30652F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

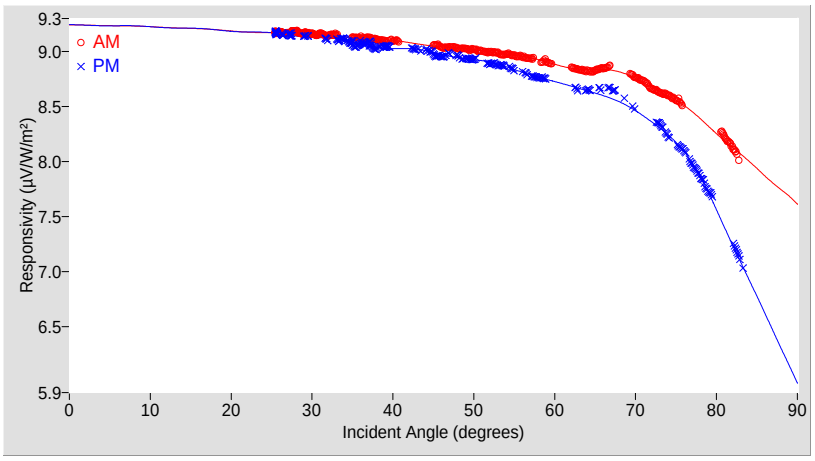


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.91	±1.91
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R^2	0.9999997	0.9999994

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.2365	*	9.2367	*	9.2366	*
9-18	9.2153	*	9.2155	*	9.2154	*
18-27	9.1803	*	9.1783	*	9.1793	*
27-36	9.1538	±1.93	9.1212	±1.95	9.1375	±2.06
36-45	9.0945	±1.95	9.0307	±1.95	9.0626	±2.13
45-54	9.0197	±1.95	8.9339	±2.02	8.9768	±2.37
54-63	8.9149	±2.05	8.7649	±2.19	8.8399	±3.08
63-72	8.8021	±2.08	8.5503	±2.51	8.6762	±4.28
72-81	8.4746	±3.30	8.0079	±5.81	8.2413	±10.80
81-90	7.9039	*	6.6943	*	7.2991	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

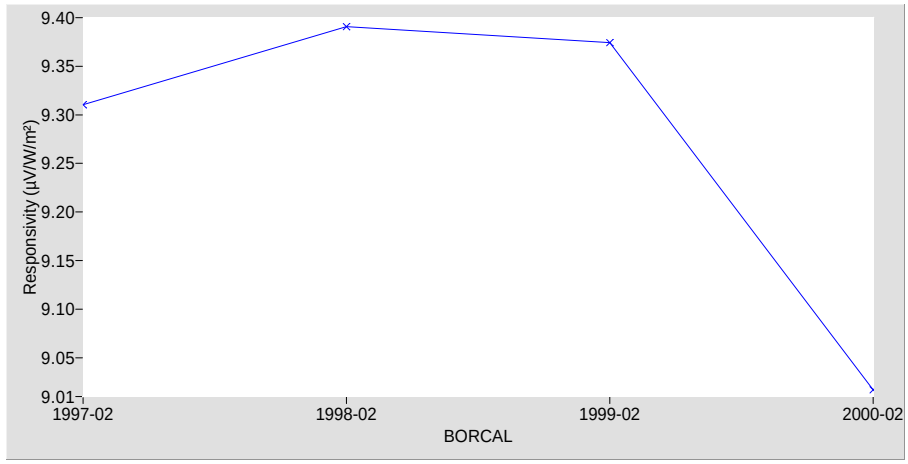
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	9.0169	+2.33 / -3.59 [1]
45° - 55°	8.9673	±2.25 [2]
Composite	9.0409	+2.42 / -21.73 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



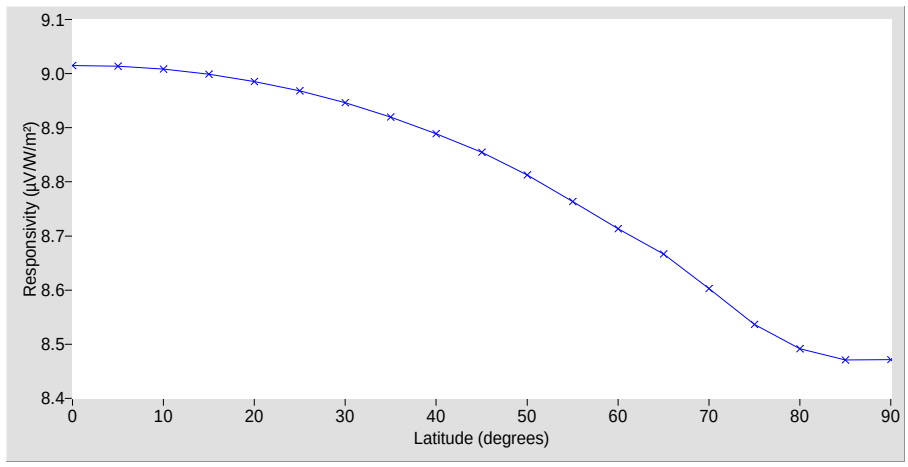
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	9.0148	+3.18 / -31.89
5	9.0135	+3.19 / -31.88
10	9.0082	+3.24 / -31.84
15	8.9987	+3.33 / -31.76
20	8.9856	+3.45 / -31.66
25	8.9681	+3.61 / -31.53
30	8.9465	+3.75 / -31.37
35	8.9199	+3.89 / -31.16
40	8.8892	+4.09 / -30.92
45	8.8544	+4.15 / -30.65
50	8.8124	+4.54 / -30.32
55	8.7638	+4.89 / -29.94
60	8.7131	+5.07 / -29.53
65	8.6664	+5.27 / -29.15
70	8.6029	+5.47 / -28.63
75	8.5367	+5.83 / -28.08
80	8.4918	+5.78 / -27.70
85	8.4709	+5.02 / -27.52
90	8.4713	+4.72 / -27.52

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30655F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30655F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

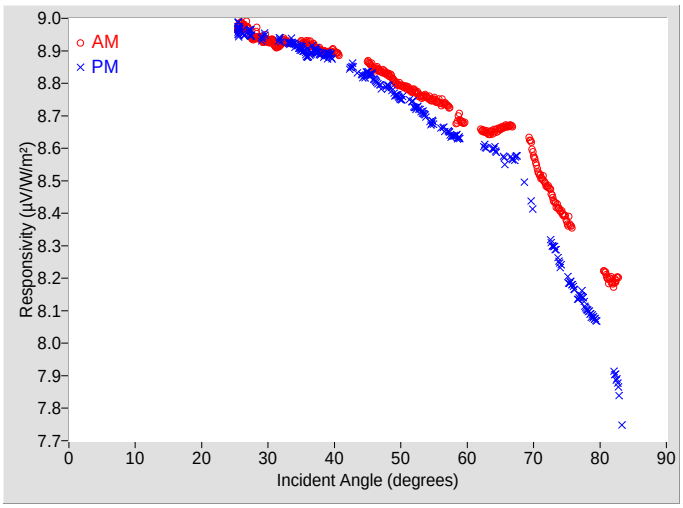


Figure 2. Responsivity vs Local Standard Time

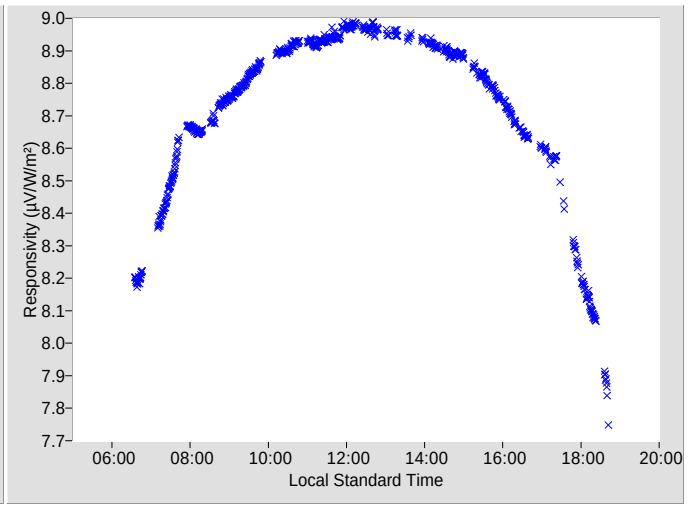


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.8484	+1.72 / -3.16	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8449	0.72	113.07	8.8134	0.72	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8285	0.73	110.68	8.7902	0.71	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7948	0.74	108.48	8.7530	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7767	0.77	106.40	8.7309	0.75	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7577	0.78	104.43	8.6959	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7425	0.82	102.59	8.6618	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.6382	0.82	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6551	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6524	1.02	95.29	8.5985	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6684	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5802	1.45	90.69	8.4131	N/A	272.44
26	8.9775	0.63	166.50	8.9660	0.67	192.61	72	8.4848	1.50	89.19	N/A	N/A	N/A
28	8.9436	0.63	153.79	N/A	N/A	N/A	74	8.4109	1.63	87.73	8.2436	1.58	275.41
30	8.9289	0.62	144.99	N/A	N/A	N/A	76	8.3545	N/A	86.42	8.1731	1.82	276.84
32	8.9250	0.63	138.24	8.9337	0.65	222.18	78	N/A	N/A	N/A	8.1045	2.17	278.31
34	N/A	N/A	N/A	8.9189	0.68	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9240	0.63	128.67	8.8871	0.65	237.64	82	8.1855	3.44	81.85	7.9086	3.57	281.35
38	8.8990	0.64	124.75	8.8895	0.66	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8986	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.8434	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.8235	0.67	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30655F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

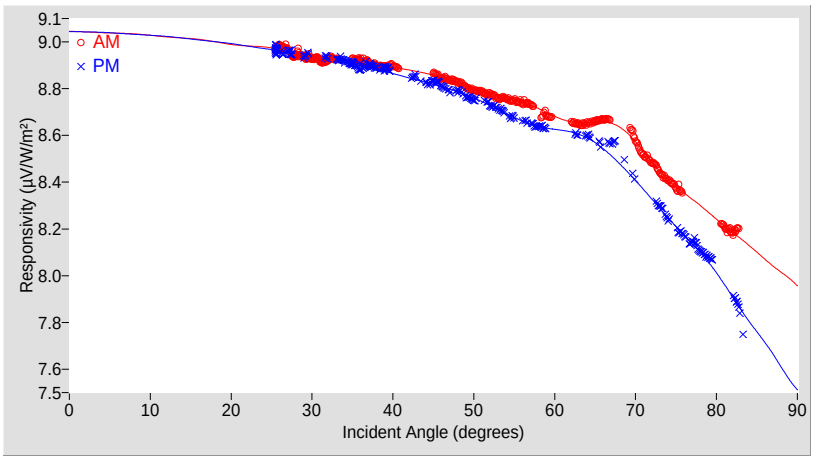


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.78	±1.78
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R²	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.0394	*	9.0393	*	9.0394	*
9-18	9.0184	*	9.0181	*	9.0183	*
18-27	8.9826	*	8.9812	*	8.9819	*
27-36	8.9317	±1.79	8.9352	±1.81	8.9335	±1.84
36-45	8.8917	±1.81	8.8618	±1.83	8.8768	±1.94
45-54	8.8085	±1.86	8.7668	±1.90	8.7876	±2.17
54-63	8.7084	±1.88	8.6435	±1.85	8.6760	±2.16
63-72	8.6209	±1.98	8.4946	±2.33	8.5577	±3.25
72-81	8.3499	±2.37	8.1625	±2.74	8.2562	±4.65
81-90	8.0858	*	7.7346	*	7.9102	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

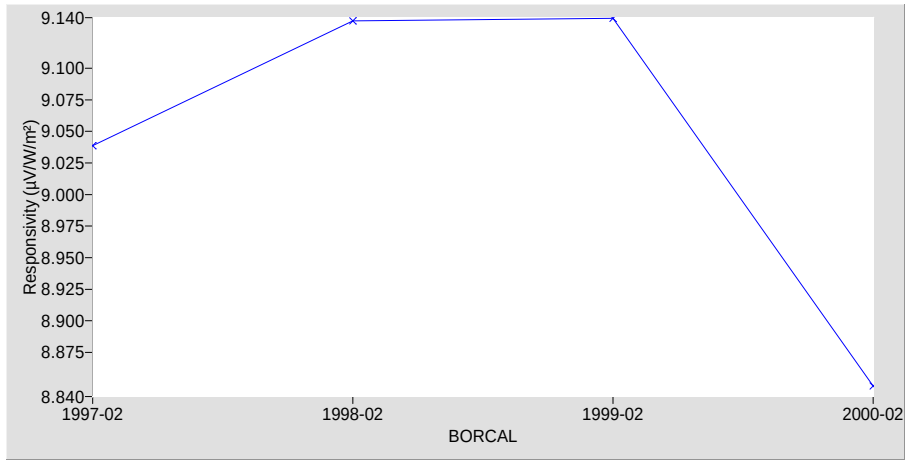
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.8484	+1.72 / -3.16 [1]
45° - 55°	8.7780	±2.05 [2]
Composite	8.8684	+2.13 / -11.56 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



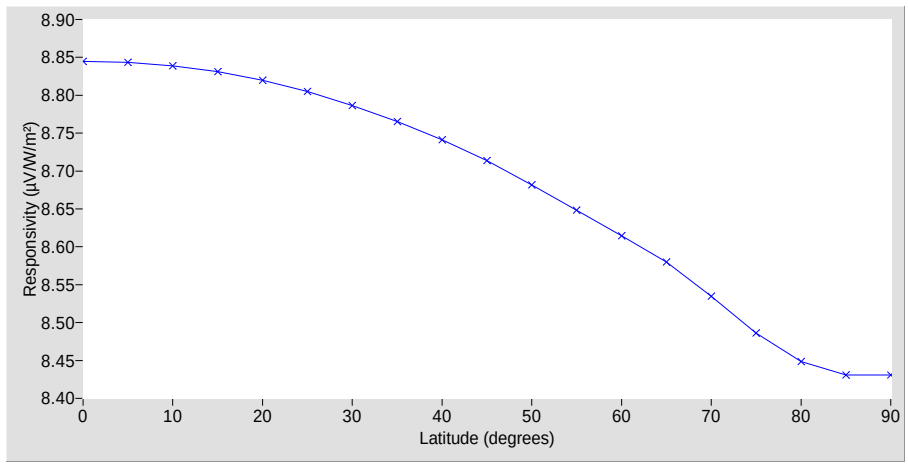
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.8446	+2.88 / -14.68
5	8.8433	+2.89 / -14.67
10	8.8389	+2.93 / -14.62
15	8.8312	+3.00 / -14.55
20	8.8200	+3.11 / -14.44
25	8.8050	+3.25 / -14.30
30	8.7865	+3.36 / -14.12
35	8.7652	+3.47 / -13.91
40	8.7414	+3.56 / -13.68
45	8.7140	+3.61 / -13.41
50	8.6816	+3.74 / -13.09
55	8.6481	+3.81 / -12.75
60	8.6146	+3.97 / -12.42
65	8.5800	+3.99 / -12.07
70	8.5347	+4.07 / -11.61
75	8.4860	+3.96 / -11.10
80	8.4485	+3.90 / -10.71
85	8.4308	+3.33 / -10.53
90	8.4308	+3.23 / -10.53

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30663F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30663F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

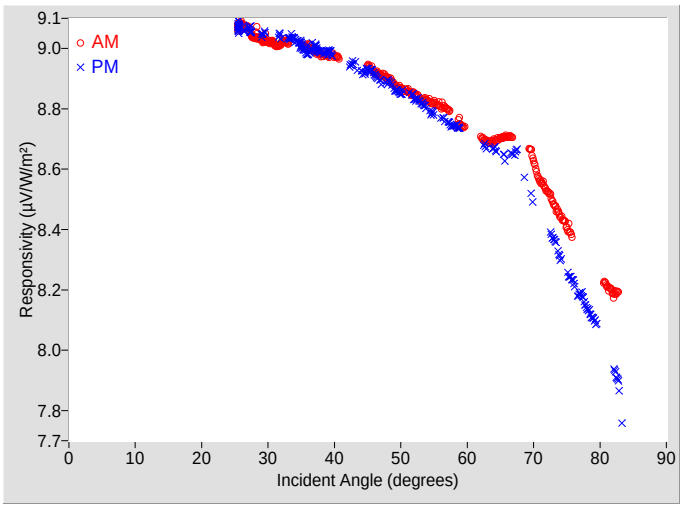


Figure 2. Responsivity vs Local Standard Time

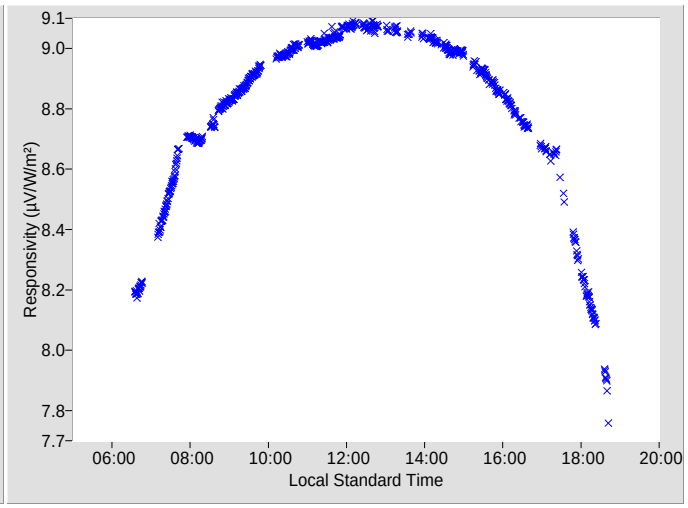


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9364	+1.95 / -2.92	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9213	0.72	113.07	8.9155	0.71	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9022	0.74	110.68	8.8894	0.71	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8699	0.74	108.48	8.8527	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8501	0.78	106.40	8.8360	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8288	0.78	104.43	8.8014	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8128	0.82	102.59	8.7688	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.7430	0.82	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7043	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6942	1.02	95.29	8.6684	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7084	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6289	1.42	90.69	8.4913	N/A	272.44
26	9.0770	0.64	166.50	9.0745	0.66	192.61	72	8.5284	1.50	89.19	N/A	N/A	N/A
28	9.0415	0.64	153.79	N/A	N/A	N/A	74	8.4478	1.65	87.73	8.3073	1.59	275.41
30	9.0223	0.63	144.99	N/A	N/A	N/A	76	8.3749	N/A	86.42	8.2260	1.83	276.84
32	9.0182	0.62	138.24	9.0419	0.65	222.18	78	N/A	N/A	N/A	8.1405	2.17	278.31
34	N/A	N/A	N/A	9.0305	0.70	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0063	0.63	128.67	8.9870	0.66	237.64	82	8.1892	3.44	81.85	7.9355	3.56	281.35
38	8.9801	0.65	124.75	8.9890	0.66	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9764	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.9384	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.9215	0.70	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30663F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

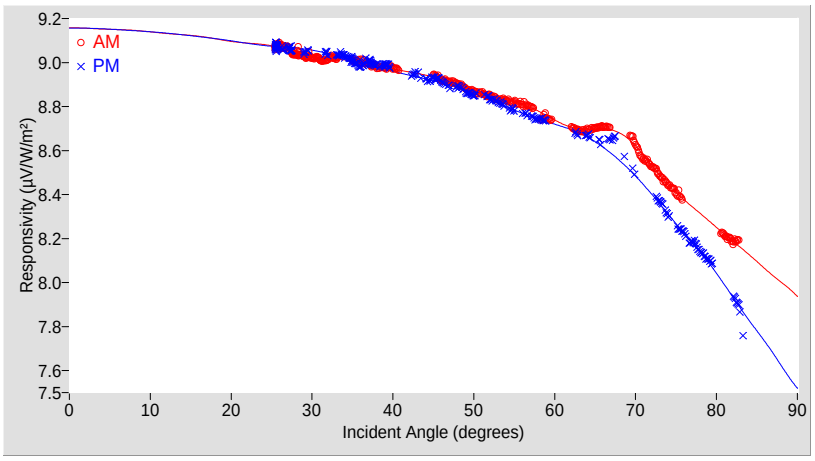


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.78	±1.78
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R^2	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.1521	*	9.1520	*	9.1520	*
9-18	9.1283	*	9.1282	*	9.1282	*
18-27	9.0872	*	9.0874	*	9.0873	*
27-36	9.0242	±1.80	9.0435	±1.81	9.0338	±1.85
36-45	8.9706	±1.82	8.9599	±1.84	8.9652	±1.89
45-54	8.8829	±1.87	8.8682	±1.89	8.8755	±2.05
54-63	8.7700	±1.93	8.7420	±1.89	8.7560	±2.12
63-72	8.6648	±1.96	8.5688	±2.33	8.6168	±3.03
72-81	8.3736	±2.52	8.2123	±2.94	8.2930	±4.76
81-90	8.0796	*	7.7536	*	7.9166	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

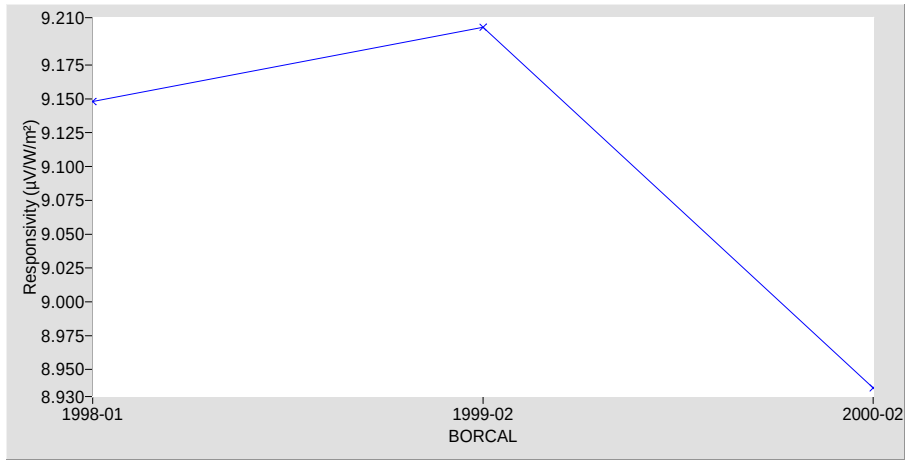
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9364	+1.95 / -2.92 [1]
45° - 55°	8.8661	±1.97 [2]
Composite	8.9626	+2.16 / -12.20 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



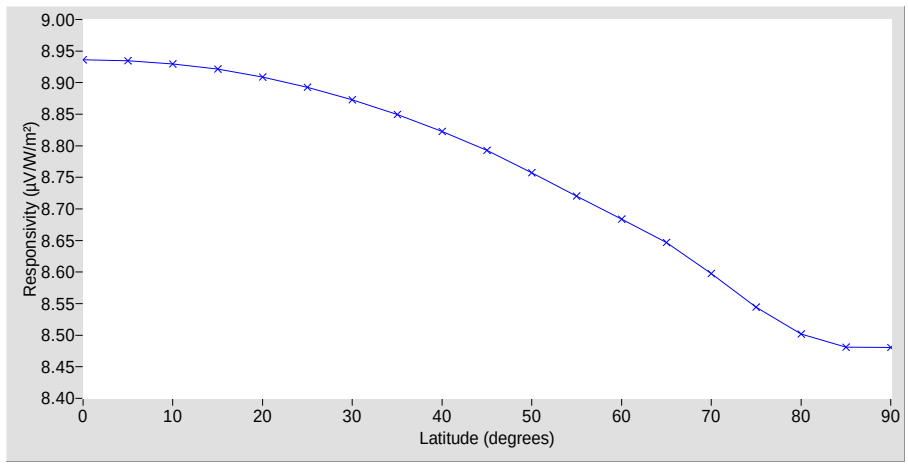
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.9361	+3.06 / -15.41
5	8.9347	+3.07 / -15.40
10	8.9298	+3.12 / -15.35
15	8.9212	+3.20 / -15.27
20	8.9089	+3.32 / -15.15
25	8.8928	+3.47 / -15.00
30	8.8727	+3.59 / -14.81
35	8.8493	+3.71 / -14.59
40	8.8226	+3.81 / -14.33
45	8.7925	+3.85 / -14.04
50	8.7573	+4.00 / -13.69
55	8.7204	+4.17 / -13.33
60	8.6837	+4.09 / -12.97
65	8.6466	+4.08 / -12.60
70	8.5978	+4.18 / -12.11
75	8.5444	+4.10 / -11.56
80	8.5021	+4.04 / -11.13
85	8.4812	+3.34 / -10.91
90	8.4805	+3.13 / -10.90

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30666F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30666F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

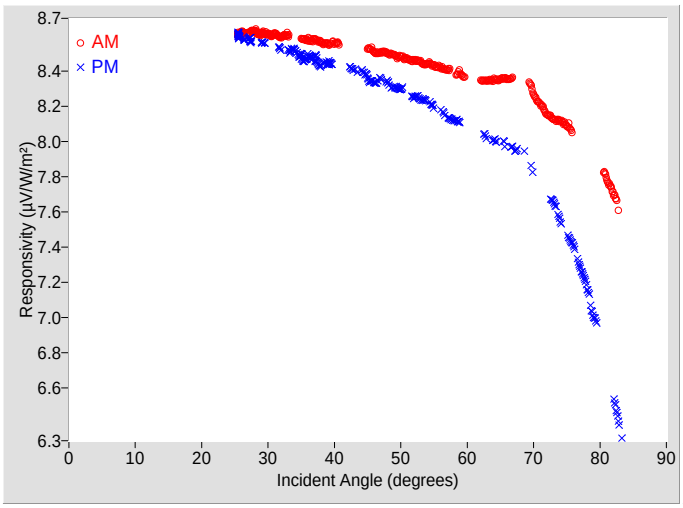


Figure 2. Responsivity vs Local Standard Time

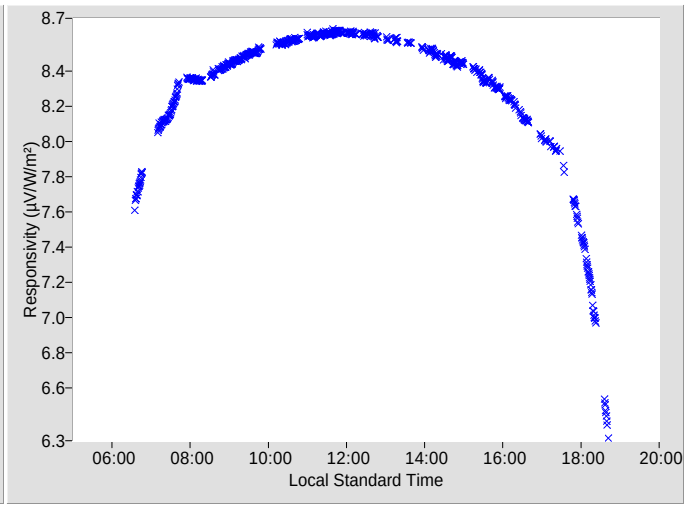


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4432	+2.77 / -4.61	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5085	0.73	113.07	8.3359	0.71	252.18
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5010	0.72	110.68	8.3350	0.75	254.31
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4842	0.75	108.48	8.2997	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4609	0.76	106.40	8.2530	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4425	0.79	104.43	8.2303	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4238	0.83	102.59	8.1799	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.1189	0.83	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3461	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3513	1.02	95.29	8.0075	0.96	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3567	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2718	1.47	90.69	7.8246	N/A	272.44
26	8.6164	0.64	166.50	8.5937	0.68	192.61	72	8.1554	1.53	89.19	N/A	N/A	N/A
28	8.6262	0.63	153.62	N/A	N/A	N/A	74	8.1192	1.61	87.73	7.5528	1.75	275.41
30	8.6101	0.62	144.99	N/A	N/A	N/A	76	8.0514	N/A	86.42	7.4102	2.14	276.84
32	8.5954	0.63	138.24	8.5260	0.65	222.18	78	N/A	N/A	N/A	7.1772	2.83	278.31
34	N/A	N/A	N/A	8.5202	0.74	227.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5789	0.64	128.67	8.4819	0.68	237.64	82	7.7088	3.64	81.85	6.5258	3.82	281.35
38	8.5642	0.66	124.75	8.4294	0.75	241.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5616	0.66	121.37	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	8.4232	N/A	247.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4000	0.73	250.13	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30666F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

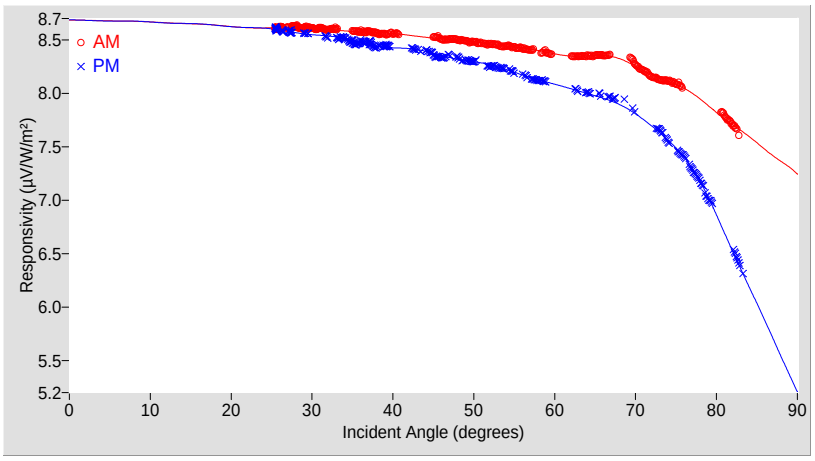


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.96	±1.96
Valid incidence angle range	25.5° to 82.8°	25.5° to 83.3°
R^2	0.9999996	0.9999992

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.6797	*	8.6799	*	8.6798	*
9-18	8.6565	*	8.6566	*	8.6566	*
18-27	8.6194	*	8.6148	*	8.6171	*
27-36	8.6022	±1.98	8.5382	±2.04	8.5702	±2.27
36-45	8.5539	±1.99	8.4274	±2.03	8.4906	±2.53
45-54	8.4865	±2.01	8.3057	±2.13	8.3961	±3.09
54-63	8.3941	±2.04	8.1240	±2.29	8.2591	±4.04
63-72	8.3104	±2.19	7.9014	±2.72	8.1059	±5.97
72-81	8.0118	±3.10	7.3214	±6.55	7.6666	±13.50
81-90	7.5063	*	5.9488	*	6.7276	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

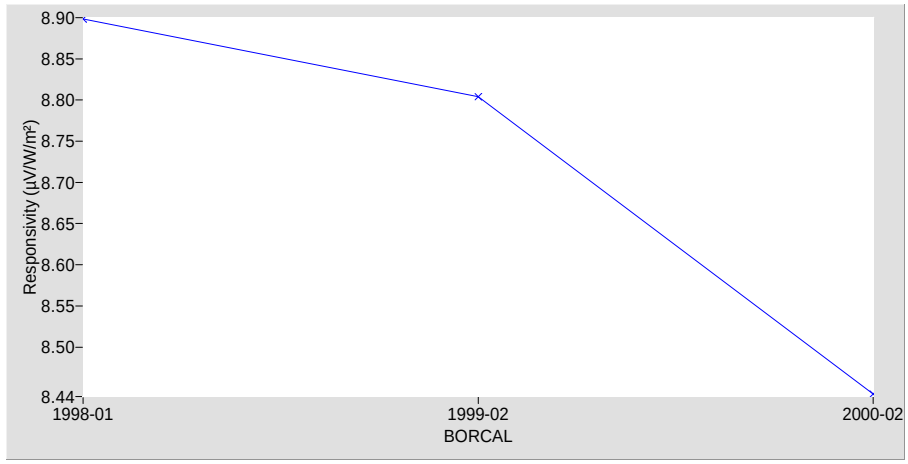
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4432	+2.77 / -4.61 [1]
45° - 55°	8.3858	±2.74 [2]
Composite	8.4737	+2.61 / -25.07 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.8°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



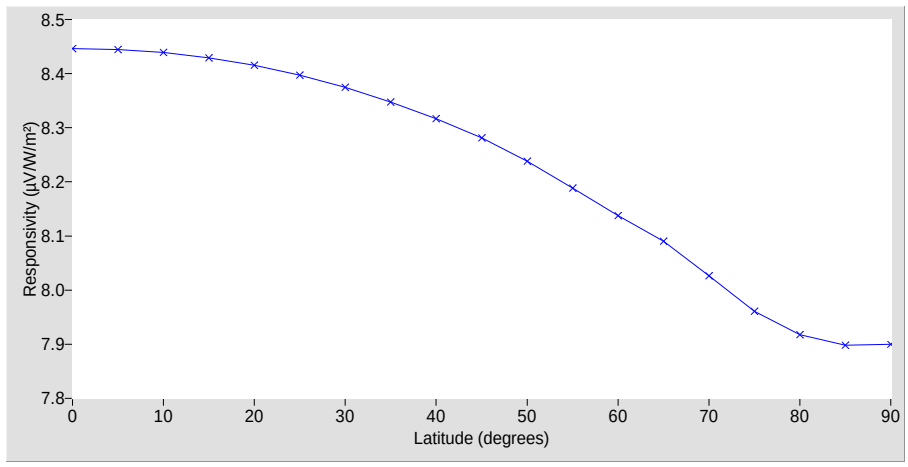
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.4459	+3.47 / -36.47
5	8.4445	+3.48 / -36.46
10	8.4389	+3.54 / -36.42
15	8.4290	+3.64 / -36.34
20	8.4153	+3.78 / -36.24
25	8.3971	+3.96 / -36.10
30	8.3746	+4.11 / -35.93
35	8.3474	+4.27 / -35.72
40	8.3165	+4.47 / -35.48
45	8.2810	+4.53 / -35.21
50	8.2379	+5.03 / -34.87
55	8.1887	+5.47 / -34.48
60	8.1374	+5.72 / -34.06
65	8.0901	+6.05 / -33.68
70	8.0263	+6.36 / -33.15
75	7.9608	+6.72 / -32.60
80	7.9174	+6.70 / -32.23
85	7.8980	+6.13 / -32.07
90	7.8998	+6.08 / -32.08

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30667F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30667F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

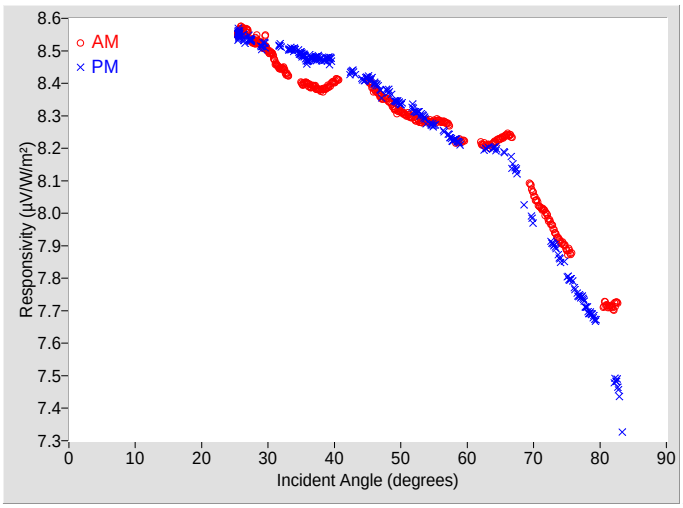


Figure 2. Responsivity vs Local Standard Time

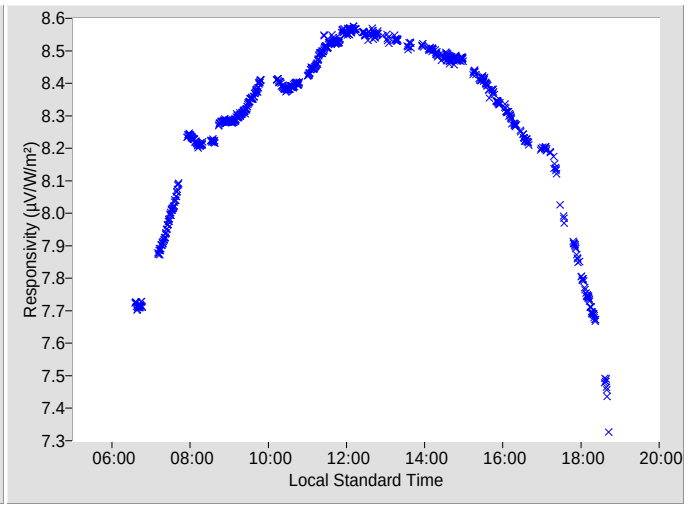


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4130	+1.98 / -3.02	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3789	0.76	112.99	8.3977	0.73	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3496	0.75	110.67	8.3766	0.71	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3134	0.74	108.47	8.3371	0.71	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2955	0.78	106.39	8.3195	0.76	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2838	0.78	104.47	8.2747	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2828	0.81	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2160	N/A	100.04	8.2251	0.84	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2140	0.97	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2175	1.03	95.32	8.2001	0.95	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2415	1.10	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0583	1.37	90.68	7.9770	1.25	272.42
26	8.5642	0.64	166.43	8.5505	0.68	192.82	72	7.9916	1.49	89.18	N/A	N/A	N/A
28	8.5278	0.62	153.95	N/A	N/A	N/A	74	7.9155	1.66	87.72	7.8608	1.57	275.36
30	8.4998	0.74	144.83	N/A	N/A	N/A	76	7.8776	N/A	86.45	7.7757	1.83	276.92
32	8.4464	0.66	138.32	8.5164	0.65	222.26	78	N/A	N/A	N/A	7.7053	2.16	278.33
34	N/A	N/A	N/A	8.5037	0.66	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3973	0.63	128.64	8.4706	0.66	237.14	82	7.7111	3.47	81.83	7.4853	3.60	281.37
38	8.3788	0.65	124.73	8.4728	0.64	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4057	0.67	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4123	0.67	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30667F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\,(am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\,(pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

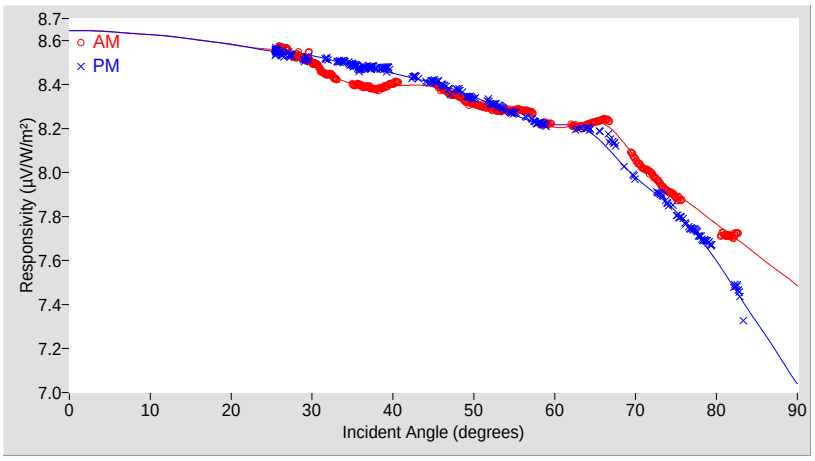


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.78	±1.78
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.3°
R^2	0.9999993	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.6401	*	8.6400	*	8.6401	*
9-18	8.6143	*	8.6141	*	8.6142	*
18-27	8.5710	*	8.5690	*	8.5700	*
27-36	8.4705	±1.98	8.5188	±1.81	8.4946	±2.19
36-45	8.3944	±1.78	8.4483	±1.83	8.4213	±1.95
45-54	8.3319	±1.87	8.3523	±1.92	8.3421	±2.04
54-63	8.2380	±1.85	8.2331	±1.83	8.2355	±1.94
63-72	8.1563	±2.29	8.0785	±2.46	8.1174	±3.23
72-81	7.8666	±2.30	7.7630	±2.85	7.8148	±4.16
81-90	7.6128	*	7.2906	*	7.4517	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

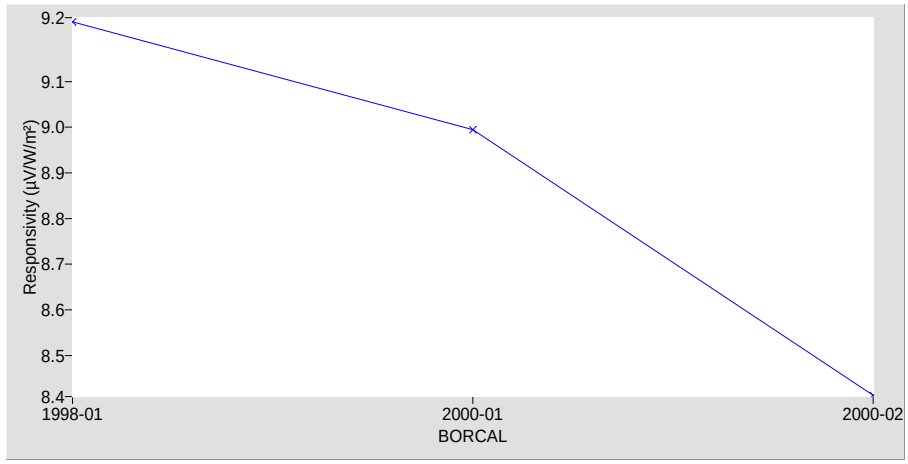
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4130	+1.98 / -3.02 [1]
45° - 55°	8.3330	±1.98 [2]
Composite	8.4418	+2.25 / -12.13 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



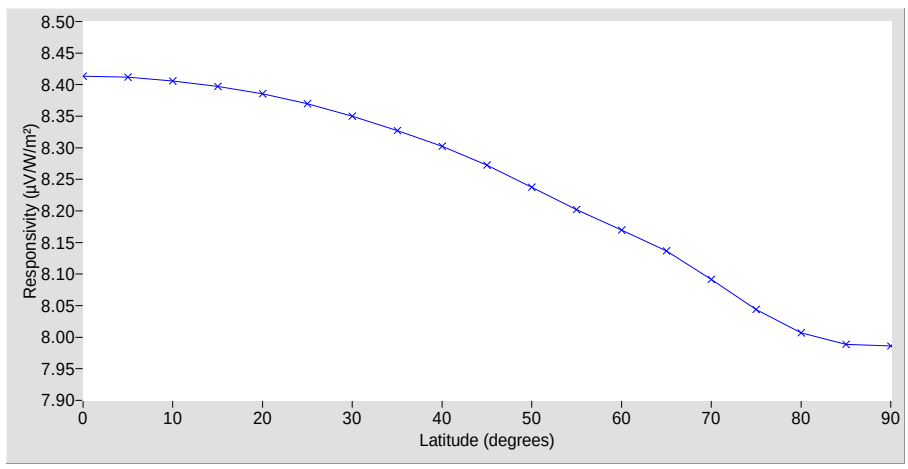
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.4133	+3.28 / -15.80
5	8.4117	+3.30 / -15.78
10	8.4058	+3.36 / -15.72
15	8.3969	+3.45 / -15.64
20	8.3854	+3.58 / -15.52
25	8.3695	+3.74 / -15.36
30	8.3499	+3.88 / -15.16
35	8.3272	+3.99 / -14.93
40	8.3023	+4.04 / -14.68
45	8.2722	+4.10 / -14.37
50	8.2375	+4.24 / -14.01
55	8.2020	+4.31 / -13.64
60	8.1693	+4.22 / -13.30
65	8.1368	+4.16 / -12.96
70	8.0917	+4.17 / -12.47
75	8.0439	+3.97 / -11.96
80	8.0072	+3.72 / -11.56
85	7.9888	+3.55 / -11.36
90	7.9861	+3.46 / -11.33

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30668F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30668F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

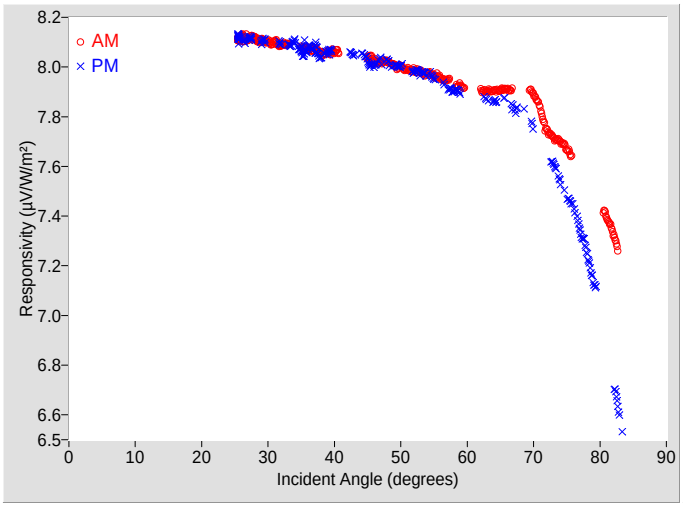


Figure 2. Responsivity vs Local Standard Time

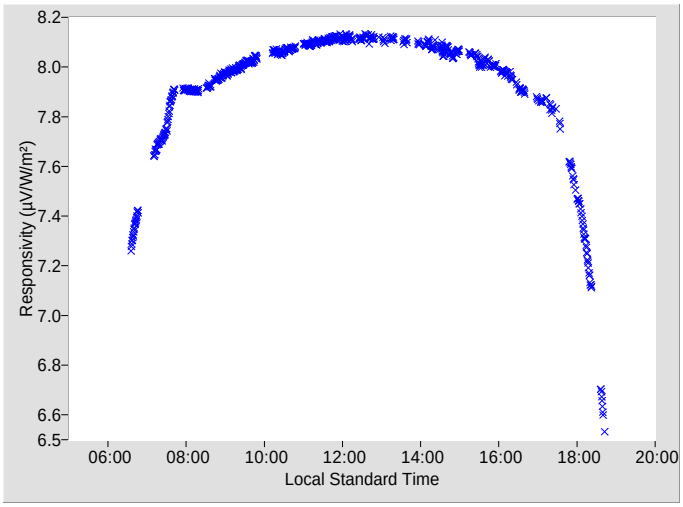


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0322	+1.68 / -2.34	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0242	0.73	112.99	8.0068	0.73	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0224	0.73	110.67	8.0228	0.72	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0037	0.75	108.47	8.0052	0.72	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9873	0.77	106.39	7.9803	0.75	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9751	0.79	104.47	7.9625	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9576	0.84	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9209	N/A	100.04	7.9027	0.83	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9055	0.97	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9054	1.02	95.32	7.8620	0.95	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9103	1.10	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8897	1.36	90.68	7.7614	1.26	272.42
26	8.1172	0.64	166.43	8.1176	0.67	192.82	72	7.7437	1.58	89.18	N/A	N/A	N/A
28	8.1168	0.62	153.72	N/A	N/A	N/A	74	7.7010	1.64	87.72	7.5456	1.69	275.36
30	8.1029	0.62	144.83	N/A	N/A	N/A	76	7.6430	N/A	86.45	7.4305	1.99	276.92
32	8.0886	0.63	138.25	8.0940	0.65	222.26	78	N/A	N/A	N/A	7.2497	2.52	278.33
34	N/A	N/A	N/A	8.1047	0.71	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0730	0.64	128.64	8.0765	0.75	237.14	82	7.3287	3.62	81.83	6.7029	3.73	281.37
38	8.0582	0.67	124.73	8.0363	0.75	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0612	0.67	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0557	0.68	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30668F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

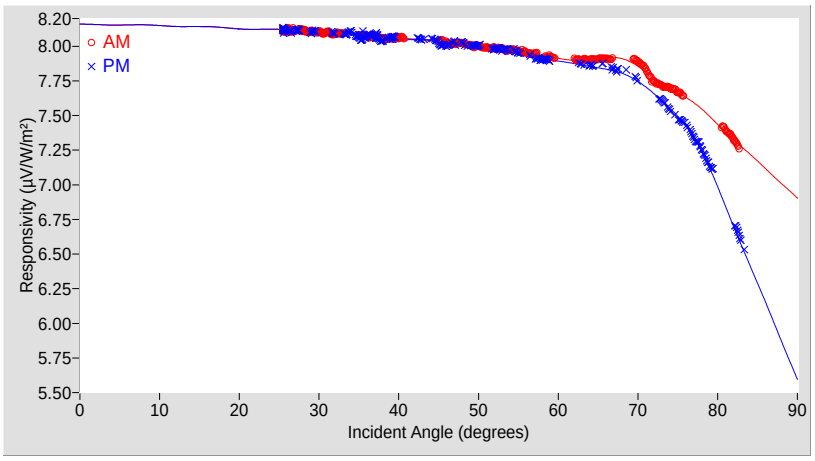


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.89	±1.89
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.3°
R^2	0.9999990	0.9999993

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.1550	*	8.1551	*	8.1550	*
9-18	8.1434	*	8.1435	*	8.1434	*
18-27	8.1236	*	8.1235	*	8.1236	*
27-36	8.0954	±1.91	8.1005	±1.90	8.0979	±1.93
36-45	8.0549	±1.90	8.0480	±1.90	8.0515	±1.92
45-54	8.0080	±1.92	8.0048	±1.94	8.0064	±1.99
54-63	7.9305	±1.95	7.9088	±1.98	7.9196	±2.09
63-72	7.8882	±2.05	7.8006	±2.22	7.8444	±2.97
72-81	7.6078	±3.06	7.3598	±5.38	7.4838	±8.73
81-90	7.1423	*	6.2185	*	6.6804	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

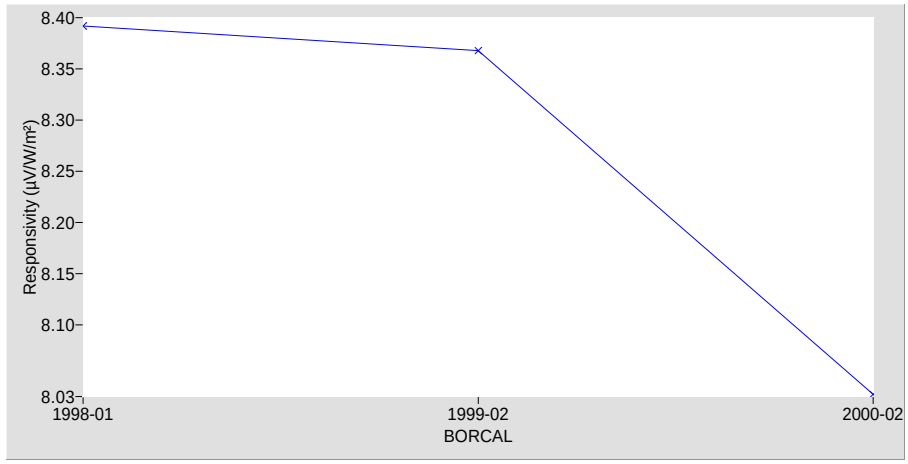
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0322	+1.68 / -2.34 [1]
45° - 55°	7.9995	±1.98 [2]
Composite	8.0352	+2.17 / -18.46 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



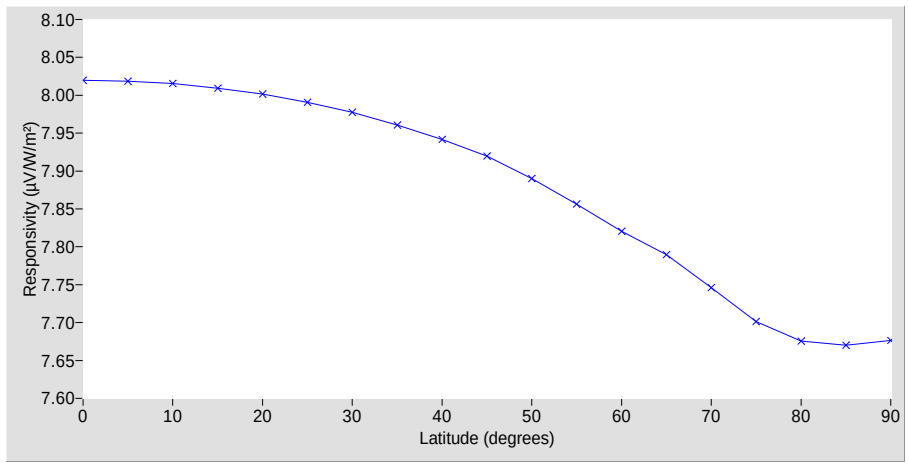
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0196	+2.58 / -28.59
5	8.0187	+2.59 / -28.58
10	8.0153	+2.62 / -28.55
15	8.0093	+2.67 / -28.50
20	8.0015	+2.74 / -28.43
25	7.9908	+2.83 / -28.33
30	7.9773	+2.92 / -28.21
35	7.9606	+3.00 / -28.06
40	7.9417	+3.16 / -27.89
45	7.9195	+3.20 / -27.69
50	7.8903	+3.46 / -27.42
55	7.8562	+3.70 / -27.11
60	7.8205	+3.71 / -26.78
65	7.7897	+3.90 / -26.49
70	7.7460	+4.08 / -26.07
75	7.7012	+4.32 / -25.64
80	7.6754	+4.06 / -25.39
85	7.6701	+3.77 / -25.34
90	7.6766	+3.69 / -25.41

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30670F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30670F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

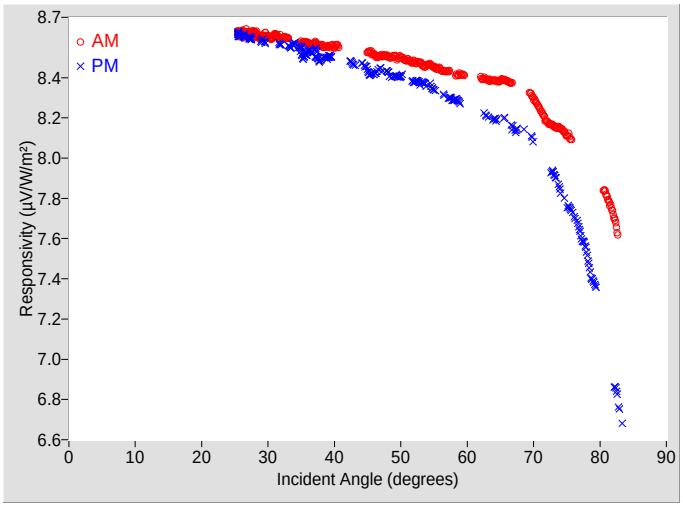


Figure 2. Responsivity vs Local Standard Time

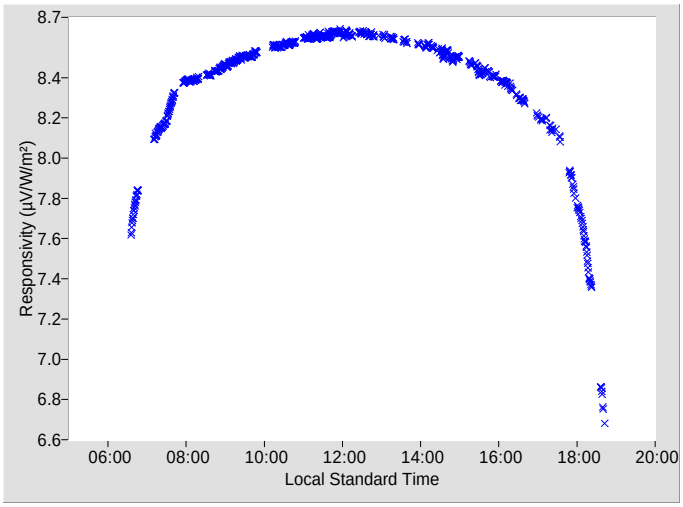


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4814	+2.24 / -3.06	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5131	0.72	112.99	8.4217	0.72	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5070	0.72	110.67	8.4255	0.72	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5032	0.75	108.47	8.4079	0.72	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4794	0.77	106.39	8.3793	0.74	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4629	0.79	104.47	8.3560	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4420	0.82	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4091	N/A	100.04	8.2889	0.84	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3976	0.97	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3870	1.02	95.32	8.1923	0.96	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3829	1.10	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2963	1.38	90.68	8.0920	1.25	272.42
26	8.6169	0.66	166.43	8.6092	0.65	192.82	72	8.1803	1.50	89.18	N/A	N/A	N/A
28	8.6223	0.63	153.72	N/A	N/A	N/A	74	8.1503	1.63	87.72	7.8493	1.70	275.36
30	8.6048	0.63	144.83	N/A	N/A	N/A	76	8.0925	N/A	86.45	7.7129	1.98	276.92
32	8.5971	0.63	138.25	8.5648	0.65	222.26	78	N/A	N/A	N/A	7.5217	2.60	278.33
34	N/A	N/A	N/A	8.5680	0.69	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5715	0.63	128.64	8.5288	0.72	237.14	82	7.7211	3.69	81.83	6.8619	3.72	281.37
38	8.5609	0.66	124.73	8.4862	0.75	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5552	0.66	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4723	0.69	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30670F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

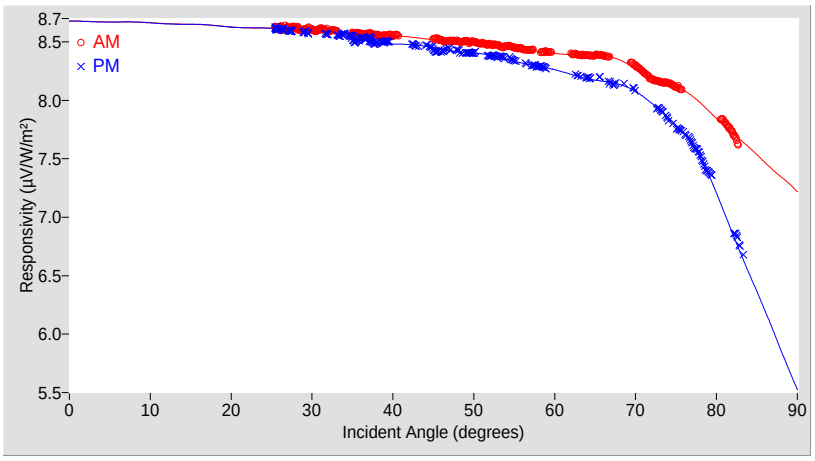


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.90	±1.90
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.3°
R^2	0.9999996	0.9999994

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.6727	*	8.6729	*	8.6728	*
9-18	8.6542	*	8.6544	*	8.6543	*
18-27	8.6236	*	8.6218	*	8.6227	*
27-36	8.5996	±1.91	8.5736	±1.93	8.5866	±2.02
36-45	8.5502	±1.92	8.4849	±1.94	8.5176	±2.12
45-54	8.4991	±1.92	8.4086	±1.97	8.4538	±2.31
54-63	8.4188	±1.94	8.2856	±2.08	8.3522	±2.84
63-72	8.3392	±2.16	8.1308	±2.26	8.2350	±3.89
72-81	8.0432	±3.08	7.6364	±5.90	7.8398	±10.44
81-90	7.5013	*	6.2773	*	6.8893	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

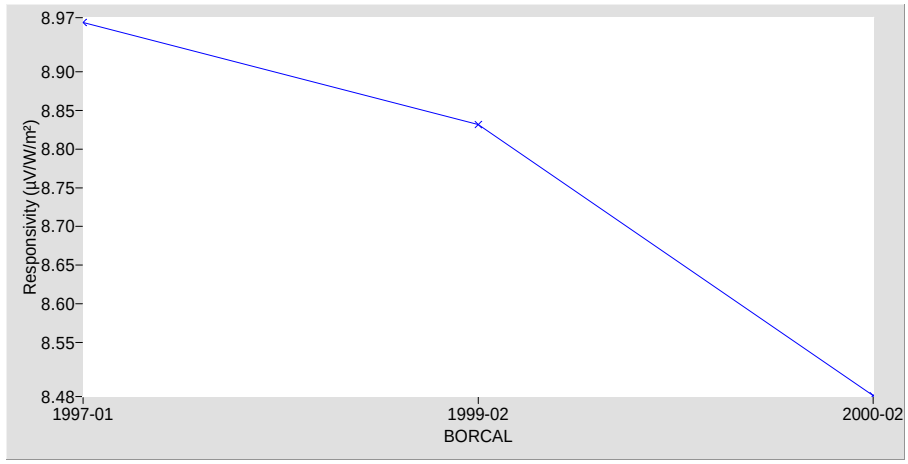
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4814	+2.24 / -3.06 [1]
45° - 55°	8.4460	±2.19 [2]
Composite	8.5081	+2.30 / -21.48 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



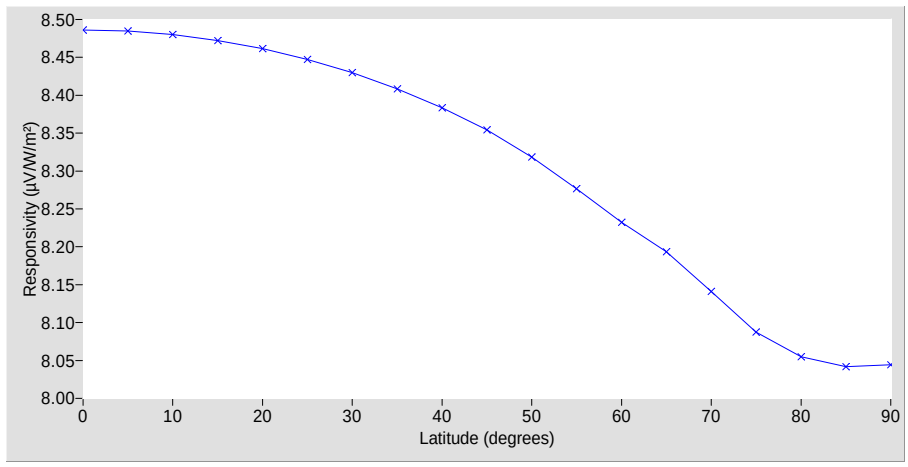
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.4859	+2.97 / -33.02
5	8.4848	+2.98 / -33.01
10	8.4803	+3.02 / -32.98
15	8.4722	+3.10 / -32.91
20	8.4614	+3.20 / -32.83
25	8.4473	+3.33 / -32.71
30	8.4298	+3.44 / -32.57
35	8.4082	+3.54 / -32.40
40	8.3834	+3.71 / -32.20
45	8.3545	+3.74 / -31.97
50	8.3185	+4.07 / -31.67
55	8.2767	+4.39 / -31.33
60	8.2323	+4.52 / -30.96
65	8.1935	+4.75 / -30.63
70	8.1410	+4.95 / -30.18
75	8.0875	+5.37 / -29.72
80	8.0548	+5.11 / -29.44
85	8.0417	+4.78 / -29.32
90	8.0444	+4.63 / -29.35

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30674F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30674F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

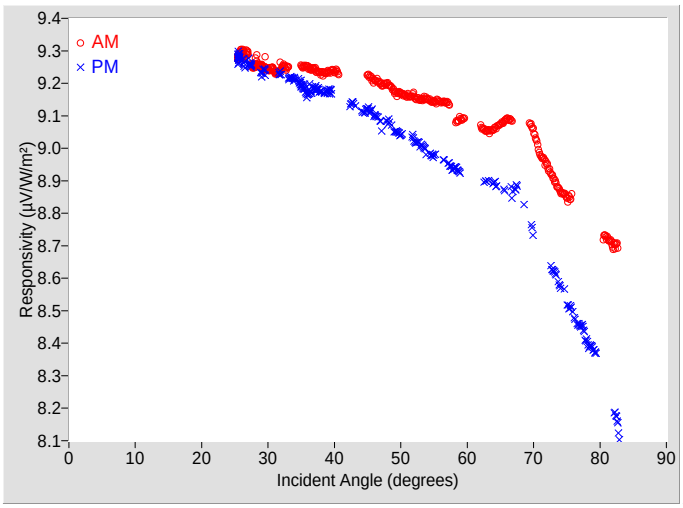


Figure 2. Responsivity vs Local Standard Time

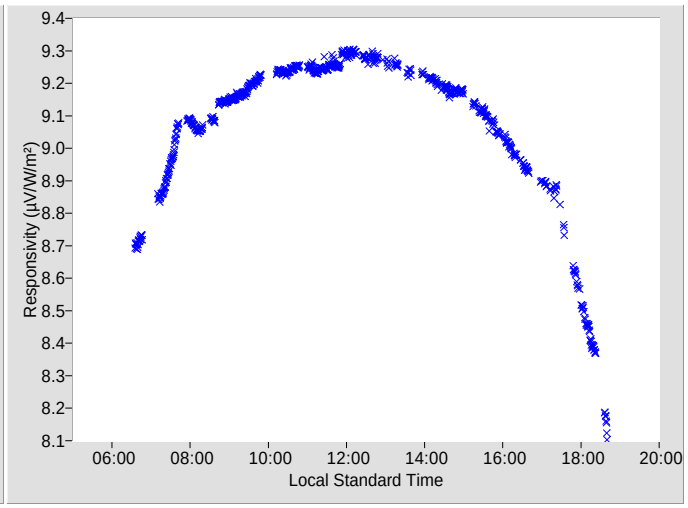


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
9.1727	+1.68 / -3.35	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2084	0.71	112.99	9.0999	0.72	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1979	0.73	110.67	9.0825	0.72	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1702	0.73	108.47	9.0421	0.71	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1610	0.76	106.39	9.0261	0.76	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1516	0.78	104.47	8.9800	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1431	0.81	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0790	N/A	100.04	8.9377	0.83	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0650	0.97	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0598	1.02	95.32	8.8921	0.95	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0904	1.09	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.0513	1.39	90.68	8.7438	1.24	272.42
26	9.2947	0.63	166.43	9.2752	0.68	192.82	72	8.9468	1.47	89.18	N/A	N/A	N/A
28	9.2546	0.63	153.95	N/A	N/A	N/A	74	8.8694	1.62	87.72	8.5785	1.55	275.36
30	9.2434	0.64	144.83	N/A	N/A	N/A	76	8.8603	N/A	86.45	8.4828	1.81	276.92
32	9.2468	0.64	138.25	9.2304	0.64	222.26	78	N/A	N/A	N/A	8.4021	2.15	278.33
34	N/A	N/A	N/A	9.2124	0.67	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.2507	0.63	128.64	9.1708	0.67	237.14	82	8.7011	3.43	81.83	8.1865	3.57	281.37
38	9.2307	0.65	124.73	9.1739	0.64	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.2384	0.65	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	9.1130	0.67	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30674F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

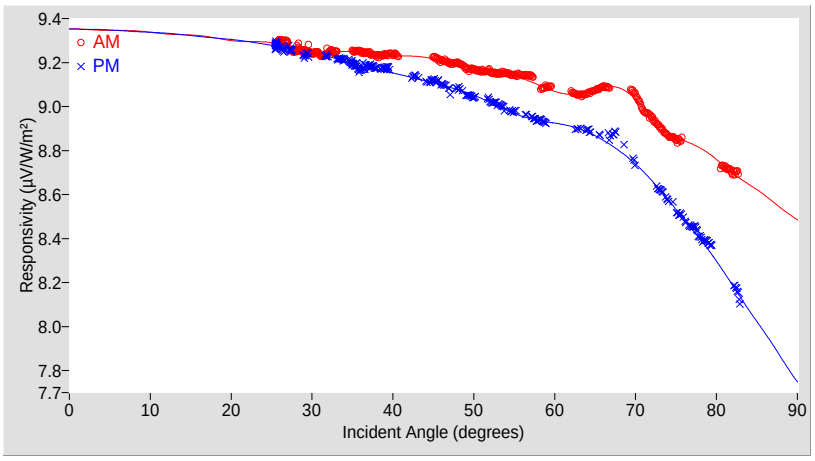


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.76	±1.76
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999994	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.3479	*	9.3477	*	9.3478	*
9-18	9.3284	*	9.3280	*	9.3282	*
18-27	9.2956	*	9.2929	*	9.2942	*
27-36	9.2506	±1.77	9.2333	±1.82	9.2420	±1.88
36-45	9.2329	±1.77	9.1491	±1.81	9.1910	±2.06
45-54	9.1832	±1.80	9.0570	±1.87	9.1201	±2.48
54-63	9.0970	±1.84	8.9395	±1.82	9.0182	±2.61
63-72	9.0589	±1.88	8.8082	±2.15	8.9335	±3.75
72-81	8.8428	±2.12	8.4736	±2.91	8.6582	±5.88
81-90	8.6061	*	7.9954	*	8.3008	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

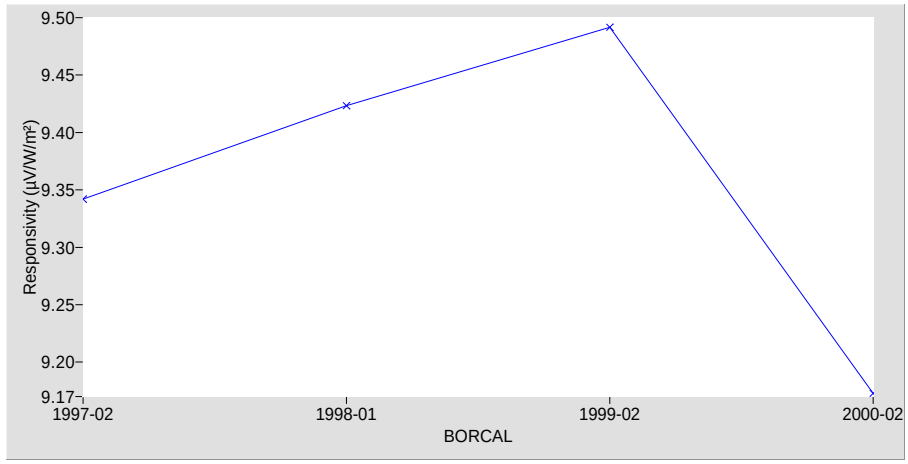
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	9.1727	+1.68 / -3.35 [1]
45° - 55°	9.1117	±2.23 [2]
Composite	9.1920	+2.04 / -11.38 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



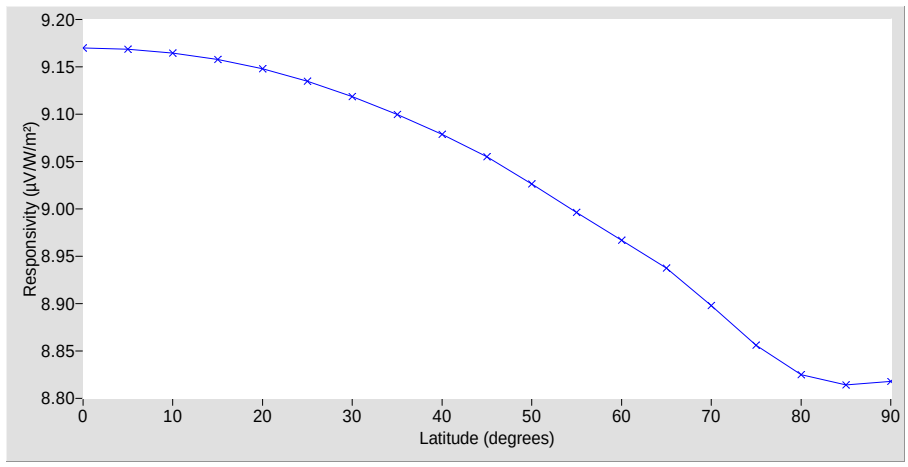
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	9.1699	+2.67 / -15.03
5	9.1686	+2.68 / -15.02
10	9.1645	+2.72 / -14.98
15	9.1576	+2.77 / -14.91
20	9.1479	+2.86 / -14.82
25	9.1349	+2.97 / -14.70
30	9.1187	+3.05 / -14.55
35	9.0996	+3.14 / -14.38
40	9.0787	+3.22 / -14.18
45	9.0550	+3.24 / -13.96
50	9.0262	+3.35 / -13.68
55	8.9964	+3.33 / -13.40
60	8.9669	+3.59 / -13.12
65	8.9375	+3.72 / -12.83
70	8.8980	+3.91 / -12.45
75	8.8560	+3.96 / -12.04
80	8.8250	+3.86 / -11.73
85	8.8143	+3.60 / -11.63
90	8.8178	+3.57 / -11.66

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30677F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30677F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

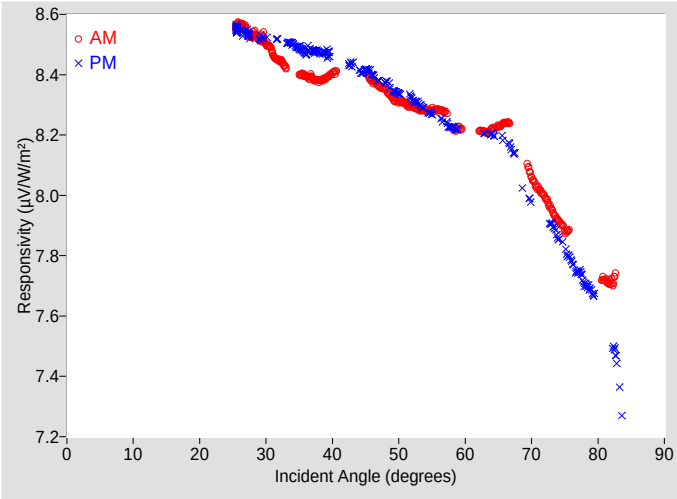


Figure 2. Responsivity vs Local Standard Time

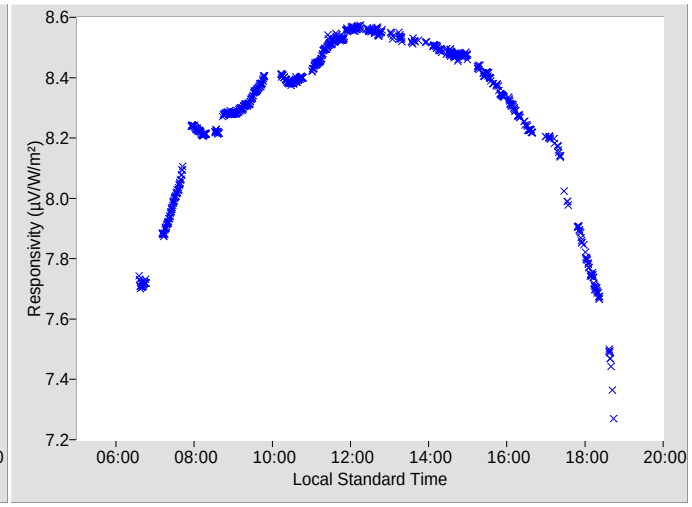


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4110	+1.97 / -3.03	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3783	0.74	113.05	8.3969	0.72	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3505	0.74	110.67	8.3758	0.71	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3110	0.74	108.47	8.3380	0.71	256.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2967	0.77	106.39	8.3189	0.75	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2822	0.78	104.46	8.2904	N/A	259.74
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2831	0.81	102.57	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2164	N/A	100.09	8.2259	0.83	263.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2143	0.97	96.76	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2212	1.03	95.33	8.2023	0.95	268.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2405	1.10	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0604	1.40	90.68	7.9839	1.24	272.38
26	8.5648	0.63	166.63	8.5498	N/A	196.28	72	7.9943	1.50	89.18	N/A	N/A	N/A
28	8.5301	0.62	153.40	N/A	N/A	N/A	74	7.9171	1.67	87.72	7.8586	1.59	275.40
30	8.5014	0.72	144.95	8.5238	N/A	216.90	76	N/A	N/A	N/A	7.7807	1.86	276.89
32	8.4476	0.66	138.43	8.5184	N/A	221.89	78	N/A	N/A	N/A	7.7044	2.17	278.33
34	N/A	N/A	N/A	8.5029	0.66	227.63	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3955	0.63	128.63	8.4712	0.65	237.90	82	7.7124	3.47	81.85	7.4926	N/A	281.38
38	8.3803	0.64	124.80	8.4732	0.64	241.88	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4046	0.66	121.43	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4117	0.70	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30677F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

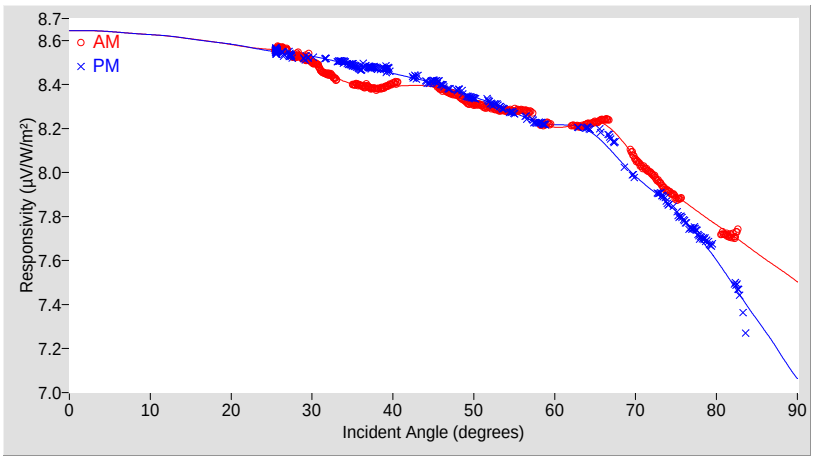


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.56	±1.56
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.6°
R^2	0.9999994	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.6404	*	8.6404	*	8.6404	*
9-18	8.6145	*	8.6144	*	8.6145	*
18-27	8.5711	*	8.5689	*	8.5700	*
27-36	8.4714	±1.79	8.5176	±1.60	8.4945	±2.02
36-45	8.3938	±1.56	8.4484	±1.62	8.4211	±1.76
45-54	8.3315	±1.67	8.3535	±1.69	8.3425	±1.84
54-63	8.2383	±1.64	8.2373	±1.63	8.2378	±1.73
63-72	8.1576	±2.12	8.0828	±2.30	8.1202	±3.10
72-81	7.8625	±2.15	7.7646	±2.72	7.8136	±4.06
81-90	7.6214	*	7.3050	*	7.4632	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

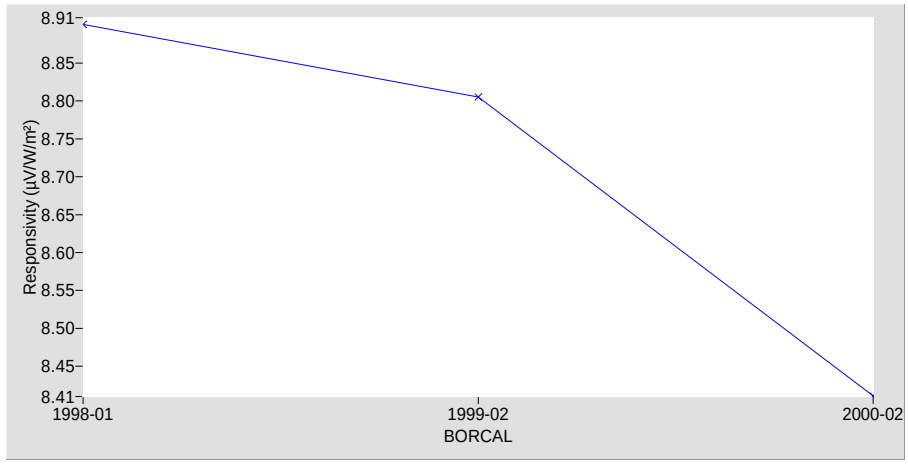
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4110	+1.97 / -3.03 [1]
45° - 55°	8.3341	±1.76 [2]
Composite	8.4423	+2.07 / -12.32 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



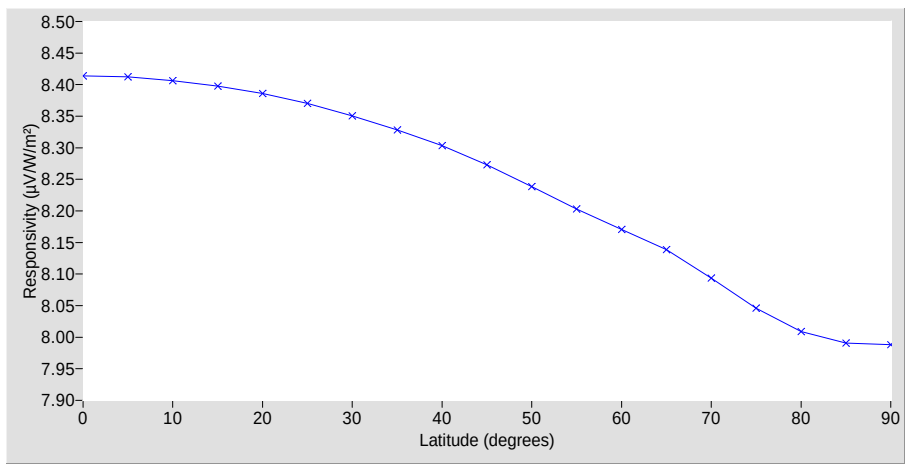
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.4138	+3.17 / -15.53
5	8.4122	+3.18 / -15.51
10	8.4063	+3.25 / -15.45
15	8.3975	+3.34 / -15.37
20	8.3860	+3.47 / -15.25
25	8.3702	+3.64 / -15.09
30	8.3507	+3.78 / -14.89
35	8.3281	+3.89 / -14.66
40	8.3032	+3.93 / -14.41
45	8.2732	+4.00 / -14.10
50	8.2385	+4.15 / -13.74
55	8.2031	+4.18 / -13.37
60	8.1707	+4.13 / -13.03
65	8.1385	+4.05 / -12.69
70	8.0936	+4.04 / -12.21
75	8.0461	+3.87 / -11.69
80	8.0088	+3.60 / -11.28
85	7.9909	+3.43 / -11.09
90	7.9884	+3.32 / -11.06

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30709F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30709F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

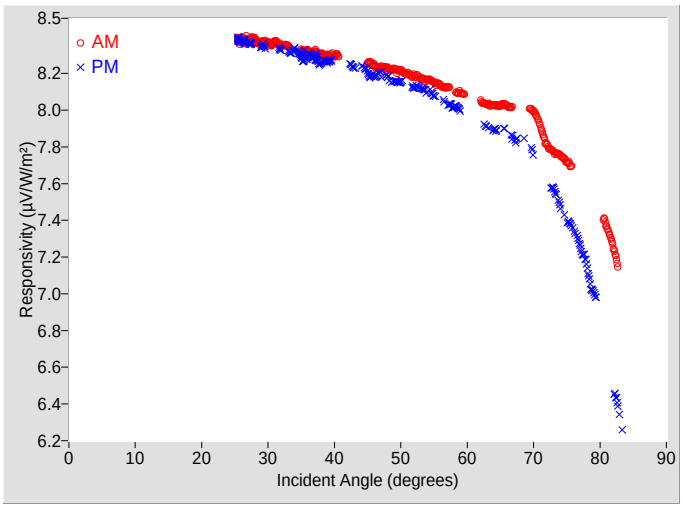


Figure 2. Responsivity vs Local Standard Time

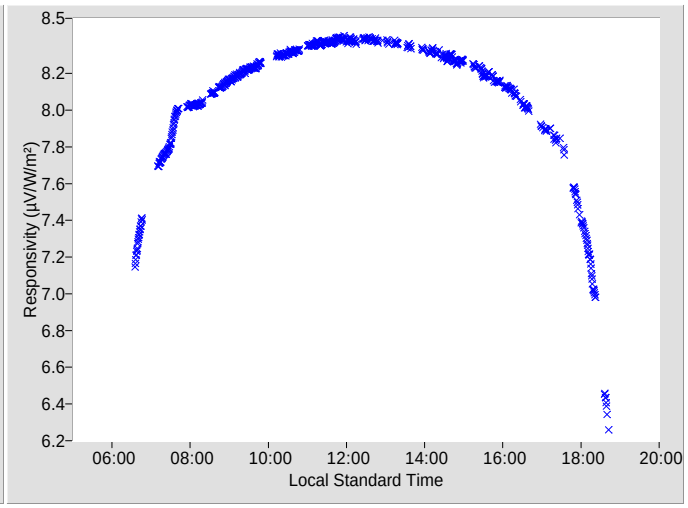


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.2325	+2.27 / -3.43	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2420	0.74	112.99	8.1856	0.71	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2286	0.73	110.67	8.1823	0.74	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2162	0.76	108.47	8.1545	0.72	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1883	0.78	106.39	8.1242	0.73	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1642	0.79	104.47	8.0928	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1365	0.83	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0955	N/A	100.04	8.0167	0.85	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0466	0.98	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0276	1.03	95.32	7.8931	0.96	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0243	1.10	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9917	1.40	90.68	7.7691	1.27	272.42
26	8.3798	0.67	166.43	8.3766	0.67	192.82	72	7.8098	1.65	89.18	N/A	N/A	N/A
28	8.3850	0.63	153.72	N/A	N/A	N/A	74	7.7555	1.65	87.72	7.4886	1.80	275.36
30	8.3665	0.62	144.83	N/A	N/A	N/A	76	7.6964	N/A	86.45	7.3417	2.01	276.92
32	8.3533	0.63	138.25	8.3293	0.65	222.26	78	N/A	N/A	N/A	7.1471	2.69	278.33
34	N/A	N/A	N/A	8.3286	0.70	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3225	0.64	128.64	8.2944	0.74	237.14	82	7.2549	3.83	81.83	6.4557	3.78	281.37
38	8.3060	0.67	124.73	8.2530	0.74	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2969	0.66	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2407	0.69	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30709F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

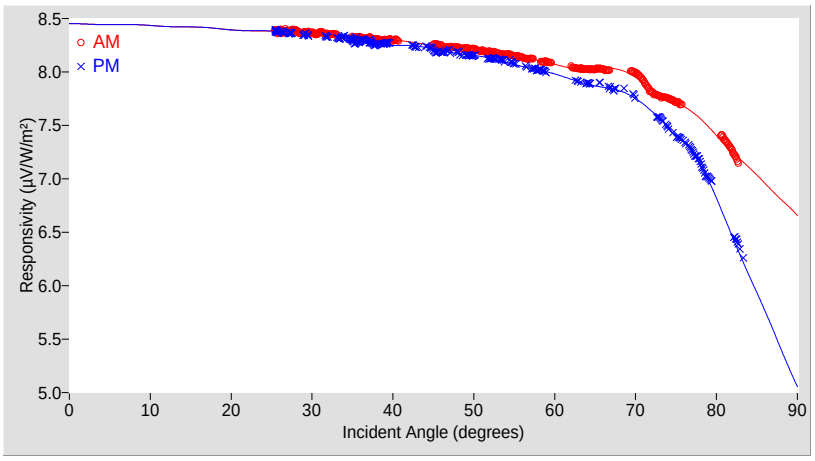


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.97	±1.97
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.3°
R^2	0.9999986	0.9999993

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.4454	*	8.4455	*	8.4454	*
9-18	8.4246	*	8.4247	*	8.4246	*
18-27	8.3896	*	8.3886	*	8.3891	*
27-36	8.3577	±2.00	8.3382	±2.01	8.3479	±2.10
36-45	8.2913	±2.01	8.2521	±2.01	8.2717	±2.14
45-54	8.2161	±2.03	8.1606	±2.09	8.1884	±2.36
54-63	8.0977	±2.13	8.0104	±2.24	8.0540	±2.89
63-72	7.9966	±2.23	7.8180	±2.51	7.9073	±3.98
72-81	7.6381	±3.72	7.2671	±6.53	7.4526	±11.22
81-90	6.9930	*	5.8428	*	6.4179	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

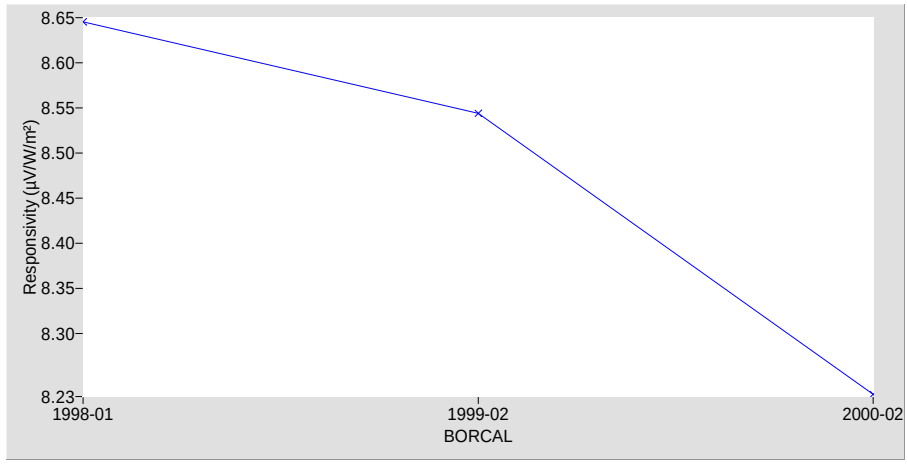
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2325	+2.27 / -3.43 [1]
45° - 55°	8.1780	±2.25 [2]
Composite	8.2514	+2.54 / -24.07 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



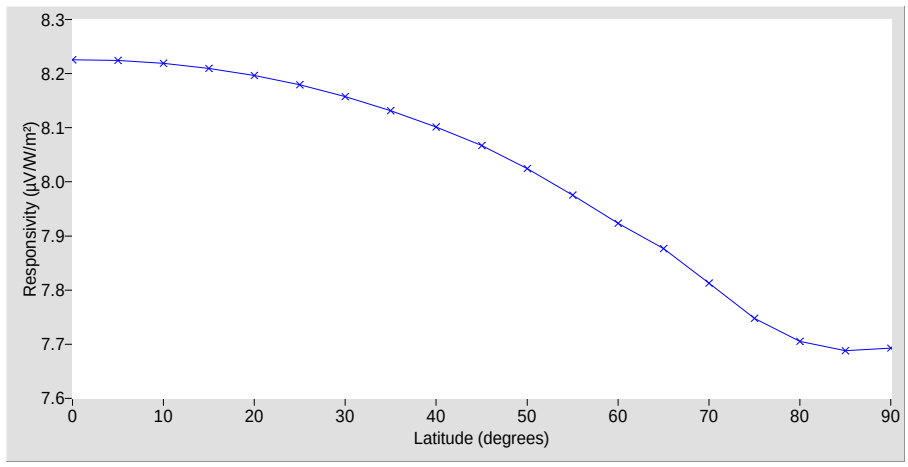
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.2256	+3.40 / -36.54
5	8.2242	+3.41 / -36.53
10	8.2189	+3.46 / -36.49
15	8.2094	+3.56 / -36.42
20	8.1965	+3.70 / -36.32
25	8.1792	+3.87 / -36.18
30	8.1578	+4.03 / -36.02
35	8.1316	+4.17 / -35.81
40	8.1013	+4.40 / -35.57
45	8.0671	+4.45 / -35.30
50	8.0245	+4.88 / -34.95
55	7.9755	+5.25 / -34.55
60	7.9235	+5.37 / -34.13
65	7.8767	+5.62 / -33.73
70	7.8130	+5.80 / -33.19
75	7.7475	+6.25 / -32.63
80	7.7055	+5.87 / -32.26
85	7.6880	+5.14 / -32.11
90	7.6927	+4.87 / -32.15

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30719E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30719E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

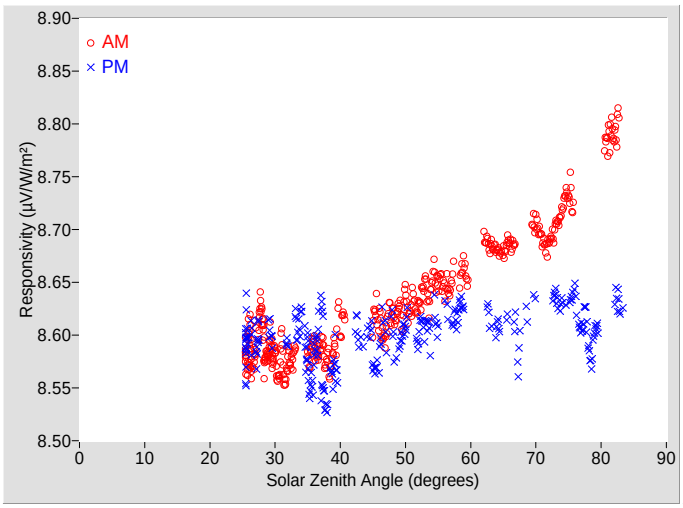


Figure 2. Responsivity vs Local Standard Time

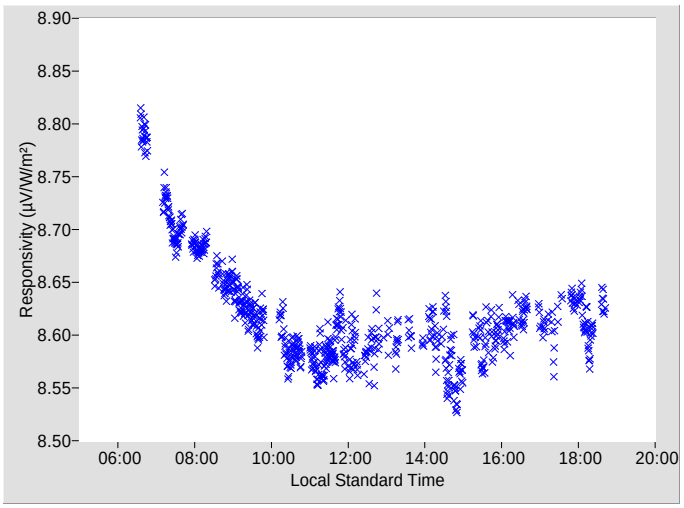


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.5989	+1.28 / -1.27	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6133	0.53	112.98	8.5856	0.57	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6177	0.47	110.72	8.6035	0.52	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6364	0.50	108.46	8.6112	0.48	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6282	0.47	106.43	8.5980	0.47	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6465	0.54	104.46	8.5807	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6448	0.46	102.63	8.6327	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6446	N/A	100.03	8.6182	0.47	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6912	0.46	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6817	0.45	95.32	8.6079	0.45	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6867	0.47	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.7041	0.49	90.67	8.6346	N/A	272.46
26	8.5876	0.56	166.57	8.6010	0.67	192.79	72	8.6875	0.50	89.17	N/A	N/A	N/A
28	8.6138	0.64	153.70	N/A	N/A	N/A	74	8.7190	0.51	87.71	8.6294	0.48	275.35
30	8.5773	0.54	144.94	N/A	N/A	N/A	76	8.7258	N/A	86.44	8.6369	0.54	276.91
32	8.5750	0.53	138.30	8.5931	0.43	222.24	78	N/A	N/A	N/A	8.5923	0.59	278.33
34	N/A	N/A	N/A	8.6175	0.56	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5903	0.46	128.63	8.5782	0.65	237.13	82	8.7894	0.64	81.83	8.6371	0.58	281.36
38	8.5750	0.49	124.80	8.5313	0.78	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6091	0.52	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.6025	0.49	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30719E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

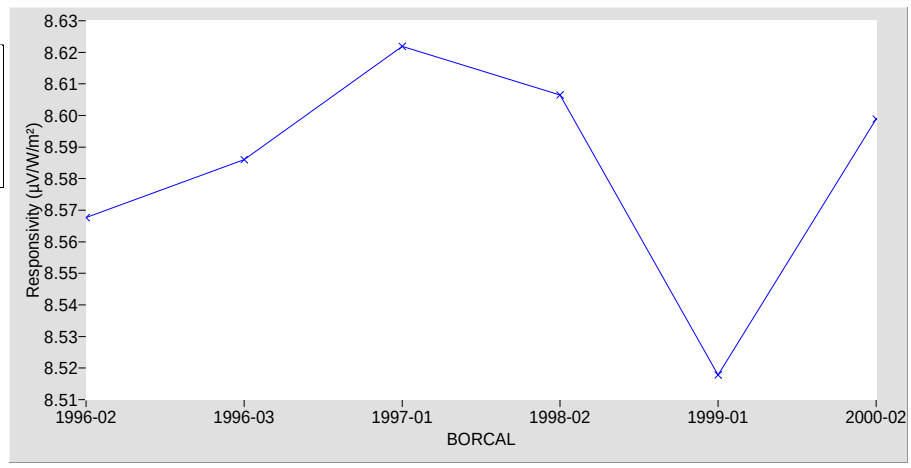
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5989	+1.28 / -1.27 †
Average	8.6268	+2.53 / -1.88 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 30720E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30720E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

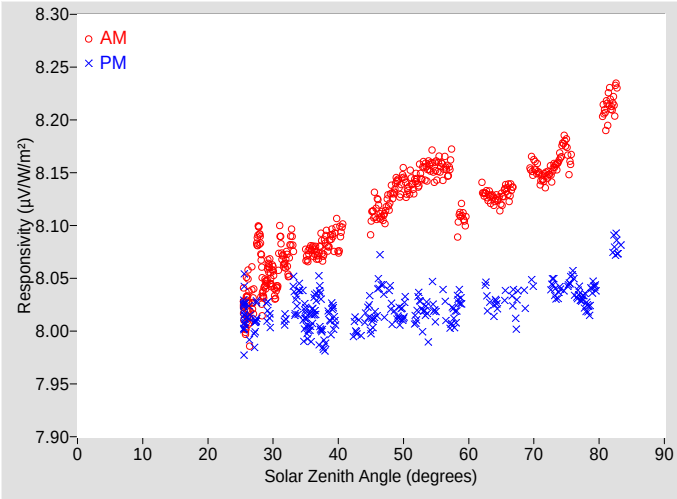


Figure 2. Responsivity vs Local Standard Time

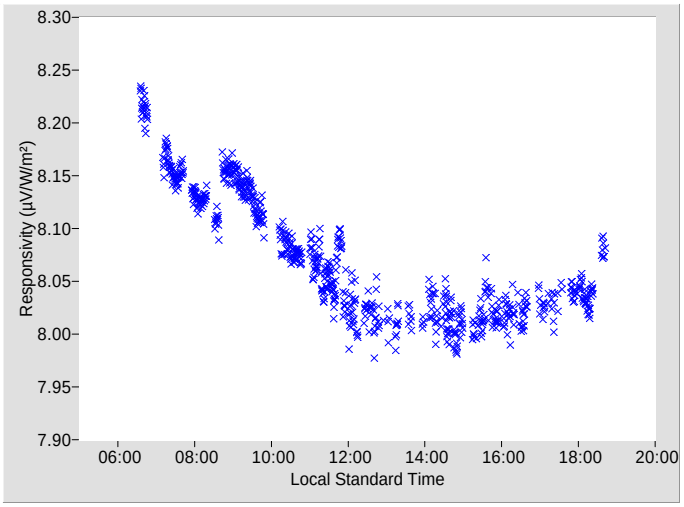


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0593	+1.84 / -1.40	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1164	0.47	112.98	8.0361	0.64	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1256	0.51	110.72	8.0269	0.49	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1465	0.47	108.46	8.0196	0.47	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1426	0.47	106.43	8.0171	0.49	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1560	0.48	104.46	7.9896	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1540	0.46	102.63	8.0395	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0892	N/A	100.03	8.0159	0.49	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1341	0.46	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1246	0.46	95.32	8.0246	0.45	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1318	0.47	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1546	0.49	90.67	8.0424	N/A	272.46
26	8.0228	0.64	166.57	8.0151	0.65	192.79	72	8.1464	0.49	89.17	N/A	N/A	N/A
28	8.0763	0.68	153.70	N/A	N/A	N/A	74	8.1659	0.52	87.71	8.0374	0.48	275.35
30	8.0482	0.51	144.94	N/A	N/A	N/A	76	8.1672	N/A	86.44	8.0485	0.50	276.91
32	8.0649	0.53	138.30	8.0111	0.44	222.24	78	N/A	N/A	N/A	8.0244	0.52	278.33
34	N/A	N/A	N/A	8.0345	0.58	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0775	0.44	128.63	8.0133	0.52	237.13	82	8.2149	0.66	81.83	8.0827	0.60	281.36
38	8.0829	0.47	124.80	7.9859	0.62	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0864	0.48	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0127	0.49	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30720E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

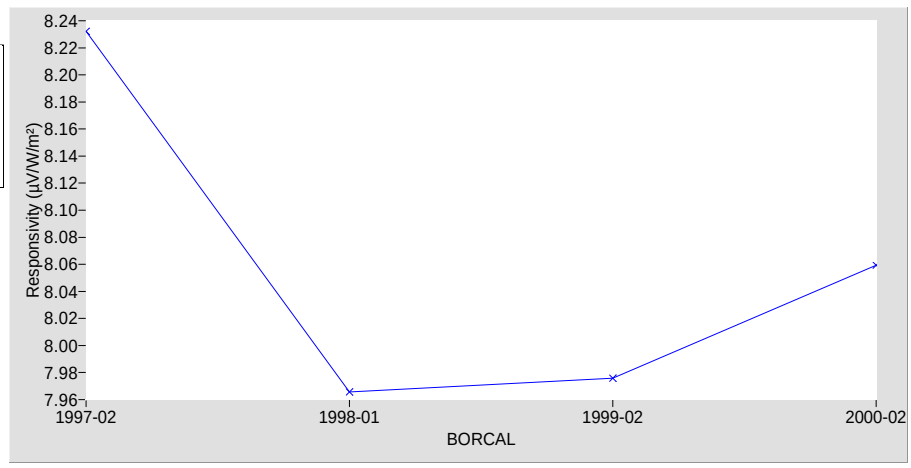
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0593	+1.84 / -1.40 †
Average	8.0754	+2.40 / -1.72 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 30775F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30775F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

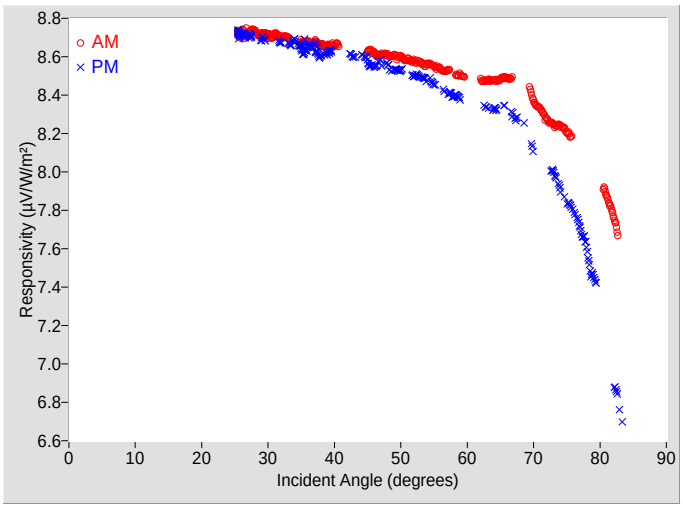


Figure 2. Responsivity vs Local Standard Time

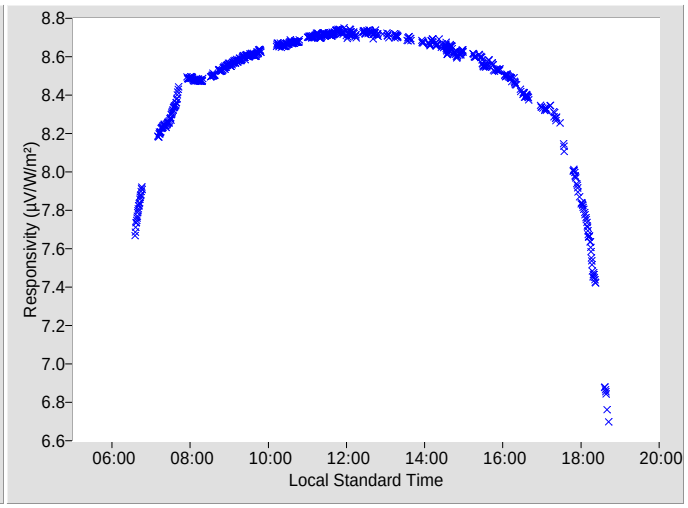


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.6023	+1.92 / -3.18	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6168	0.73	112.99	8.5497	0.72	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6091	0.72	110.67	8.5561	0.74	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6015	0.75	108.47	8.5305	0.71	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5778	0.77	106.39	8.5007	0.73	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5603	0.79	104.47	8.4695	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5379	0.82	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5041	N/A	100.04	8.3944	0.85	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4780	0.97	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4779	1.02	95.32	8.3265	0.95	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4883	1.09	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3724	1.44	90.68	8.1204	1.26	272.42
26	8.7206	0.68	166.43	8.7158	0.68	192.82	72	8.2717	1.50	89.18	N/A	N/A	N/A
28	8.7315	0.63	153.72	N/A	N/A	N/A	74	8.2415	1.62	87.72	7.9201	1.73	275.36
30	8.7148	0.62	144.83	N/A	N/A	N/A	76	8.1867	N/A	86.45	7.7897	1.97	276.92
32	8.7021	0.63	138.25	8.6745	0.65	222.26	78	N/A	N/A	N/A	7.5920	2.65	278.33
34	N/A	N/A	N/A	8.6843	0.70	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6764	0.63	128.64	8.6510	0.78	237.14	82	7.7728	3.72	81.83	6.8778	3.73	281.37
38	8.6639	0.67	124.73	8.6013	0.79	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6597	0.66	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.6102	0.68	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30775F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

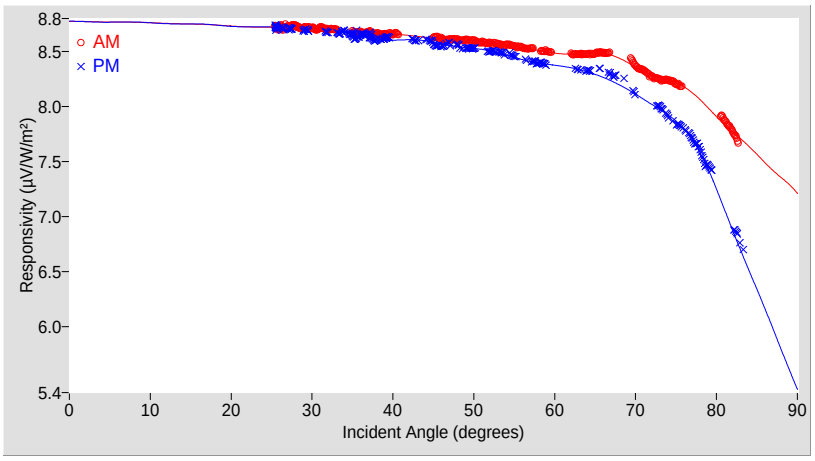


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.91	±1.91
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.3°
R²	0.9999997	0.9999993

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.7696	*	8.7697	*	8.7696	*
9-18	8.7536	*	8.7538	*	8.7537	*
18-27	8.7274	*	8.7260	*	8.7267	*
27-36	8.7064	±1.93	8.6848	±1.93	8.6956	±2.00
36-45	8.6543	±1.93	8.6099	±1.93	8.6321	±2.02
45-54	8.5994	±1.94	8.5342	±2.00	8.5668	±2.25
54-63	8.5104	±1.97	8.3993	±2.05	8.4548	±2.61
63-72	8.4300	±2.20	8.2105	±2.61	8.3203	±4.33
72-81	8.1273	±3.19	7.7001	±5.92	7.9137	±10.82
81-90	7.5283	*	6.2452	*	6.8867	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

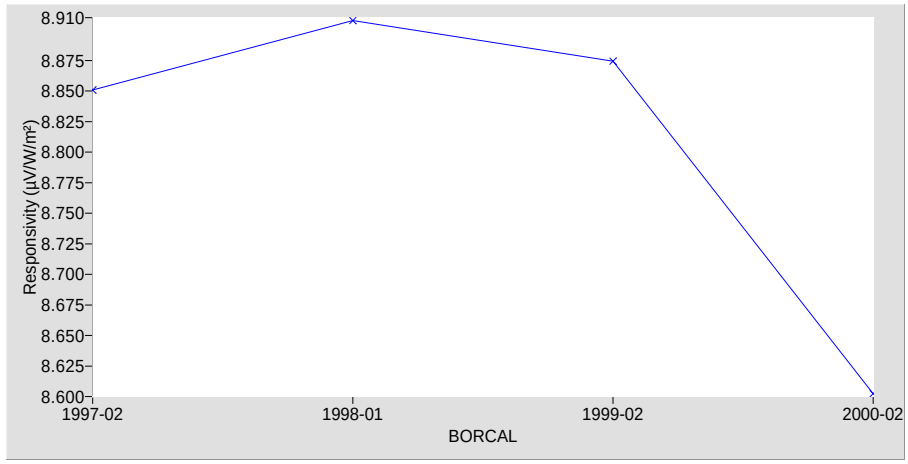
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.6023	+1.92 / -3.18 [1]
45° - 55°	8.5581	±2.16 [2]
Composite	8.6098	+2.33 / -22.37 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



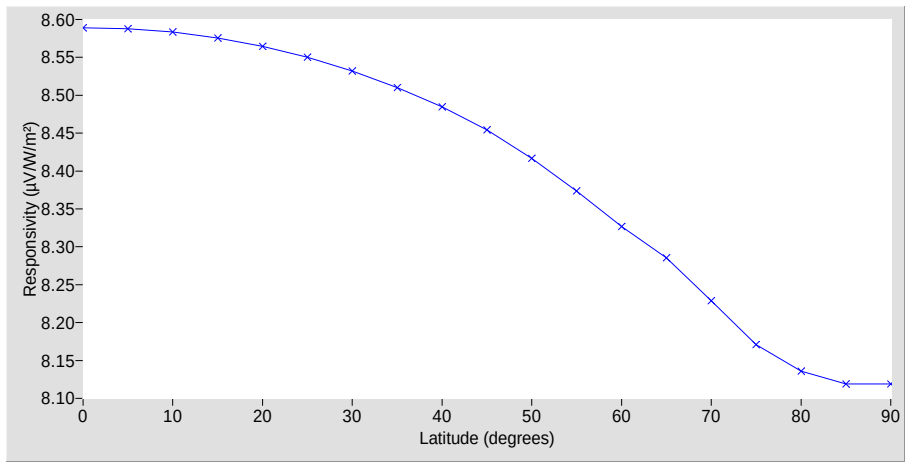
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.5889	+2.89 / -34.75
5	8.5877	+2.90 / -34.74
10	8.5833	+2.94 / -34.71
15	8.5753	+3.02 / -34.65
20	8.5646	+3.12 / -34.56
25	8.5502	+3.24 / -34.45
30	8.5322	+3.37 / -34.32
35	8.5099	+3.49 / -34.14
40	8.4846	+3.67 / -33.95
45	8.4541	+3.75 / -33.71
50	8.4168	+4.12 / -33.42
55	8.3735	+4.48 / -33.07
60	8.3268	+4.58 / -32.70
65	8.2856	+4.84 / -32.36
70	8.2286	+5.10 / -31.89
75	8.1710	+5.48 / -31.41
80	8.1358	+5.28 / -31.12
85	8.1188	+4.92 / -30.97
90	8.1188	+4.87 / -30.97

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30777F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30777F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

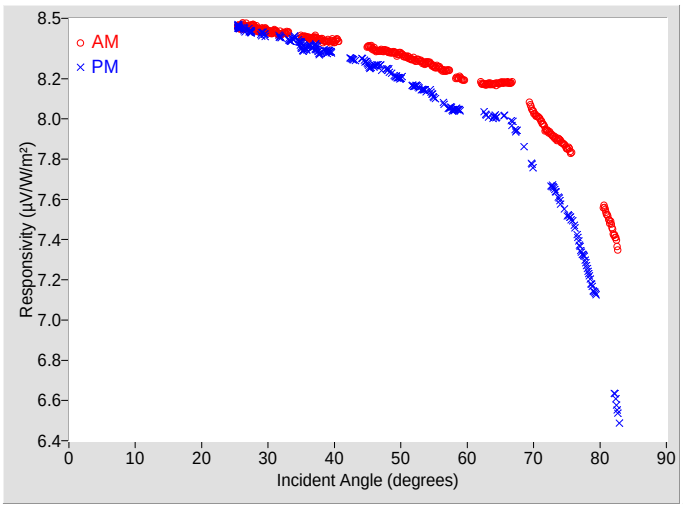


Figure 2. Responsivity vs Local Standard Time

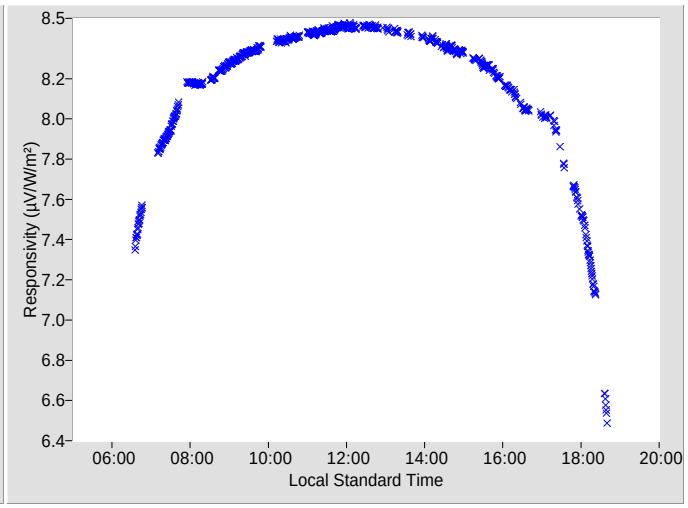


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3169	+2.11 / -4.02	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3446	0.72	112.99	8.2638	0.69	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3356	0.72	110.67	8.2444	0.71	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3260	0.75	108.47	8.2033	0.72	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2950	0.77	106.39	8.1628	0.74	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2796	0.80	104.47	8.1335	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2504	0.83	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2006	N/A	100.04	8.0437	0.83	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1780	0.97	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1742	1.02	95.32	8.0102	0.96	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1811	1.09	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0335	1.39	90.68	7.7653	1.25	272.42
26	8.4582	0.64	166.43	8.4517	0.66	192.82	72	7.9403	1.51	89.18	N/A	N/A	N/A
28	8.4562	0.63	153.72	N/A	N/A	N/A	74	7.8929	1.66	87.72	7.5961	1.69	275.36
30	8.4370	0.62	144.83	N/A	N/A	N/A	76	7.8341	N/A	86.45	7.4735	2.09	276.92
32	8.4229	0.63	138.25	8.4063	0.65	222.26	78	N/A	N/A	N/A	7.2631	2.54	278.33
34	N/A	N/A	N/A	8.4037	0.72	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4045	0.63	128.64	8.3585	0.68	237.14	82	7.4391	3.69	81.83	6.6345	3.82	281.37
38	8.3937	0.67	124.73	8.3255	0.71	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3859	0.66	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2998	0.68	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30777F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

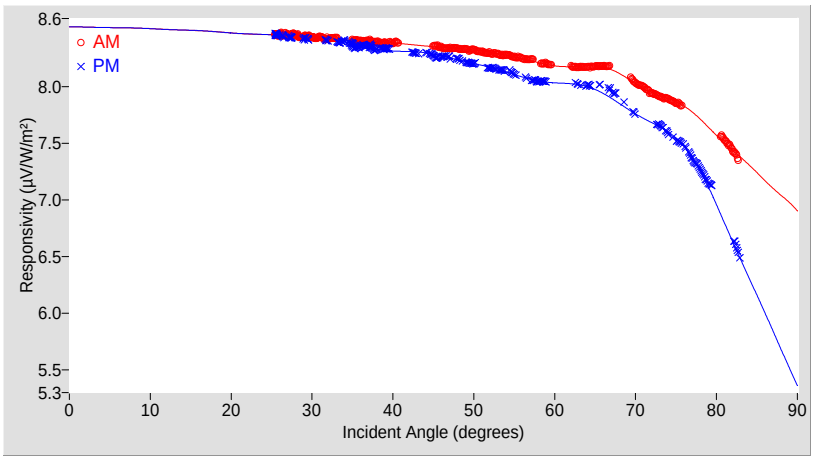


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.91	±1.91
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999998	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.5212	*	8.5212	*	8.5212	*
9-18	8.5006	*	8.5006	*	8.5006	*
18-27	8.4662	*	8.4647	*	8.4655	*
27-36	8.4305	±1.93	8.4133	±1.96	8.4219	±2.04
36-45	8.3819	±1.93	8.3192	±1.95	8.3505	±2.13
45-54	8.3235	±1.95	8.2156	±2.11	8.2696	±2.66
54-63	8.2141	±2.01	8.0589	±2.03	8.1365	±2.94
63-72	8.1118	±2.34	7.8747	±2.77	7.9933	±4.78
72-81	7.7818	±3.27	7.3819	±5.77	7.5819	±10.64
81-90	7.2057	*	6.0779	*	6.6418	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

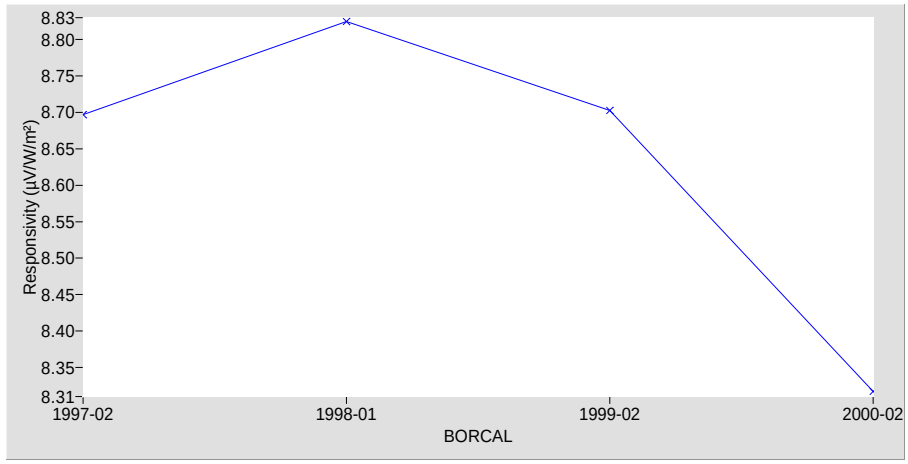
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3169	+2.11 / -4.02 [1]
45° - 55°	8.2588	±2.42 [2]
Composite	8.3328	+2.43 / -21.46 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



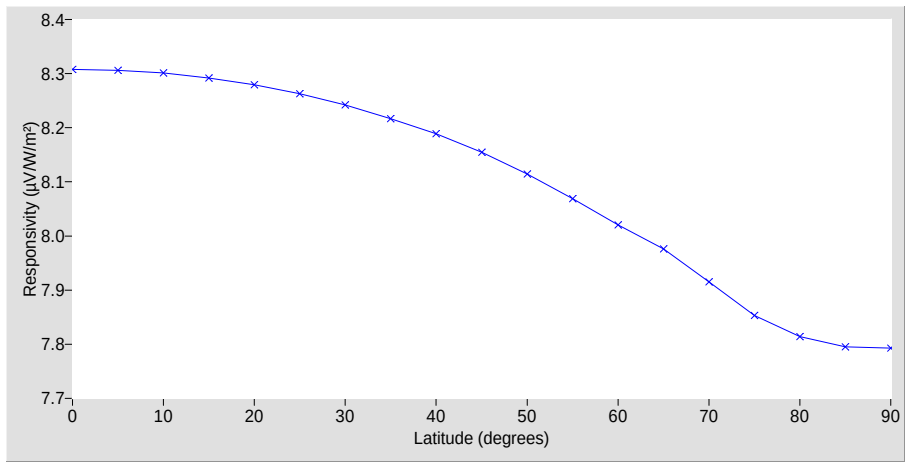
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.3075	+3.26 / -33.62
5	8.3062	+3.27 / -33.61
10	8.3010	+3.32 / -33.57
15	8.2920	+3.42 / -33.50
20	8.2796	+3.54 / -33.40
25	8.2630	+3.71 / -33.26
30	8.2420	+3.87 / -33.09
35	8.2167	+4.02 / -32.89
40	8.1887	+4.18 / -32.66
45	8.1549	+4.29 / -32.38
50	8.1145	+4.64 / -32.04
55	8.0687	+4.90 / -31.66
60	8.0203	+5.14 / -31.24
65	7.9759	+5.40 / -30.86
70	7.9154	+5.78 / -30.33
75	7.8531	+6.15 / -29.78
80	7.8139	+5.85 / -29.43
85	7.7952	+5.33 / -29.26
90	7.7930	+5.23 / -29.24

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30791F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30791F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

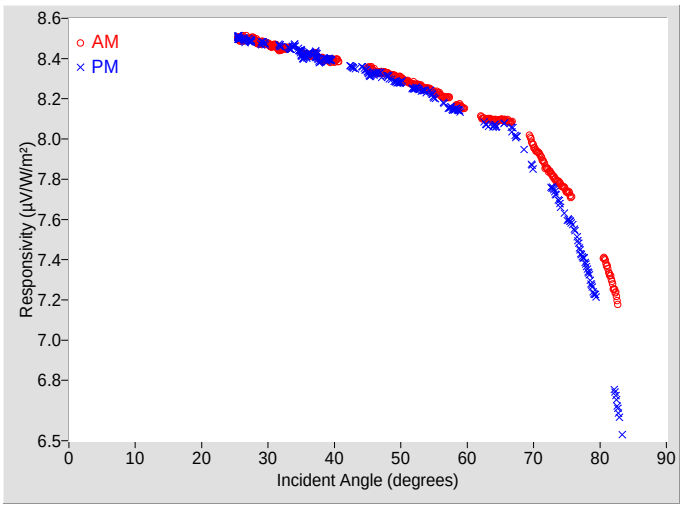


Figure 2. Responsivity vs Local Standard Time

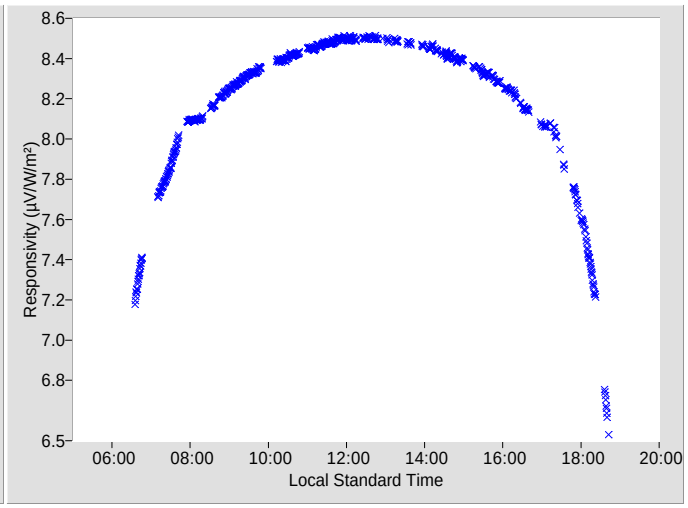


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3430	+2.23 / -3.09	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3382	0.72	112.99	8.3242	0.69	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3264	0.72	110.67	8.3109	0.70	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3066	0.76	108.47	8.2821	0.72	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2737	0.78	106.39	8.2510	0.73	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2516	0.81	104.47	8.2297	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2198	0.83	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1659	N/A	100.04	8.1459	0.83	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1087	0.98	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0963	1.02	95.32	8.0650	0.95	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0916	1.10	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9650	1.43	90.68	7.8598	1.25	272.42
26	8.4984	0.63	166.43	8.4988	0.65	192.82	72	7.8518	1.57	89.18	N/A	N/A	N/A
28	8.4927	0.63	153.72	N/A	N/A	N/A	74	7.7786	1.68	87.72	7.6821	1.71	275.36
30	8.4713	0.63	144.83	N/A	N/A	N/A	76	7.7133	N/A	86.45	7.5565	2.07	276.92
32	8.4476	0.63	138.25	8.4617	0.65	222.26	78	N/A	N/A	N/A	7.3595	2.49	278.33
34	N/A	N/A	N/A	8.4651	0.72	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4191	0.63	128.64	8.4204	0.68	237.14	82	7.2674	3.75	81.83	6.7482	3.78	281.37
38	8.3999	0.69	124.73	8.3833	0.72	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3889	0.66	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3594	0.68	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30791F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

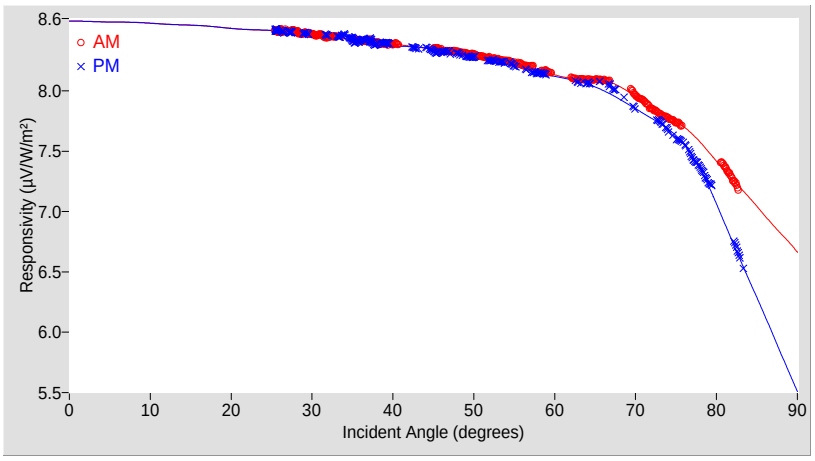


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.92	±1.92
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.3°
R²	0.9999997	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.5730	*	8.5731	*	8.5731	*
9-18	8.5499	*	8.5500	*	8.5499	*
18-27	8.5106	*	8.5104	*	8.5105	*
27-36	8.4585	±1.97	8.4683	±1.95	8.4634	±2.02
36-45	8.3852	±1.96	8.3782	±1.96	8.3817	±2.01
45-54	8.3085	±1.99	8.2905	±2.03	8.2995	±2.15
54-63	8.1711	±2.11	8.1501	±2.10	8.1606	±2.38
63-72	8.0319	±2.36	7.9508	±2.62	7.9913	±3.43
72-81	7.6571	±3.69	7.4736	±5.61	7.5653	±8.81
81-90	7.0036	*	6.2069	*	6.6052	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

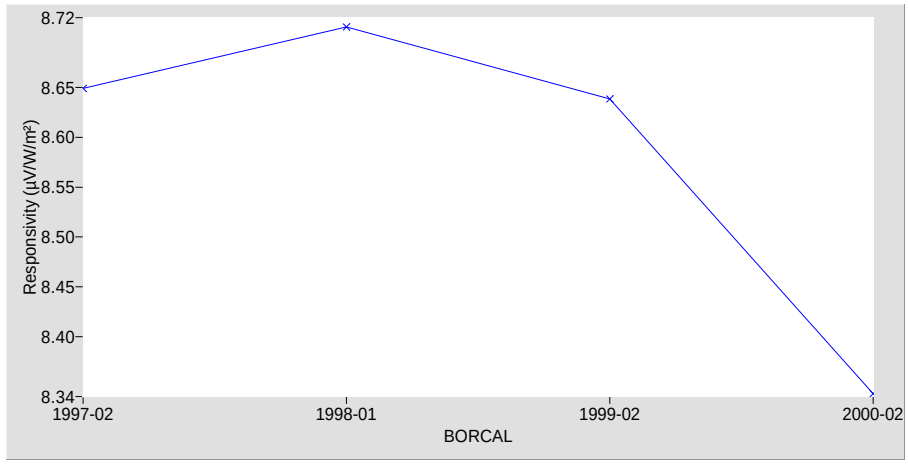
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3430	+2.23 / -3.09 [1]
45° - 55°	8.2894	±2.10 [2]
Composite	8.3681	+2.48 / -21.34 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



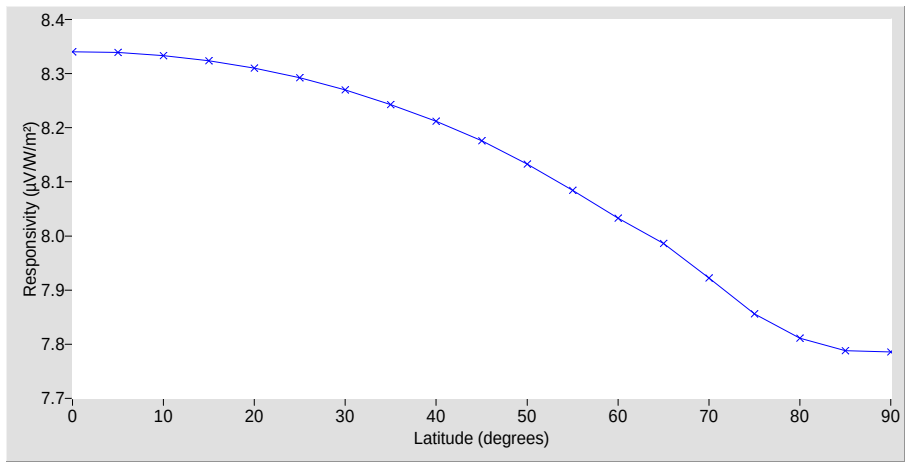
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.3404	+3.45 / -32.16
5	8.3390	+3.46 / -32.14
10	8.3335	+3.52 / -32.10
15	8.3236	+3.63 / -32.02
20	8.3102	+3.77 / -31.91
25	8.2924	+3.95 / -31.76
30	8.2701	+4.11 / -31.58
35	8.2429	+4.27 / -31.35
40	8.2119	+4.46 / -31.09
45	8.1758	+4.55 / -30.79
50	8.1329	+4.89 / -30.43
55	8.0842	+5.18 / -30.01
60	8.0329	+5.21 / -29.56
65	7.9861	+5.30 / -29.15
70	7.9224	+5.61 / -28.58
75	7.8559	+5.87 / -27.98
80	7.8110	+5.52 / -27.56
85	7.7879	+4.64 / -27.35
90	7.7857	+4.33 / -27.33

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30793F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30793F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

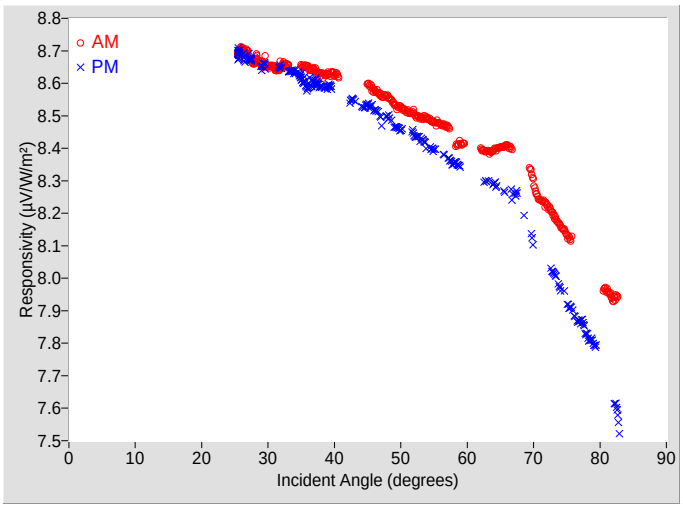


Figure 2. Responsivity vs Local Standard Time

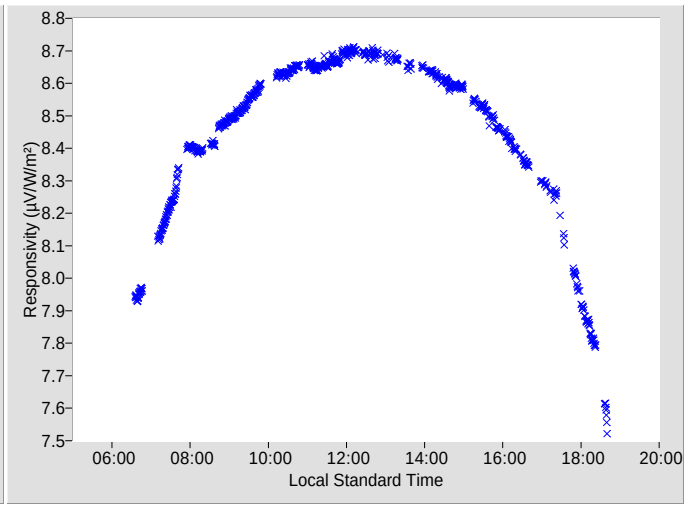


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.5658	+1.87 / -3.24	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5776	0.73	112.99	8.5164	0.73	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5590	0.74	110.67	8.4963	0.72	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5269	0.74	108.47	8.4571	0.71	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5078	0.77	106.39	8.4423	0.76	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4919	0.79	104.47	8.3990	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4743	0.82	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4063	N/A	100.04	8.3535	0.83	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3970	0.97	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3951	1.02	95.32	8.2897	0.95	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4086	1.09	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2945	1.42	90.68	8.1136	1.25	272.42
26	8.7003	0.64	166.43	8.6904	0.67	192.82	72	8.2224	1.46	89.18	N/A	N/A	N/A
28	8.6691	0.62	153.72	N/A	N/A	N/A	74	8.1631	1.65	87.72	7.9723	1.57	275.36
30	8.6529	0.63	144.83	N/A	N/A	N/A	76	8.1291	N/A	86.45	7.8895	1.82	276.92
32	8.6538	0.63	138.25	8.6500	0.64	222.26	78	N/A	N/A	N/A	7.8228	2.17	278.33
34	N/A	N/A	N/A	8.6346	0.66	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6503	0.63	128.64	8.5910	0.68	237.14	82	7.9365	3.47	81.83	7.6140	3.62	281.37
38	8.6270	0.66	124.73	8.5884	0.66	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6289	0.66	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.5278	0.67	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30793F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

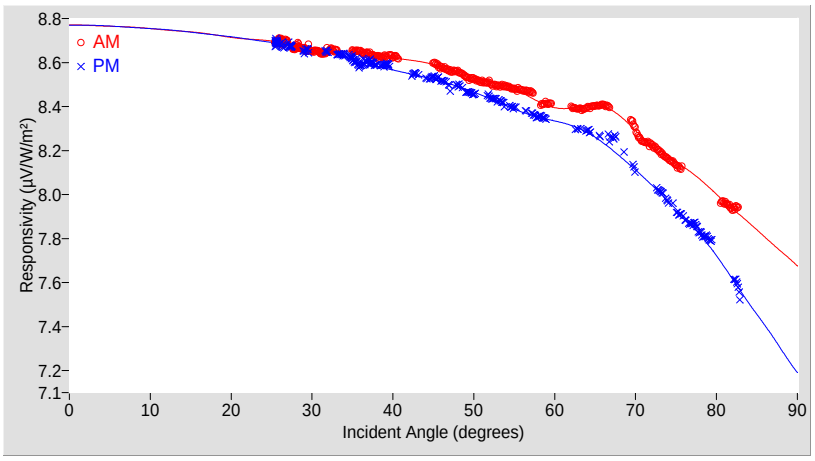


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.78	±1.78
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999996	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.7659	*	8.7658	*	8.7659	*
9-18	8.7440	*	8.7438	*	8.7439	*
18-27	8.7067	*	8.7054	*	8.7060	*
27-36	8.6581	±1.79	8.6523	±1.83	8.6552	±1.89
36-45	8.6217	±1.81	8.5646	±1.84	8.5932	±2.04
45-54	8.5409	±1.86	8.4725	±1.90	8.5067	±2.32
54-63	8.4285	±1.88	8.3525	±1.87	8.3905	±2.37
63-72	8.3534	±2.05	8.1923	±2.31	8.2728	±3.51
72-81	8.1102	±2.30	7.8804	±2.83	7.9953	±5.01
81-90	7.8225	*	7.4291	*	7.6258	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

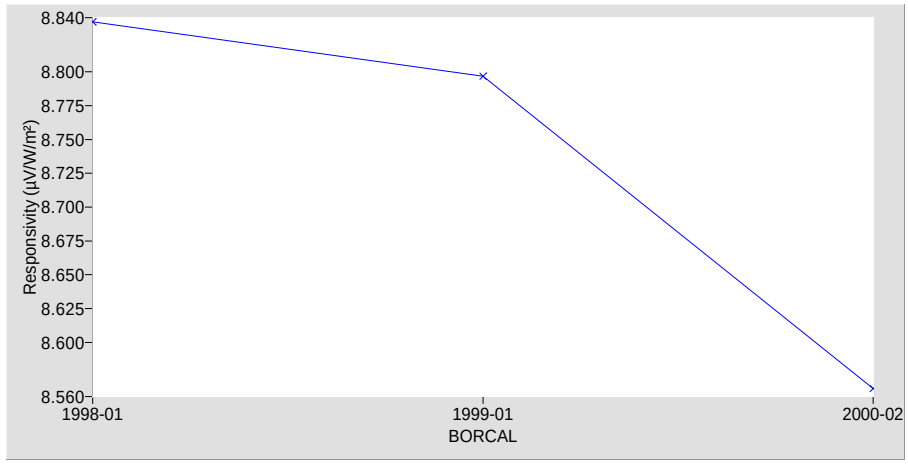
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5658	+1.87 / -3.24 [1]
45° - 55°	8.4973	±2.14 [2]
Composite	8.5905	+2.15 / -11.82 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



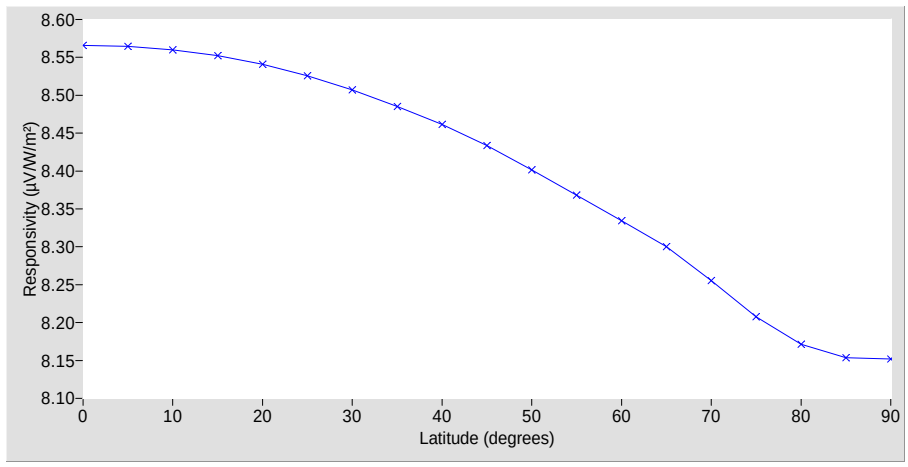
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.5660	+2.99 / -15.57
5	8.5646	+3.00 / -15.55
10	8.5601	+3.04 / -15.51
15	8.5521	+3.12 / -15.43
20	8.5408	+3.23 / -15.32
25	8.5257	+3.38 / -15.17
30	8.5070	+3.50 / -14.99
35	8.4852	+3.61 / -14.77
40	8.4613	+3.70 / -14.53
45	8.4337	+3.75 / -14.25
50	8.4017	+3.88 / -13.93
55	8.3683	+3.90 / -13.59
60	8.3345	+4.16 / -13.24
65	8.3003	+4.20 / -12.88
70	8.2555	+4.31 / -12.41
75	8.2079	+4.20 / -11.91
80	8.1712	+3.97 / -11.52
85	8.1535	+3.57 / -11.33
90	8.1517	+3.53 / -11.31

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30796F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30796F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

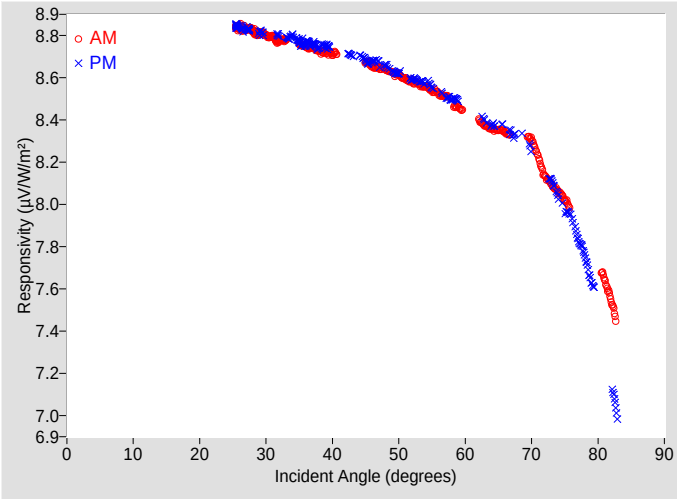


Figure 2. Responsivity vs Local Standard Time

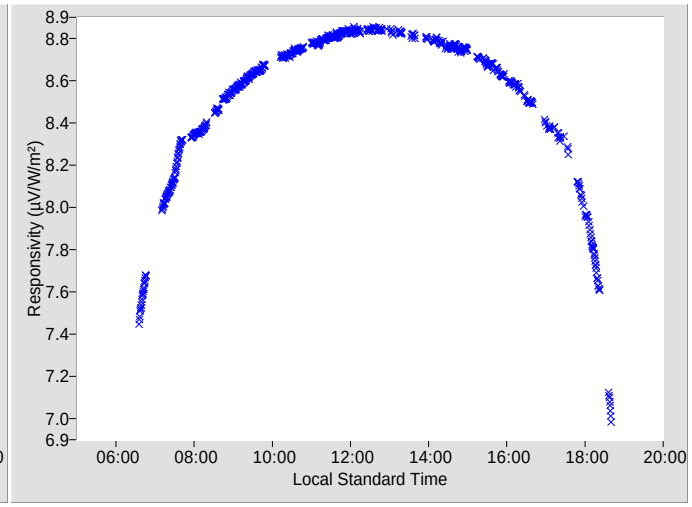


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.6786	+2.16 / -3.21	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6548	0.72	112.99	8.6777	0.69	252.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6404	0.73	110.67	8.6563	0.70	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6157	0.76	108.47	8.6223	0.71	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5824	0.78	106.39	8.5926	0.73	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5582	0.80	104.47	8.5698	N/A	259.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5253	0.83	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4613	N/A	100.04	8.4970	0.82	263.36
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3974	0.99	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3586	1.03	95.32	8.3760	0.95	268.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3417	1.10	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3048	1.39	90.68	8.2635	1.25	272.42
26	8.8360	0.64	166.43	8.8418	0.66	192.82	72	8.1332	1.61	89.18	N/A	N/A	N/A
28	8.8229	0.63	153.72	N/A	N/A	N/A	74	8.0638	1.67	87.72	8.0458	1.66	275.36
30	8.8003	0.62	144.83	N/A	N/A	N/A	76	7.9851	N/A	86.45	7.9329	1.96	276.92
32	8.7755	0.63	138.25	8.8007	0.65	222.26	78	N/A	N/A	N/A	7.7519	2.46	278.33
34	N/A	N/A	N/A	8.7978	0.68	227.73	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7468	0.63	128.64	8.7627	0.67	237.14	82	7.5431	3.72	81.83	7.1163	3.74	281.37
38	8.7265	0.68	124.73	8.7378	0.67	241.79	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7120	0.66	121.38	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.7057	0.67	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30796F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

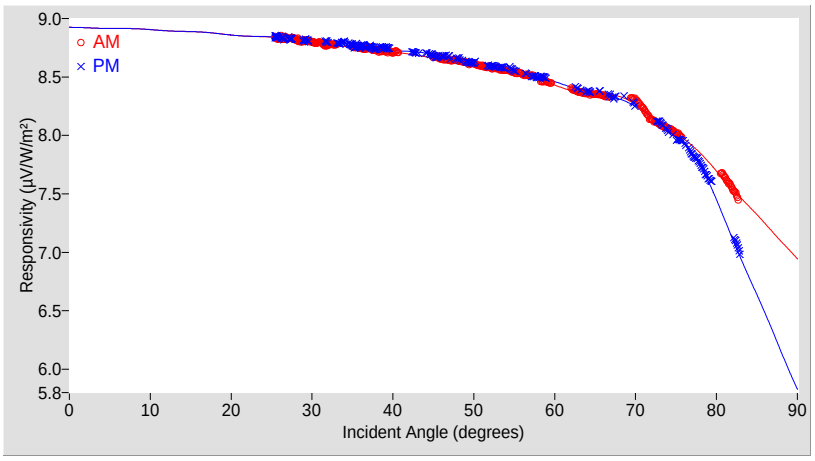


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.91	±1.91
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999989	0.9999996

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.9174	*	8.9174	*	8.9174	*
9-18	8.8931	*	8.8931	*	8.8931	*
18-27	8.8509	*	8.8518	*	8.8514	*
27-36	8.7877	±1.96	8.8075	±1.94	8.7976	±2.03
36-45	8.7085	±1.96	8.7279	±1.95	8.7182	±2.06
45-54	8.6205	±2.00	8.6344	±2.03	8.6275	±2.20
54-63	8.4673	±2.18	8.4902	±2.14	8.4787	±2.48
63-72	8.3175	±2.18	8.3093	±2.29	8.3134	±2.65
72-81	7.9355	±3.74	7.8532	±5.38	7.8944	±7.75
81-90	7.2808	*	6.5528	*	6.9168	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

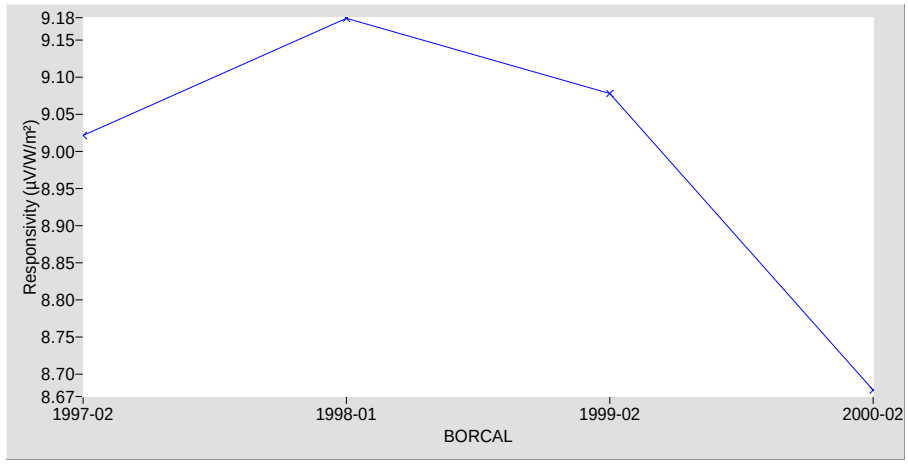
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.6786	+2.16 / -3.21 [1]
45° - 55°	8.6163	±2.12 [2]
Composite	8.7033	+2.48 / -19.33 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



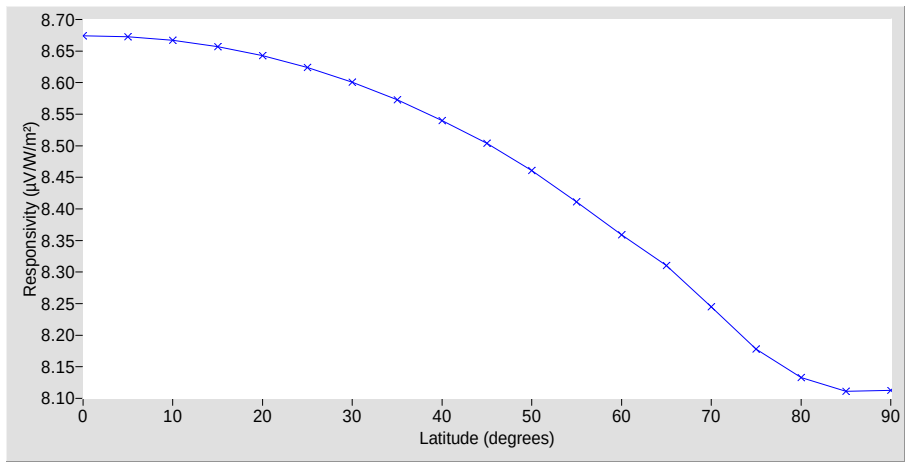
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.6742	+3.46 / -31.07
5	8.6727	+3.48 / -31.06
10	8.6668	+3.54 / -31.01
15	8.6567	+3.64 / -30.93
20	8.6428	+3.78 / -30.82
25	8.6242	+3.96 / -30.67
30	8.6009	+4.12 / -30.49
35	8.5727	+4.27 / -30.26
40	8.5401	+4.47 / -29.99
45	8.5040	+4.52 / -29.70
50	8.4606	+4.86 / -29.33
55	8.4109	+5.13 / -28.92
60	8.3587	+5.22 / -28.47
65	8.3103	+5.31 / -28.06
70	8.2452	+5.60 / -27.49
75	8.1778	+5.64 / -26.90
80	8.1330	+5.27 / -26.49
85	8.1114	+4.45 / -26.30
90	8.1128	+3.53 / -26.31

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30799F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30799F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

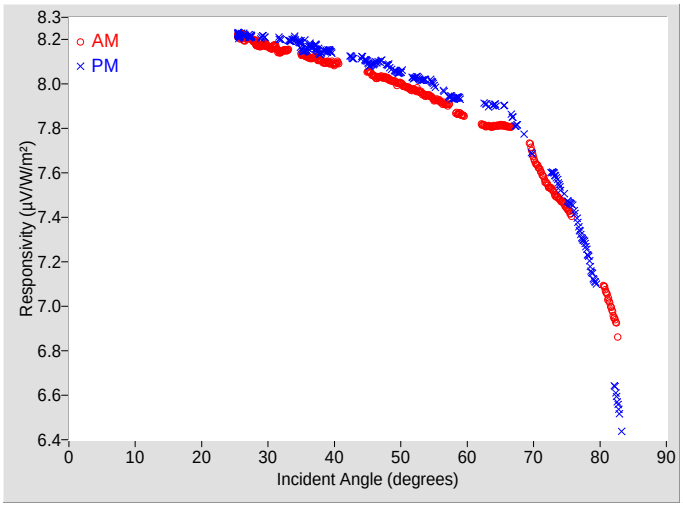


Figure 2. Responsivity vs Local Standard Time

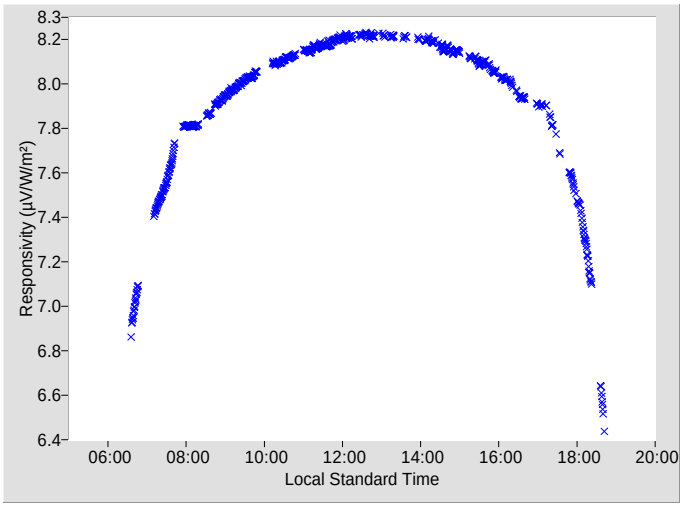


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0764	+2.39 / -3.31	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0348	0.73	113.00	8.0944	0.69	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0260	0.73	110.68	8.0835	0.74	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0029	0.76	108.48	8.0546	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9755	0.77	106.40	8.0266	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9503	0.81	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9182	0.83	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8682	N/A	100.05	7.9345	0.82	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8179	0.98	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8106	1.02	95.28	7.9054	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8097	1.10	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.6709	1.50	90.69	7.6849	N/A	272.39
26	8.2137	0.64	166.46	8.2189	0.65	191.04	72	7.5505	1.55	89.19	N/A	N/A	N/A
28	8.1891	0.64	153.47	N/A	N/A	N/A	74	7.4800	1.69	87.73	7.5400	1.66	275.36
30	8.1679	0.63	144.86	N/A	N/A	N/A	76	7.4044	N/A	86.46	7.4346	2.02	276.93
32	8.1455	0.64	138.35	8.2016	0.65	222.41	78	N/A	N/A	N/A	7.2538	2.53	278.30
34	N/A	N/A	N/A	8.2042	0.71	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1212	0.63	128.57	8.1645	0.71	237.87	82	6.9588	3.80	81.81	6.6408	3.78	281.39
38	8.1050	0.66	124.74	8.1368	0.69	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0903	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.1201	0.68	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30799F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

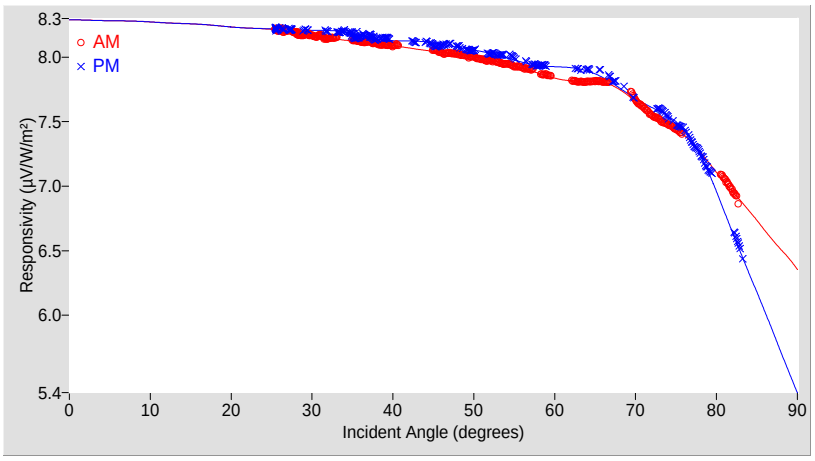


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.94	±1.94
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999997	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2845	*	8.2845	*	8.2845	*
9-18	8.2632	*	8.2633	*	8.2633	*
18-27	8.2262	*	8.2275	*	8.2269	*
27-36	8.1577	±2.00	8.2033	±1.95	8.1805	±2.10
36-45	8.0866	±1.99	8.1335	±1.97	8.1101	±2.20
45-54	8.0070	±2.02	8.0620	±2.05	8.0345	±2.37
54-63	7.8743	±2.12	7.9441	±2.01	7.9092	±2.53
63-72	7.7434	±2.45	7.7835	±2.66	7.7635	±3.57
72-81	7.3513	±3.88	7.3489	±5.34	7.3501	±7.57
81-90	6.6954	*	6.0979	*	6.3966	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

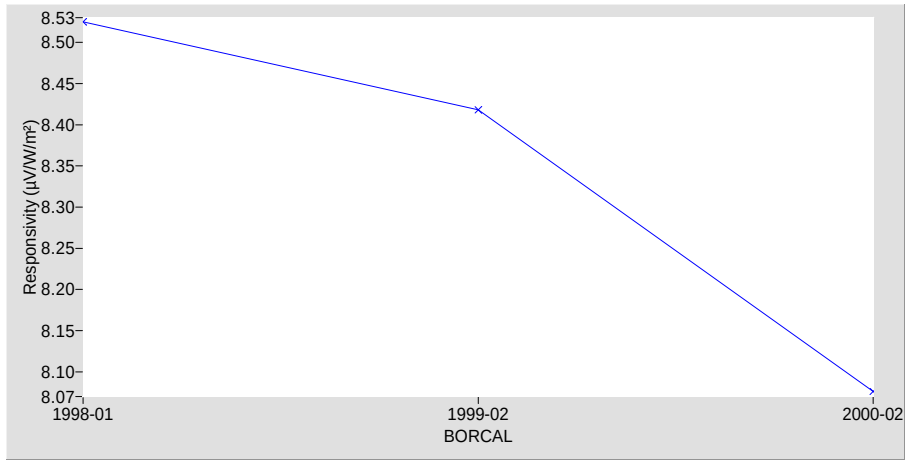
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0764	+2.39 / -3.31 [1]
45° - 55°	8.0245	±2.24 [2]
Composite	8.0961	+2.45 / -20.04 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



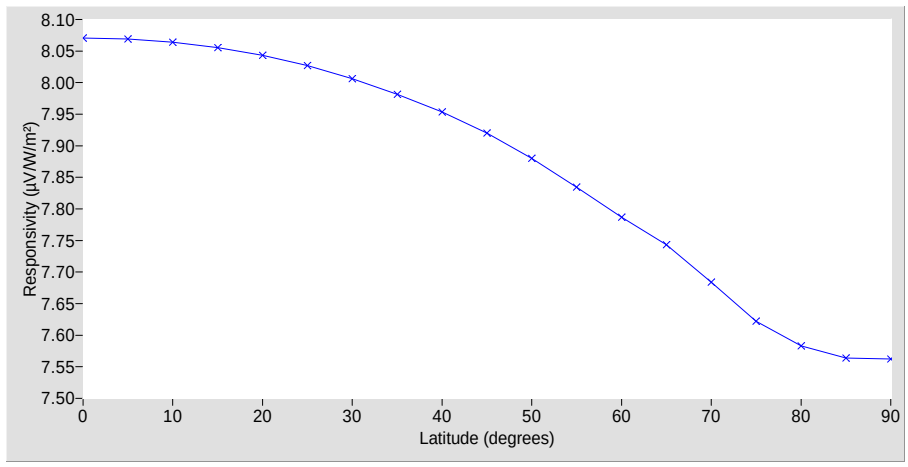
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0706	+3.34 / -31.27
5	8.0692	+3.36 / -31.25
10	8.0642	+3.41 / -31.21
15	8.0553	+3.50 / -31.13
20	8.0430	+3.63 / -31.03
25	8.0268	+3.80 / -30.89
30	8.0063	+3.95 / -30.71
35	7.9815	+4.10 / -30.50
40	7.9535	+4.27 / -30.25
45	7.9200	+4.37 / -29.96
50	7.8798	+4.69 / -29.60
55	7.8347	+5.16 / -29.20
60	7.7867	+5.26 / -28.76
65	7.7430	+5.32 / -28.36
70	7.6838	+5.76 / -27.81
75	7.6223	+5.86 / -27.23
80	7.5833	+5.35 / -26.85
85	7.5639	+5.14 / -26.67
90	7.5624	+4.16 / -26.65

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30811F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30811F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

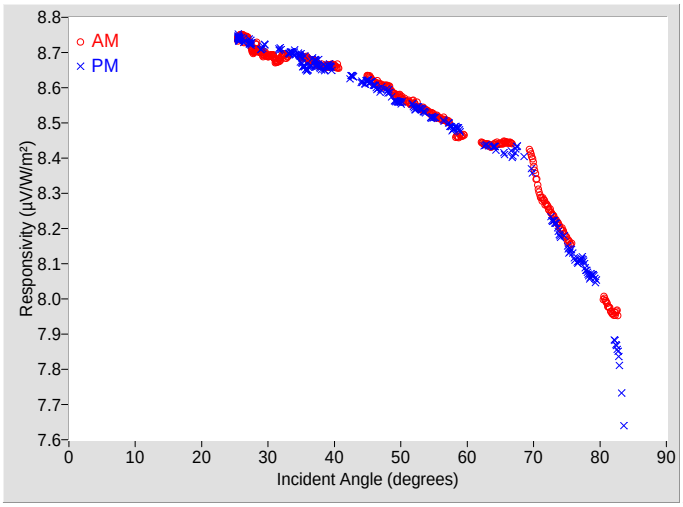


Figure 2. Responsivity vs Local Standard Time

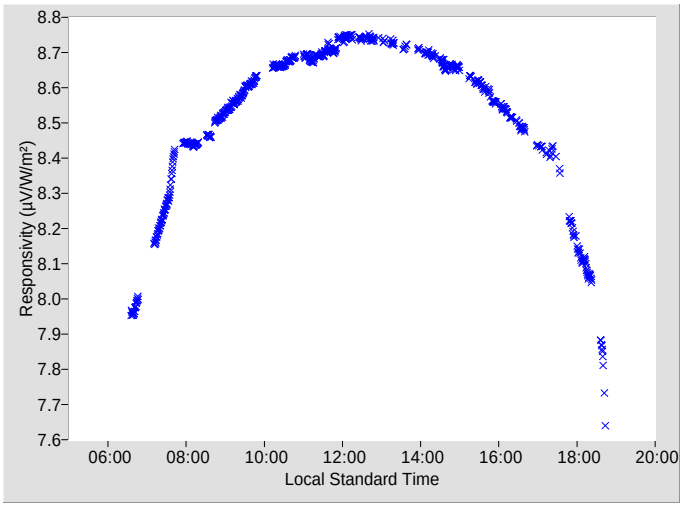


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.6263	+1.69 / -2.62	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6150	0.72	113.00	8.6052	0.71	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6046	0.73	110.68	8.5901	0.71	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5743	0.74	108.48	8.5584	0.71	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5577	0.77	106.40	8.5437	0.73	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5338	0.79	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5113	0.81	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4591	N/A	100.05	8.4844	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4445	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4388	1.02	95.28	8.4308	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4441	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3816	1.50	90.69	8.3569	N/A	272.39
26	8.7451	0.63	166.46	8.7377	0.64	191.04	72	8.2651	1.46	89.19	N/A	N/A	N/A
28	8.7087	0.62	153.47	N/A	N/A	N/A	74	8.2049	1.64	87.73	8.1821	1.55	275.36
30	8.6893	0.61	144.86	N/A	N/A	N/A	76	8.1581	N/A	86.46	8.1186	1.81	276.93
32	8.6871	0.62	138.35	8.7110	0.64	222.41	78	N/A	N/A	N/A	8.0792	2.14	278.30
34	N/A	N/A	N/A	8.6984	0.67	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6822	0.63	128.57	8.6528	0.67	238.73	82	7.9575	3.48	81.81	7.8824	3.59	281.39
38	8.6621	0.64	124.74	8.6559	0.66	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6620	0.65	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.6159	0.67	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30811F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

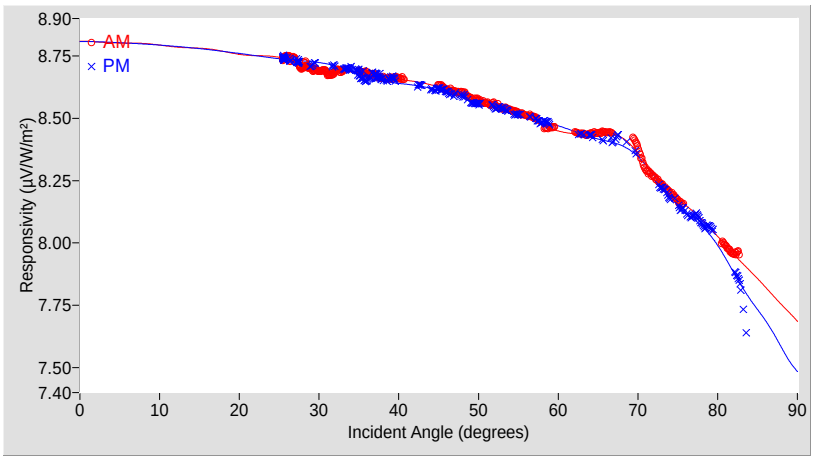


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.79	±1.79
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999996	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.8036	*	8.8035	*	8.8036	*
9-18	8.7843	*	8.7841	*	8.7842	*
18-27	8.7511	*	8.7504	*	8.7507	*
27-36	8.6936	±1.81	8.7104	±1.83	8.7020	±1.86
36-45	8.6558	±1.82	8.6398	±1.82	8.6478	±1.87
45-54	8.5853	±1.86	8.5713	±1.86	8.5783	±1.97
54-63	8.4750	±1.88	8.4834	±1.85	8.4792	±1.96
63-72	8.4080	±1.99	8.3856	±1.99	8.3968	±2.26
72-81	8.1430	±2.45	8.1181	±2.60	8.1306	±3.27
81-90	7.8385	*	7.7076	*	7.7730	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

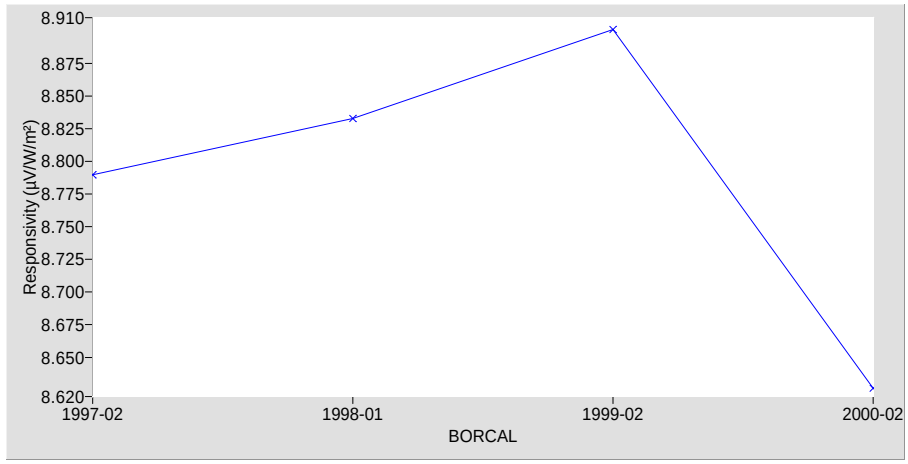
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.6263	+1.69 / -2.62 [1]
45° - 55°	8.5701	±1.91 [2]
Composite	8.6505	+2.07 / -9.97 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



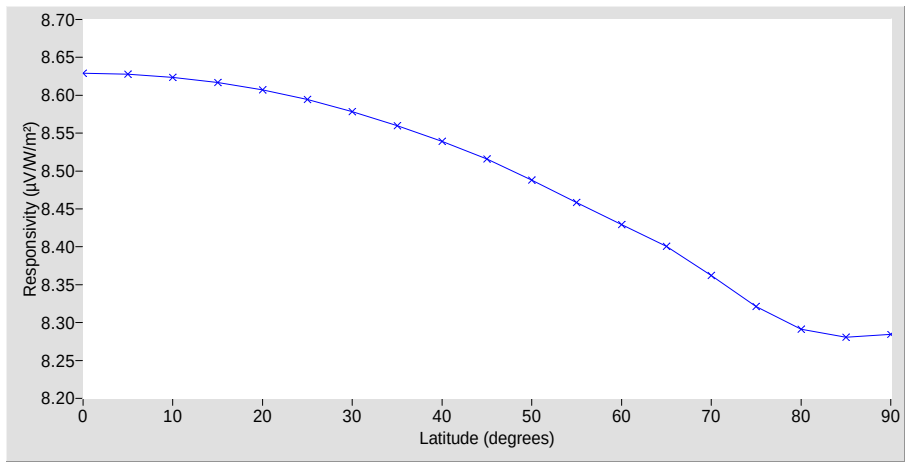
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.6289	+2.75 / -12.90
5	8.6276	+2.77 / -12.89
10	8.6236	+2.80 / -12.85
15	8.6167	+2.87 / -12.78
20	8.6071	+2.96 / -12.68
25	8.5942	+3.07 / -12.56
30	8.5783	+3.16 / -12.39
35	8.5597	+3.24 / -12.21
40	8.5391	+3.33 / -12.00
45	8.5160	+3.34 / -11.76
50	8.4878	+3.43 / -11.47
55	8.4585	+3.55 / -11.17
60	8.4292	+3.47 / -10.86
65	8.4005	+3.49 / -10.56
70	8.3620	+3.53 / -10.15
75	8.3214	+3.49 / -9.72
80	8.2911	+3.11 / -9.40
85	8.2807	+2.80 / -9.29
90	8.2845	+2.63 / -9.33

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:**	30812F3
Calibration Date:	8/24/2000	**Due Date:**	8/24/2001
Customer:	Dan Nelson	**Calibration Site Parameters:**	see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30812F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

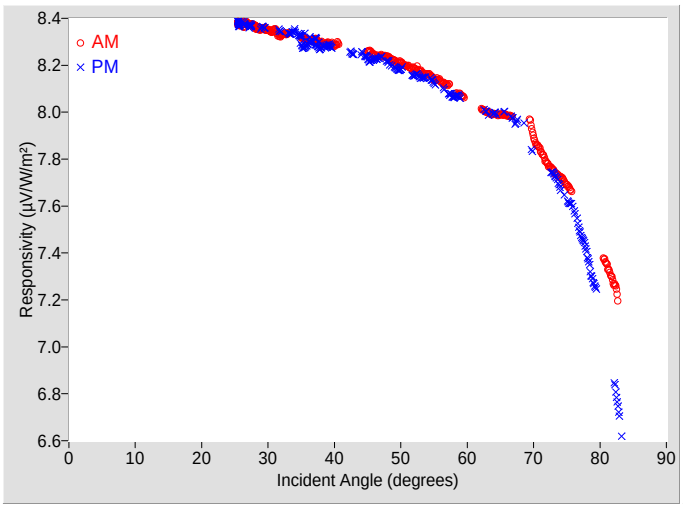


Figure 2. Responsivity vs Local Standard Time

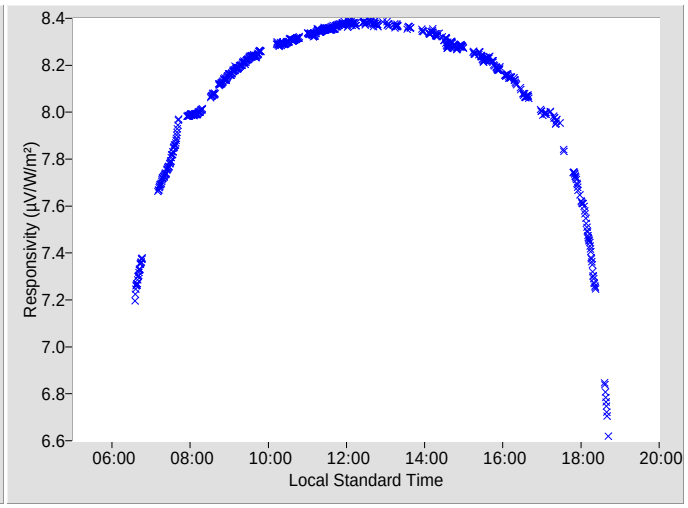


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.2450	+2.02 / -2.89	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2428	0.72	113.00	8.2272	0.69	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2365	0.73	110.68	8.2133	0.74	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2127	0.75	108.48	8.1833	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1883	0.77	106.40	8.1559	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1625	0.81	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1307	0.83	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0787	N/A	100.05	8.0654	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0126	0.98	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9925	1.03	95.28	7.9952	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9868	1.10	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8975	1.51	90.69	7.8324	N/A	272.39
26	8.3799	0.64	166.46	8.3747	0.65	191.04	72	7.7833	1.51	89.19	N/A	N/A	N/A
28	8.3650	0.61	153.47	N/A	N/A	N/A	74	7.7252	1.66	87.73	7.6834	1.64	275.36
30	8.3499	0.61	144.86	N/A	N/A	N/A	76	7.6624	N/A	86.46	7.5810	1.99	276.93
32	8.3280	0.64	138.35	8.3450	0.65	222.41	78	N/A	N/A	N/A	7.4011	2.52	278.30
34	N/A	N/A	N/A	8.3453	0.75	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3095	0.63	128.57	8.2954	0.73	237.87	82	7.2751	3.68	81.81	6.8427	3.79	281.39
38	8.2975	0.65	124.74	8.2710	0.70	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2864	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2530	0.68	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30812F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

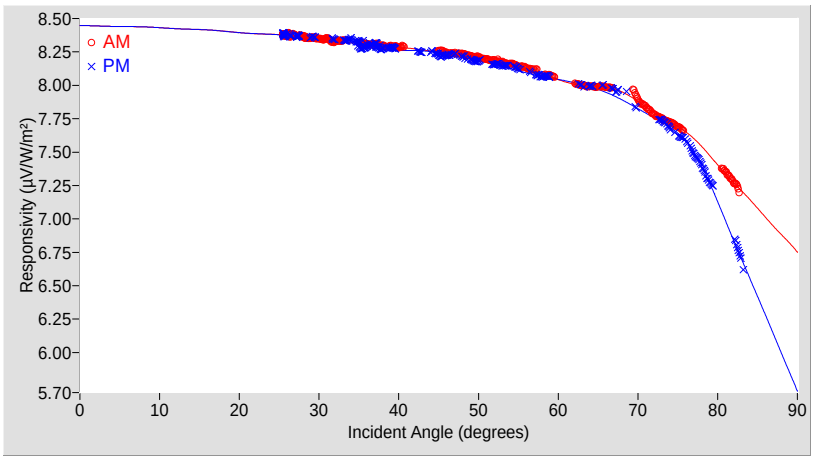


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.91	±1.91
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999997	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.4416	*	8.4417	*	8.4417	*
9-18	8.4217	*	8.4217	*	8.4217	*
18-27	8.3878	*	8.3870	*	8.3874	*
27-36	8.3391	±1.95	8.3483	±1.95	8.3437	±1.99
36-45	8.2832	±1.94	8.2669	±1.94	8.2750	±1.98
45-54	8.2172	±1.98	8.1919	±2.03	8.2046	±2.17
54-63	8.0806	±2.15	8.0663	±2.04	8.0734	±2.36
63-72	7.9427	±2.23	7.9041	±2.41	7.9234	±2.87
72-81	7.6153	±3.40	7.5002	±5.05	7.5577	±7.58
81-90	7.0458	*	6.3482	*	6.6970	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

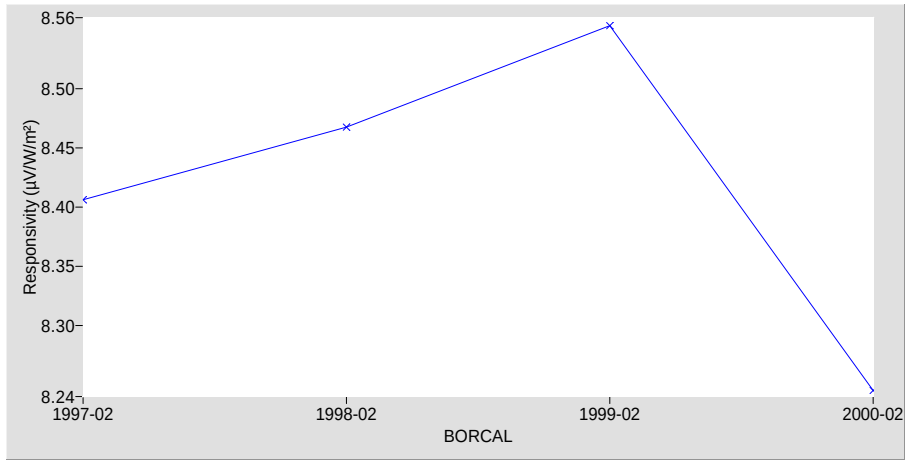
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2450	+2.02 / -2.89 [1]
45° - 55°	8.1946	±2.10 [2]
Composite	8.2610	+2.39 / -19.02 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



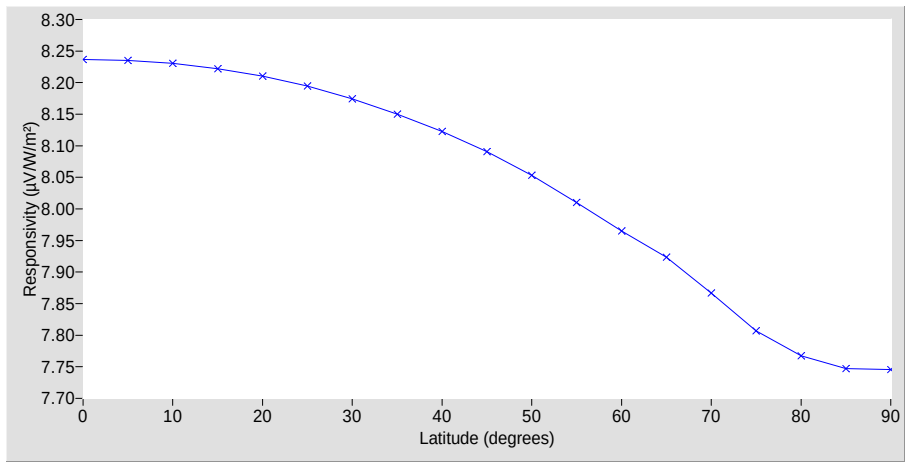
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.2367	+3.19 / -29.00
5	8.2354	+3.21 / -28.99
10	8.2304	+3.26 / -28.95
15	8.2218	+3.34 / -28.88
20	8.2101	+3.47 / -28.77
25	8.1945	+3.62 / -28.64
30	8.1745	+3.77 / -28.46
35	8.1502	+3.91 / -28.25
40	8.1225	+4.08 / -28.01
45	8.0908	+4.16 / -27.73
50	8.0532	+4.45 / -27.39
55	8.0103	+4.71 / -27.00
60	7.9650	+4.71 / -26.59
65	7.9235	+4.89 / -26.20
70	7.8666	+5.17 / -25.67
75	7.8070	+5.43 / -25.10
80	7.7675	+5.01 / -24.72
85	7.7469	+4.16 / -24.52
90	7.7455	+3.65 / -24.51

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30813F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30813F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

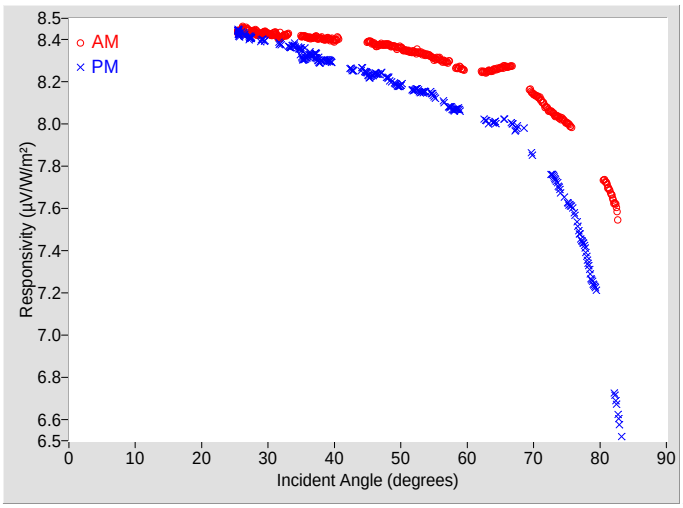


Figure 2. Responsivity vs Local Standard Time

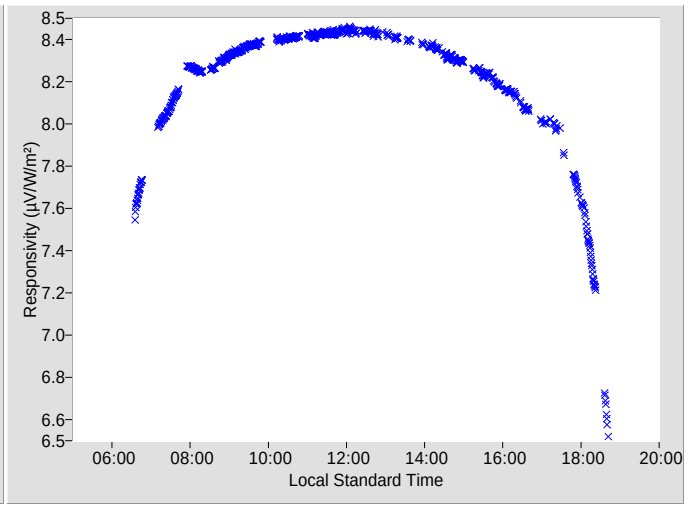


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3120	+2.14 / -3.70	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3775	0.72	113.00	8.2369	0.70	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3766	0.72	110.68	8.2159	0.75	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3619	0.75	108.48	8.1823	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3422	0.77	106.40	8.1604	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3278	0.80	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3023	0.82	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2631	N/A	100.05	8.0664	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2471	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2568	1.03	95.28	8.0070	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2704	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1413	1.31	90.69	7.8518	N/A	272.39
26	8.4441	0.65	166.46	8.4233	0.66	191.04	72	8.0744	1.48	89.19	N/A	N/A	N/A
28	8.4340	0.61	153.47	N/A	N/A	N/A	74	8.0284	1.63	87.73	7.6915	1.66	275.36
30	8.4267	0.61	144.86	N/A	N/A	N/A	76	7.9835	N/A	86.46	7.5822	2.05	276.93
32	8.4140	0.63	138.27	8.3768	0.65	222.41	78	N/A	N/A	N/A	7.3743	2.57	278.30
34	N/A	N/A	N/A	8.3718	0.73	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4097	0.63	128.57	8.3232	0.72	237.87	82	7.6372	3.66	81.81	6.7198	3.82	281.39
38	8.4060	0.65	124.74	8.2944	0.70	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3955	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2610	0.68	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30813F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

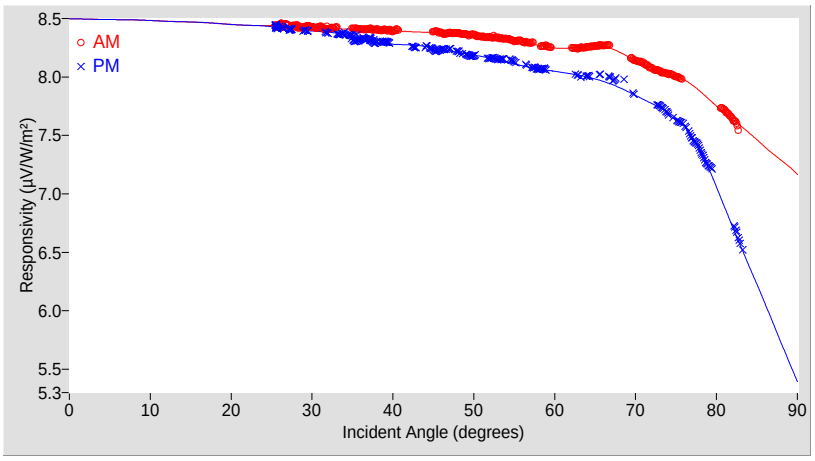


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.92	±1.92
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.4923	*	8.4924	*	8.4924	*
9-18	8.4741	*	8.4741	*	8.4741	*
18-27	8.4446	*	8.4410	*	8.4428	*
27-36	8.4215	±1.92	8.3831	±1.97	8.4023	±2.11
36-45	8.3960	±1.92	8.2847	±1.96	8.3404	±2.32
45-54	8.3628	±1.94	8.1955	±2.04	8.2791	±2.86
54-63	8.2749	±1.98	8.0700	±2.03	8.1725	±3.26
63-72	8.2086	±2.20	7.9193	±2.38	8.0640	±4.64
72-81	7.9358	±2.94	7.4843	±5.68	7.7100	±10.83
81-90	7.4325	*	6.1400	*	6.7863	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

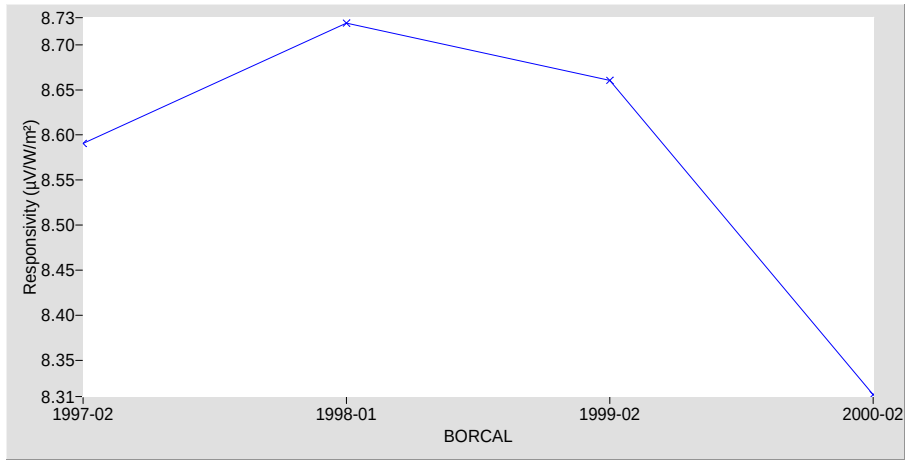
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3120	+2.14 / -3.70 [1]
45° - 55°	8.2707	±2.52 [2]
Composite	8.3317	+2.31 / -21.48 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



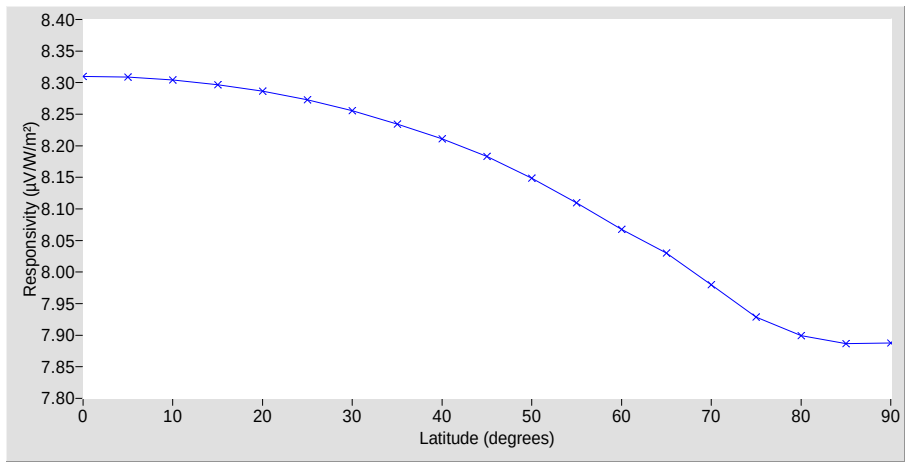
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.3098	+2.96 / -33.17
5	8.3086	+2.97 / -33.16
10	8.3043	+3.02 / -33.12
15	8.2967	+3.09 / -33.06
20	8.2864	+3.19 / -32.98
25	8.2727	+3.32 / -32.87
30	8.2553	+3.43 / -32.73
35	8.2344	+3.55 / -32.55
40	8.2109	+3.67 / -32.36
45	8.1829	+3.73 / -32.13
50	8.1489	+4.04 / -31.85
55	8.1095	+4.29 / -31.52
60	8.0674	+4.65 / -31.16
65	8.0303	+4.90 / -30.84
70	7.9797	+5.38 / -30.40
75	7.9285	+5.69 / -29.96
80	7.8993	+5.43 / -29.70
85	7.8866	+5.19 / -29.58
90	7.8876	+5.10 / -29.59

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30818F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30818F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

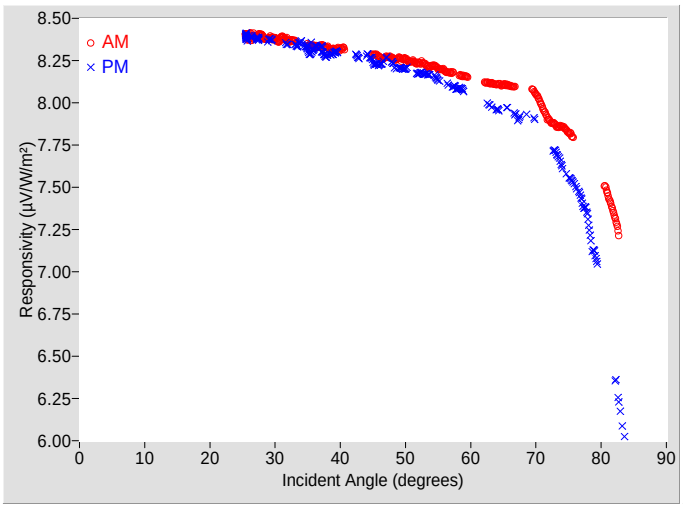


Figure 2. Responsivity vs Local Standard Time

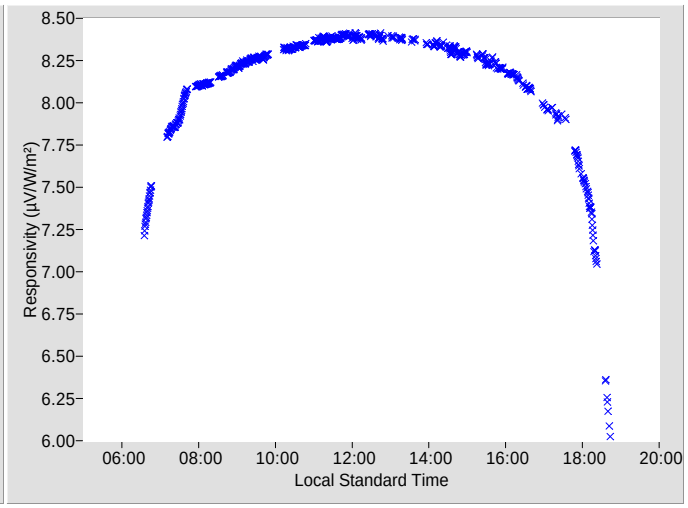


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.2663	+2.12 / -3.00	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2703	0.73	113.00	8.2271	0.70	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2658	0.73	110.68	8.2310	0.82	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2600	0.75	108.48	8.2028	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2368	0.77	106.40	8.1733	0.73	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2186	0.80	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1897	0.82	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1611	N/A	100.05	8.0829	0.85	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1213	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1098	1.03	95.28	7.9595	0.96	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1006	1.10	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0518	1.43	90.69	7.9018	N/A	272.39
26	8.3896	0.67	166.46	8.3820	0.68	191.04	72	7.8985	1.55	89.19	N/A	N/A	N/A
28	8.3946	0.63	153.47	N/A	N/A	N/A	74	7.8601	1.63	87.73	7.6310	1.75	275.36
30	8.3800	0.63	144.86	N/A	N/A	N/A	76	7.7963	N/A	86.46	7.5046	1.98	276.93
32	8.3688	0.64	138.27	8.3455	0.65	222.41	78	N/A	N/A	N/A	7.3052	2.89	278.30
34	N/A	N/A	N/A	8.3570	0.71	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3382	0.63	128.57	8.3255	0.76	237.87	82	7.3295	3.86	81.81	6.3583	3.98	281.39
38	8.3281	0.66	124.74	8.2770	0.75	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3189	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2848	0.70	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30818F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

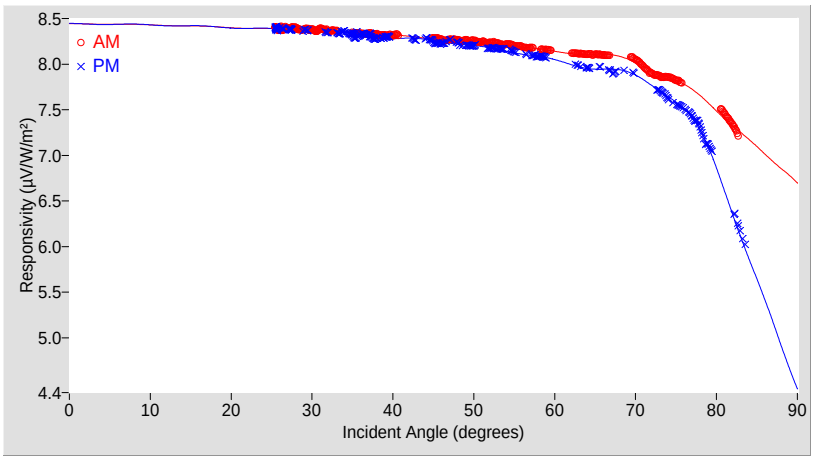


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±2.04	±2.04
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999990	0.9999984

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.4385	*	8.4387	*	8.4386	*
9-18	8.4222	*	8.4224	*	8.4223	*
18-27	8.3952	*	8.3936	*	8.3944	*
27-36	8.3715	±2.06	8.3552	±2.06	8.3633	±2.11
36-45	8.3137	±2.07	8.2850	±2.06	8.2993	±2.13
45-54	8.2564	±2.07	8.2080	±2.14	8.2322	±2.33
54-63	8.1622	±2.13	8.0727	±2.26	8.1174	±2.88
63-72	8.0697	±2.26	7.9191	±2.31	7.9944	±3.51
72-81	7.7320	±3.75	7.3967	±7.24	7.5643	±12.12
81-90	7.0531	*	5.5186	*	6.2858	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

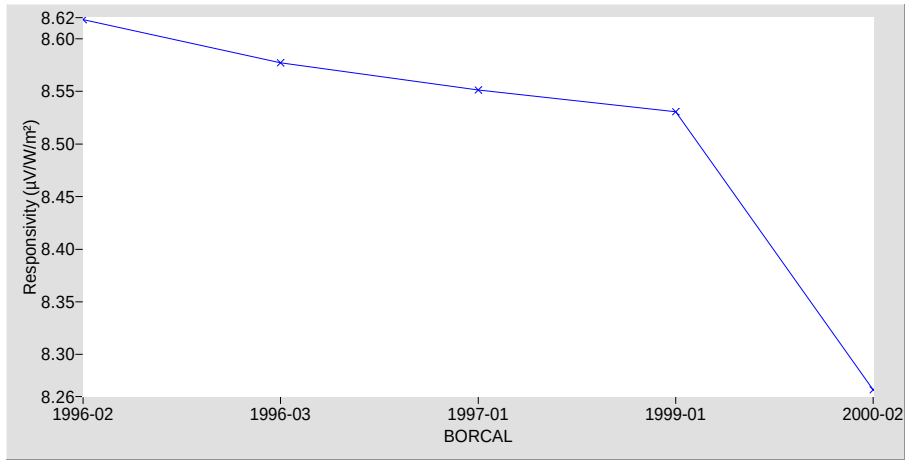
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2663	+2.12 / -3.00 [1]
45° - 55°	8.2232	±2.24 [2]
Composite	8.2741	+2.48 / -27.74 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



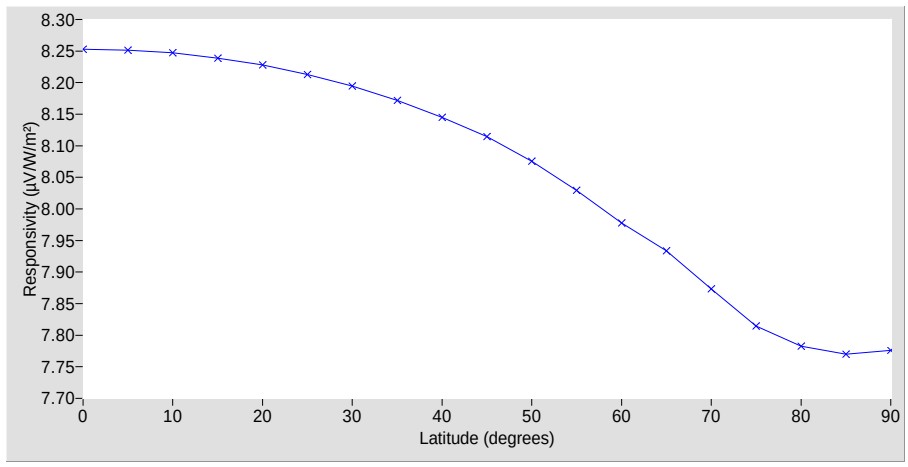
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.2527	+3.11 / -43.48
5	8.2515	+3.12 / -43.47
10	8.2471	+3.16 / -43.44
15	8.2389	+3.24 / -43.38
20	8.2278	+3.35 / -43.30
25	8.2130	+3.48 / -43.20
30	8.1945	+3.62 / -43.07
35	8.1716	+3.73 / -42.91
40	8.1449	+3.96 / -42.73
45	8.1146	+4.01 / -42.51
50	8.0758	+4.41 / -42.24
55	8.0294	+4.79 / -41.90
60	7.9778	+4.94 / -41.53
65	7.9336	+5.22 / -41.20
70	7.8732	+5.43 / -40.75
75	7.8145	+5.97 / -40.31
80	7.7828	+5.60 / -40.06
85	7.7698	+5.03 / -39.96
90	7.7762	+4.75 / -40.01

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30820F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30820F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

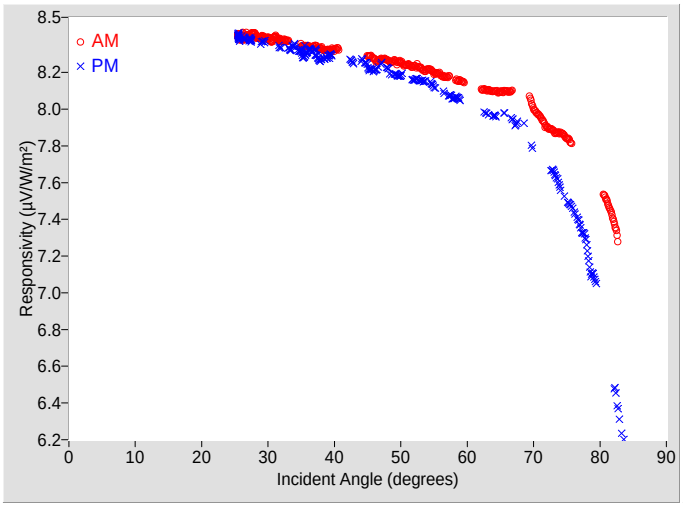


Figure 2. Responsivity vs Local Standard Time

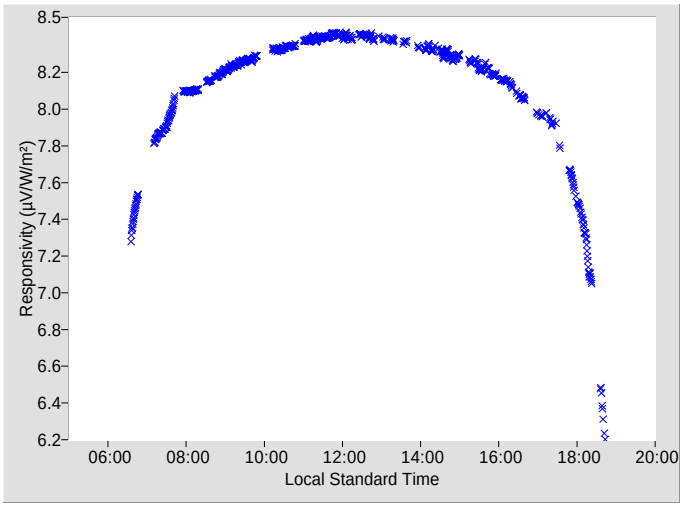


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.2610	+2.18 / -3.18	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2720	0.73	113.00	8.2117	0.70	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2674	0.73	110.68	8.2169	0.81	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2569	0.76	108.48	8.1840	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2345	0.77	106.40	8.1609	0.73	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2158	0.80	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1865	0.82	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1575	N/A	100.05	8.0600	0.84	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1075	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0977	1.03	95.28	7.9631	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0968	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0061	1.45	90.69	7.7870	N/A	272.39
26	8.3955	0.66	166.46	8.3829	0.68	191.04	72	7.9022	1.50	89.19	N/A	N/A	N/A
28	8.4036	0.62	153.47	N/A	N/A	N/A	74	7.8712	1.63	87.73	7.5799	1.77	275.36
30	8.3878	0.63	144.86	N/A	N/A	N/A	76	7.8131	N/A	86.46	7.4418	1.98	276.93
32	8.3730	0.64	138.27	8.3351	0.65	222.41	78	N/A	N/A	N/A	7.2551	2.81	278.30
34	N/A	N/A	N/A	8.3460	0.70	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3433	0.63	128.57	8.3183	0.75	237.87	82	7.3916	3.81	81.81	6.4804	3.91	281.39
38	8.3317	0.66	124.74	8.2662	0.75	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3251	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2680	0.69	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30820F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

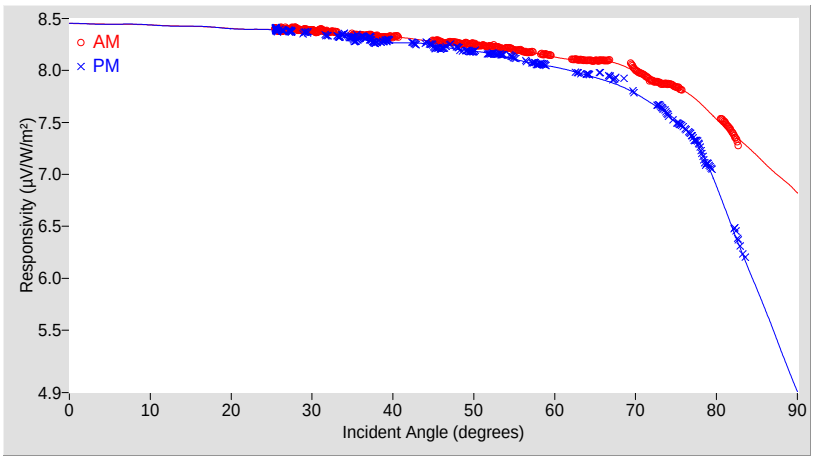


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±2.00	±2.00
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999996	0.9999991

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.4473	*	8.4474	*	8.4473	*
9-18	8.4293	*	8.4294	*	8.4293	*
18-27	8.4000	*	8.3974	*	8.3987	*
27-36	8.3775	±2.02	8.3479	±2.02	8.3627	±2.11
36-45	8.3184	±2.03	8.2723	±2.03	8.2953	±2.14
45-54	8.2558	±2.03	8.1927	±2.10	8.2243	±2.35
54-63	8.1560	±2.11	8.0575	±2.18	8.1067	±2.80
63-72	8.0513	±2.25	7.8631	±2.63	7.9572	±4.14
72-81	7.7537	±3.40	7.3542	±6.41	7.5540	±11.42
81-90	7.1425	*	5.7940	*	6.4682	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

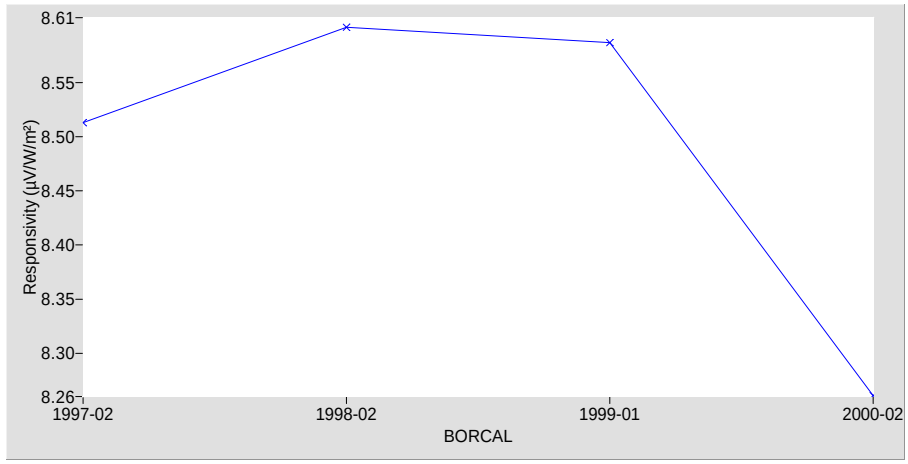
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2610	+2.18 / -3.18 [1]
45° - 55°	8.2154	±2.25 [2]
Composite	8.2741	+2.49 / -25.41 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



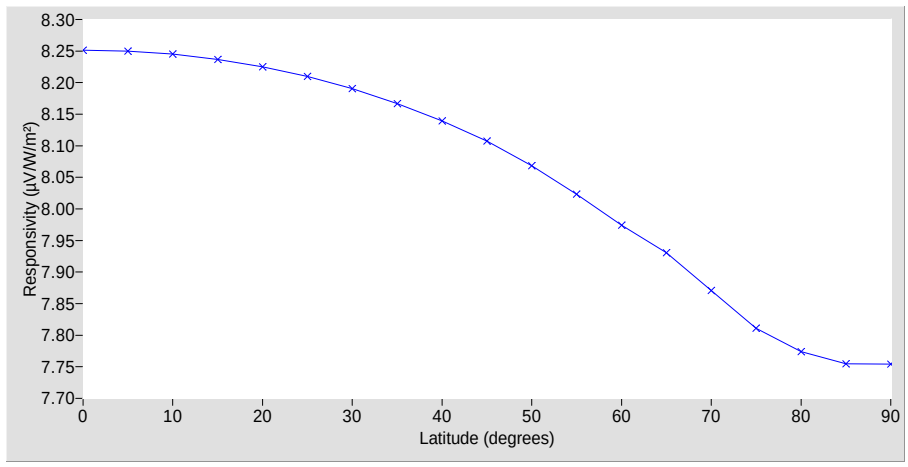
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.2513	+3.17 / -38.23
5	8.2500	+3.18 / -38.22
10	8.2453	+3.22 / -38.18
15	8.2368	+3.31 / -38.12
20	8.2252	+3.42 / -38.03
25	8.2099	+3.57 / -37.92
30	8.1906	+3.71 / -37.77
35	8.1669	+3.84 / -37.59
40	8.1395	+4.05 / -37.38
45	8.1074	+4.12 / -37.13
50	8.0686	+4.54 / -36.83
55	8.0233	+4.92 / -36.47
60	7.9741	+5.02 / -36.08
65	7.9304	+5.28 / -35.73
70	7.8710	+5.49 / -35.25
75	7.8111	+5.94 / -34.75
80	7.7741	+5.69 / -34.44
85	7.7546	+5.07 / -34.27
90	7.7540	+4.83 / -34.27

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30823F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30823F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

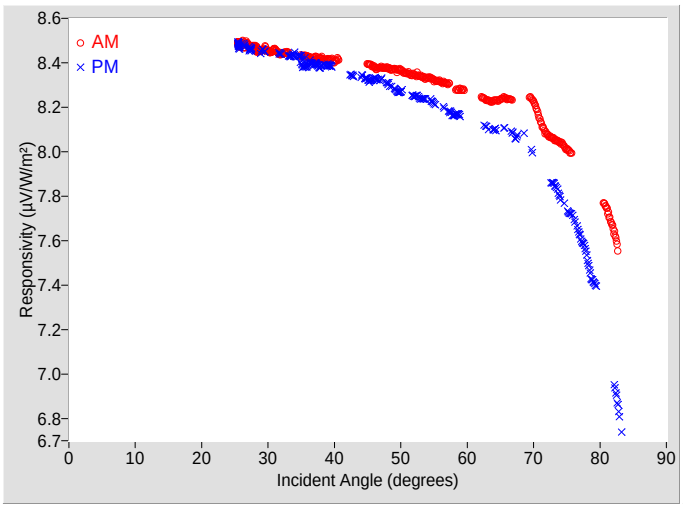

Figure 2. Responsivity vs Local Standard Time

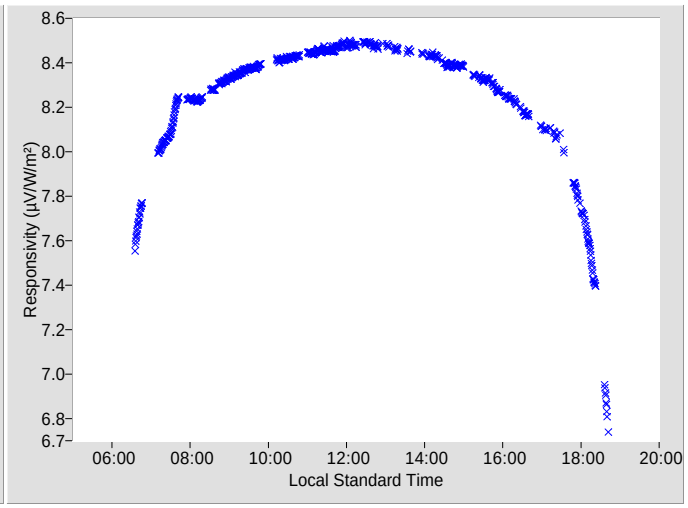

Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3592	+1.77 / -3.05	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3802	0.71	113.00	8.3290	0.69	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3775	0.72	110.68	8.3049	0.73	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3674	0.74	108.48	8.2703	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3480	0.77	106.40	8.2499	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3334	0.79	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3141	0.81	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2780	N/A	100.05	8.1642	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2442	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2295	1.02	95.28	8.0998	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2383	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2247	1.42	90.69	7.9948	N/A	272.39
26	8.4828	0.64	166.46	8.4742	0.65	191.04	72	8.0790	1.50	89.19	N/A	N/A	N/A
28	8.4672	0.63	153.47	N/A	N/A	N/A	74	8.0419	1.64	87.73	7.7993	1.64	275.36
30	8.4524	0.62	144.86	N/A	N/A	N/A	76	7.9940	N/A	86.46	7.6972	1.93	276.93
32	8.4411	0.63	138.35	8.4411	0.64	222.41	78	N/A	N/A	N/A	7.5318	2.48	278.30
34	N/A	N/A	N/A	8.4356	0.70	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4276	0.63	128.57	8.3935	0.68	237.87	82	7.6478	3.71	81.81	6.9448	3.78	281.39
38	8.4210	0.65	124.74	8.3818	0.65	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4077	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3411	0.68	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

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Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

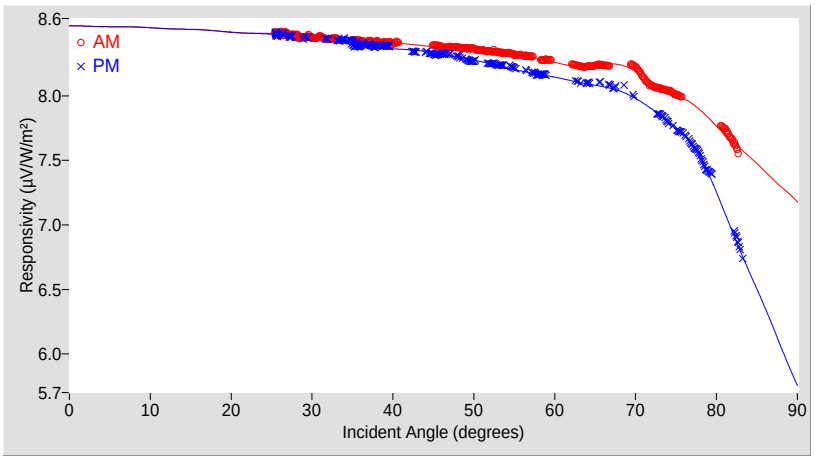


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.92	±1.92
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999990	0.9999996

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.5382	*	8.5381	*	8.5382	*
9-18	8.5197	*	8.5196	*	8.5197	*
18-27	8.4885	*	8.4871	*	8.4878	*
27-36	8.4482	±1.94	8.4444	±1.95	8.4463	±2.00
36-45	8.4077	±1.93	8.3674	±1.95	8.3875	±2.05
45-54	8.3666	±1.94	8.2845	±2.03	8.3256	±2.36
54-63	8.2819	±2.01	8.1653	±2.03	8.2236	±2.67
63-72	8.2186	±2.05	8.0372	±2.24	8.1279	±3.52
72-81	7.9482	±3.05	7.6232	±5.11	7.7857	±9.06
81-90	7.4425	*	6.4243	*	6.9334	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

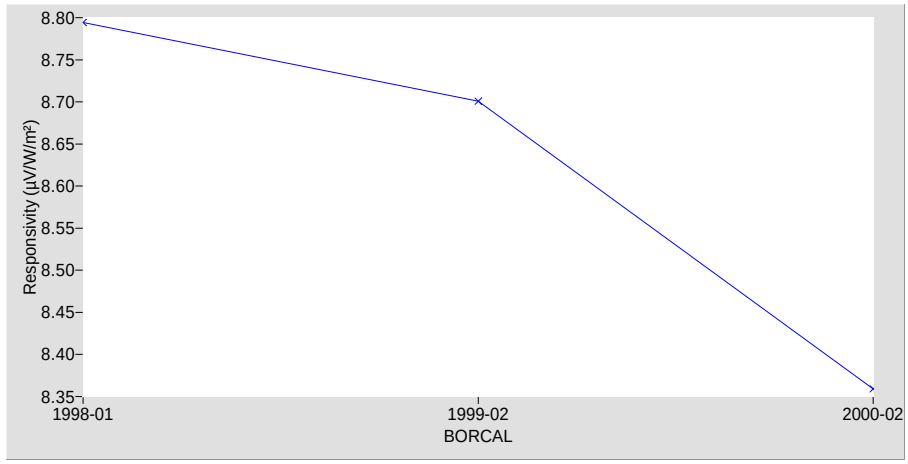
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3592	+1.77 / -3.05 [1]
45° - 55°	8.3172	±2.20 [2]
Composite	8.3808	+2.27 / -19.09 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



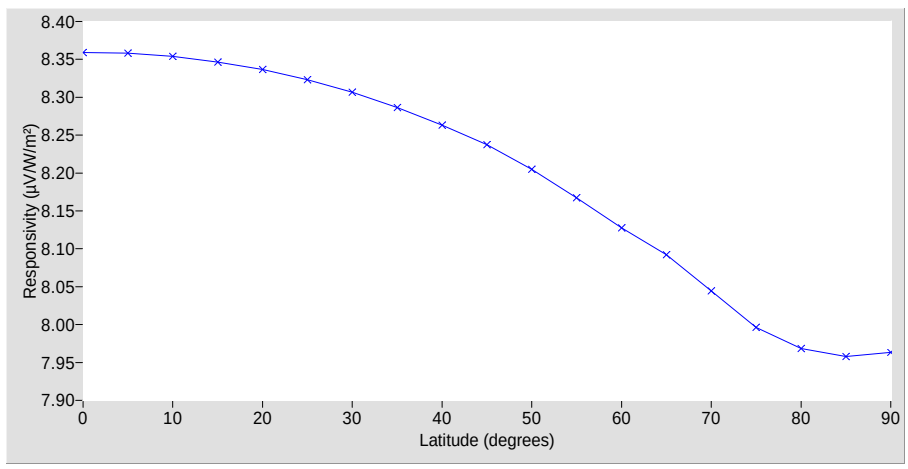
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.3592	+2.93 / -29.50
5	8.3581	+2.94 / -29.49
10	8.3539	+2.98 / -29.46
15	8.3466	+3.05 / -29.40
20	8.3365	+3.15 / -29.31
25	8.3233	+3.27 / -29.20
30	8.3065	+3.37 / -29.06
35	8.2864	+3.46 / -28.88
40	8.2634	+3.60 / -28.69
45	8.2374	+3.62 / -28.46
50	8.2048	+3.86 / -28.18
55	8.1673	+3.95 / -27.85
60	8.1276	+4.15 / -27.50
65	8.0921	+4.33 / -27.18
70	8.0444	+4.58 / -26.75
75	7.9961	+4.96 / -26.31
80	7.9682	+4.69 / -26.05
85	7.9581	+4.13 / -25.95
90	7.9632	+4.07 / -26.00

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30890F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30890F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

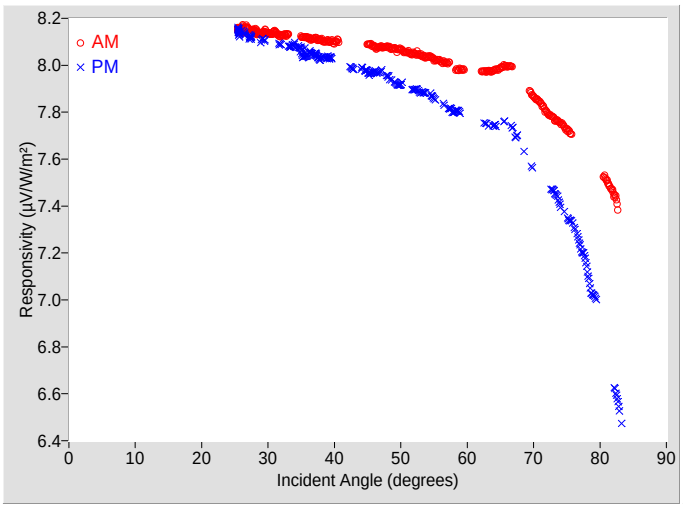


Figure 2. Responsivity vs Local Standard Time

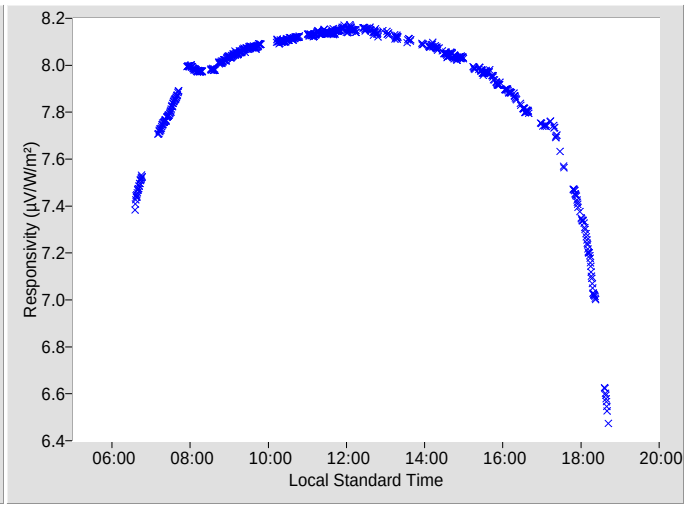


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0303	+1.97 / -3.57	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0788	0.71	113.00	7.9723	0.69	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0786	0.72	110.68	7.9506	0.75	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0677	0.74	108.48	7.9182	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0511	0.77	106.40	7.8962	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0367	0.79	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0160	0.82	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9791	N/A	100.05	7.8014	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9736	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9788	1.03	95.28	7.7431	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9960	1.10	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8671	1.32	90.69	7.5637	N/A	272.39
26	8.1536	0.65	166.46	8.1339	0.67	191.04	72	7.7987	1.48	89.19	N/A	N/A	N/A
28	8.1455	0.62	153.47	N/A	N/A	N/A	74	7.7558	1.65	87.73	7.4113	1.66	275.36
30	8.1369	0.61	144.86	N/A	N/A	N/A	76	7.7059	N/A	86.46	7.3118	1.97	276.93
32	8.1268	0.63	138.35	8.0895	0.65	222.41	78	N/A	N/A	N/A	7.1395	2.54	278.30
34	N/A	N/A	N/A	8.0861	0.69	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1179	0.63	128.57	8.0484	0.68	237.87	82	7.4537	3.61	81.81	6.6248	3.74	281.39
38	8.1083	0.65	124.74	8.0281	0.66	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0989	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.9880	0.68	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30890F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

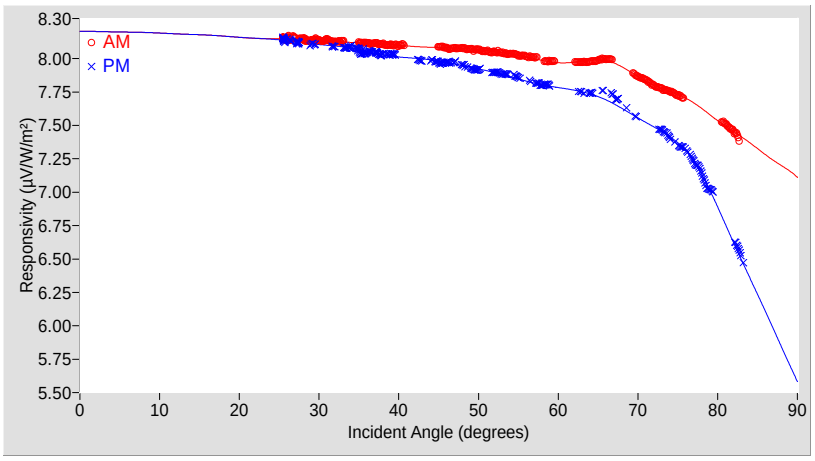


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.89	±1.89
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2001	*	8.2001	*	8.2001	*
9-18	8.1826	*	8.1826	*	8.1826	*
18-27	8.1543	*	8.1508	*	8.1526	*
27-36	8.1323	±1.89	8.0967	±1.93	8.1145	±2.04
36-45	8.0994	±1.90	8.0148	±1.93	8.0571	±2.21
45-54	8.0676	±1.90	7.9304	±2.01	7.9990	±2.68
54-63	7.9924	±1.93	7.8055	±2.00	7.8990	±3.12
63-72	7.9340	±2.19	7.6430	±2.48	7.7885	±4.85
72-81	7.6781	±2.65	7.2375	±4.96	7.4578	±9.84
81-90	7.3049	*	6.1689	*	6.7369	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

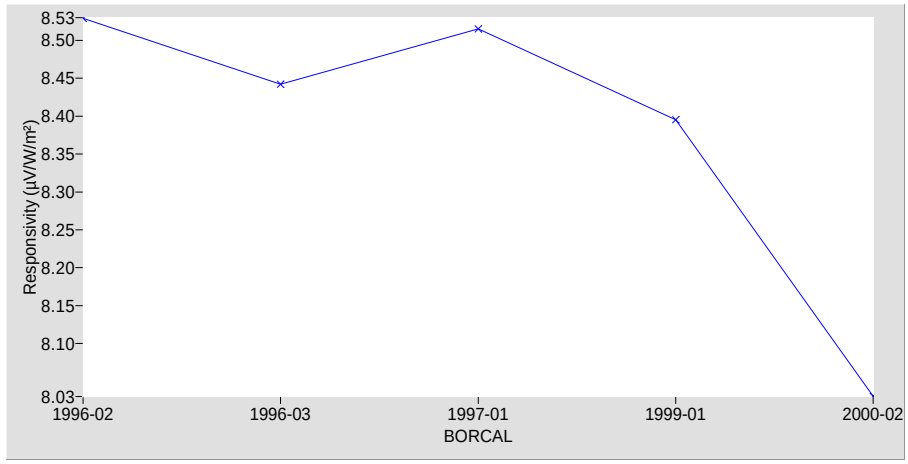
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0303	+1.97 / -3.57 [1]
45° - 55°	7.9911	±2.39 [2]
Composite	8.0492	+2.26 / -19.45 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



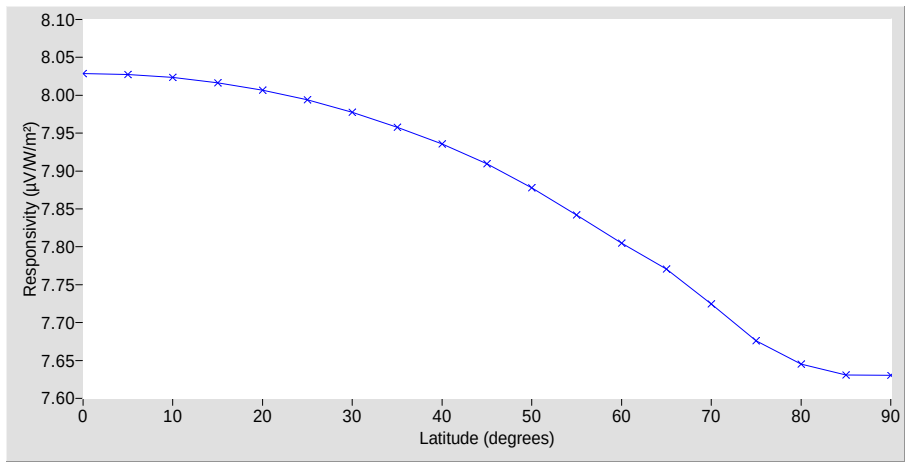
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0285	+2.89 / -28.93
5	8.0275	+2.90 / -28.92
10	8.0234	+2.94 / -28.88
15	8.0164	+3.01 / -28.82
20	8.0066	+3.11 / -28.73
25	7.9938	+3.24 / -28.62
30	7.9776	+3.35 / -28.47
35	7.9579	+3.46 / -28.30
40	7.9359	+3.57 / -28.10
45	7.9095	+3.64 / -27.86
50	7.8777	+3.93 / -27.57
55	7.8421	+4.16 / -27.24
60	7.8048	+4.42 / -26.89
65	7.7708	+4.57 / -26.57
70	7.7247	+5.00 / -26.14
75	7.6762	+5.34 / -25.67
80	7.6451	+5.17 / -25.37
85	7.6308	+5.08 / -25.23
90	7.6302	+5.01 / -25.22

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30891F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30891F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

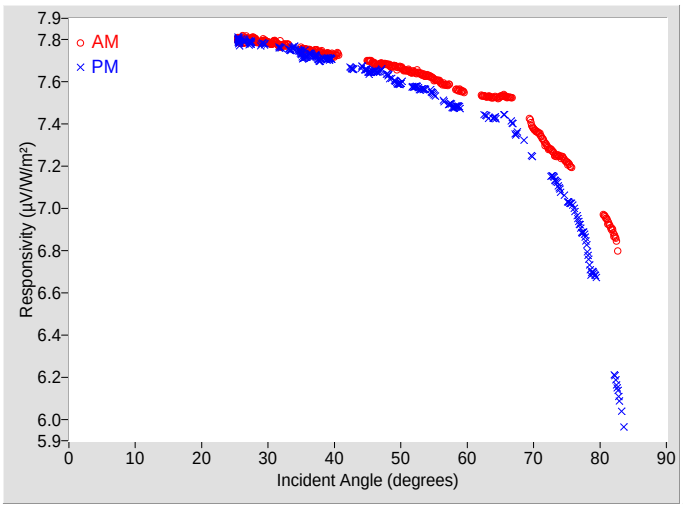


Figure 2. Responsivity vs Local Standard Time

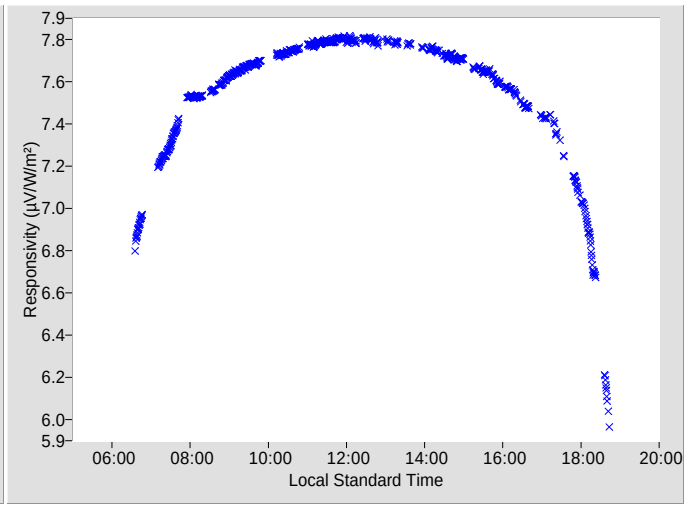


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.6743	+2.23 / -3.30	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6857	0.72	113.00	7.6503	0.70	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6816	0.73	110.68	7.6290	0.76	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6683	0.75	108.48	7.5920	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6459	0.77	106.40	7.5756	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6288	0.80	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5941	0.83	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5616	N/A	100.05	7.4781	0.84	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5341	0.98	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5259	1.03	95.28	7.4278	0.96	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5272	1.10	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.3788	1.39	90.69	7.2452	N/A	272.39
26	7.7975	0.66	166.46	7.7855	0.68	191.04	72	7.2945	1.53	89.19	N/A	N/A	N/A
28	7.7997	0.62	153.47	N/A	N/A	N/A	74	7.2460	1.65	87.73	7.0924	1.66	275.36
30	7.7856	0.62	144.86	N/A	N/A	N/A	76	7.1933	N/A	86.46	7.0003	1.97	276.93
32	7.7728	0.64	138.27	7.7603	0.65	222.41	78	N/A	N/A	N/A	6.8215	2.70	278.30
34	N/A	N/A	N/A	7.7598	0.69	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7514	0.64	128.57	7.7257	0.68	237.87	82	6.8825	3.71	81.81	6.2099	3.84	281.39
38	7.7393	0.66	124.74	7.7020	0.67	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7251	0.67	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.6695	0.68	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30891F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

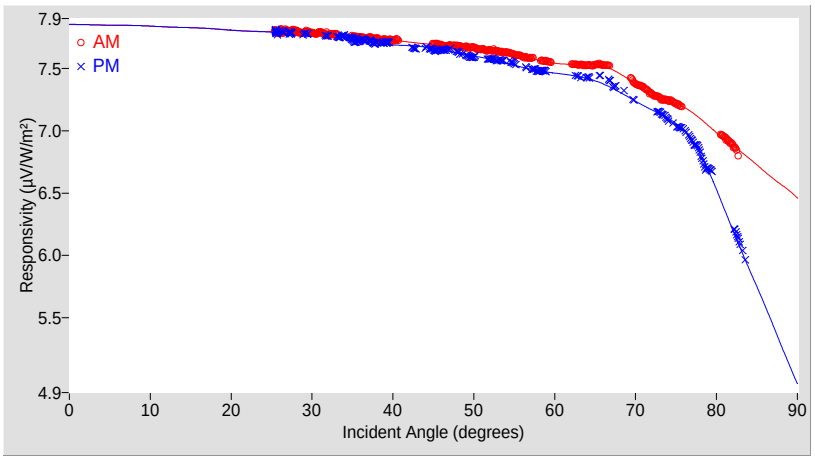


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.94	±1.94
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999998	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	7.8479	*	7.8480	*	7.8480	*
9-18	7.8304	*	7.8304	*	7.8304	*
18-27	7.8018	*	7.7994	*	7.8006	*
27-36	7.7780	±1.96	7.7637	±1.96	7.7708	±2.02
36-45	7.7237	±1.98	7.6921	±1.98	7.7079	±2.09
45-54	7.6685	±1.98	7.6080	±2.07	7.6383	±2.36
54-63	7.5687	±2.03	7.4843	±2.06	7.5265	±2.60
63-72	7.4599	±2.44	7.3257	±2.59	7.3928	±3.93
72-81	7.1557	±3.08	6.9118	±5.55	7.0338	±9.33
81-90	6.6988	*	5.6678	*	6.1833	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

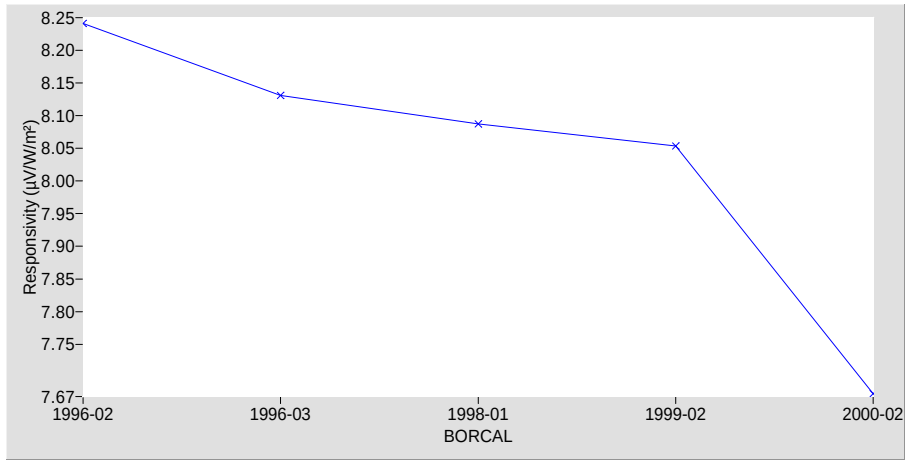
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.6743	+2.23 / -3.30 [1]
45° - 55°	7.6294	±2.23 [2]
Composite	7.6886	+2.40 / -22.40 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



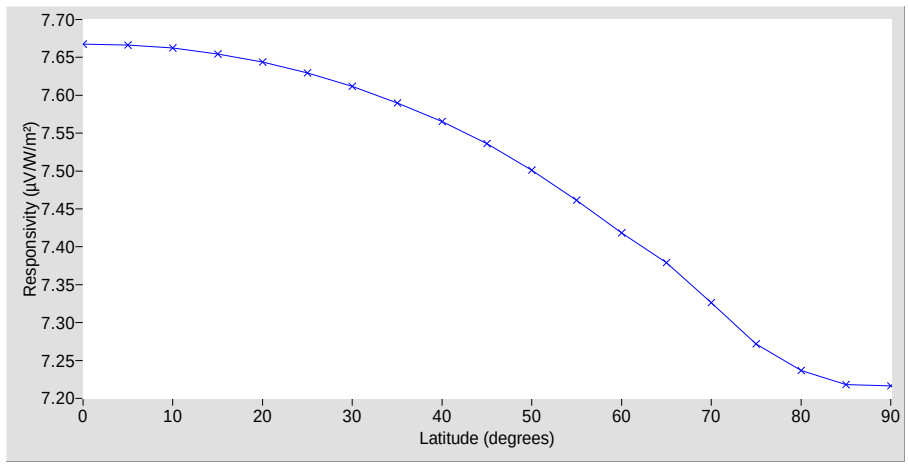
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	7.6674	+3.10 / -33.26
5	7.6664	+3.11 / -33.25
10	7.6622	+3.16 / -33.21
15	7.6545	+3.24 / -33.14
20	7.6437	+3.36 / -33.05
25	7.6295	+3.51 / -32.92
30	7.6115	+3.64 / -32.77
35	7.5899	+3.78 / -32.57
40	7.5655	+3.94 / -32.36
45	7.5361	+4.03 / -32.09
50	7.5012	+4.40 / -31.78
55	7.4613	+4.71 / -31.41
60	7.4183	+4.88 / -31.02
65	7.3790	+5.00 / -30.65
70	7.3262	+5.31 / -30.15
75	7.2717	+5.67 / -29.63
80	7.2367	+5.34 / -29.29
85	7.2183	+4.80 / -29.11
90	7.2163	+4.60 / -29.09

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30894F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30894F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

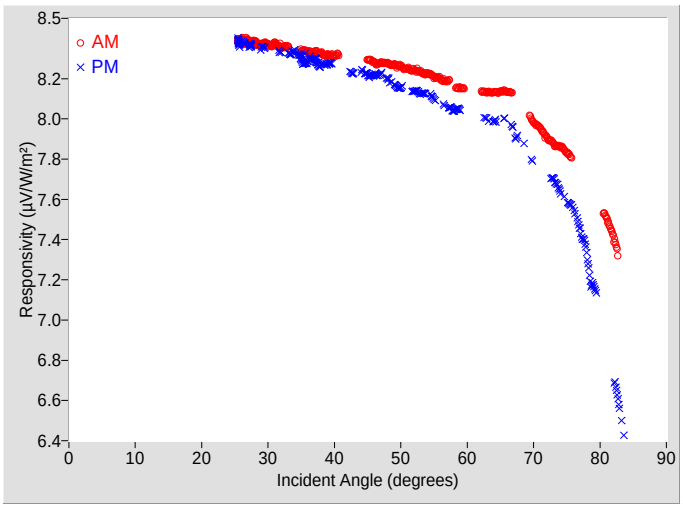


Figure 2. Responsivity vs Local Standard Time

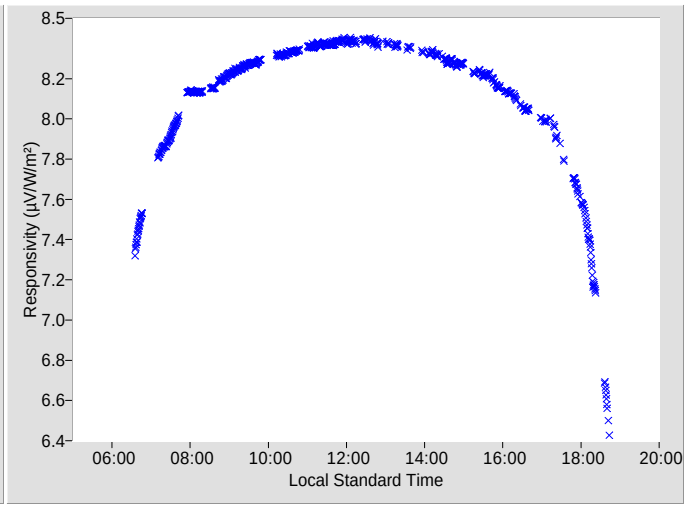


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.2566	+2.13 / -3.32	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2806	0.72	113.00	8.2192	0.69	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2775	0.72	110.68	8.1961	0.77	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2635	0.75	108.48	8.1552	0.72	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2433	0.77	106.40	8.1373	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2254	0.80	104.43	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1972	0.82	102.53	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1533	N/A	100.05	8.0421	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1357	0.97	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1334	1.02	95.28	7.9890	0.95	268.17
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1348	1.10	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9845	1.34	90.69	7.7911	N/A	272.39
26	8.3871	0.65	166.56	8.3711	0.68	191.04	72	7.9057	1.50	89.19	N/A	N/A	N/A
28	8.3818	0.61	153.47	N/A	N/A	N/A	74	7.8626	1.63	87.73	7.6438	1.64	275.36
30	8.3701	0.61	144.86	N/A	N/A	N/A	76	7.8061	N/A	86.46	7.5443	1.99	276.93
32	8.3583	0.63	138.27	8.3325	0.65	222.41	78	N/A	N/A	N/A	7.3309	2.79	278.30
34	N/A	N/A	N/A	8.3337	0.71	227.75	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3364	0.63	128.57	8.2907	0.70	237.87	82	7.4113	3.72	81.81	6.6895	3.79	281.39
38	8.3263	0.65	124.74	8.2650	0.69	241.81	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3142	0.66	121.39	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2398	0.68	250.06	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30894F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

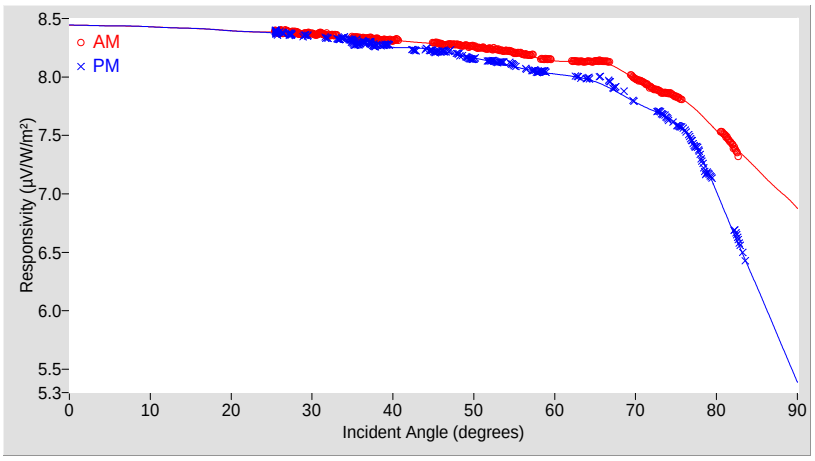


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.94	±1.94
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R²	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.4388	*	8.4388	*	8.4388	*
9-18	8.4202	*	8.4202	*	8.4202	*
18-27	8.3900	*	8.3871	*	8.3885	*
27-36	8.3628	±1.96	8.3390	±1.97	8.3509	±2.06
36-45	8.3131	±1.96	8.2585	±1.97	8.2858	±2.12
45-54	8.2644	±1.97	8.1732	±2.07	8.2188	±2.47
54-63	8.1664	±2.02	8.0474	±2.04	8.1069	±2.74
63-72	8.0669	±2.36	7.8791	±2.56	7.9730	±4.17
72-81	7.7524	±3.25	7.4409	±5.59	7.5967	±9.81
81-90	7.1781	*	6.1214	*	6.6497	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

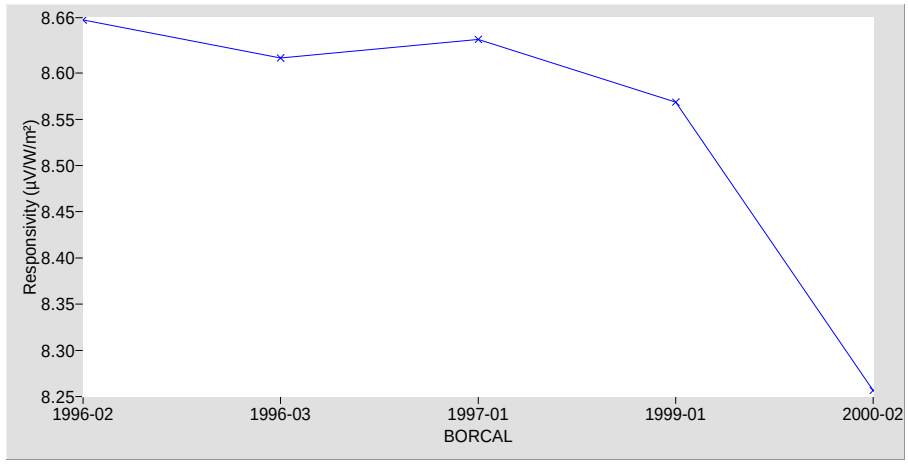
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2566	+2.13 / -3.32 [1]
45° - 55°	8.2099	±2.29 [2]
Composite	8.2711	+2.37 / -22.18 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



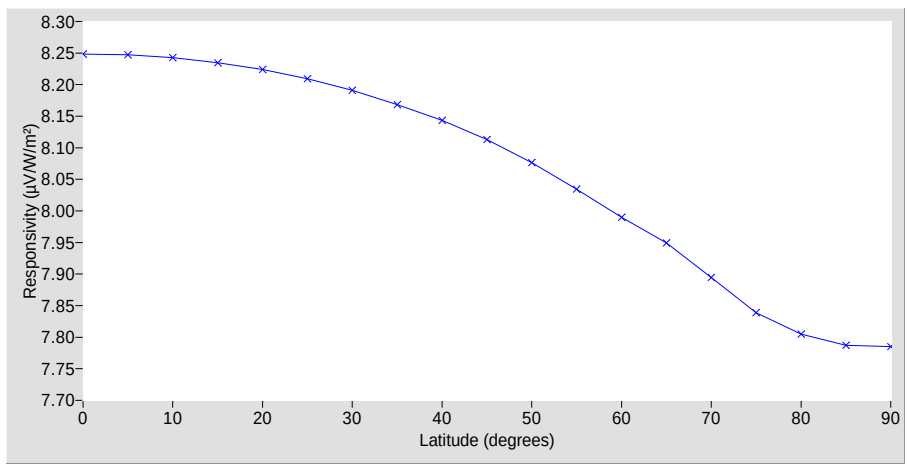
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.2486	+3.06 / -32.75
5	8.2474	+3.07 / -32.74
10	8.2429	+3.12 / -32.70
15	8.2348	+3.20 / -32.64
20	8.2238	+3.31 / -32.55
25	8.2093	+3.45 / -32.43
30	8.1908	+3.58 / -32.27
35	8.1685	+3.71 / -32.09
40	8.1433	+3.85 / -31.88
45	8.1128	+3.94 / -31.62
50	8.0764	+4.27 / -31.32
55	8.0346	+4.55 / -30.96
60	7.9896	+4.75 / -30.57
65	7.9496	+4.92 / -30.22
70	7.8948	+5.29 / -29.74
75	7.8389	+5.65 / -29.24
80	7.8050	+5.35 / -28.93
85	7.7872	+4.95 / -28.77
90	7.7851	+4.79 / -28.75

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30901F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30901F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

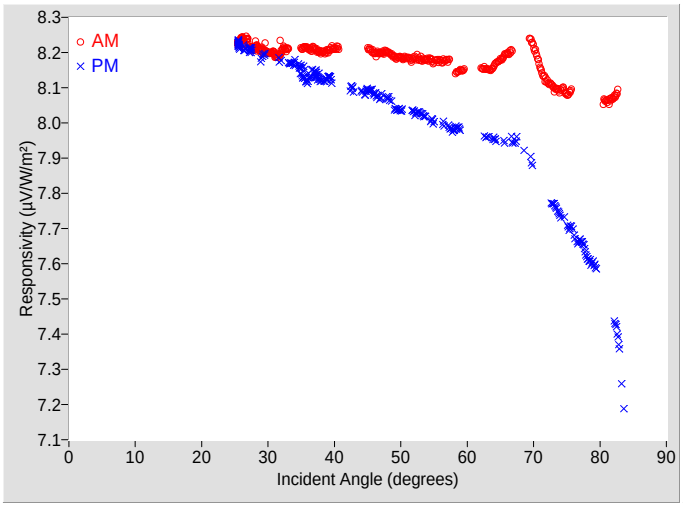


Figure 2. Responsivity vs Local Standard Time

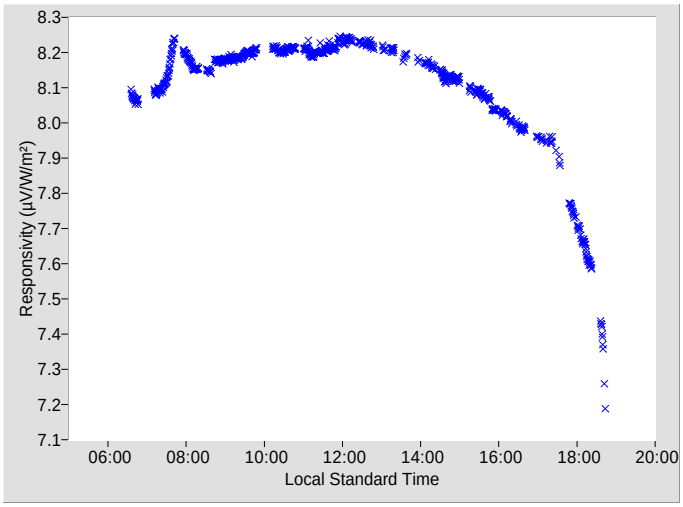


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.1519	+1.69 / -2.86	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1984	0.72	113.01	8.0816	0.71	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2014	0.73	110.63	8.0703	0.71	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1864	0.73	108.49	8.0369	0.71	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1849	0.77	106.41	8.0303	0.74	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1791	0.79	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1755	0.81	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1401	N/A	100.06	7.9813	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1557	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1617	1.04	95.30	7.9548	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1963	1.11	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2177	1.38	90.70	7.8791	N/A	272.39
26	8.2368	0.63	166.60	8.2210	N/A	196.20	72	8.1184	1.46	89.20	N/A	N/A	N/A
28	8.2144	0.62	153.49	N/A	N/A	N/A	74	8.0934	1.61	87.74	7.7387	1.56	275.37
30	8.2000	0.63	144.88	N/A	N/A	N/A	76	8.0961	N/A	86.47	7.6835	1.83	276.94
32	8.2060	0.68	138.29	8.1773	N/A	222.63	78	N/A	N/A	N/A	7.6210	2.17	278.31
34	N/A	N/A	N/A	8.1693	0.69	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2122	0.63	128.58	8.1210	0.69	238.74	82	8.0723	3.47	81.82	7.4336	3.63	281.39
38	8.2016	0.64	124.76	8.1209	0.66	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2111	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0902	0.68	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30901F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

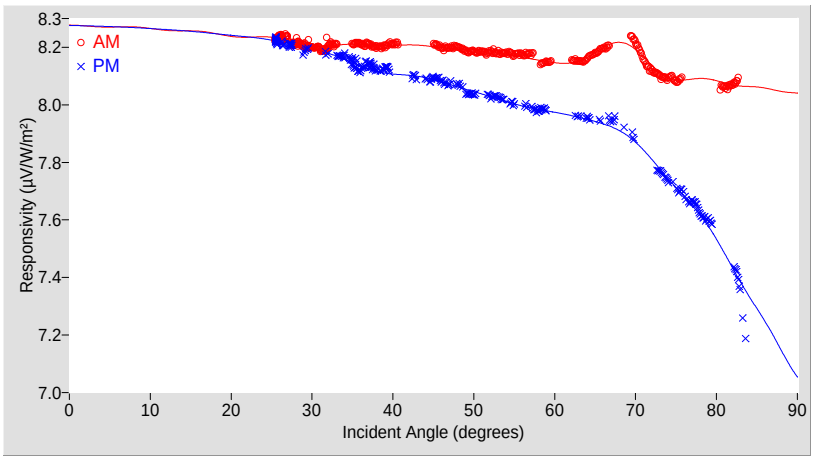


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.84	±1.84
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999994	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2725	*	8.2723	*	8.2724	*
9-18	8.2590	*	8.2588	*	8.2589	*
18-27	8.2367	*	8.2341	*	8.2354	*
27-36	8.2087	±1.84	8.1821	±1.89	8.1954	±1.98
36-45	8.2070	±1.84	8.1092	±1.86	8.1581	±2.11
45-54	8.1924	±1.84	8.0523	±1.89	8.1223	±2.46
54-63	8.1564	±1.85	7.9841	±1.87	8.0702	±2.64
63-72	8.1883	±1.88	7.9096	±2.01	8.0490	±3.92
72-81	8.0949	±1.87	7.6691	±2.69	7.8820	±6.02
81-90	8.0577	*	7.2672	*	7.6624	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

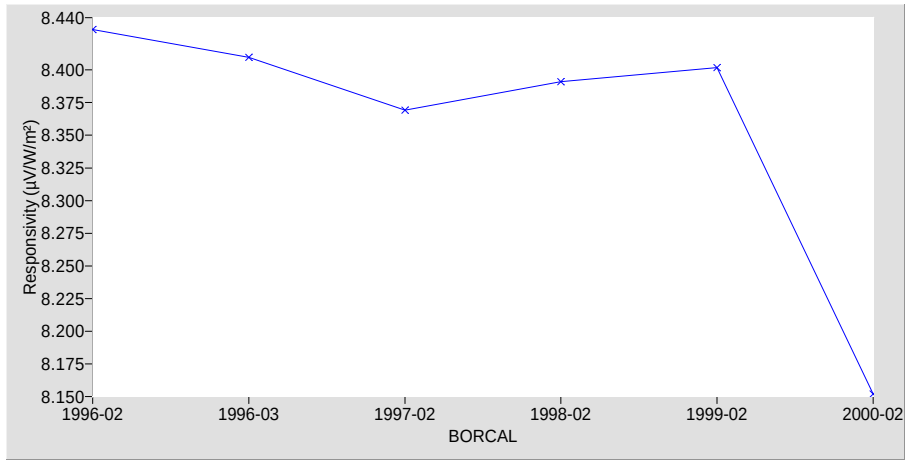
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1519	+1.69 / -2.86 [1]
45° - 55°	8.1178	±2.21 [2]
Composite	8.1745	+1.97 / -10.14 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



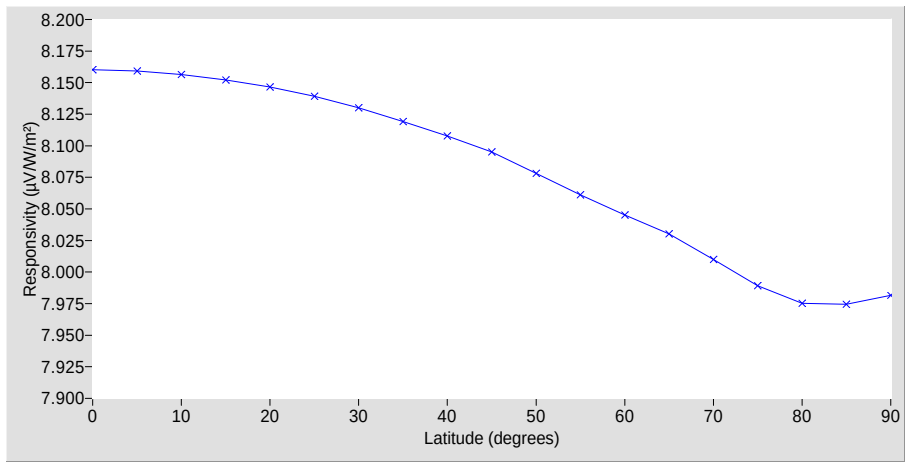
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.1601	+2.33 / -13.15
5	8.1592	+2.34 / -13.14
10	8.1565	+2.36 / -13.11
15	8.1522	+2.39 / -13.07
20	8.1467	+2.44 / -13.01
25	8.1392	+2.49 / -12.93
30	8.1300	+2.53 / -12.83
35	8.1193	+2.56 / -12.72
40	8.1078	+2.59 / -12.60
45	8.0950	+2.56 / -12.46
50	8.0782	+2.63 / -12.28
55	8.0612	+2.67 / -12.10
60	8.0451	+2.82 / -11.92
65	8.0303	+2.97 / -11.76
70	8.0101	+3.17 / -11.54
75	7.9892	+3.39 / -11.31
80	7.9752	+3.55 / -11.16
85	7.9745	+3.56 / -11.15
90	7.9816	+3.48 / -11.23

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30948F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30948F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

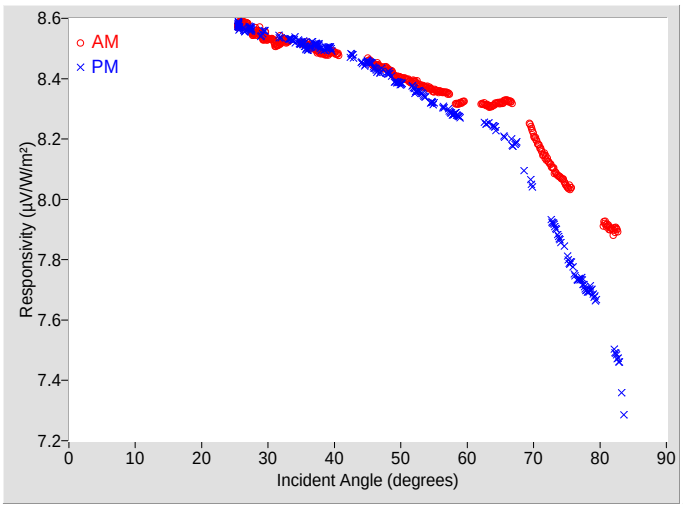


Figure 2. Responsivity vs Local Standard Time

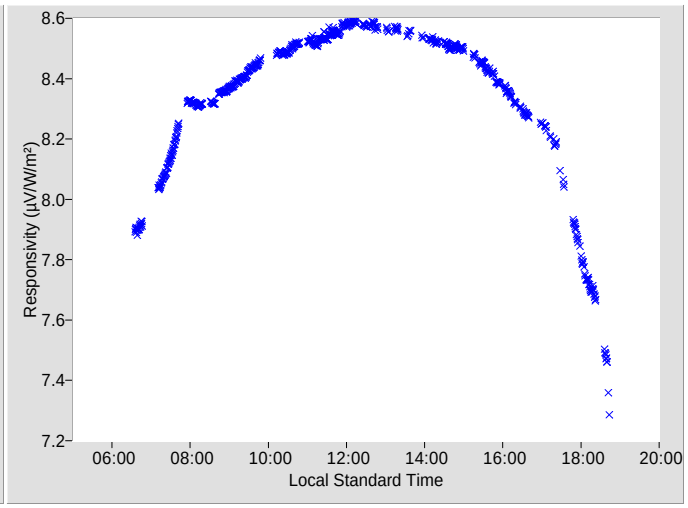


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4594	+1.66 / -2.86	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4458	0.72	113.01	8.4338	0.72	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4329	0.73	110.63	8.4180	0.71	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4044	0.74	108.49	8.3833	0.71	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3920	0.77	106.41	8.3642	0.74	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3709	0.79	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3572	0.81	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3165	N/A	100.06	8.2825	0.84	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3169	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3136	1.02	95.30	8.2419	0.96	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3266	1.09	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2171	1.38	90.70	8.0412	N/A	272.39
26	8.5867	0.63	166.60	8.5708	N/A	196.20	72	8.1332	1.48	89.20	N/A	N/A	N/A
28	8.5521	0.62	153.49	N/A	N/A	N/A	74	8.0739	1.64	87.74	7.8668	1.60	275.37
30	8.5320	0.64	144.88	N/A	N/A	N/A	76	8.0386	N/A	86.47	7.7581	1.86	276.94
32	8.5250	0.64	138.29	8.5350	N/A	222.63	78	N/A	N/A	N/A	7.6970	2.14	278.31
34	N/A	N/A	N/A	8.5280	0.66	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5127	0.64	128.58	8.4991	0.65	238.74	82	7.8968	3.48	81.82	7.4975	3.60	281.39
38	8.4845	0.65	124.76	8.4998	0.65	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4869	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4530	0.68	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30948F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

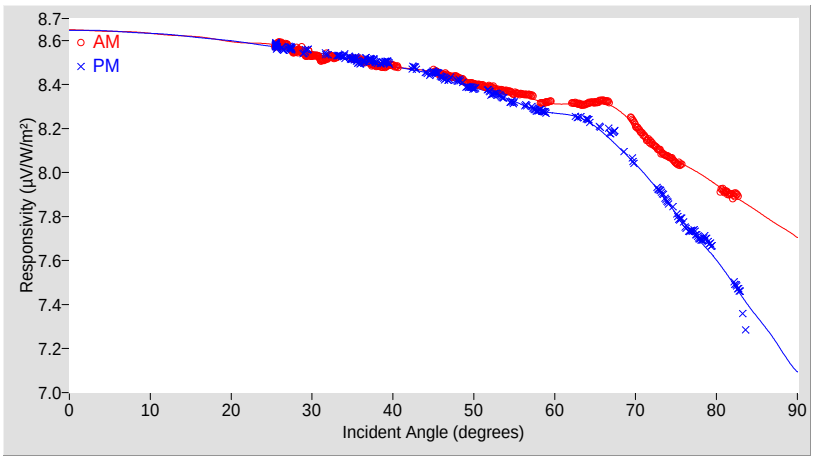


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.83	±1.83
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.6433	*	8.6431	*	8.6432	*
9-18	8.6232	*	8.6229	*	8.6231	*
18-27	8.5896	*	8.5874	*	8.5885	*
27-36	8.5325	±1.86	8.5397	±1.86	8.5361	±1.89
36-45	8.4821	±1.85	8.4809	±1.86	8.4815	±1.89
45-54	8.4164	±1.89	8.3966	±1.93	8.4065	±2.06
54-63	8.3319	±1.87	8.2883	±1.90	8.3101	±2.09
63-72	8.2726	±2.10	8.1302	±2.48	8.2014	±3.60
72-81	8.0302	±2.23	7.7634	±3.05	7.8968	±5.36
81-90	7.8128	*	7.3206	*	7.5667	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

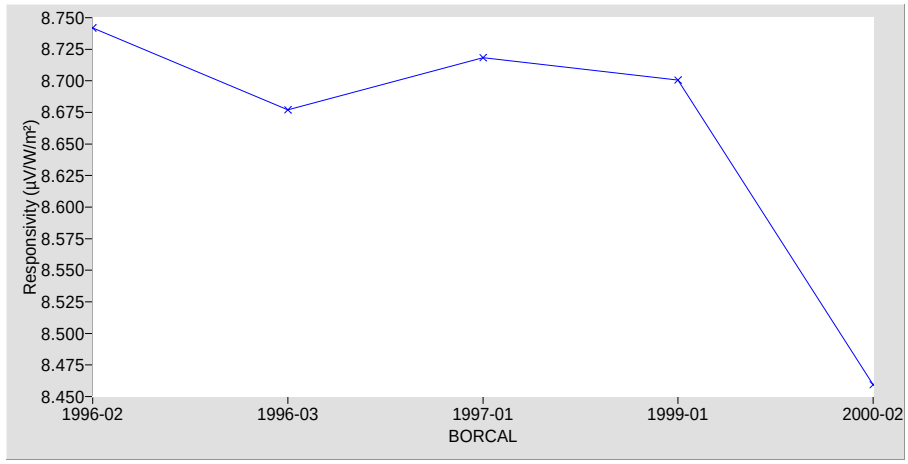
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4594	+1.66 / -2.86 [1]
45° - 55°	8.3983	±2.00 [2]
Composite	8.4811	+2.17 / -12.67 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



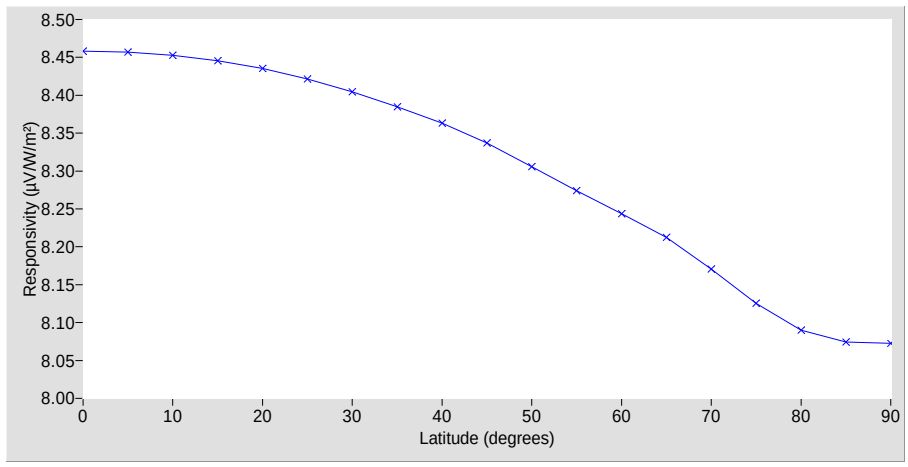
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.4583	+2.90 / -15.72
5	8.4570	+2.92 / -15.70
10	8.4526	+2.96 / -15.66
15	8.4454	+3.03 / -15.59
20	8.4352	+3.13 / -15.49
25	8.4215	+3.26 / -15.35
30	8.4046	+3.36 / -15.18
35	8.3849	+3.46 / -14.98
40	8.3630	+3.54 / -14.76
45	8.3368	+3.59 / -14.50
50	8.3058	+3.74 / -14.18
55	8.2742	+3.72 / -13.85
60	8.2436	+3.70 / -13.54
65	8.2125	+3.70 / -13.21
70	8.1707	+3.85 / -12.77
75	8.1255	+3.84 / -12.29
80	8.0899	+3.69 / -11.91
85	8.0743	+3.58 / -11.74
90	8.0727	+3.54 / -11.72

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30952F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30952F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

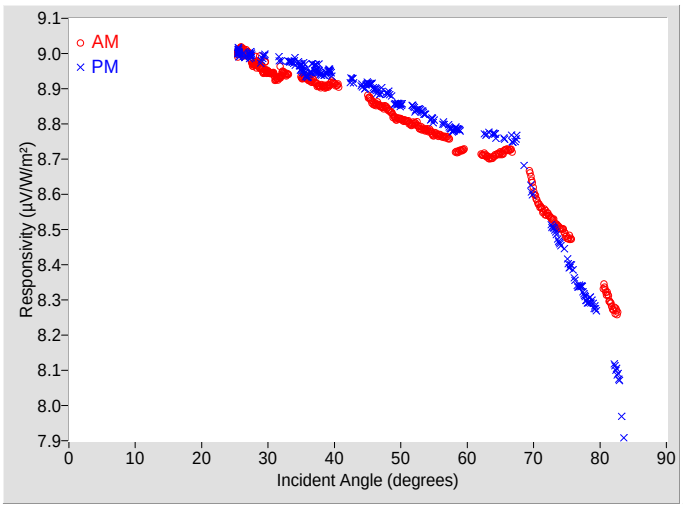


Figure 2. Responsivity vs Local Standard Time

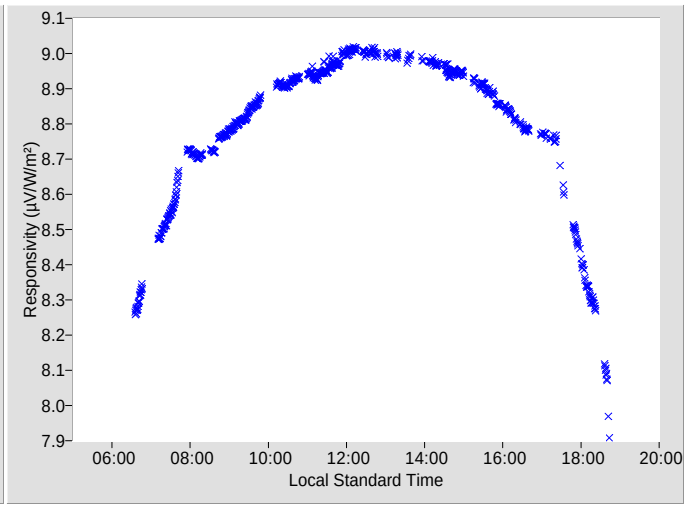


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.8956	+1.71 / -2.67	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8577	0.72	113.01	8.8985	0.70	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8427	0.74	110.63	8.8869	0.70	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8142	0.73	108.49	8.8544	0.71	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8025	0.77	106.41	8.8442	0.73	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7821	0.79	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7670	0.81	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7200	N/A	100.06	8.7834	0.82	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7134	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7077	1.02	95.30	8.7717	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7261	1.09	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6162	1.42	90.70	8.5982	N/A	272.39
26	9.0103	0.63	166.60	9.0030	N/A	196.20	72	8.5448	1.44	89.20	N/A	N/A	N/A
28	8.9713	0.62	153.49	N/A	N/A	N/A	74	8.5047	1.62	87.74	8.4607	1.56	275.37
30	8.9476	0.64	144.88	N/A	N/A	N/A	76	8.4729	N/A	86.47	8.3675	1.84	276.94
32	8.9418	0.65	138.29	8.9790	N/A	222.63	78	N/A	N/A	N/A	8.2975	2.12	278.31
34	N/A	N/A	N/A	8.9762	0.67	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9281	0.63	128.58	8.9379	0.66	238.74	82	8.2730	3.47	81.82	8.1153	3.56	281.39
38	8.9074	0.64	124.76	8.9416	0.65	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9142	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.9086	0.67	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30952F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

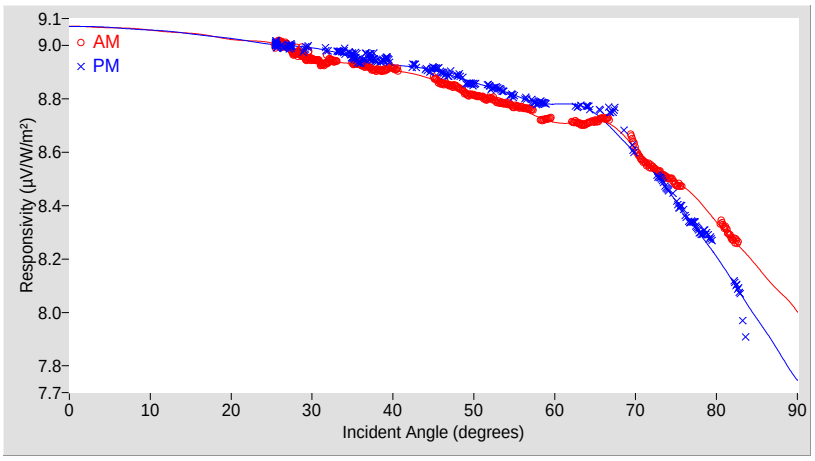


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.82	±1.82
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999997	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.0667	*	9.0666	*	9.0667	*
9-18	9.0481	*	9.0478	*	9.0479	*
18-27	9.0159	*	9.0153	*	9.0156	*
27-36	8.9493	±1.85	8.9811	±1.83	8.9652	±1.90
36-45	8.9039	±1.84	8.9283	±1.83	8.9161	±1.91
45-54	8.8271	±1.87	8.8683	±1.87	8.8477	±2.05
54-63	8.7355	±1.87	8.7915	±1.83	8.7635	±2.05
63-72	8.6717	±2.03	8.6753	±2.24	8.6735	±2.60
72-81	8.4490	±2.26	8.3630	±2.75	8.4060	±3.60
81-90	8.1551	*	7.9539	*	8.0545	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

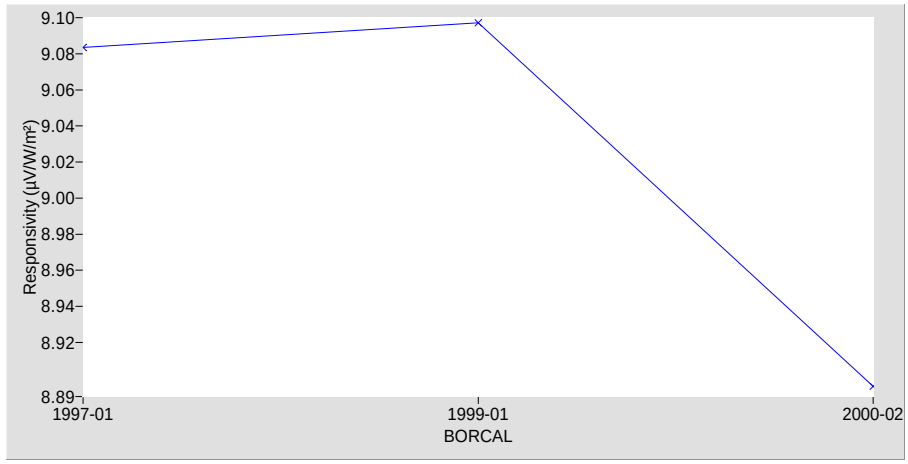
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.8956	+1.71 / -2.67 [1]
45° - 55°	8.8407	±1.97 [2]
Composite	8.9185	+2.06 / -9.97 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



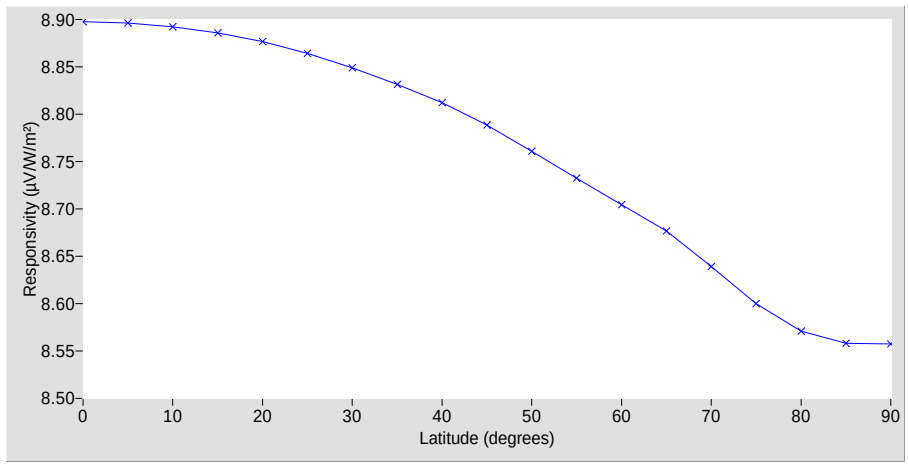
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.8976	+2.67 / -12.59
5	8.8963	+2.68 / -12.58
10	8.8923	+2.71 / -12.54
15	8.8858	+2.77 / -12.48
20	8.8767	+2.85 / -12.39
25	8.8643	+2.96 / -12.27
30	8.8491	+3.04 / -12.12
35	8.8314	+3.12 / -11.94
40	8.8120	+3.18 / -11.75
45	8.7886	+3.21 / -11.52
50	8.7609	+3.28 / -11.24
55	8.7324	+3.42 / -10.95
60	8.7044	+3.37 / -10.67
65	8.6766	+3.38 / -10.39
70	8.6392	+3.51 / -10.01
75	8.6000	+3.45 / -9.60
80	8.5708	+3.25 / -9.30
85	8.5583	+3.17 / -9.17
90	8.5575	+2.62 / -9.16

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30957F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30957F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

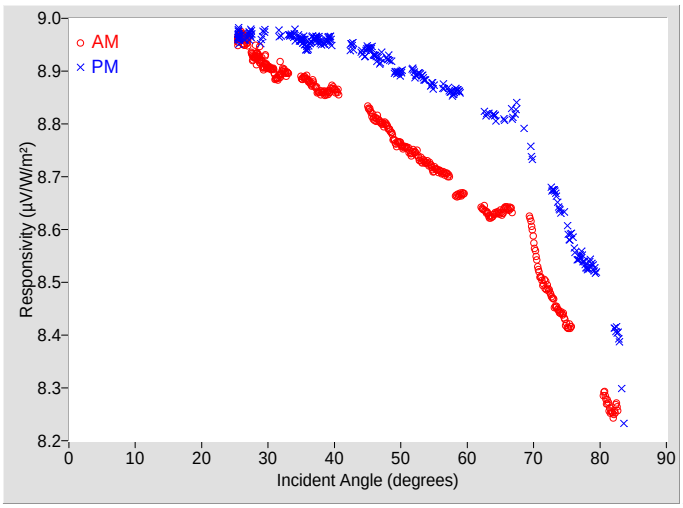


Figure 2. Responsivity vs Local Standard Time

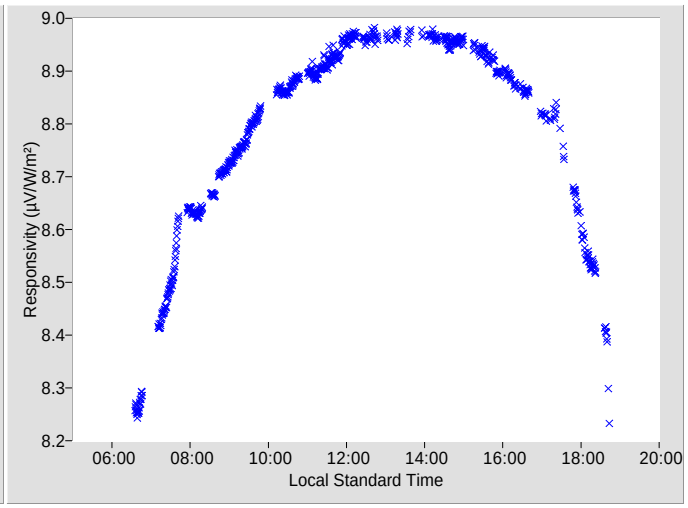


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.8867	+1.72 / -3.21	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8107	0.72	113.01	8.9294	0.70	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7945	0.74	110.63	8.9238	0.70	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7623	0.74	108.49	8.8978	0.71	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7477	0.77	106.41	8.8969	0.73	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7258	0.79	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7092	0.81	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6639	N/A	100.06	8.8591	0.82	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6411	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6284	1.02	95.30	8.8169	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6402	1.09	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5820	1.45	90.70	8.7326	N/A	272.39
26	8.9662	0.63	166.60	8.9724	N/A	196.20	72	8.4907	1.44	89.20	N/A	N/A	N/A
28	8.9282	0.63	153.49	N/A	N/A	N/A	74	8.4437	1.62	87.74	8.6371	1.54	275.37
30	8.9078	0.63	144.88	N/A	N/A	N/A	76	8.4161	N/A	86.47	8.5686	1.81	276.94
32	8.8986	0.64	138.29	8.9664	N/A	222.63	78	N/A	N/A	N/A	8.5275	2.10	278.31
34	N/A	N/A	N/A	8.9675	0.66	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8836	0.63	128.58	8.9449	0.64	238.74	82	8.2515	3.46	81.82	8.4134	3.54	281.39
38	8.8597	0.64	124.76	8.9538	0.64	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8656	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.9358	0.67	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30957F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

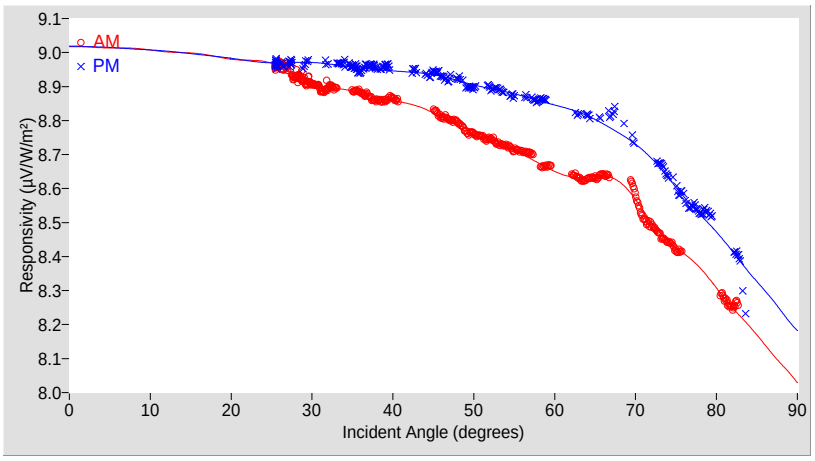


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.81	±1.81
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999997	0.9999999

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.0150	*	9.0149	*	9.0150	*
9-18	9.0008	*	9.0006	*	9.0007	*
18-27	8.9751	*	8.9770	*	8.9761	*
27-36	8.9067	±1.84	8.9663	±1.81	8.9365	±1.94
36-45	8.8563	±1.83	8.9457	±1.81	8.9010	±2.07
45-54	8.7762	±1.88	8.9102	±1.83	8.8432	±2.43
54-63	8.6741	±1.88	8.8571	±1.83	8.7656	±2.72
63-72	8.6067	±1.94	8.7696	±1.94	8.6881	±3.10
72-81	8.3995	±2.19	8.5711	±2.25	8.4853	±3.76
81-90	8.1540	*	8.3124	*	8.2332	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

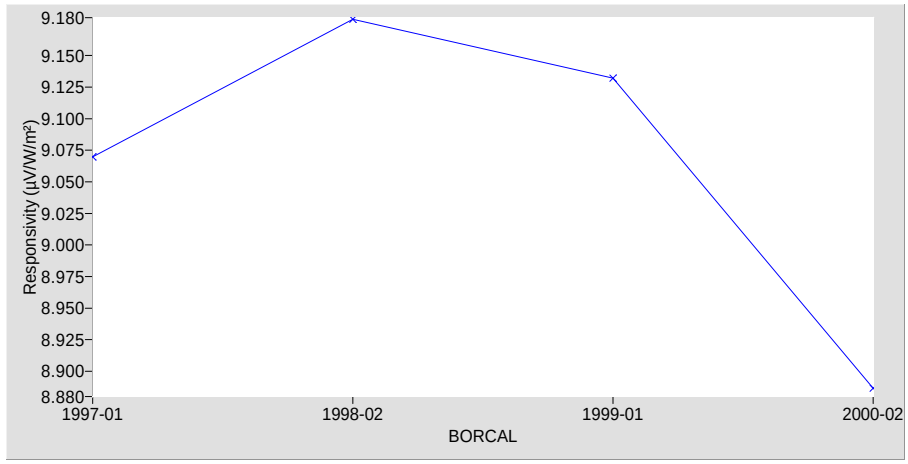
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.8867	+1.72 / -3.21 [1]
45° - 55°	8.8371	±2.20 [2]
Composite	8.8972	+1.99 / -7.93 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



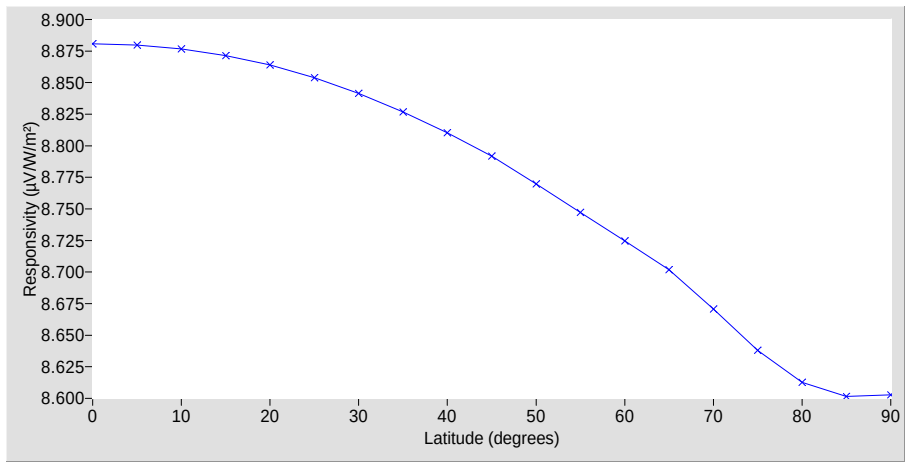
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.8807	+2.39 / -9.43
5	8.8797	+2.39 / -9.42
10	8.8766	+2.42 / -9.39
15	8.8714	+2.46 / -9.34
20	8.8640	+2.52 / -9.26
25	8.8539	+2.59 / -9.16
30	8.8414	+2.66 / -9.04
35	8.8267	+2.72 / -8.89
40	8.8103	+2.78 / -8.72
45	8.7919	+2.80 / -8.53
50	8.7698	+2.92 / -8.31
55	8.7472	+3.11 / -8.08
60	8.7247	+3.19 / -7.85
65	8.7018	+3.32 / -7.61
70	8.6708	+3.49 / -7.29
75	8.6380	+3.52 / -6.95
80	8.6126	+3.52 / -6.68
85	8.6016	+3.30 / -6.57
90	8.6027	+2.83 / -6.58

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30958F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30958F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

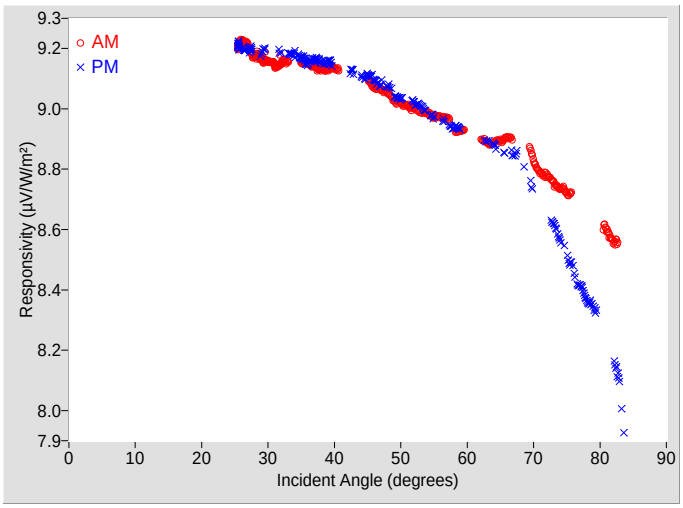


Figure 2. Responsivity vs Local Standard Time

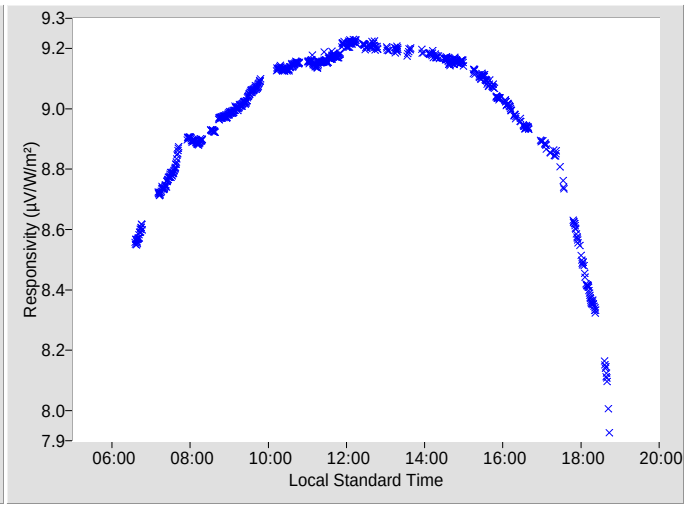


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
9.1027	+1.67 / -2.65	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0723	0.73	113.01	9.0946	0.71	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0534	0.74	110.63	9.0743	0.71	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0207	0.74	108.49	9.0343	0.71	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0044	0.77	106.41	9.0196	0.73	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9855	0.79	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9732	0.81	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9229	N/A	100.06	8.9375	0.82	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8987	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8886	1.02	95.30	8.8821	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9045	1.09	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.8319	1.37	90.70	8.7349	N/A	272.39
26	9.2211	0.64	166.60	9.2061	N/A	196.20	72	8.7782	1.43	89.20	N/A	N/A	N/A
28	9.1752	0.61	153.62	N/A	N/A	N/A	74	8.7363	1.61	87.74	8.5668	1.58	275.37
30	9.1571	0.64	144.88	N/A	N/A	N/A	76	8.7236	N/A	86.47	8.4591	1.87	276.94
32	9.1555	0.65	138.29	9.1854	N/A	222.63	78	N/A	N/A	N/A	8.3648	2.14	278.31
34	N/A	N/A	N/A	9.1805	0.66	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1508	0.63	128.58	9.1514	0.64	238.74	82	8.5598	3.45	81.82	8.1576	3.57	281.39
38	9.1300	0.64	124.76	9.1543	0.64	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1348	0.65	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	9.1073	0.67	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30958F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

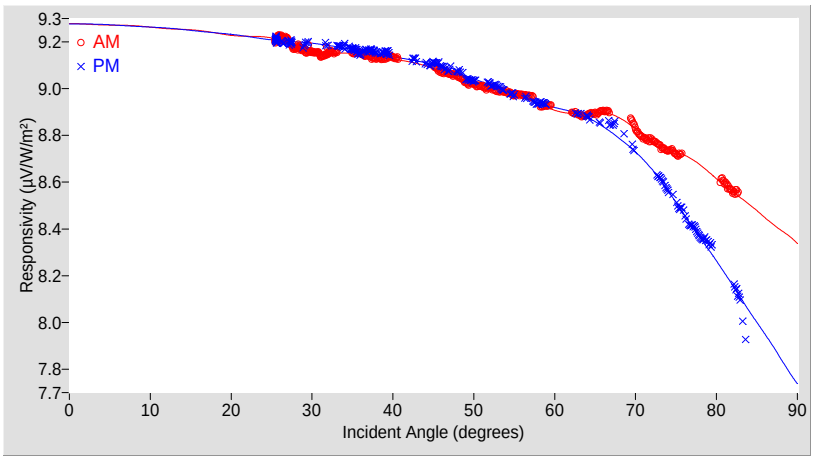


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.82	±1.82
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999997	0.9999999

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.2733	*	9.2731	*	9.2732	*
9-18	9.2548	*	9.2545	*	9.2546	*
18-27	9.2232	*	9.2216	*	9.2224	*
27-36	9.1619	±1.83	9.1869	±1.83	9.1744	±1.86
36-45	9.1241	±1.84	9.1353	±1.84	9.1297	±1.89
45-54	9.0354	±1.89	9.0518	±1.90	9.0436	±2.01
54-63	8.9340	±1.89	8.9402	±1.89	8.9371	±1.98
63-72	8.8672	±1.92	8.7990	±2.19	8.8331	±2.65
72-81	8.7008	±2.08	8.4496	±3.07	8.5752	±4.93
81-90	8.4630	*	7.9741	*	8.2186	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

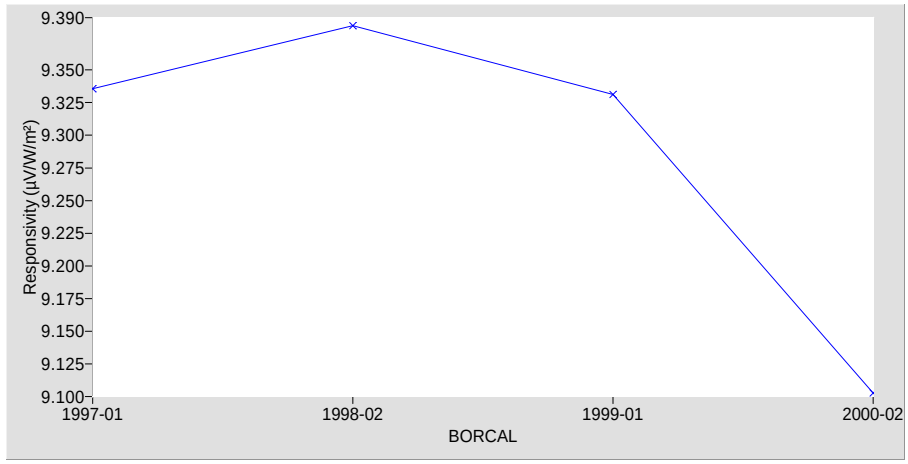
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	9.1027	+1.67 / -2.65 [1]
45° - 55°	9.0350	±1.95 [2]
Composite	9.1178	+2.09 / -11.55 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



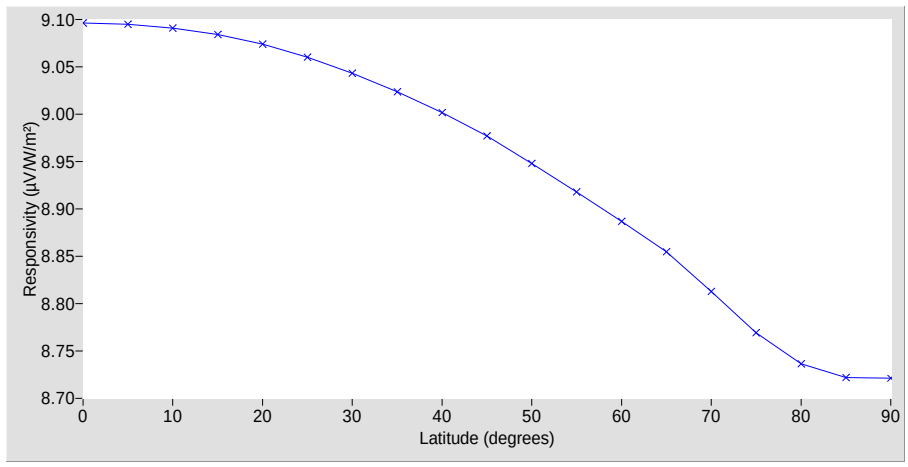
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	9.0962	+2.70 / -14.50
5	9.0949	+2.71 / -14.49
10	9.0909	+2.75 / -14.45
15	9.0841	+2.80 / -14.39
20	9.0740	+2.89 / -14.29
25	9.0601	+3.01 / -14.16
30	9.0432	+3.11 / -14.00
35	9.0235	+3.20 / -13.82
40	9.0018	+3.29 / -13.61
45	8.9771	+3.33 / -13.38
50	8.9481	+3.42 / -13.10
55	8.9178	+3.55 / -12.80
60	8.8869	+3.59 / -12.50
65	8.8549	+3.61 / -12.19
70	8.8127	+3.66 / -11.78
75	8.7691	+3.48 / -11.34
80	8.7365	+3.18 / -11.01
85	8.7219	+2.83 / -10.87
90	8.7212	+2.71 / -10.86

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 30961F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

30961F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

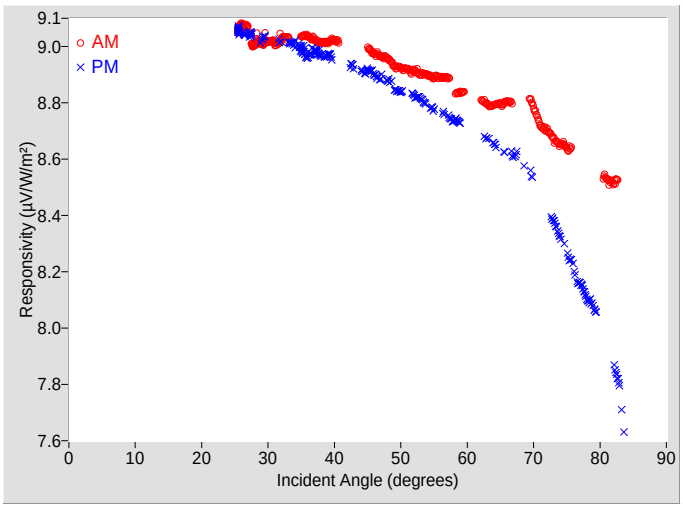


Figure 2. Responsivity vs Local Standard Time

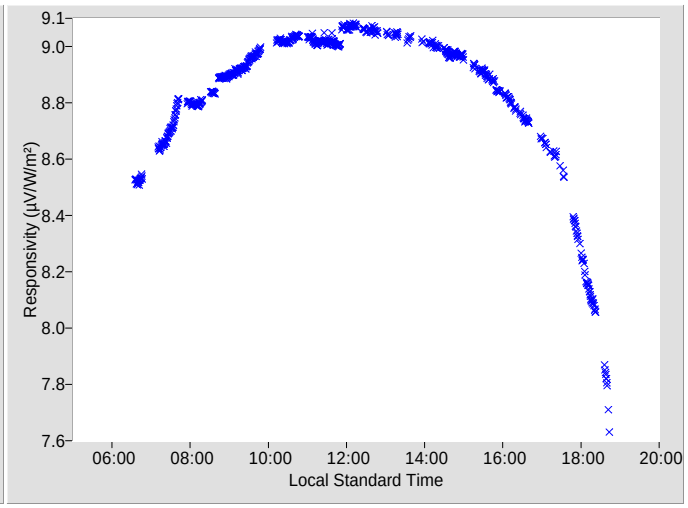


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9543	+1.71 / -3.18	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9740	0.72	113.01	8.8988	0.71	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9573	0.74	110.63	8.8785	0.71	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9252	0.73	108.49	8.8401	0.71	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9155	0.76	106.41	8.8247	0.73	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8983	0.79	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8904	0.81	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8319	N/A	100.06	8.7371	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8090	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7923	1.02	95.30	8.6552	0.96	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8041	1.09	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.7853	1.39	90.70	8.5356	N/A	272.39
26	9.0738	0.64	166.60	9.0534	N/A	196.20	72	8.7026	1.44	89.20	N/A	N/A	N/A
28	9.0110	0.65	153.62	N/A	N/A	N/A	74	8.6523	1.61	87.74	8.3257	1.60	275.37
30	9.0179	0.64	144.88	N/A	N/A	N/A	76	8.6437	N/A	86.47	8.2068	1.90	276.94
32	9.0272	0.65	138.29	9.0174	N/A	222.63	78	N/A	N/A	N/A	8.1052	2.16	278.31
34	N/A	N/A	N/A	9.0092	0.68	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0363	0.63	128.58	8.9655	0.66	238.74	82	8.5165	3.44	81.82	7.8603	3.60	281.39
38	9.0155	0.64	124.76	8.9678	0.65	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0217	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.9137	0.67	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

30961F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

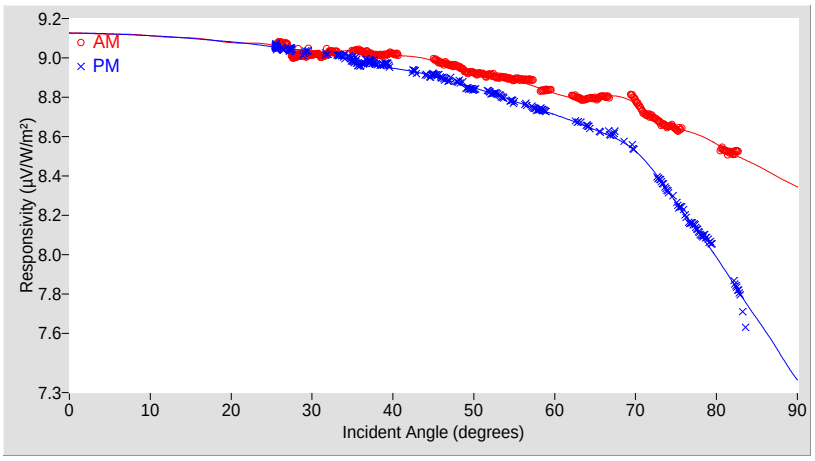


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.83	±1.83
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999994	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.1225	*	9.1223	*	9.1224	*
9-18	9.1042	*	9.1039	*	9.1040	*
18-27	9.0726	*	9.0709	*	9.0718	*
27-36	9.0266	±1.83	9.0206	±1.86	9.0236	±1.90
36-45	9.0134	±1.84	8.9461	±1.87	8.9797	±2.06
45-54	8.9410	±1.88	8.8566	±1.92	8.8988	±2.34
54-63	8.8453	±1.92	8.7353	±1.95	8.7903	±2.57
63-72	8.7874	±1.89	8.5853	±2.18	8.6863	±3.46
72-81	8.6288	±2.05	8.1976	±3.46	8.4132	±6.73
81-90	8.4407	*	7.6432	*	8.0420	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

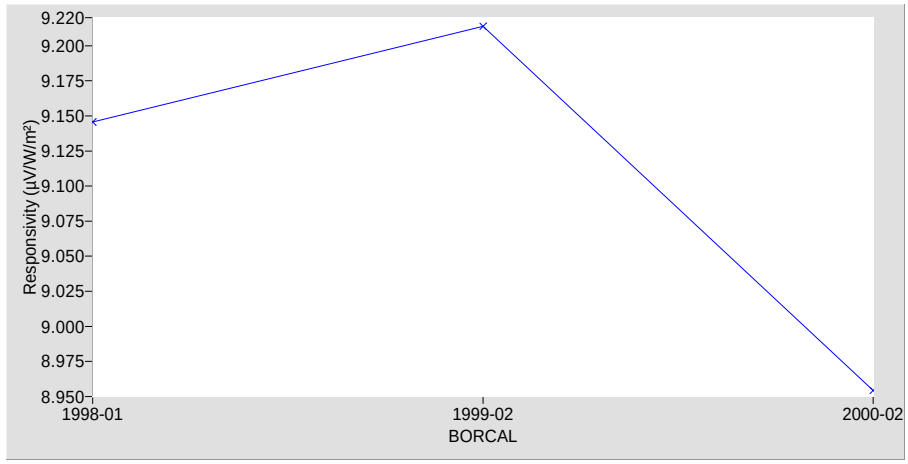
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9543	+1.71 / -3.18 [1]
45° - 55°	8.8905	±2.16 [2]
Composite	8.9676	+2.10 / -13.54 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



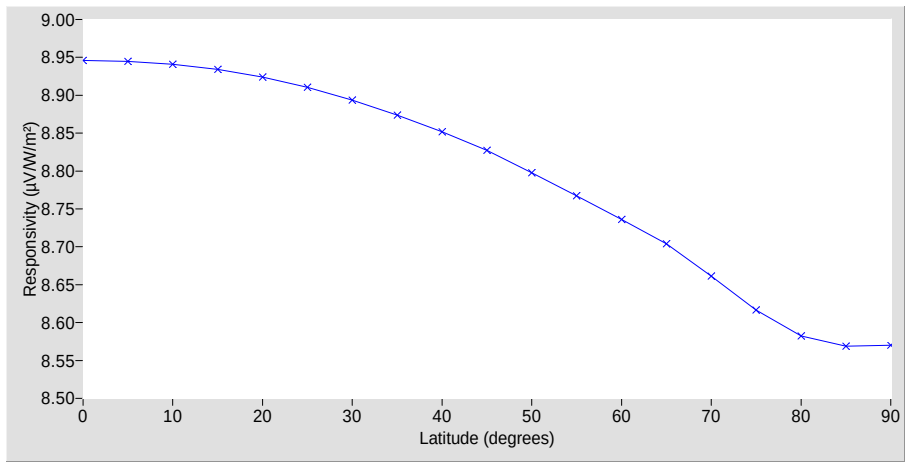
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.9461	+2.73 / -17.13
5	8.9447	+2.74 / -17.12
10	8.9409	+2.78 / -17.08
15	8.9341	+2.83 / -17.02
20	8.9241	+2.92 / -16.93
25	8.9104	+3.04 / -16.80
30	8.8937	+3.14 / -16.64
35	8.8739	+3.23 / -16.46
40	8.8517	+3.34 / -16.25
45	8.8272	+3.38 / -16.02
50	8.7979	+3.44 / -15.74
55	8.7674	+3.58 / -15.45
60	8.7359	+3.87 / -15.15
65	8.7040	+3.97 / -14.84
70	8.6613	+4.03 / -14.42
75	8.6166	+4.02 / -13.98
80	8.5824	+3.87 / -13.64
85	8.5687	+3.34 / -13.50
90	8.5702	+3.32 / -13.52

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31099F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31099F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

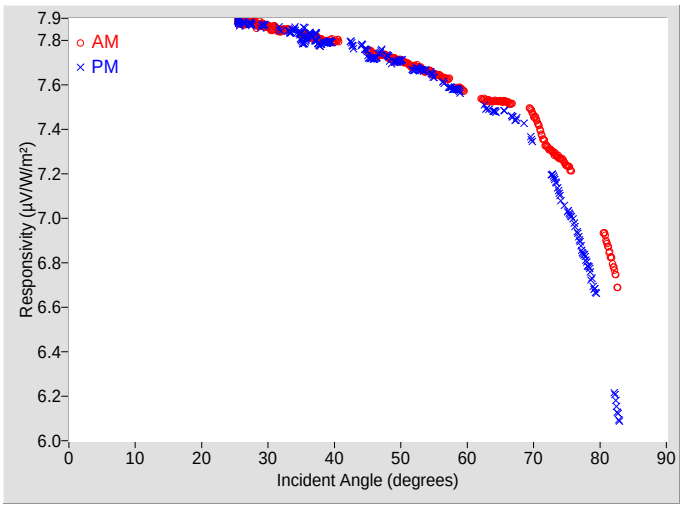


Figure 2. Responsivity vs Local Standard Time

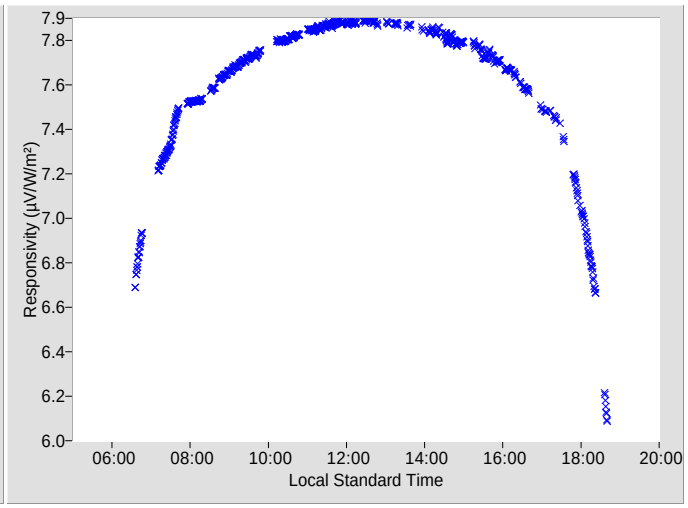


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.7475	+2.14 / -2.97	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7357	0.74	113.01	7.7189	0.72	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7261	0.73	110.63	7.7265	0.81	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7131	0.75	108.49	7.7105	0.72	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6846	0.77	106.41	7.6677	0.74	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6638	0.82	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6388	0.83	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5856	N/A	100.06	7.5805	0.84	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5379	0.98	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5276	1.03	95.30	7.4824	0.96	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5230	1.11	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.4658	1.45	90.70	7.3457	N/A	272.39
26	7.8823	0.64	166.71	7.8870	N/A	196.20	72	7.3240	1.59	89.20	N/A	N/A	N/A
28	7.8810	0.65	153.49	N/A	N/A	N/A	74	7.2729	1.68	87.74	7.1049	1.78	275.37
30	7.8642	0.64	144.88	N/A	N/A	N/A	76	7.2129	N/A	86.47	6.9797	2.04	276.94
32	7.8454	0.63	138.29	7.8421	N/A	222.63	78	N/A	N/A	N/A	6.8024	2.61	278.31
34	N/A	N/A	N/A	7.8514	0.74	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8206	0.64	128.58	7.8227	0.79	237.88	82	6.7830	3.84	81.82	6.2115	3.86	281.39
38	7.8058	0.66	124.76	7.7792	0.74	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7969	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.7800	0.70	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31099F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

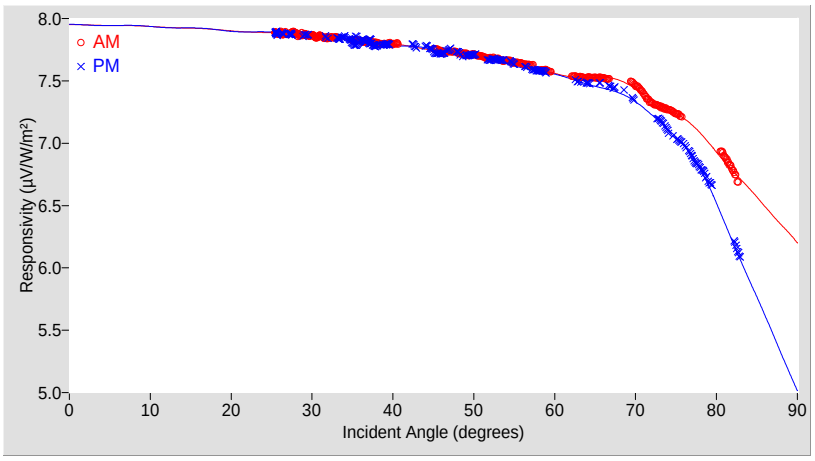


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±2.03	±2.03
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999991	0.9999992

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	7.9459	*	7.9460	*	7.9460	*
9-18	7.9269	*	7.9271	*	7.9270	*
18-27	7.8942	*	7.8948	*	7.8945	*
27-36	7.8534	±2.06	7.8536	±2.06	7.8535	±2.10
36-45	7.7898	±2.08	7.7834	±2.06	7.7866	±2.12
45-54	7.7128	±2.09	7.7059	±2.14	7.7094	±2.24
54-63	7.5923	±2.21	7.5751	±2.22	7.5837	±2.50
63-72	7.4887	±2.29	7.4017	±2.59	7.4452	±3.45
72-81	7.1562	±3.80	6.9112	±6.03	7.0337	±9.73
81-90	6.5283	*	5.6881	*	6.1082	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

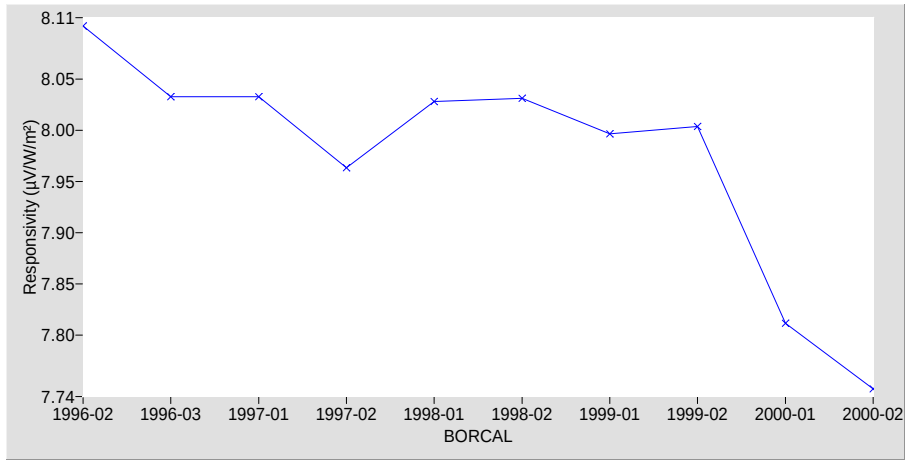
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.7475	+2.14 / -2.97 [1]
45° - 55°	7.6997	±2.20 [2]
Composite	7.7670	+2.56 / -21.16 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



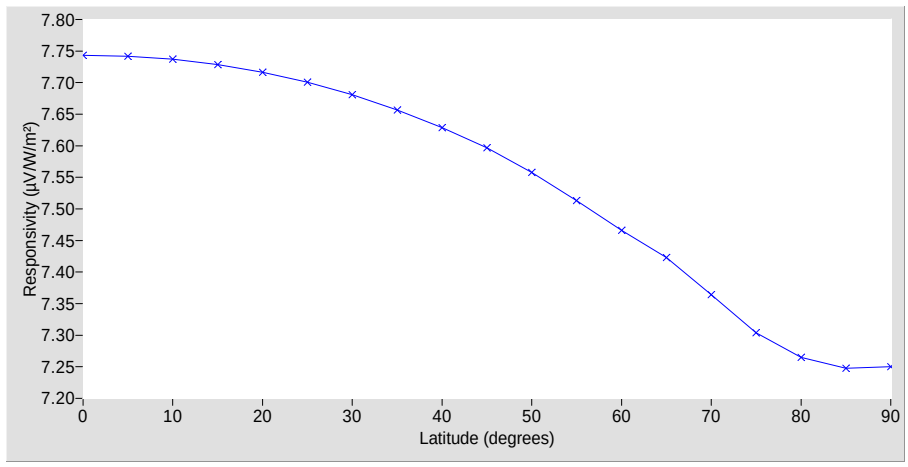
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	7.7432	+3.39 / -33.39
5	7.7419	+3.40 / -33.38
10	7.7370	+3.45 / -33.34
15	7.7283	+3.55 / -33.27
20	7.7164	+3.68 / -33.16
25	7.7005	+3.84 / -33.03
30	7.6807	+3.99 / -32.85
35	7.6565	+4.14 / -32.64
40	7.6287	+4.36 / -32.40
45	7.5970	+4.42 / -32.11
50	7.5578	+4.78 / -31.76
55	7.5132	+5.01 / -31.36
60	7.4660	+5.13 / -30.92
65	7.4229	+5.33 / -30.52
70	7.3644	+5.49 / -29.97
75	7.3040	+5.82 / -29.39
80	7.2648	+5.43 / -29.01
85	7.2477	+4.56 / -28.85
90	7.2504	+4.35 / -28.87

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31100F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31100F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

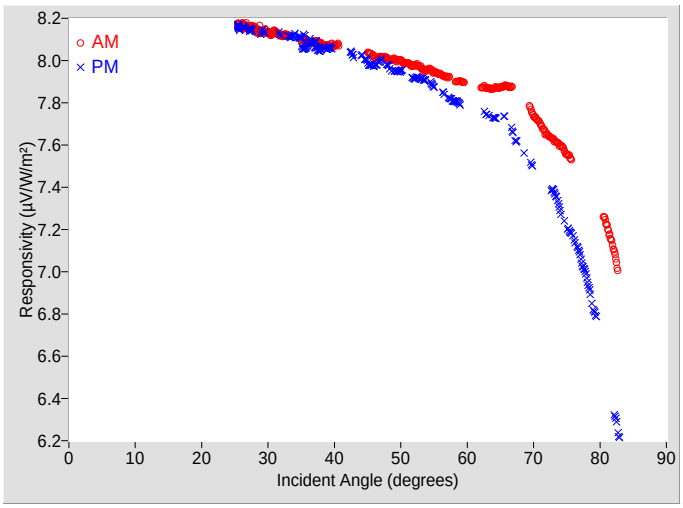


Figure 2. Responsivity vs Local Standard Time

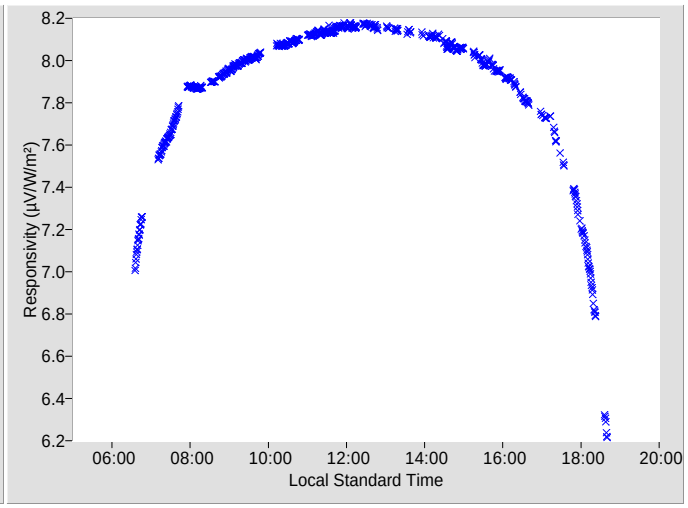


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0146	+2.10 / -3.42	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0184	0.73	113.01	7.9778	0.70	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0103	0.73	110.63	7.9752	0.79	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0013	0.75	108.49	7.9514	0.72	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9783	0.77	106.41	7.9157	0.73	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9571	0.81	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9351	0.83	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9007	N/A	100.06	7.8079	0.85	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8730	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8690	1.02	95.30	7.7292	0.96	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8789	1.10	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7414	1.40	90.70	7.5019	N/A	272.39
26	8.1628	0.64	166.60	8.1632	N/A	196.20	72	7.6504	1.50	89.20	N/A	N/A	N/A
28	8.1515	0.64	153.49	N/A	N/A	N/A	74	7.6006	1.68	87.74	7.2971	1.80	275.37
30	8.1322	0.63	144.88	N/A	N/A	N/A	76	7.5302	N/A	86.47	7.1521	1.97	276.94
32	8.1196	0.62	138.37	8.1173	N/A	222.63	78	N/A	N/A	N/A	6.9690	2.84	278.31
34	N/A	N/A	N/A	8.1176	0.66	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0934	0.64	128.58	8.0800	0.77	237.88	82	7.1098	3.84	81.82	6.3186	3.80	281.39
38	8.0803	0.66	124.76	8.0474	0.71	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0708	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0252	0.69	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31100F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

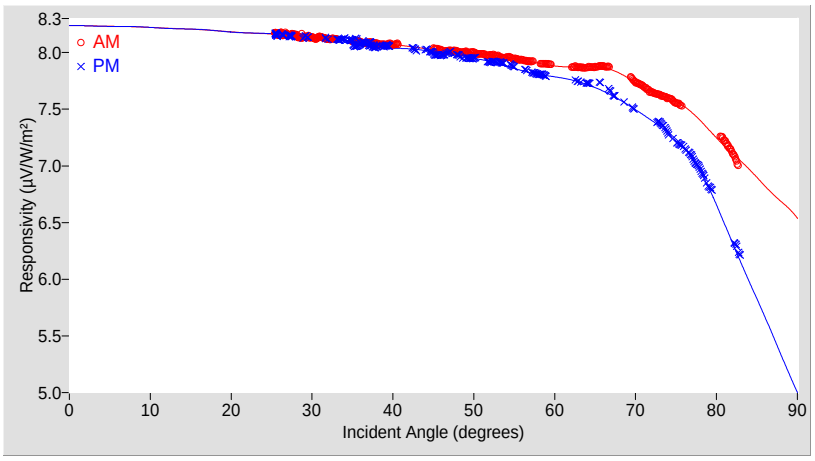


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±2.03	±2.03
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999998	0.9999995

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2327	*	8.2328	*	8.2327	*
9-18	8.2110	*	8.2111	*	8.2111	*
18-27	8.1739	*	8.1740	*	8.1739	*
27-36	8.1256	±2.06	8.1259	±2.07	8.1257	±2.11
36-45	8.0654	±2.06	8.0416	±2.07	8.0535	±2.15
45-54	8.0000	±2.06	7.9533	±2.15	7.9766	±2.37
54-63	7.9067	±2.10	7.8102	±2.19	7.8585	±2.75
63-72	7.8132	±2.41	7.6022	±2.91	7.7077	±4.74
72-81	7.4770	±3.61	7.0796	±6.18	7.2783	±11.18
81-90	6.8616	*	5.7427	*	6.3021	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

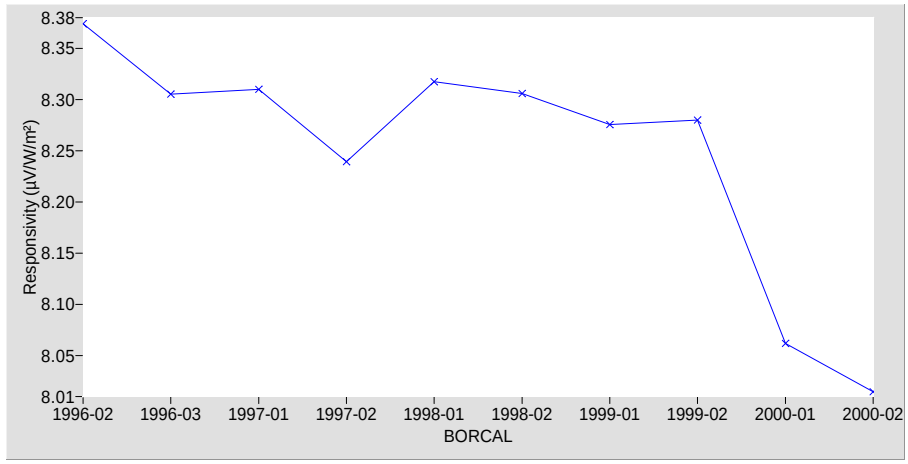
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0146	+2.10 / -3.42 [1]
45° - 55°	7.9673	±2.28 [2]
Composite	8.0411	+2.53 / -22.59 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



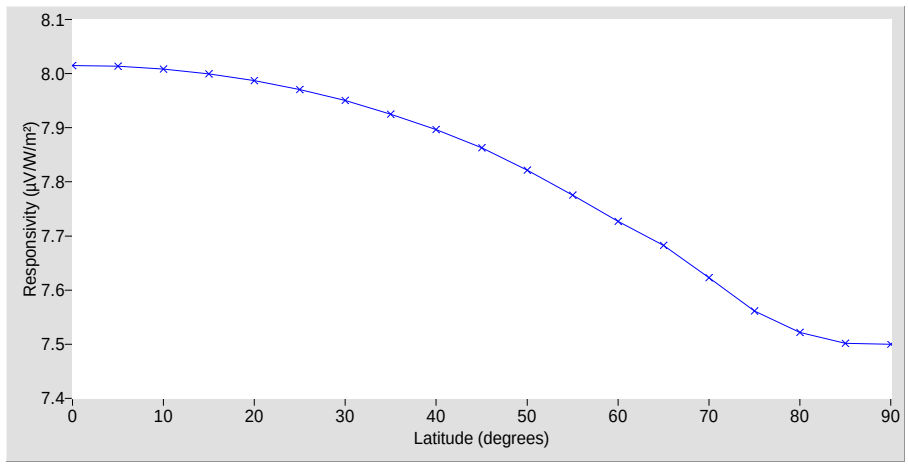
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0151	+3.45 / -35.65
5	8.0137	+3.47 / -35.63
10	8.0085	+3.52 / -35.59
15	7.9995	+3.61 / -35.52
20	7.9871	+3.75 / -35.42
25	7.9706	+3.92 / -35.29
30	7.9502	+4.07 / -35.12
35	7.9252	+4.21 / -34.92
40	7.8968	+4.39 / -34.68
45	7.8627	+4.48 / -34.40
50	7.8217	+4.78 / -34.06
55	7.7755	+4.99 / -33.66
60	7.7269	+5.15 / -33.25
65	7.6827	+5.34 / -32.86
70	7.6230	+5.60 / -32.34
75	7.5613	+6.02 / -31.79
80	7.5215	+5.83 / -31.43
85	7.5018	+5.40 / -31.25
90	7.4998	+5.32 / -31.23

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:**	31101F3
Calibration Date:	8/24/2000	**Due Date:**	8/24/2001
Customer:	Calibration System	**Calibration Site Parameters:**	see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31101F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

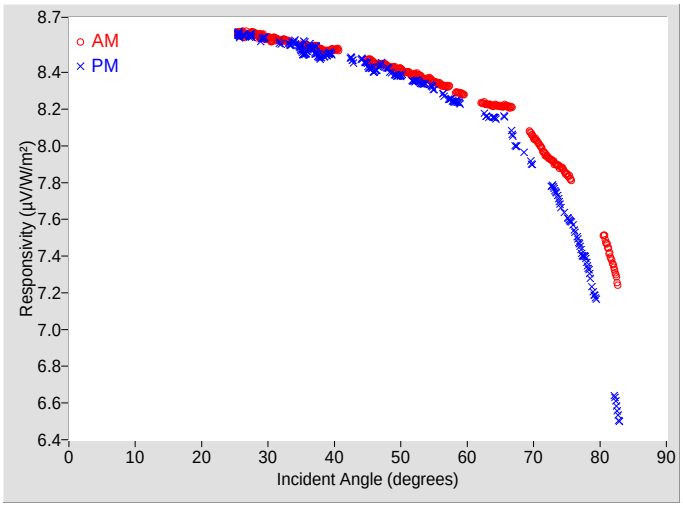


Figure 2. Responsivity vs Local Standard Time

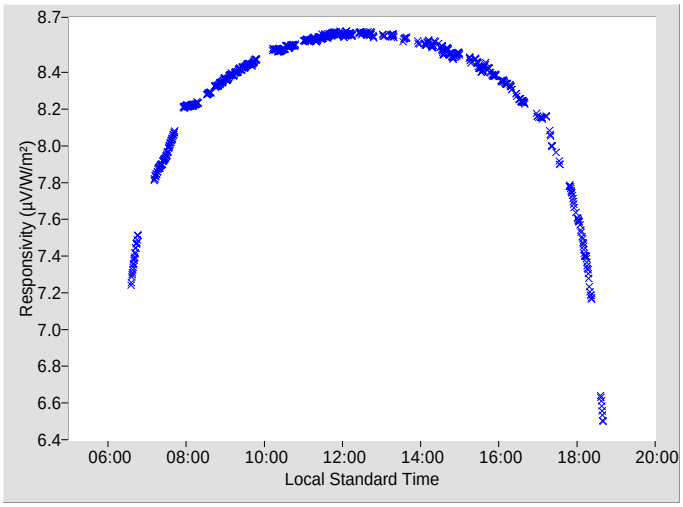


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4546	+2.18 / -3.31	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4515	0.73	113.01	8.4061	0.72	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4352	0.73	110.63	8.4183	0.77	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4192	0.75	108.49	8.3842	0.71	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3880	0.77	106.41	8.3519	0.74	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3636	0.81	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3342	0.82	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2893	N/A	100.06	8.2417	0.84	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2348	0.97	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2191	1.02	95.30	8.1543	0.95	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2152	1.10	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0478	1.38	90.70	7.8987	N/A	272.39
26	8.6096	0.64	166.60	8.6084	N/A	196.20	72	7.9434	1.52	89.20	N/A	N/A	N/A
28	8.6096	0.62	153.67	N/A	N/A	N/A	74	7.8864	1.67	87.74	7.6885	1.76	275.37
30	8.5891	0.64	144.88	N/A	N/A	N/A	76	7.8110	N/A	86.47	7.5462	2.03	276.94
32	8.5731	0.61	138.37	8.5542	N/A	222.63	78	N/A	N/A	N/A	7.3655	2.71	278.31
34	N/A	N/A	N/A	8.5659	0.73	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5441	0.64	128.58	8.5258	0.77	237.88	82	7.3439	3.83	81.82	6.6351	3.82	281.39
38	8.5263	0.67	124.76	8.4780	0.76	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5240	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4730	0.68	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31101F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

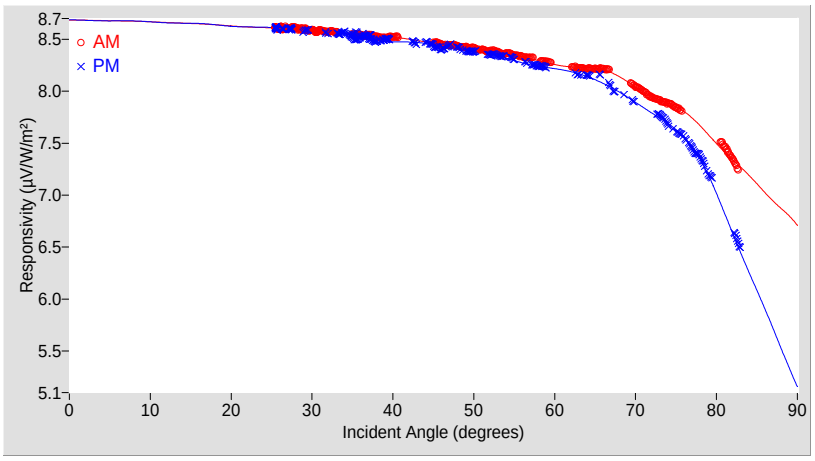


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±2.02	±2.02
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999998	0.9999990

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.6798	*	8.6799	*	8.6798	*
9-18	8.6577	*	8.6580	*	8.6578	*
18-27	8.6206	*	8.6201	*	8.6203	*
27-36	8.5797	±2.05	8.5677	±2.05	8.5737	±2.12
36-45	8.5129	±2.06	8.4806	±2.06	8.4967	±2.15
45-54	8.4208	±2.09	8.3898	±2.13	8.4053	±2.32
54-63	8.2919	±2.17	8.2428	±2.19	8.2673	±2.56
63-72	8.1397	±2.57	8.0122	±2.98	8.0760	±4.25
72-81	7.7512	±3.78	7.4665	±6.15	7.6088	±10.27
81-90	7.0681	*	5.9882	*	6.5281	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

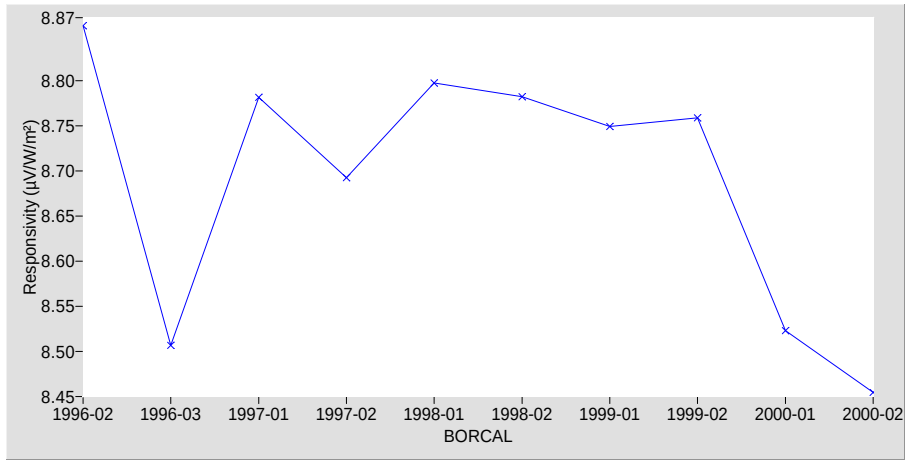
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4546	+2.18 / -3.31 [1]
45° - 55°	8.3947	±2.25 [2]
Composite	8.4713	+2.60 / -22.92 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



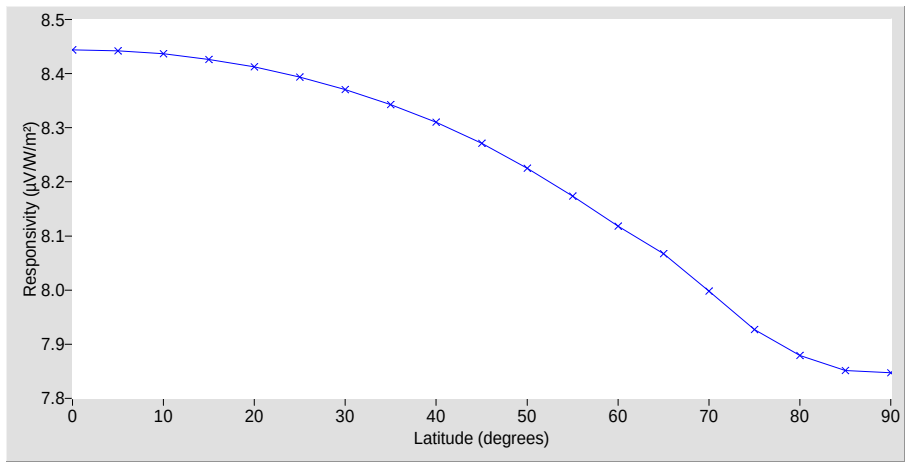
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.4436	+3.52 / -36.86
5	8.4421	+3.53 / -36.85
10	8.4364	+3.59 / -36.81
15	8.4264	+3.69 / -36.73
20	8.4125	+3.84 / -36.63
25	8.3939	+4.02 / -36.49
30	8.3707	+4.19 / -36.31
35	8.3425	+4.36 / -36.09
40	8.3100	+4.59 / -35.85
45	8.2712	+4.71 / -35.54
50	8.2252	+5.09 / -35.18
55	8.1735	+5.42 / -34.77
60	8.1183	+5.59 / -34.33
65	8.0673	+5.87 / -33.92
70	7.9982	+6.04 / -33.35
75	7.9271	+6.34 / -32.75
80	7.8790	+6.09 / -32.34
85	7.8515	+5.38 / -32.10
90	7.8470	+4.99 / -32.06

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31120E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31120E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

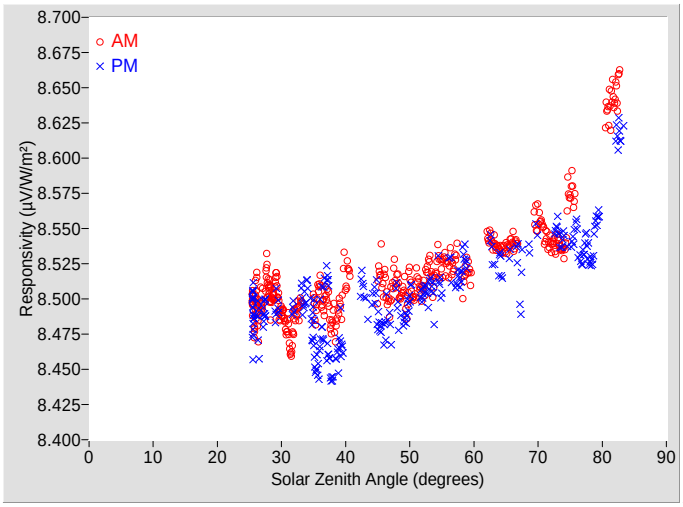


Figure 2. Responsivity vs Local Standard Time

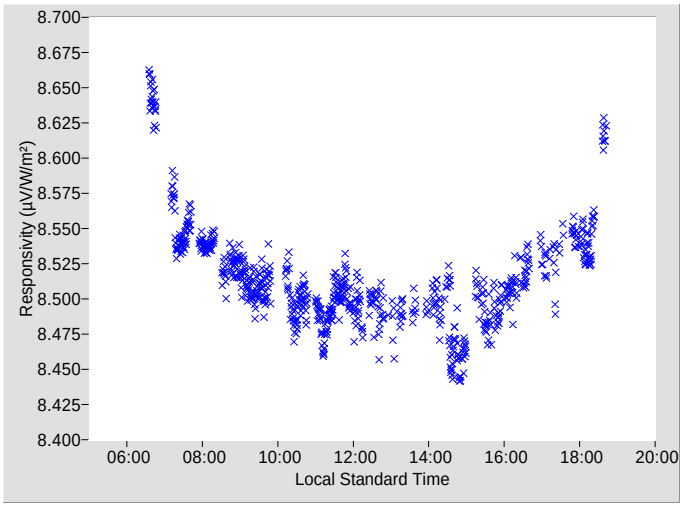


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.5025	+0.87 / -1.15	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5111	0.53	112.98	8.4759	0.48	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5130	0.47	110.72	8.4976	0.50	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5129	0.48	108.46	8.5015	0.46	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5075	0.47	106.43	8.5035	0.44	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5172	0.49	104.46	8.4818	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5233	0.45	102.63	8.5291	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5003	N/A	100.03	8.5186	0.47	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5440	0.45	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5368	0.45	95.32	8.5255	0.45	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5408	0.46	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5556	0.49	90.67	8.5452	N/A	272.46
26	8.4948	0.52	166.57	8.4911	0.54	192.79	72	8.5389	0.47	89.17	N/A	N/A	N/A
28	8.5100	0.51	153.70	N/A	N/A	N/A	74	8.5350	0.58	87.71	8.5429	0.48	275.35
30	8.4908	0.50	144.94	N/A	N/A	N/A	76	8.5747	N/A	86.44	8.5475	0.51	276.91
32	8.4838	0.49	138.30	8.4945	0.44	222.24	78	N/A	N/A	N/A	8.5287	0.52	278.33
34	N/A	N/A	N/A	8.5079	0.50	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5075	0.48	128.63	8.4734	0.60	237.13	82	8.6436	0.64	81.83	8.6179	0.58	281.36
38	8.4843	0.48	124.80	8.4431	0.65	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5166	0.51	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4999	0.47	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31120E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

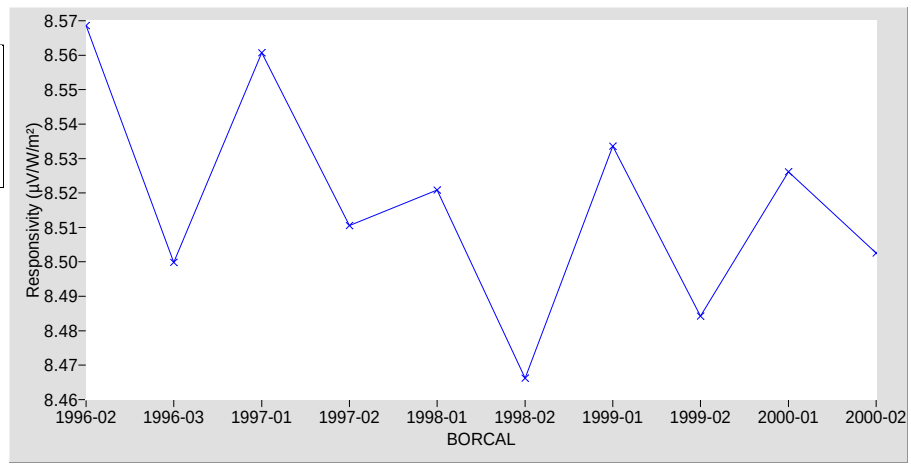
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5025	+0.87 / -1.15 †
Average	8.5185	+2.11 / -1.53 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31121E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

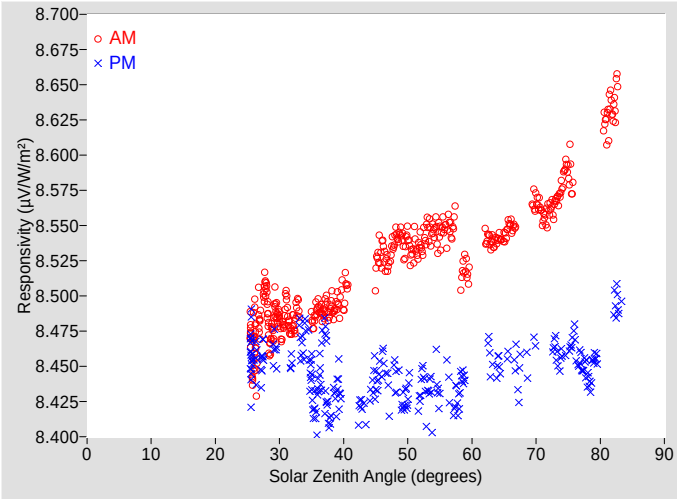


Figure 2. Responsivity vs Local Standard Time

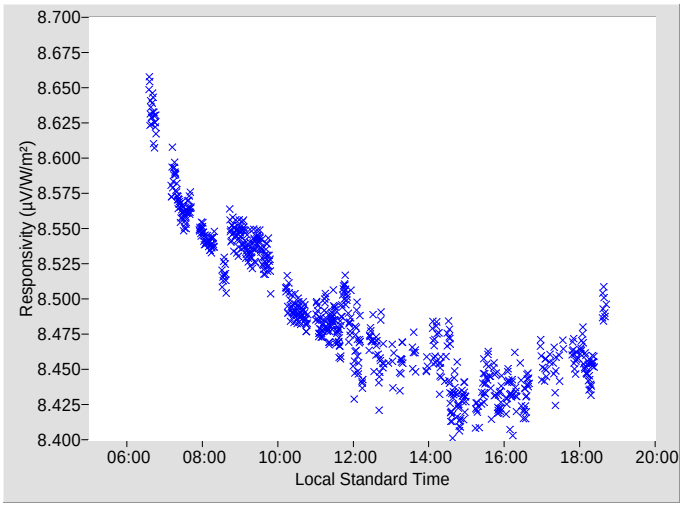


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4807	+1.41 / -1.37	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5315	0.46	112.98	8.4545	0.47	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5399	0.46	110.72	8.4429	0.49	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5416	0.46	108.46	8.4312	0.46	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5366	0.46	106.43	8.4345	0.50	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5461	0.46	104.46	8.4030	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5459	0.46	102.63	8.4544	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5041	N/A	100.03	8.4277	0.48	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5407	0.45	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5408	0.45	95.32	8.4512	0.45	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5502	0.46	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5657	0.48	90.67	8.4646	N/A	272.46
26	8.4646	0.63	166.57	8.4587	0.60	192.79	72	8.5600	0.48	89.17	N/A	N/A	N/A
28	8.4992	0.55	153.70	N/A	N/A	N/A	74	8.5778	0.51	87.71	8.4556	0.48	275.35
30	8.4804	0.49	144.94	N/A	N/A	N/A	76	8.5807	N/A	86.44	8.4695	0.50	276.91
32	8.4790	0.47	138.30	8.4531	0.44	222.24	78	N/A	N/A	N/A	8.4426	0.51	278.33
34	N/A	N/A	N/A	8.4736	0.53	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4913	0.45	128.63	8.4324	0.62	237.13	82	8.6328	0.65	81.83	8.4953	0.59	281.36
38	8.4923	0.45	124.80	8.4110	0.63	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5006	0.47	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4295	0.52	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31121E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

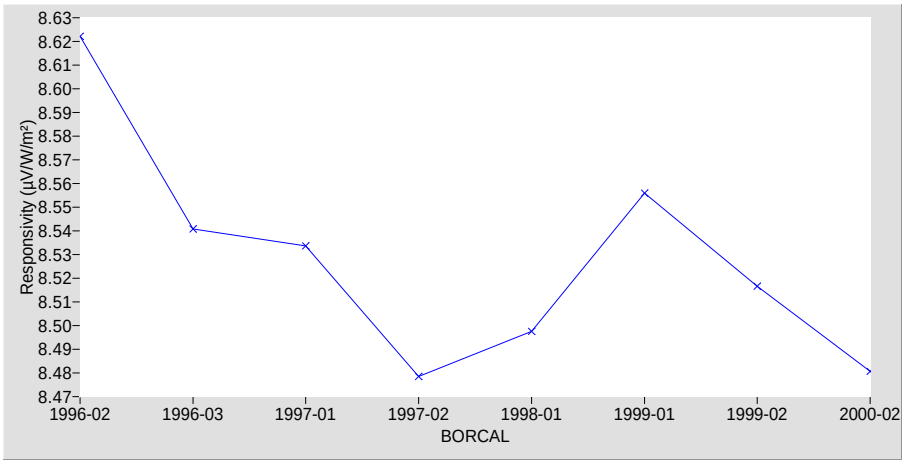
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4807	+1.41 / -1.37 †
Average	8.4910	+2.34 / -1.57 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 31122E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31122E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

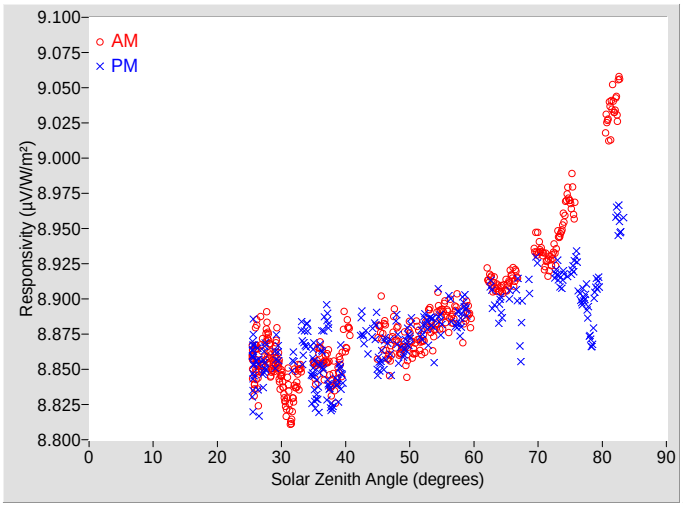


Figure 2. Responsivity vs Local Standard Time

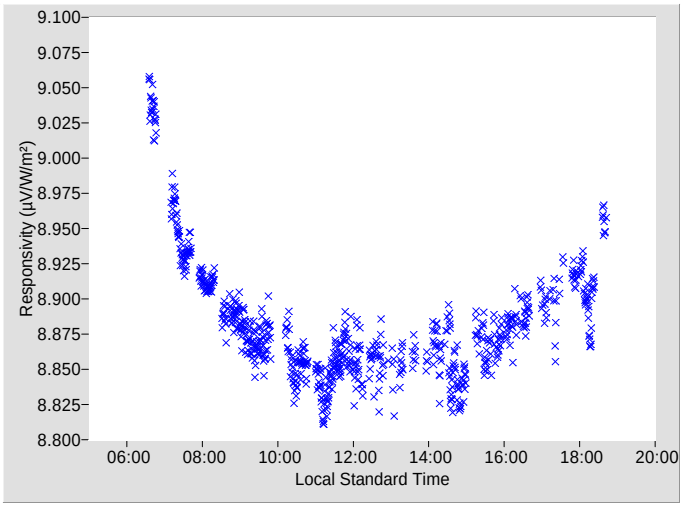


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.8682	+0.87 / -0.98	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8752	0.54	112.98	8.8624	0.46	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8727	0.47	110.72	8.8740	0.49	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8740	0.49	108.46	8.8759	0.46	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8691	0.47	106.43	8.8786	0.45	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8807	0.49	104.46	8.8547	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8868	0.45	102.63	8.9023	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8690	N/A	100.03	8.8856	0.46	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9162	0.45	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9077	0.45	95.32	8.8942	0.45	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9160	0.46	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.9367	0.48	90.67	8.9255	N/A	272.46
26	8.8557	0.56	166.57	8.8583	0.58	192.79	72	8.9270	0.48	89.17	N/A	N/A	N/A
28	8.8691	0.50	153.70	N/A	N/A	N/A	74	8.9576	0.51	87.71	8.9146	0.47	275.35
30	8.8427	0.56	144.94	N/A	N/A	N/A	76	8.9687	N/A	86.44	8.9240	0.51	276.91
32	8.8372	0.49	138.30	8.8580	0.44	222.24	78	N/A	N/A	N/A	8.8776	0.54	278.33
34	N/A	N/A	N/A	8.8770	0.54	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8614	0.46	128.63	8.8525	0.58	237.13	82	9.0367	0.63	81.83	8.9615	0.57	281.36
38	8.8409	0.48	124.80	8.8231	0.60	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8738	0.50	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.8760	0.49	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31122E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

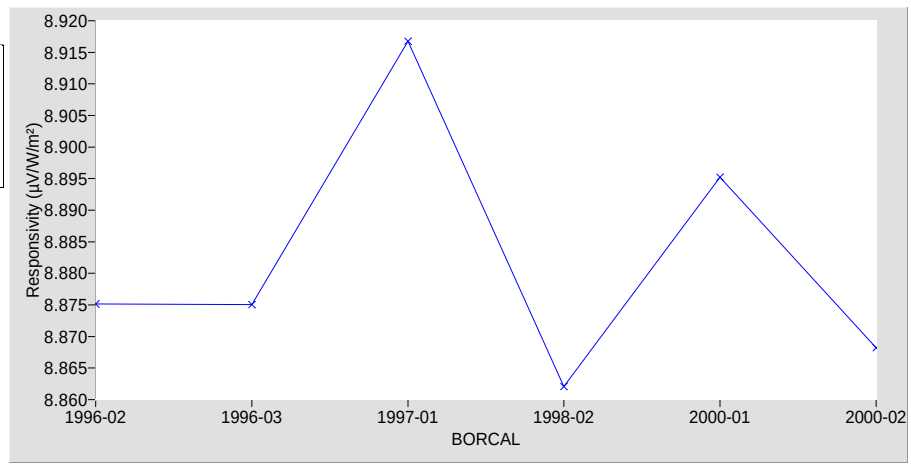
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.8682	+0.87 / -0.98 †
Average	8.8899	+2.29 / -1.35 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 31146F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31146F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

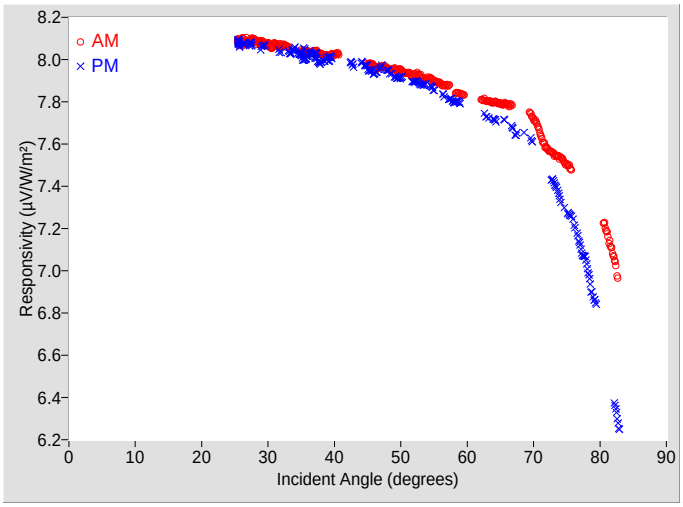


Figure 2. Responsivity vs Local Standard Time

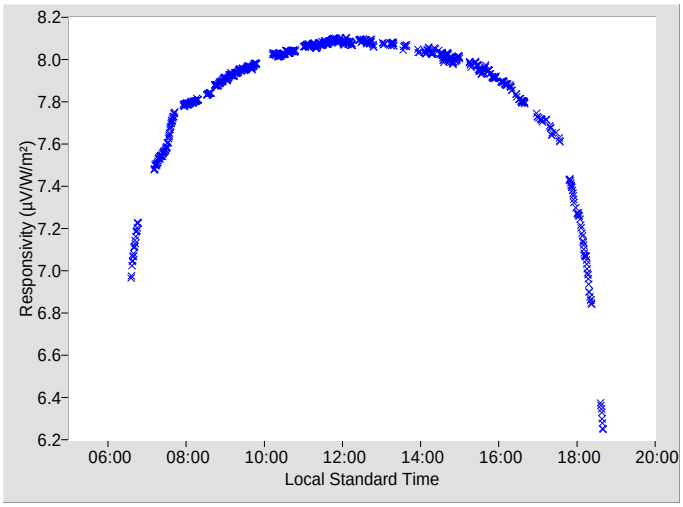


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.9699	+2.00 / -2.88	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9678	0.73	113.01	7.9359	0.71	252.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9575	0.73	110.63	7.9459	0.75	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9521	0.75	108.49	7.9160	0.72	256.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9276	0.77	106.41	7.8943	0.74	258.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9093	0.81	104.44	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8851	0.82	102.54	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8410	N/A	100.06	7.8000	0.83	263.38
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8101	0.98	96.78	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7979	1.03	95.30	7.7162	0.96	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7878	1.10	93.71	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7195	1.44	90.70	7.6104	N/A	272.39
26	8.0829	0.66	166.60	8.0808	N/A	196.20	72	7.5794	1.54	89.20	N/A	N/A	N/A
28	8.0912	0.62	153.67	N/A	N/A	N/A	74	7.5376	1.65	87.74	7.3456	1.74	275.37
30	8.0743	0.64	144.88	N/A	N/A	N/A	76	7.4769	N/A	86.47	7.2207	2.06	276.94
32	8.0651	0.62	138.29	8.0333	N/A	222.63	78	N/A	N/A	N/A	7.0298	2.76	278.31
34	N/A	N/A	N/A	8.0486	0.69	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0381	0.63	128.58	8.0228	0.73	237.88	82	7.0706	3.86	81.82	6.3682	3.83	281.39
38	8.0274	0.66	124.76	7.9839	0.72	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0243	0.66	121.41	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.9862	0.68	250.07	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31146F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

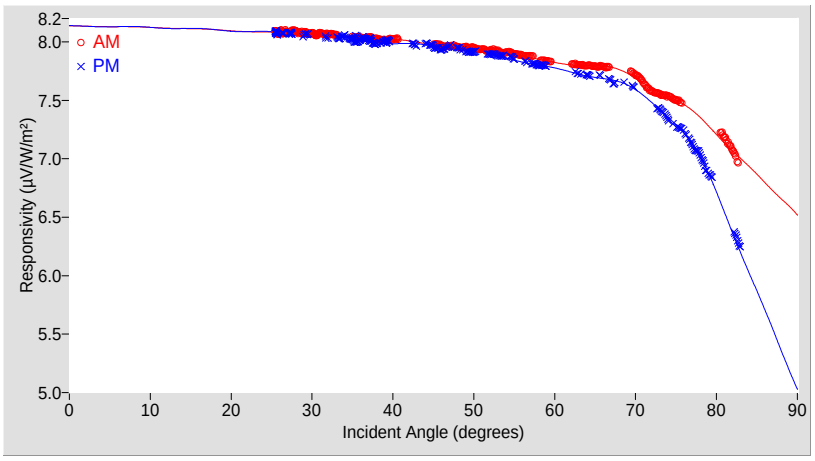


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±2.04	±2.04
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999992	0.9999991

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.1321	*	8.1322	*	8.1321	*
9-18	8.1165	*	8.1167	*	8.1166	*
18-27	8.0905	*	8.0897	*	8.0901	*
27-36	8.0677	±2.06	8.0475	±2.06	8.0576	±2.11
36-45	8.0157	±2.07	7.9887	±2.06	8.0022	±2.12
45-54	7.9496	±2.08	7.9224	±2.12	7.9360	±2.25
54-63	7.8494	±2.15	7.7986	±2.20	7.8240	±2.57
63-72	7.7507	±2.32	7.6505	±2.47	7.7006	±3.43
72-81	7.4238	±3.57	7.1419	±6.30	7.2829	±10.21
81-90	6.8299	*	5.7816	*	6.3058	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

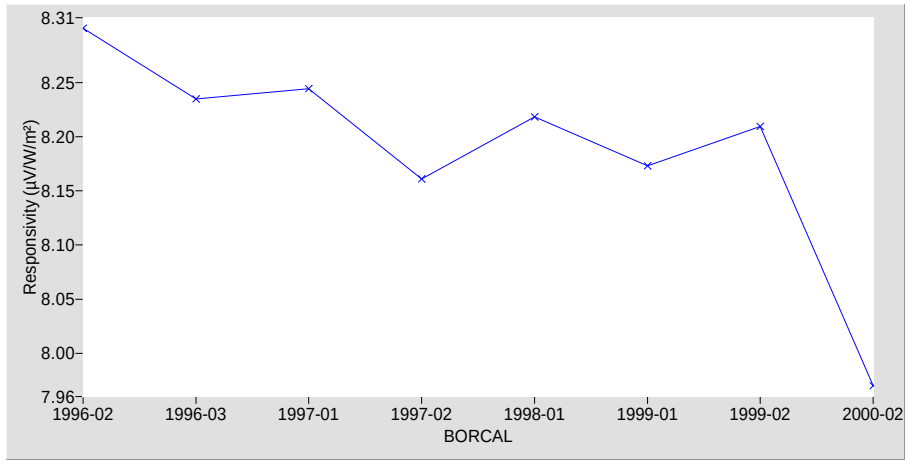
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.9699	+2.00 / -2.88 [1]
45° - 55°	7.9274	±2.20 [2]
Composite	7.9763	+2.46 / -21.40 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



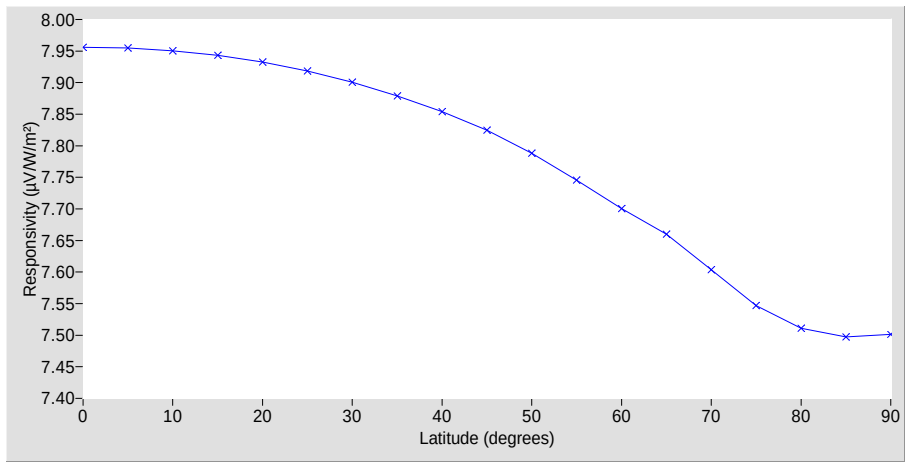
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	7.9559	+3.07 / -34.83
5	7.9548	+3.08 / -34.82
10	7.9506	+3.12 / -34.78
15	7.9430	+3.20 / -34.72
20	7.9325	+3.30 / -34.64
25	7.9185	+3.44 / -34.52
30	7.9008	+3.57 / -34.37
35	7.8790	+3.68 / -34.19
40	7.8540	+3.90 / -33.98
45	7.8248	+3.96 / -33.74
50	7.7881	+4.33 / -33.43
55	7.7457	+4.69 / -33.06
60	7.7005	+4.81 / -32.67
65	7.6598	+5.09 / -32.31
70	7.6040	+5.19 / -31.82
75	7.5468	+5.64 / -31.30
80	7.5112	+5.30 / -30.97
85	7.4974	+4.67 / -30.85
90	7.5013	+4.41 / -30.88

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31147F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31147F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

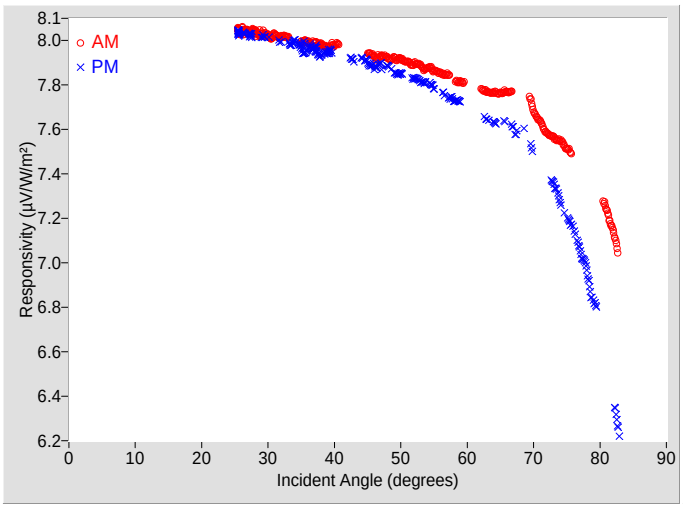


Figure 2. Responsivity vs Local Standard Time

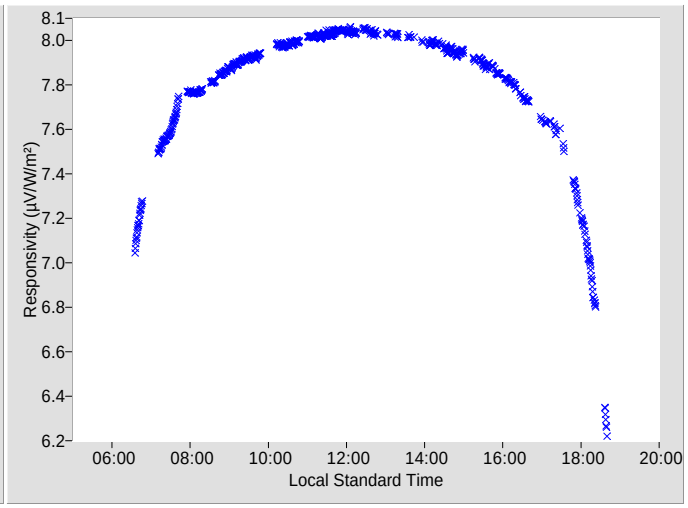


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.9224	+2.08 / -3.17	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9279	0.73	113.02	7.8799	0.71	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9227	0.73	110.64	7.8856	0.72	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9184	0.75	108.50	7.8516	0.72	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8954	0.77	106.42	7.8296	0.75	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8761	0.81	104.45	7.8146	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8526	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8155	N/A	100.07	7.7293	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7823	0.98	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7672	1.03	95.31	7.6323	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7686	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.6829	1.47	90.66	7.5016	N/A	272.40
26	8.0406	0.65	166.63	8.0360	N/A	196.23	72	7.5848	1.50	89.21	N/A	N/A	N/A
28	8.0410	0.63	153.36	N/A	N/A	N/A	74	7.5504	1.66	87.70	7.2792	1.78	275.38
30	8.0217	0.65	144.90	8.0149	N/A	216.85	76	N/A	N/A	N/A	7.1452	2.03	276.95
32	8.0166	0.61	138.39	7.9929	0.65	222.24	78	N/A	N/A	N/A	6.9644	2.67	278.32
34	N/A	N/A	N/A	7.9962	0.68	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9927	0.64	128.60	7.9653	0.72	237.90	82	7.1401	3.77	81.82	6.3479	3.85	281.41
38	7.9840	0.66	124.77	7.9309	0.72	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9787	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.9224	0.67	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31147F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

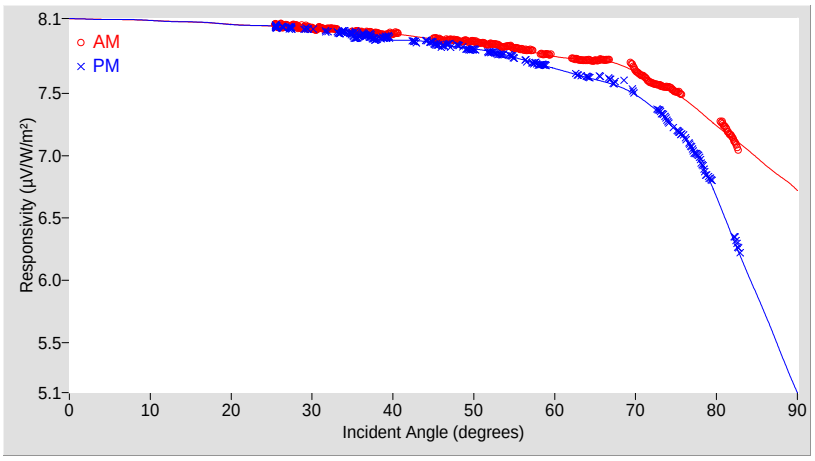


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.99	±1.99
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999996	0.9999994

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.0934	*	8.0935	*	8.0934	*
9-18	8.0763	*	8.0764	*	8.0763	*
18-27	8.0477	*	8.0467	*	8.0472	*
27-36	8.0188	±2.01	8.0043	±2.02	8.0116	±2.08
36-45	7.9717	±2.01	7.9310	±2.01	7.9514	±2.12
45-54	7.9145	±2.02	7.8618	±2.07	7.8881	±2.27
54-63	7.8208	±2.08	7.7303	±2.22	7.7755	±2.84
63-72	7.7263	±2.23	7.5558	±2.48	7.6411	±3.93
72-81	7.4272	±3.29	7.0749	±6.02	7.2510	±10.51
81-90	6.9578	*	5.8015	*	6.3796	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

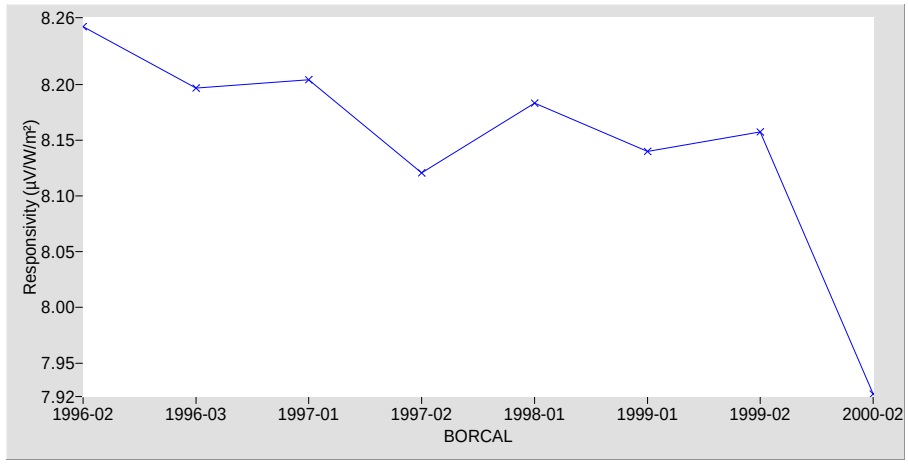
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.9224	+2.08 / -3.17 [1]
45° - 55°	7.8804	±2.20 [2]
Composite	7.9327	+2.41 / -21.13 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



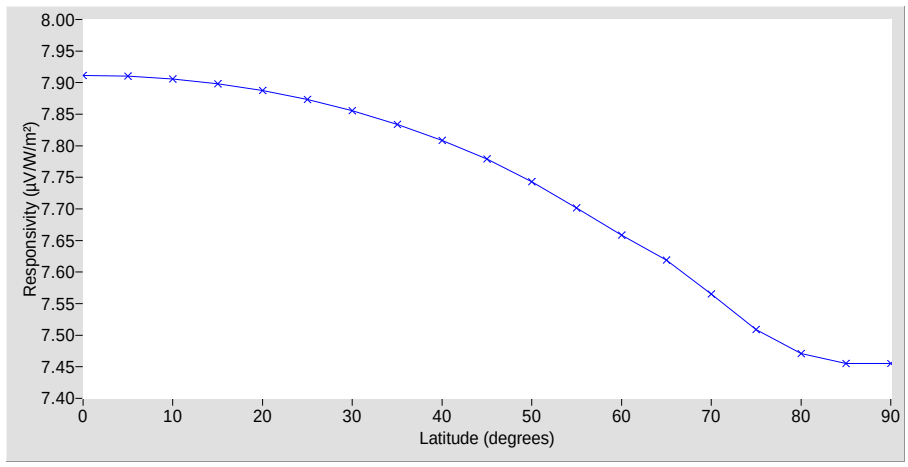
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	7.9114	+3.09 / -33.71
5	7.9102	+3.11 / -33.70
10	7.9059	+3.15 / -33.66
15	7.8981	+3.23 / -33.59
20	7.8875	+3.34 / -33.51
25	7.8734	+3.48 / -33.39
30	7.8557	+3.60 / -33.24
35	7.8336	+3.74 / -33.05
40	7.8083	+3.92 / -32.83
45	7.7789	+4.00 / -32.58
50	7.7431	+4.32 / -32.27
55	7.7017	+4.61 / -31.90
60	7.6585	+4.80 / -31.52
65	7.6192	+5.02 / -31.17
70	7.5653	+5.22 / -30.68
75	7.5089	+5.67 / -30.16
80	7.4712	+5.43 / -29.80
85	7.4551	+4.87 / -29.65
90	7.4554	+4.59 / -29.66

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31148F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31148F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

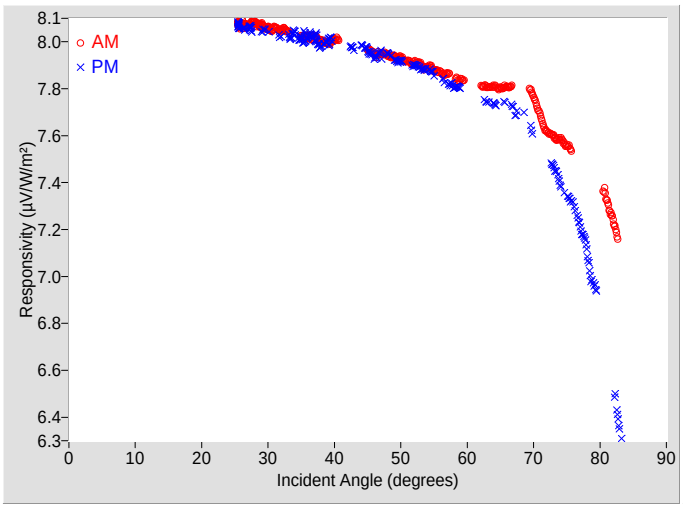


Figure 2. Responsivity vs Local Standard Time

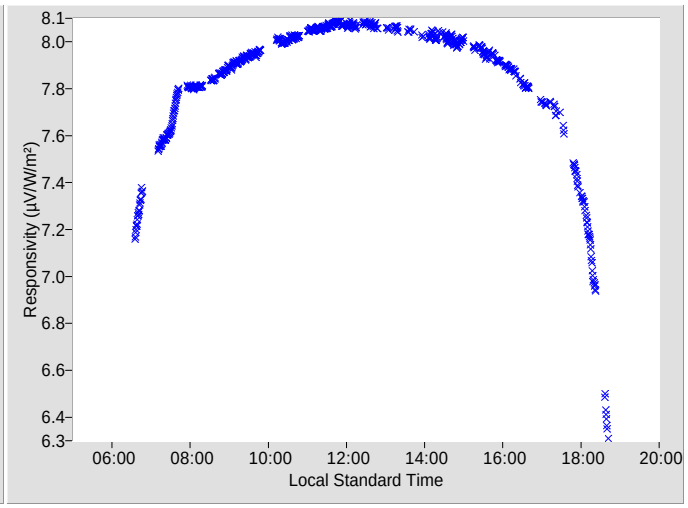


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
7.9643	+1.95 / -2.73	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9478	0.73	113.02	7.9336	0.72	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9441	0.73	110.64	7.9501	0.73	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9344	0.75	108.50	7.9179	0.72	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9116	0.77	106.42	7.8992	0.75	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8936	0.81	104.45	7.8861	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8690	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8428	N/A	100.07	7.8057	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8120	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8108	1.03	95.31	7.7353	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8075	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7640	1.46	90.66	7.6078	N/A	272.40
26	8.0717	0.66	166.63	8.0602	N/A	196.23	72	7.6182	1.53	89.21	N/A	N/A	N/A
28	8.0821	0.62	153.55	N/A	N/A	N/A	74	7.5864	1.65	87.70	7.3981	1.71	275.38
30	8.0609	0.64	144.90	8.0422	N/A	216.85	76	N/A	N/A	N/A	7.2984	1.97	276.95
32	8.0503	0.62	138.39	8.0208	0.65	222.24	78	N/A	N/A	N/A	7.1119	2.72	278.32
34	N/A	N/A	N/A	8.0403	0.70	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0204	0.64	128.60	8.0245	0.71	237.90	82	7.2358	3.69	81.82	6.4933	3.88	281.41
38	8.0066	0.67	124.77	7.9775	0.75	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0084	0.68	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	7.9848	0.67	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31148F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

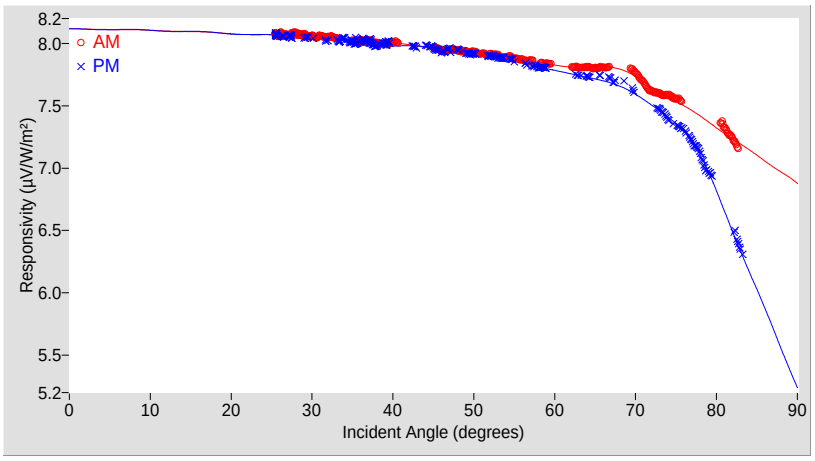


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.99	±1.99
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999992	0.9999990

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.1130	*	8.1131	*	8.1131	*
9-18	8.0985	*	8.0986	*	8.0985	*
18-27	8.0750	*	8.0727	*	8.0739	*
27-36	8.0538	±2.01	8.0373	±2.00	8.0455	±2.04
36-45	7.9977	±2.02	7.9852	±2.01	7.9914	±2.05
45-54	7.9328	±2.02	7.9266	±2.05	7.9297	±2.11
54-63	7.8456	±2.06	7.8108	±2.15	7.8282	±2.36
63-72	7.7782	±2.18	7.6603	±2.43	7.7193	±3.40
72-81	7.4824	±3.07	7.2130	±5.69	7.3477	±9.49
81-90	7.0797	*	5.9449	*	6.5123	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

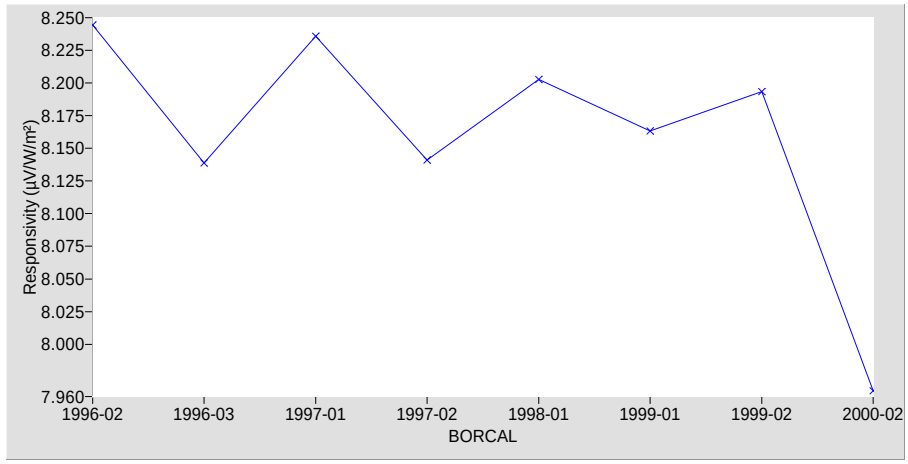
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	7.9643	+1.95 / -2.73 [1]
45° - 55°	7.9222	±2.09 [2]
Composite	7.9707	+2.37 / -20.69 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



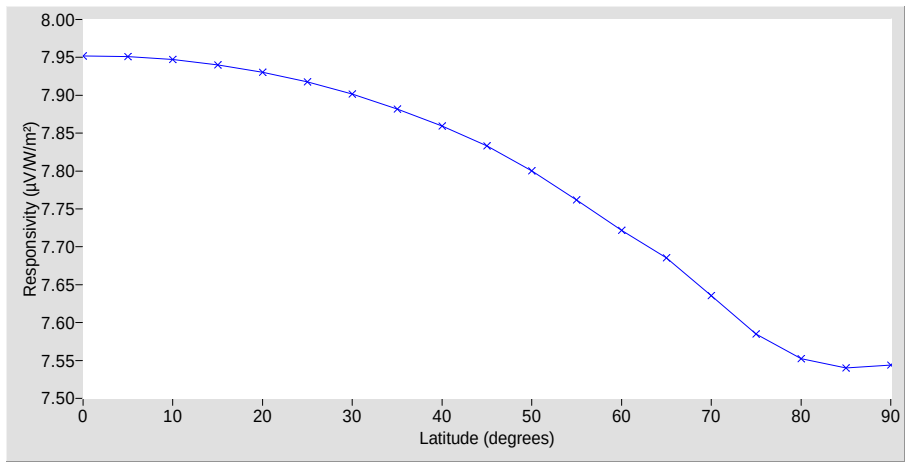
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	7.9520	+2.89 / -32.25
5	7.9510	+2.90 / -32.25
10	7.9471	+2.94 / -32.21
15	7.9401	+3.01 / -32.15
20	7.9305	+3.10 / -32.07
25	7.9176	+3.22 / -31.96
30	7.9016	+3.33 / -31.82
35	7.8818	+3.43 / -31.65
40	7.8593	+3.61 / -31.46
45	7.8331	+3.66 / -31.23
50	7.8001	+4.04 / -30.94
55	7.7620	+4.33 / -30.60
60	7.7217	+4.32 / -30.24
65	7.6854	+4.54 / -29.91
70	7.6357	+4.61 / -29.45
75	7.5849	+4.92 / -28.98
80	7.5523	+4.62 / -28.67
85	7.5403	+4.17 / -28.56
90	7.5437	+4.08 / -28.59

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31149F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31149F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

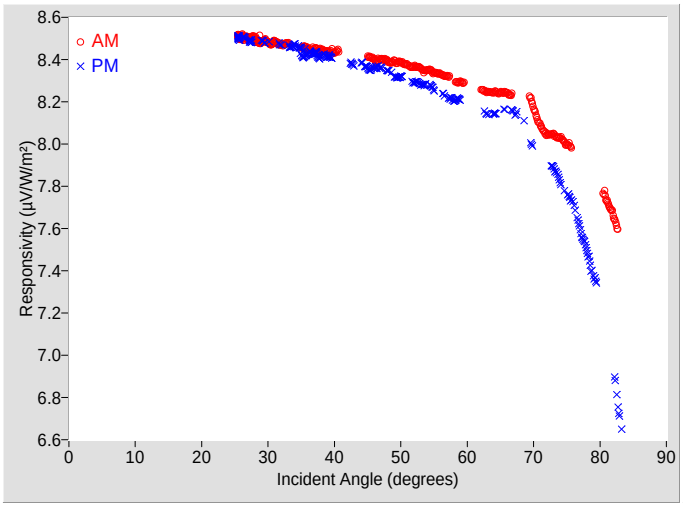


Figure 2. Responsivity vs Local Standard Time

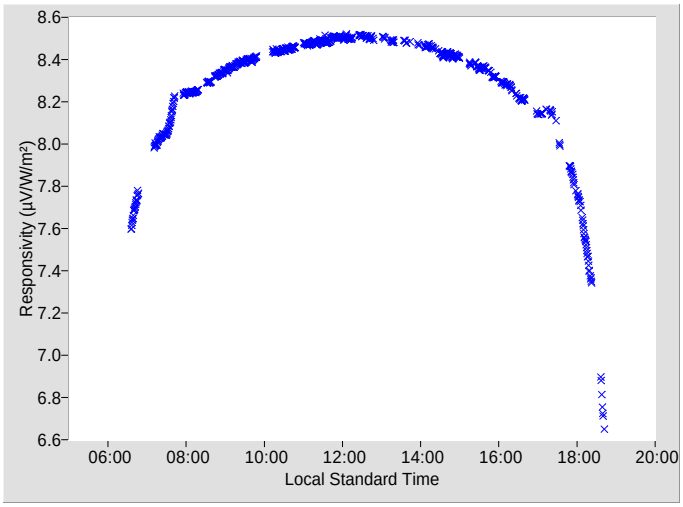


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3869	+1.91 / -2.87	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4002	0.72	113.02	8.3629	0.69	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3930	0.73	110.64	8.3472	0.71	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3882	0.74	108.50	8.3193	0.71	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3674	0.76	106.42	8.2913	0.74	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3496	0.80	104.45	8.2853	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3310	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2936	N/A	100.07	8.2064	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2575	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2458	1.02	95.31	8.1443	0.95	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2408	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1697	1.51	90.66	7.9913	N/A	272.40
26	8.5038	0.64	166.63	8.5093	N/A	196.23	72	8.0472	1.45	89.21	N/A	N/A	N/A
28	8.4997	0.64	153.36	N/A	N/A	N/A	74	8.0299	1.64	87.70	7.8246	1.67	275.38
30	8.4812	0.62	144.90	8.4847	N/A	216.85	76	N/A	N/A	N/A	7.7076	2.04	276.95
32	8.4717	0.62	138.39	8.4689	0.64	222.24	78	N/A	N/A	N/A	7.4949	2.58	278.32
34	N/A	N/A	N/A	8.4681	0.70	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4523	0.64	128.60	8.4297	0.67	237.90	82	7.6610	3.60	81.82	6.8882	3.90	281.41
38	8.4483	0.64	124.77	8.4131	0.66	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4333	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3853	0.68	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31149F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

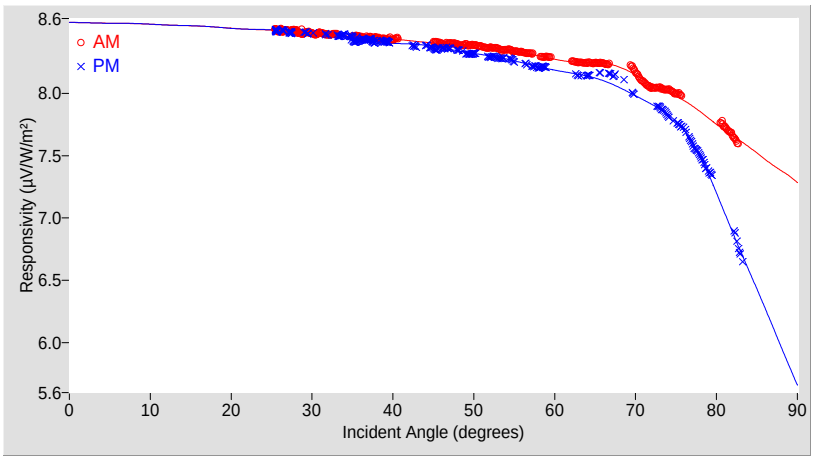


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.96	±1.96
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999994	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.5636	*	8.5636	*	8.5636	*
9-18	8.5458	*	8.5459	*	8.5459	*
18-27	8.5153	*	8.5160	*	8.5156	*
27-36	8.4770	±1.98	8.4762	±1.99	8.4766	±2.02
36-45	8.4324	±1.98	8.4041	±1.98	8.4183	±2.05
45-54	8.3854	±1.98	8.3292	±2.04	8.3573	±2.22
54-63	8.2977	±2.04	8.2127	±2.08	8.2552	±2.55
63-72	8.2034	±2.18	8.0577	±2.40	8.1306	±3.48
72-81	7.9179	±2.95	7.6154	±5.54	7.7666	±9.41
81-90	7.4970	*	6.3509	*	6.9239	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

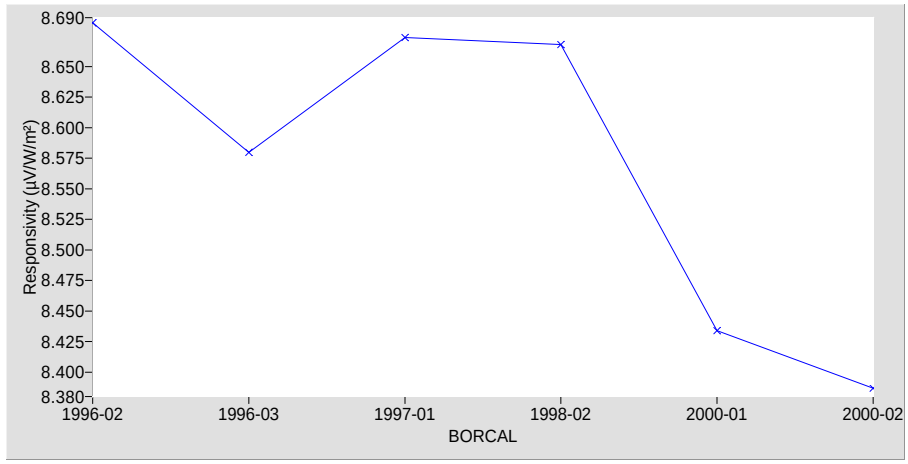
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3869	+1.91 / -2.87 [1]
45° - 55°	8.3500	±2.14 [2]
Composite	8.4058	+2.30 / -20.02 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



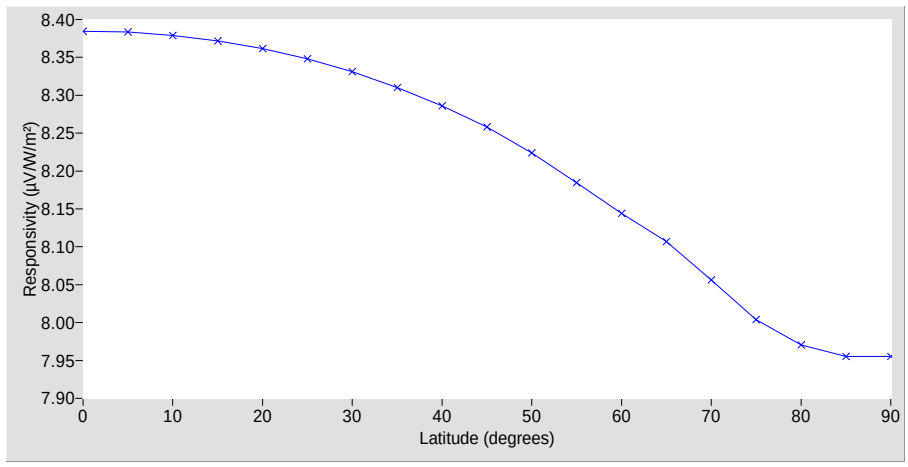
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.3845	+2.94 / -30.75
5	8.3834	+2.95 / -30.74
10	8.3791	+2.99 / -30.71
15	8.3717	+3.06 / -30.64
20	8.3615	+3.16 / -30.56
25	8.3480	+3.28 / -30.45
30	8.3310	+3.39 / -30.31
35	8.3101	+3.50 / -30.13
40	8.2861	+3.64 / -29.93
45	8.2581	+3.70 / -29.69
50	8.2241	+3.95 / -29.40
55	8.1848	+4.10 / -29.06
60	8.1439	+4.27 / -28.71
65	8.1069	+4.44 / -28.38
70	8.0565	+4.70 / -27.93
75	8.0040	+5.07 / -27.46
80	7.9706	+4.88 / -27.16
85	7.9553	+4.32 / -27.02
90	7.9552	+4.10 / -27.02

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31150F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31150F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

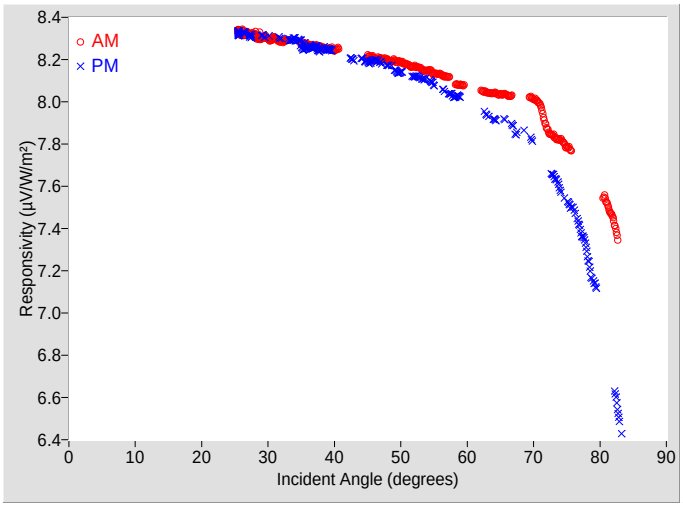


Figure 2. Responsivity vs Local Standard Time

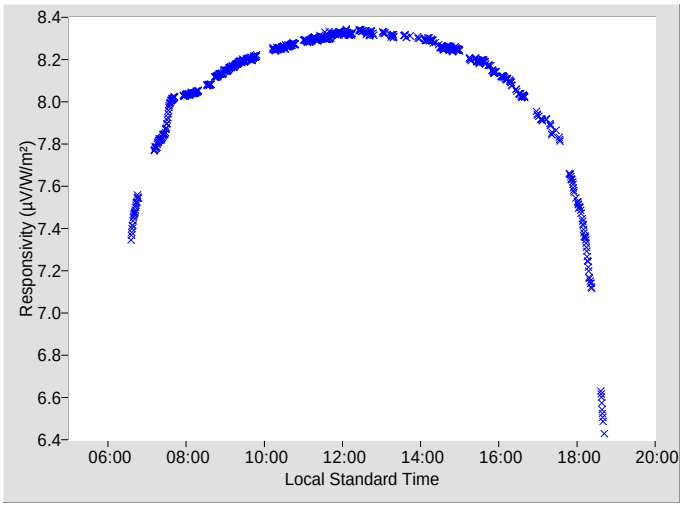


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.2043	+1.93 / -2.92	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2072	0.72	113.02	8.1980	0.69	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1987	0.72	110.64	8.1721	0.70	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1897	0.74	108.50	8.1403	0.72	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1679	0.76	106.42	8.1193	0.73	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1476	0.81	104.45	8.1099	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1293	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0819	N/A	100.07	8.0233	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0530	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0416	1.02	95.31	7.9165	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0313	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0136	1.31	90.66	7.8134	N/A	272.40
26	8.3253	0.64	166.63	8.3317	N/A	196.23	72	7.8782	1.69	89.21	N/A	N/A	N/A
28	8.3158	0.64	153.36	N/A	N/A	N/A	74	7.8211	1.66	87.70	7.5882	1.68	275.38
30	8.2972	0.62	144.90	8.3115	N/A	216.85	76	N/A	N/A	N/A	7.4860	1.95	276.95
32	8.2867	0.62	138.39	8.2996	0.64	222.24	78	N/A	N/A	N/A	7.2893	2.71	278.32
34	N/A	N/A	N/A	8.2967	0.68	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2691	0.64	128.60	8.2590	0.66	237.90	82	7.4405	3.69	81.82	6.6241	3.84	281.41
38	8.2605	0.65	124.77	8.2465	0.66	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2446	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.2059	0.68	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31150F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

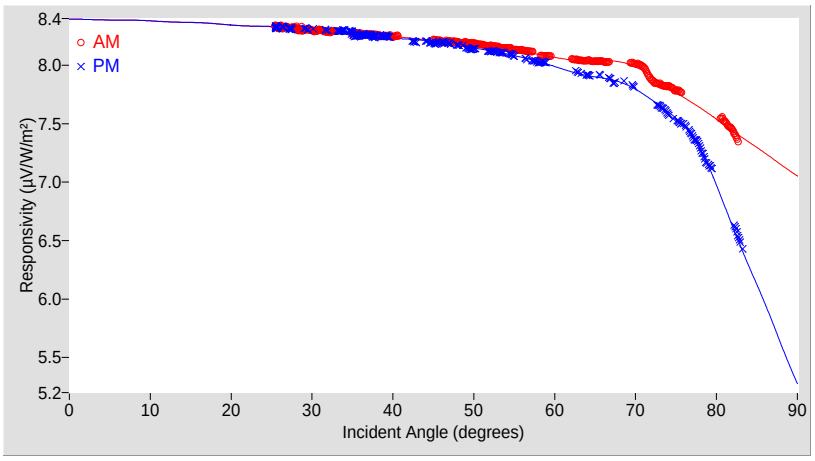


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.98	±1.98
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999993	0.9999993

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.3894	*	8.3894	*	8.3894	*
9-18	8.3705	*	8.3706	*	8.3705	*
18-27	8.3376	*	8.3386	*	8.3381	*
27-36	8.2932	±2.00	8.3041	±2.00	8.2986	±2.03
36-45	8.2439	±2.00	8.2324	±2.01	8.2382	±2.05
45-54	8.1890	±2.01	8.1548	±2.07	8.1719	±2.20
54-63	8.0915	±2.08	8.0224	±2.22	8.0569	±2.72
63-72	8.0158	±2.10	7.8542	±2.35	7.9350	±3.53
72-81	7.7115	±3.22	7.3943	±5.87	7.5529	±10.17
81-90	7.2705	*	6.0340	*	6.6523	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

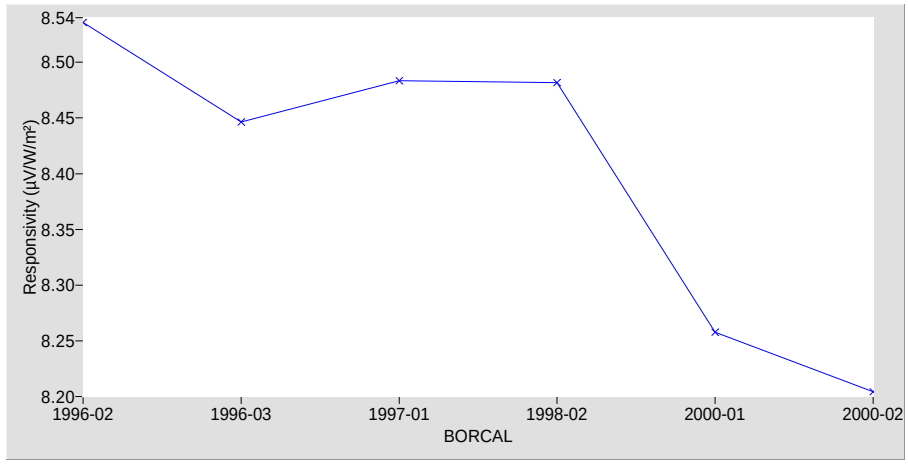
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2043	+1.93 / -2.92 [1]
45° - 55°	8.1638	±2.13 [2]
Composite	8.2228	+2.38 / -21.69 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



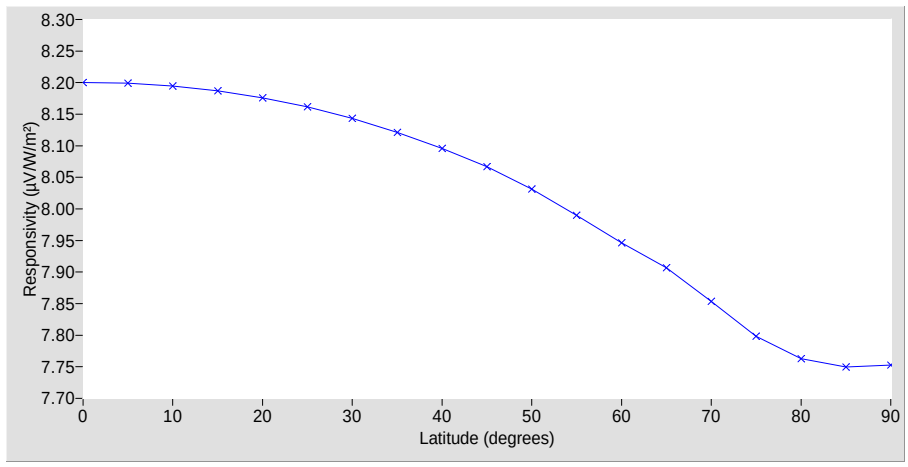
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.2003	+3.09 / -33.75
5	8.1991	+3.10 / -33.74
10	8.1947	+3.15 / -33.71
15	8.1869	+3.22 / -33.64
20	8.1760	+3.33 / -33.56
25	8.1617	+3.47 / -33.44
30	8.1436	+3.59 / -33.29
35	8.1213	+3.71 / -33.11
40	8.0957	+3.87 / -32.90
45	8.0669	+3.92 / -32.66
50	8.0313	+4.21 / -32.36
55	7.9899	+4.44 / -32.01
60	7.9463	+4.52 / -31.64
65	7.9068	+4.66 / -31.30
70	7.8533	+4.92 / -30.83
75	7.7982	+5.30 / -30.34
80	7.7628	+5.01 / -30.02
85	7.7494	+4.42 / -29.90
90	7.7526	+4.20 / -29.93

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31151F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31151F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

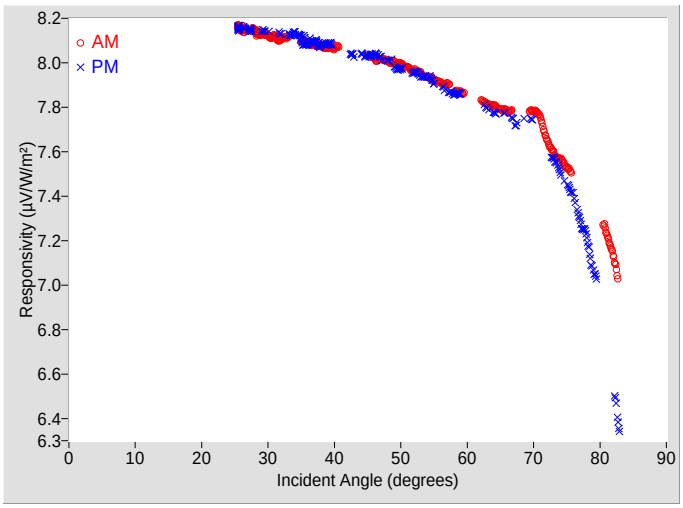


Figure 2. Responsivity vs Local Standard Time

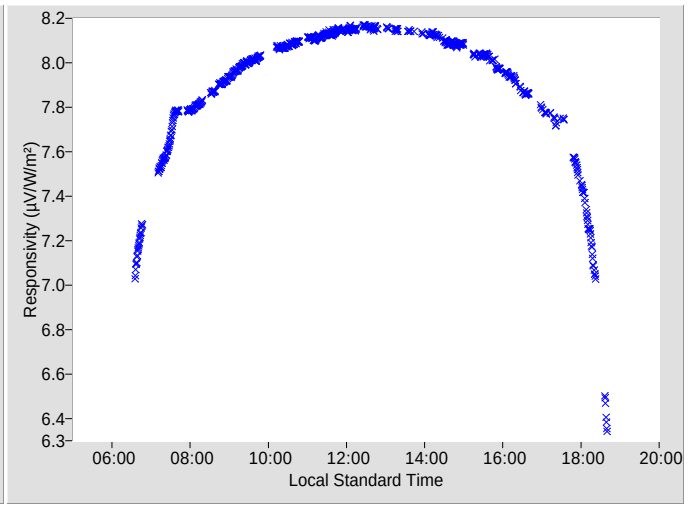


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0323	+2.01 / -2.89	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0196	0.72	113.02	8.0377	0.69	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0077	0.73	110.64	8.0104	0.71	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9965	0.75	108.50	7.9735	0.72	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9665	0.78	106.42	7.9566	0.75	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9369	0.83	104.45	7.9418	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9108	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8702	N/A	100.07	7.8578	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8323	0.98	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8080	1.03	95.31	7.7756	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7850	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7835	1.30	90.66	7.7440	N/A	272.40
26	8.1527	0.65	166.63	8.1614	N/A	196.23	72	7.6568	1.74	89.21	N/A	N/A	N/A
28	8.1414	0.64	153.36	N/A	N/A	N/A	74	7.5672	1.69	87.70	7.5122	1.67	275.38
30	8.1204	0.62	144.90	8.1410	N/A	216.85	76	N/A	N/A	N/A	7.3922	2.07	276.95
32	8.1081	0.62	138.39	8.1302	0.65	222.24	78	N/A	N/A	N/A	7.2105	2.64	278.32
34	N/A	N/A	N/A	8.1331	0.69	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0900	0.64	128.60	8.0894	0.68	237.90	82	7.1291	3.78	81.82	6.4972	3.90	281.41
38	8.0778	0.65	124.77	8.0764	0.67	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0650	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0399	0.67	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31151F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

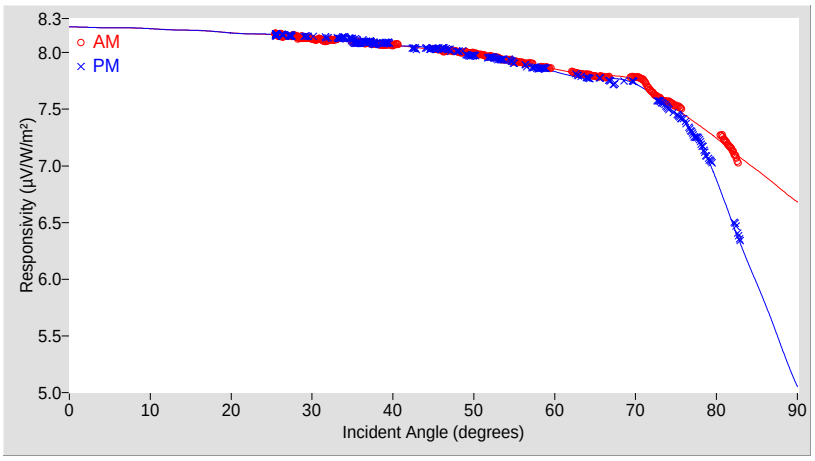


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±2.01	±2.01
Valid incidence angle range	25.5° to 82.7°	25.5° to 82.9°
R^2	0.9999995	0.9999990

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2201	*	8.2201	*	8.2201	*
9-18	8.2005	*	8.2006	*	8.2005	*
18-27	8.1663	*	8.1677	*	8.1670	*
27-36	8.1159	±2.03	8.1353	±2.03	8.1256	±2.08
36-45	8.0621	±2.04	8.0645	±2.03	8.0633	±2.09
45-54	7.9946	±2.07	7.9911	±2.10	7.9929	±2.20
54-63	7.8758	±2.14	7.8610	±2.20	7.8684	±2.41
63-72	7.7805	±2.13	7.7506	±2.16	7.7655	±2.51
72-81	7.4442	±3.70	7.3090	±6.16	7.3766	±9.24
81-90	6.9333	*	5.8644	*	6.3988	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

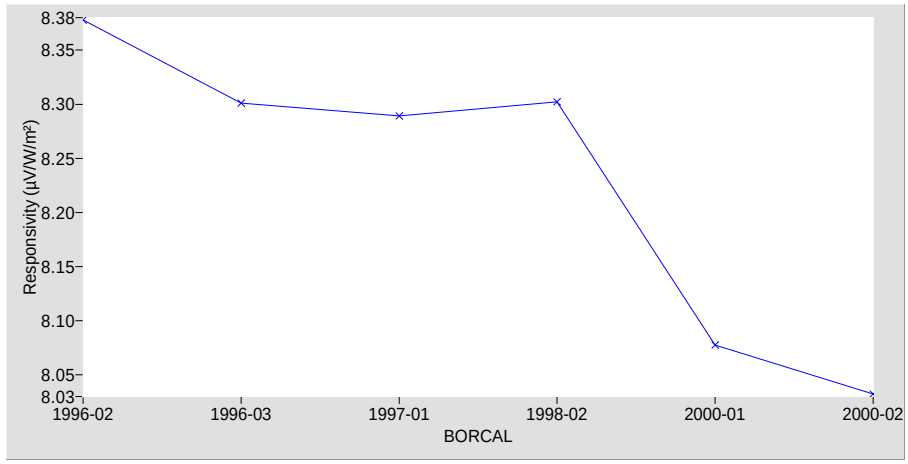
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0323	+2.01 / -2.89 [1]
45° - 55°	7.9831	±2.15 [2]
Composite	8.0483	+2.44 / -20.61 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



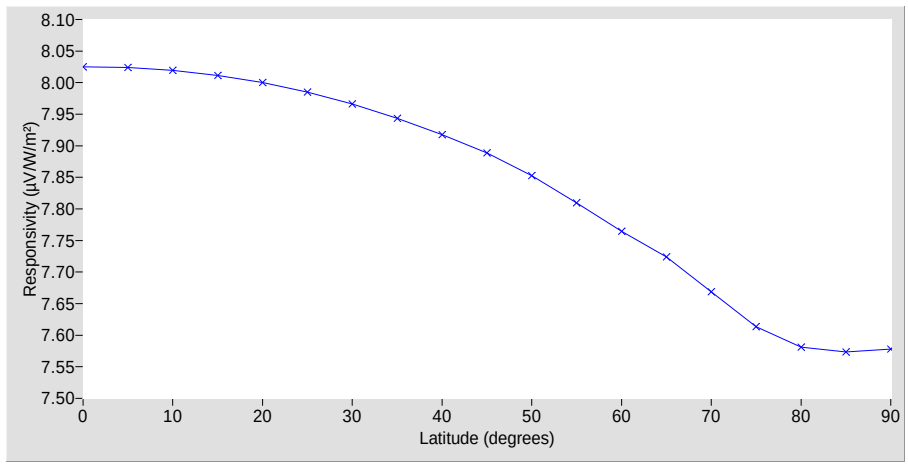
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0250	+3.21 / -34.99
5	8.0238	+3.22 / -34.98
10	8.0192	+3.27 / -34.94
15	8.0112	+3.35 / -34.88
20	8.0000	+3.47 / -34.79
25	7.9851	+3.62 / -34.67
30	7.9662	+3.74 / -34.51
35	7.9434	+3.87 / -34.32
40	7.9175	+4.04 / -34.11
45	7.8888	+4.08 / -33.87
50	7.8527	+4.39 / -33.57
55	7.8098	+4.66 / -33.20
60	7.7645	+4.75 / -32.81
65	7.7239	+4.78 / -32.46
70	7.6690	+5.10 / -31.98
75	7.6135	+5.27 / -31.48
80	7.5813	+4.69 / -31.19
85	7.5734	+4.06 / -31.12
90	7.5780	+3.50 / -31.16

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31152F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31152F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

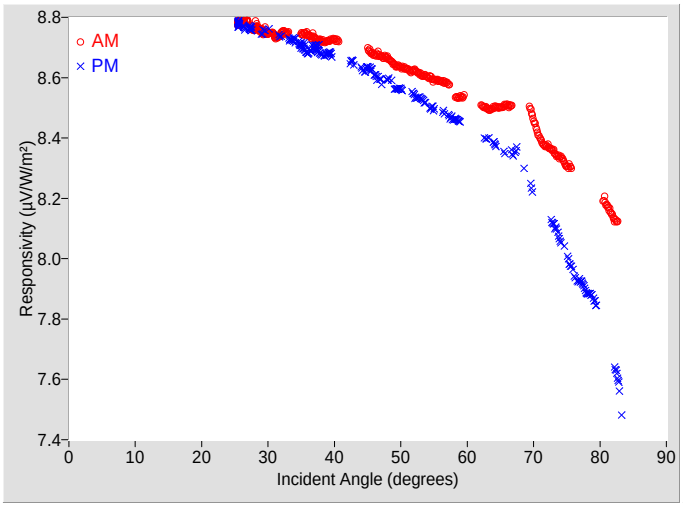


Figure 2. Responsivity vs Local Standard Time

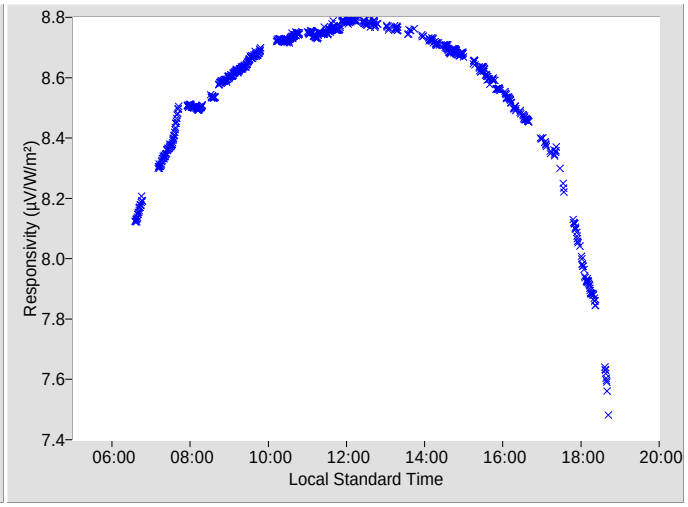


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.6624	+1.75 / -3.06	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6761	0.72	113.02	8.6074	0.73	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6654	0.73	110.64	8.5943	0.70	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6355	0.74	108.50	8.5620	0.71	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6250	0.76	106.42	8.5410	0.74	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6022	0.80	104.45	8.5168	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5881	0.81	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5353	N/A	100.07	8.4617	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5088	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5013	1.02	95.31	8.3823	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5080	1.09	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4589	1.43	90.66	8.2214	N/A	272.40
26	8.7919	0.63	166.63	8.7733	N/A	196.23	72	8.3740	1.44	89.21	N/A	N/A	N/A
28	8.7656	0.63	153.36	N/A	N/A	N/A	74	8.3365	1.64	87.70	8.0629	1.60	275.38
30	8.7467	0.63	144.90	8.7618	N/A	216.85	76	N/A	N/A	N/A	7.9477	1.87	276.95
32	8.7468	0.62	138.39	8.7368	0.64	222.24	78	N/A	N/A	N/A	7.8865	2.14	278.32
34	N/A	N/A	N/A	8.7250	0.67	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7422	0.64	128.60	8.6830	0.65	238.76	82	8.1365	3.47	81.82	7.6366	3.64	281.41
38	8.7229	0.64	124.77	8.6782	0.67	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7266	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.6299	0.67	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31152F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\,(am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\,(pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

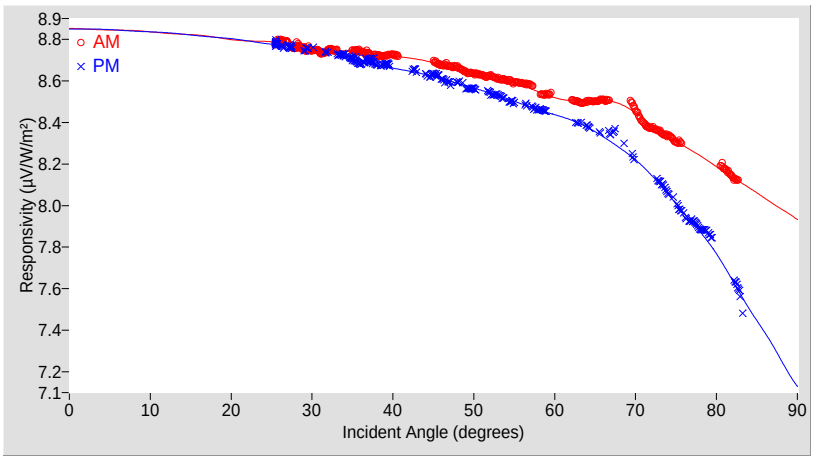


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.82	±1.82
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R^2	0.9999997	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.8464	*	8.8462	*	8.8463	*
9-18	8.8266	*	8.8263	*	8.8264	*
18-27	8.7937	*	8.7910	*	8.7923	*
27-36	8.7516	±1.83	8.7431	±1.87	8.7474	±1.93
36-45	8.7183	±1.84	8.6592	±1.86	8.6888	±2.04
45-54	8.6482	±1.87	8.5734	±1.91	8.6108	±2.27
54-63	8.5470	±1.91	8.4595	±1.94	8.5033	±2.47
63-72	8.4799	±1.92	8.2928	±2.29	8.3863	±3.51
72-81	8.2795	±2.23	7.9494	±3.14	8.1145	±6.01
81-90	8.0474	*	7.4151	*	7.7313	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

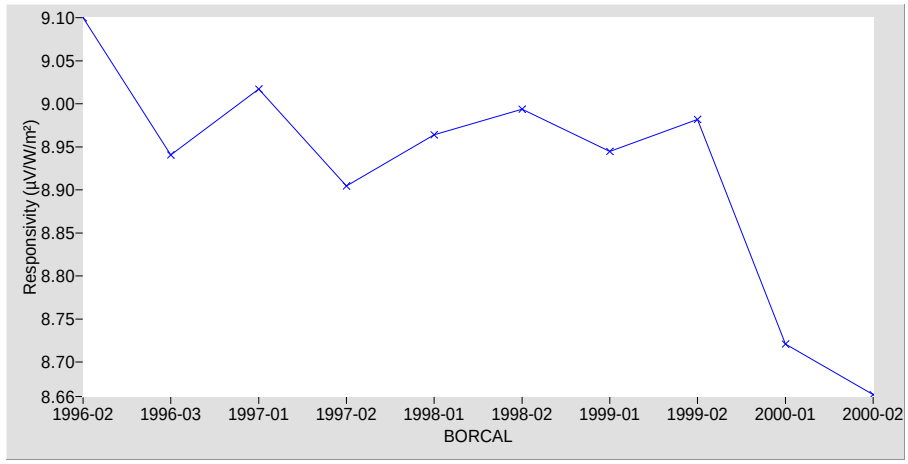
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.6624	+1.75 / -3.06 [1]
45° - 55°	8.6027	±2.11 [2]
Composite	8.6843	+2.16 / -12.95 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



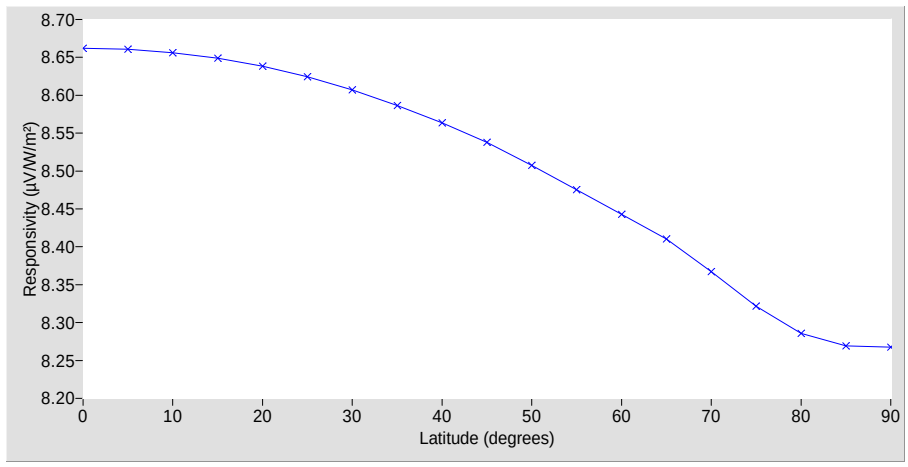
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.6618	+2.85 / -17.11
5	8.6606	+2.86 / -17.10
10	8.6563	+2.90 / -17.06
15	8.6488	+2.97 / -16.99
20	8.6383	+3.07 / -16.89
25	8.6243	+3.20 / -16.75
30	8.6071	+3.30 / -16.59
35	8.5866	+3.41 / -16.39
40	8.5637	+3.50 / -16.17
45	8.5378	+3.55 / -15.91
50	8.5075	+3.72 / -15.62
55	8.4751	+3.74 / -15.30
60	8.4428	+3.96 / -14.97
65	8.4103	+4.06 / -14.65
70	8.3673	+4.14 / -14.21
75	8.3216	+4.16 / -13.74
80	8.2858	+3.97 / -13.37
85	8.2691	+3.43 / -13.20
90	8.2675	+3.42 / -13.18

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31153F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31153F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

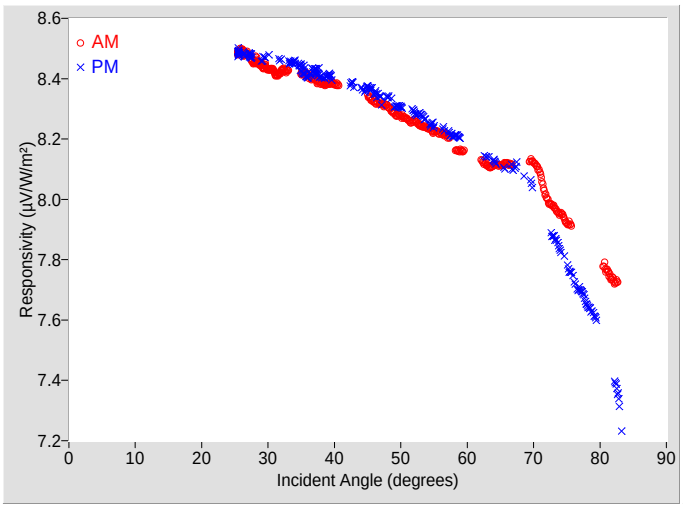


Figure 2. Responsivity vs Local Standard Time

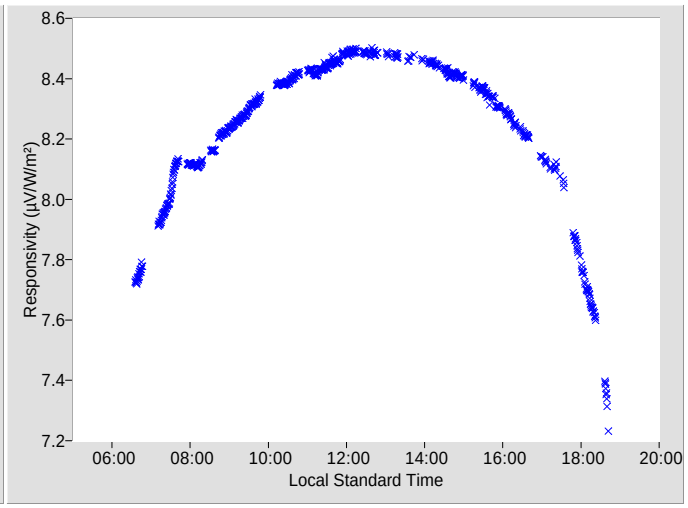


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3560	+2.00 / -3.05	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3229	0.72	113.02	8.3523	0.72	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3083	0.74	110.64	8.3397	0.72	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2770	0.74	108.50	8.3062	0.71	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2609	0.77	106.42	8.2888	0.74	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2357	0.80	104.45	8.2657	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2185	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1620	N/A	100.07	8.2101	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1299	0.98	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1141	1.02	95.31	8.1275	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1186	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1224	1.32	90.66	8.0394	N/A	272.40
26	8.4905	0.63	166.63	8.4881	N/A	196.23	72	8.0052	1.57	89.21	N/A	N/A	N/A
28	8.4578	0.62	153.36	N/A	N/A	N/A	74	7.9530	1.65	87.70	7.8343	1.60	275.38
30	8.4311	0.63	144.90	8.4790	N/A	216.85	76	N/A	N/A	N/A	7.7309	1.87	276.95
32	8.4248	0.62	138.39	8.4615	0.64	222.24	78	N/A	N/A	N/A	7.6507	2.18	278.32
34	N/A	N/A	N/A	8.4539	0.67	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4104	0.64	128.60	8.4066	0.67	238.76	82	7.7319	3.49	81.82	7.3949	3.66	281.41
38	8.3872	0.65	124.77	8.4051	0.66	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3823	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3676	0.68	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31153F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

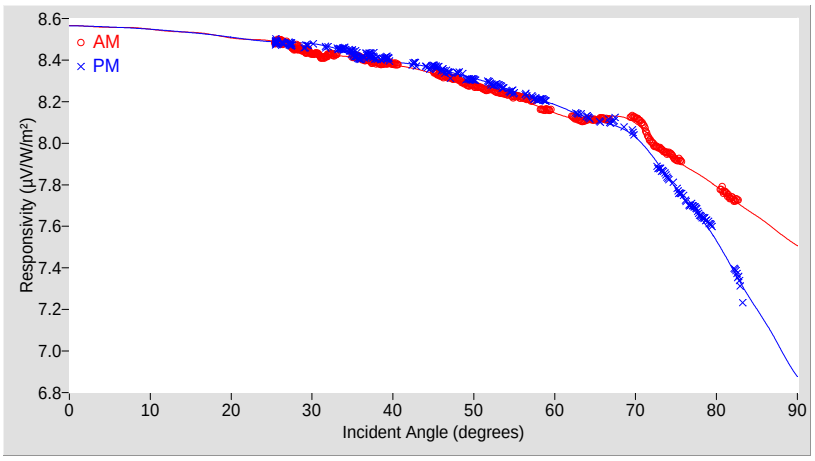


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.84	±1.84
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.2°
R²	0.9999994	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.5599	*	8.5598	*	8.5599	*
9-18	8.5380	*	8.5378	*	8.5379	*
18-27	8.5001	*	8.5002	*	8.5002	*
27-36	8.4329	±1.87	8.4647	±1.87	8.4488	±1.94
36-45	8.3757	±1.88	8.3905	±1.86	8.3831	±1.95
45-54	8.2896	±1.92	8.3187	±1.92	8.3042	±2.10
54-63	8.1734	±1.98	8.2070	±1.97	8.1902	±2.23
63-72	8.1100	±1.91	8.0742	±2.12	8.0921	±2.47
72-81	7.8924	±2.43	7.7239	±3.41	7.8081	±5.19
81-90	7.6328	*	7.1679	*	7.4004	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

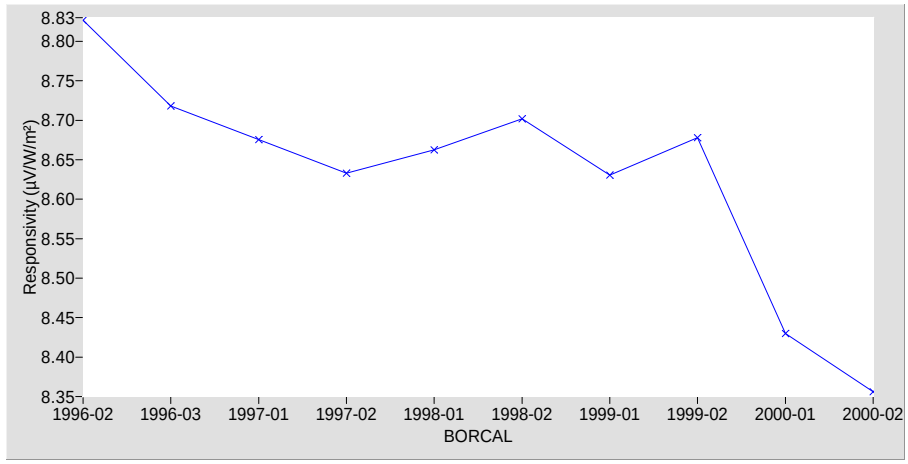
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3560	+2.00 / -3.05 [1]
45° - 55°	8.2953	±2.02 [2]
Composite	8.3868	+2.20 / -12.78 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



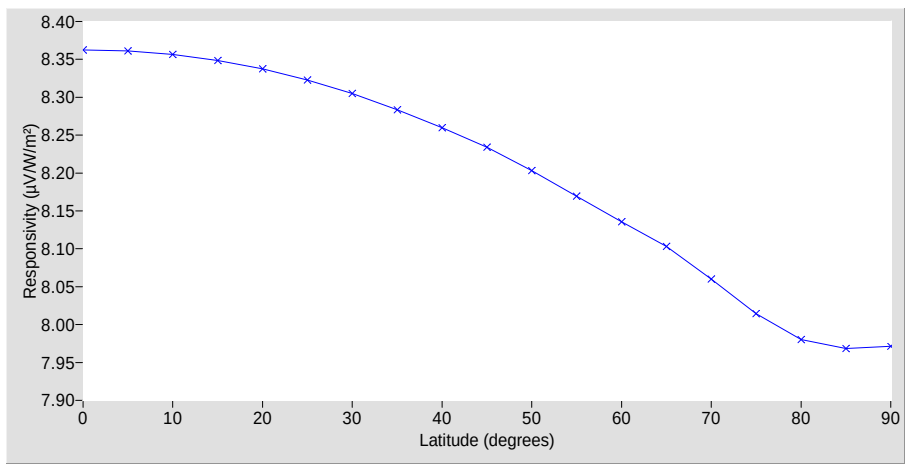
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.3624	+3.05 / -17.16
5	8.3611	+3.07 / -17.15
10	8.3565	+3.11 / -17.10
15	8.3485	+3.19 / -17.03
20	8.3375	+3.30 / -16.92
25	8.3229	+3.45 / -16.77
30	8.3049	+3.55 / -16.59
35	8.2837	+3.66 / -16.38
40	8.2599	+3.77 / -16.14
45	8.2341	+3.77 / -15.88
50	8.2030	+3.91 / -15.56
55	8.1693	+4.15 / -15.21
60	8.1358	+3.93 / -14.87
65	8.1032	+3.95 / -14.53
70	8.0600	+4.07 / -14.07
75	8.0142	+4.03 / -13.59
80	7.9801	+3.70 / -13.22
85	7.9683	+3.13 / -13.09
90	7.9715	+2.71 / -13.13

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31154F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31154F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

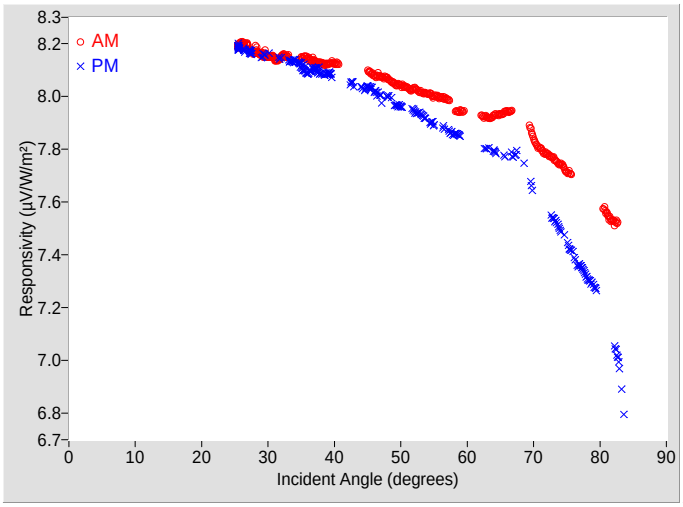


Figure 2. Responsivity vs Local Standard Time

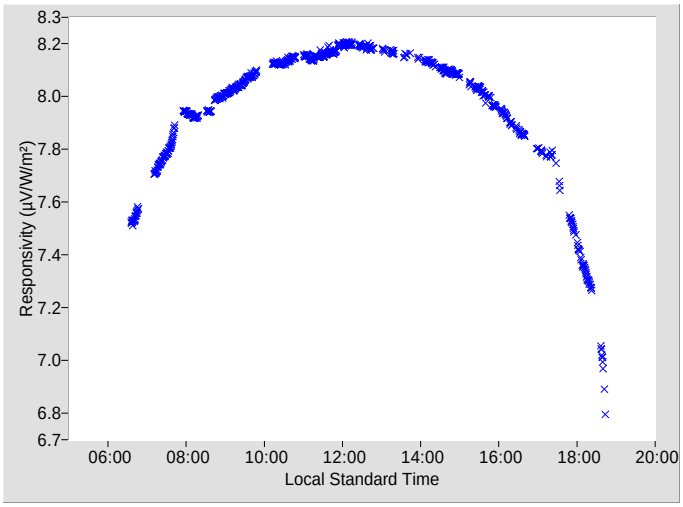


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0660	+1.87 / -3.33	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0797	0.72	113.02	8.0184	0.72	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0685	0.74	110.64	8.0006	0.72	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0430	0.74	108.50	7.9629	0.71	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0305	0.77	106.42	7.9445	0.74	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0102	0.80	104.45	7.9170	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9958	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9440	N/A	100.07	7.8571	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9288	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9286	1.03	95.31	7.7923	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9434	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8406	1.41	90.66	7.6446	N/A	272.40
26	8.1994	0.63	166.63	8.1826	N/A	196.23	72	7.7835	1.45	89.21	N/A	N/A	N/A
28	8.1704	0.64	153.36	N/A	N/A	N/A	74	7.7441	1.66	87.70	7.4961	1.60	275.38
30	8.1503	0.63	144.90	8.1645	N/A	216.85	76	N/A	N/A	N/A	7.3946	1.91	276.95
32	8.1503	0.63	138.39	8.1446	0.64	222.24	78	N/A	N/A	N/A	7.3147	2.19	278.32
34	N/A	N/A	N/A	8.1340	0.67	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1443	0.64	128.60	8.0886	0.66	238.76	82	7.5272	3.50	81.82	7.0496	3.70	281.41
38	8.1269	0.65	124.77	8.0857	0.66	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1253	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0344	0.68	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31154F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

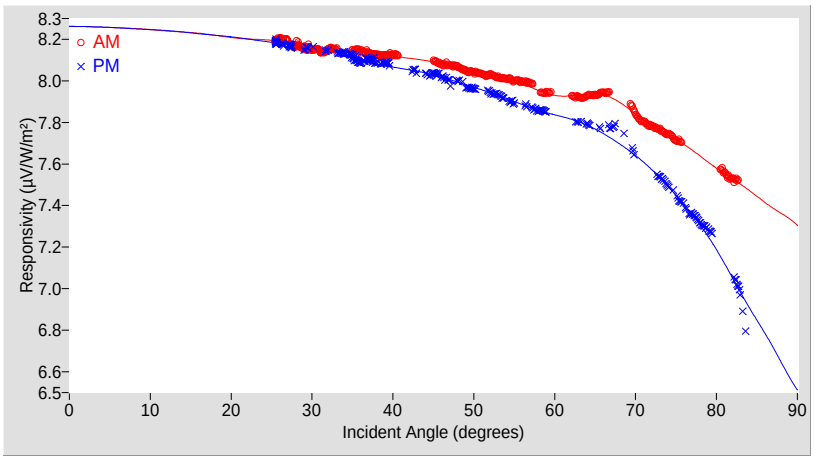


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.84	±1.84
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999998	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2575	*	8.2574	*	8.2575	*
9-18	8.2368	*	8.2366	*	8.2367	*
18-27	8.2023	*	8.1999	*	8.2011	*
27-36	8.1553	±1.86	8.1496	±1.89	8.1524	±1.96
36-45	8.1195	±1.87	8.0657	±1.89	8.0926	±2.08
45-54	8.0534	±1.90	7.9779	±1.96	8.0156	±2.37
54-63	7.9589	±1.92	7.8589	±1.96	7.9089	±2.59
63-72	7.8939	±2.05	7.7098	±2.30	7.8018	±3.71
72-81	7.6812	±2.33	7.3820	±3.38	7.5316	±6.30
81-90	7.4309	*	6.8148	*	7.1228	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

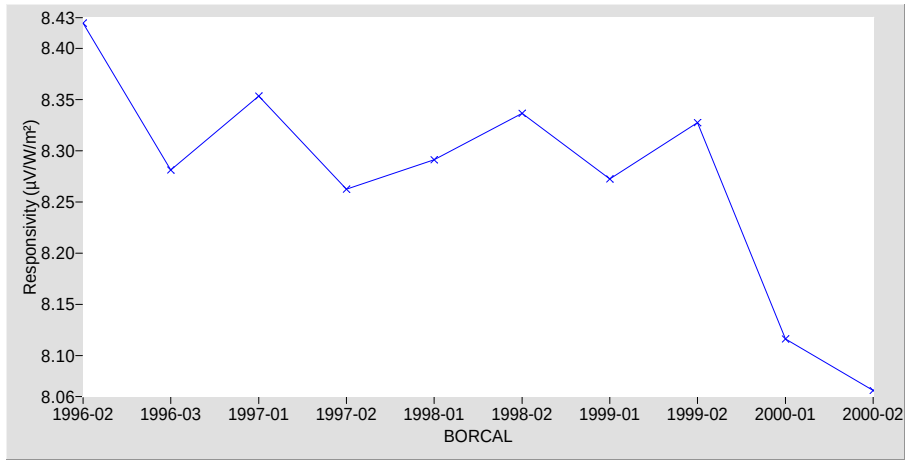
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0660	+1.87 / -3.33 [1]
45° - 55°	8.0075	±2.19 [2]
Composite	8.0925	+2.22 / -14.29 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



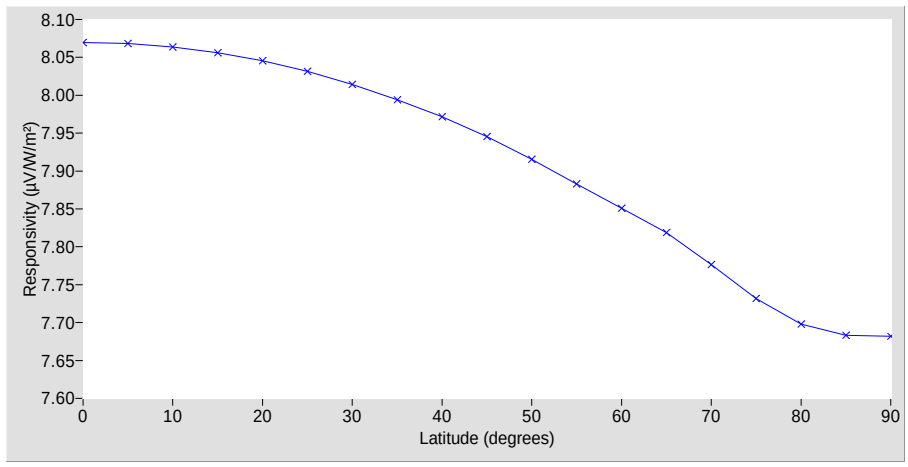
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0694	+3.02 / -18.61
5	8.0682	+3.03 / -18.59
10	8.0638	+3.08 / -18.55
15	8.0563	+3.15 / -18.47
20	8.0457	+3.26 / -18.37
25	8.0317	+3.41 / -18.23
30	8.0144	+3.53 / -18.05
35	7.9940	+3.64 / -17.84
40	7.9715	+3.72 / -17.61
45	7.9456	+3.77 / -17.34
50	7.9154	+3.92 / -17.03
55	7.8831	+3.93 / -16.69
60	7.8507	+4.16 / -16.35
65	7.8186	+4.20 / -16.01
70	7.7763	+4.35 / -15.55
75	7.7317	+4.36 / -15.07
80	7.6982	+4.18 / -14.70
85	7.6833	+3.80 / -14.54
90	7.6820	+3.75 / -14.52

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31155F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31155F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

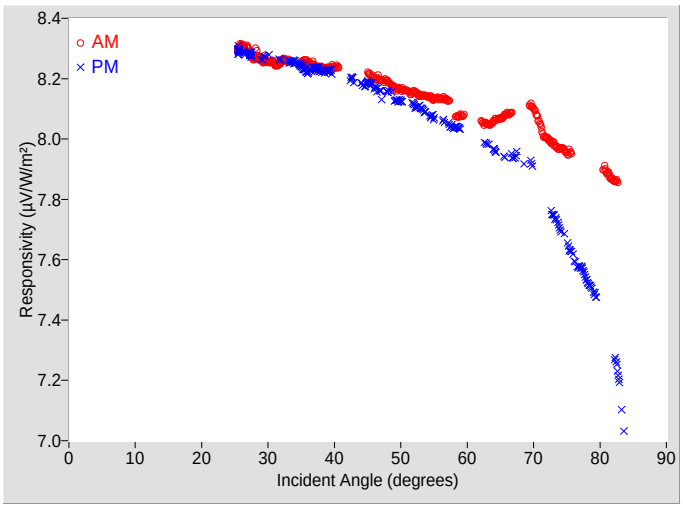


Figure 2. Responsivity vs Local Standard Time

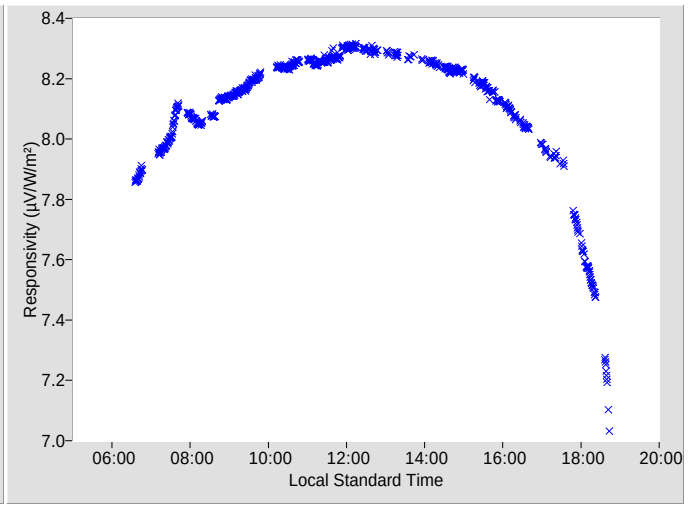


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.2021	+1.47 / -2.72	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2014	0.72	113.02	8.1698	0.72	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1911	0.74	110.64	8.1577	0.72	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1655	0.74	108.50	8.1263	0.71	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1575	0.76	106.42	8.1111	0.74	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1404	0.79	104.45	8.0895	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1338	0.81	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0741	N/A	100.07	8.0382	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0596	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0601	1.03	95.31	7.9637	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0824	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0999	1.35	90.66	7.9105	N/A	272.40
26	8.3066	0.63	166.63	8.2928	N/A	196.23	72	8.0037	1.48	89.21	N/A	N/A	N/A
28	8.2732	0.64	153.36	N/A	N/A	N/A	74	7.9695	1.62	87.70	7.7025	1.59	275.38
30	8.2547	0.63	144.90	8.2789	N/A	216.85	76	N/A	N/A	N/A	7.6021	1.88	276.95
32	8.2575	0.63	138.39	8.2617	0.64	222.24	78	N/A	N/A	N/A	7.5307	2.20	278.32
34	N/A	N/A	N/A	8.2549	0.66	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2530	0.64	128.60	8.2213	0.64	238.76	82	7.8636	3.48	81.82	7.2721	3.67	281.41
38	8.2378	0.64	124.77	8.2239	0.65	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2386	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.1829	0.67	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31155F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

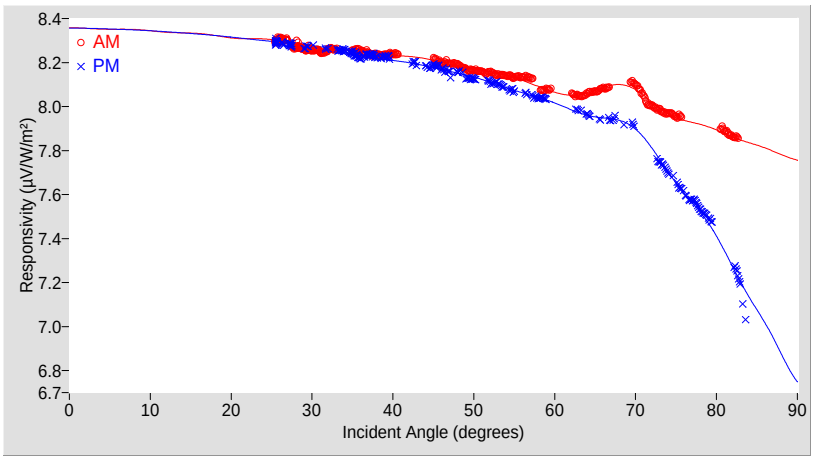


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.83	±1.83
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999994	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.3531	*	8.3529	*	8.3530	*
9-18	8.3365	*	8.3363	*	8.3364	*
18-27	8.3086	*	8.3068	*	8.3077	*
27-36	8.2614	±1.85	8.2669	±1.86	8.2641	±1.89
36-45	8.2335	±1.85	8.2072	±1.86	8.2203	±1.93
45-54	8.1772	±1.87	8.1383	±1.91	8.1577	±2.10
54-63	8.0906	±1.92	8.0356	±1.95	8.0631	±2.33
63-72	8.0763	±1.88	7.9286	±2.02	8.0025	±3.02
72-81	7.9422	±2.03	7.5978	±3.39	7.7700	±6.27
81-90	7.8160	*	7.0425	*	7.4292	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

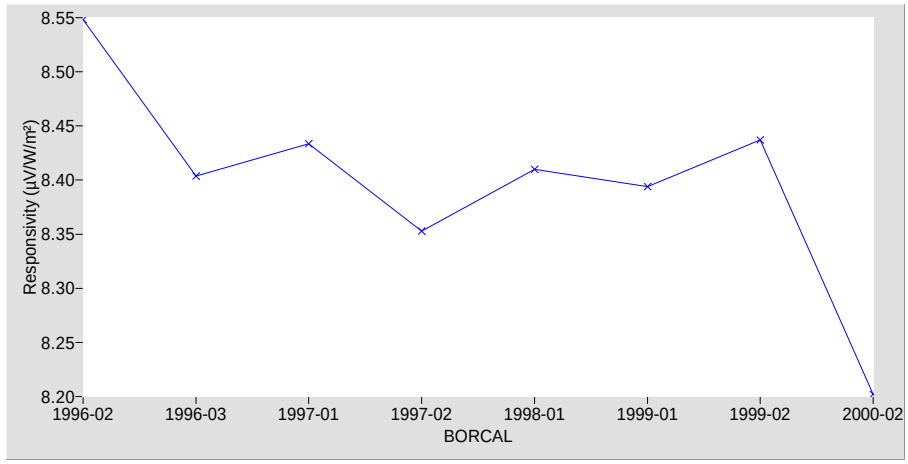
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.2021	+1.47 / -2.72 [1]
45° - 55°	8.1507	±2.02 [2]
Composite	8.2197	+2.09 / -12.93 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



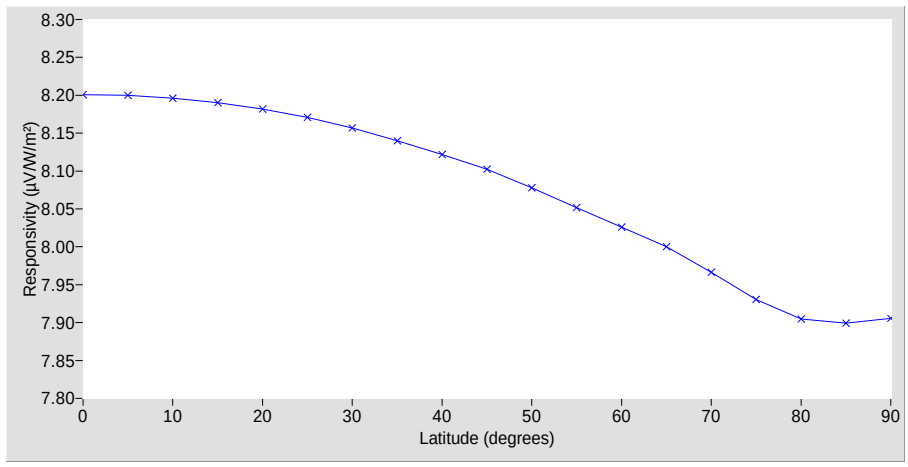
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.2009	+2.65 / -17.11
5	8.1998	+2.66 / -17.10
10	8.1962	+2.70 / -17.06
15	8.1903	+2.75 / -17.00
20	8.1819	+2.83 / -16.92
25	8.1706	+2.93 / -16.80
30	8.1566	+3.01 / -16.66
35	8.1400	+3.09 / -16.49
40	8.1218	+3.17 / -16.30
45	8.1024	+3.17 / -16.11
50	8.0780	+3.28 / -15.85
55	8.0519	+3.29 / -15.58
60	8.0260	+3.36 / -15.31
65	8.0003	+3.41 / -15.04
70	7.9662	+3.48 / -14.68
75	7.9306	+3.48 / -14.30
80	7.9047	+3.27 / -14.02
85	7.8992	+3.13 / -13.96
90	7.9057	+3.07 / -14.03

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31156F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

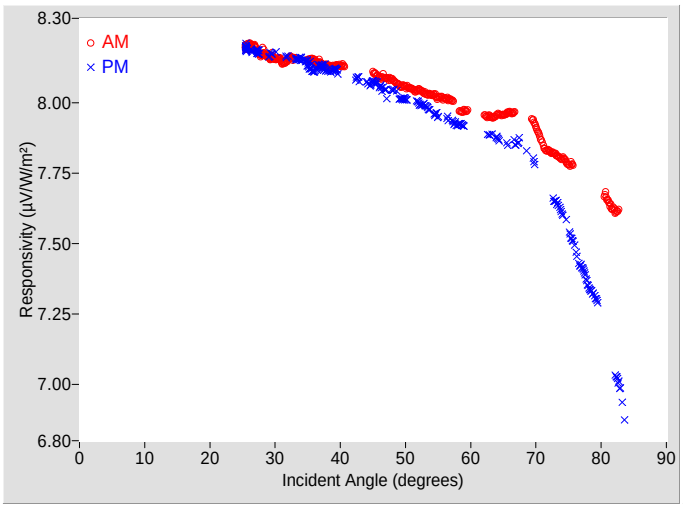


Figure 2. Responsivity vs Local Standard Time

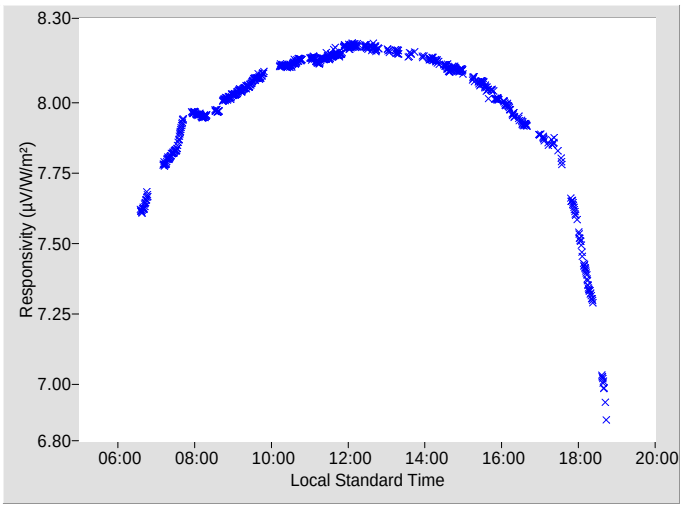


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0906	+1.61 / -2.81	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0903	0.72	113.02	8.0570	0.72	252.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0821	0.73	110.64	8.0453	0.72	254.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0583	0.74	108.50	8.0132	0.71	256.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0466	0.76	106.42	7.9987	0.74	258.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0279	0.80	104.45	7.9746	N/A	259.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0144	0.82	102.55	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9703	N/A	100.07	7.9224	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9563	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9571	1.03	95.31	7.8753	0.96	268.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9656	1.10	93.72	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9127	1.39	90.66	7.7812	N/A	272.40
26	8.2034	0.63	166.63	8.1911	N/A	196.23	72	7.8293	1.44	89.21	N/A	N/A	N/A
28	8.1741	0.63	153.36	N/A	N/A	N/A	74	7.8032	1.63	87.70	7.6093	1.60	275.38
30	8.1560	0.63	144.90	8.1810	N/A	216.85	76	N/A	N/A	N/A	7.4726	1.97	276.95
32	8.1544	0.63	138.39	8.1631	0.64	222.24	78	N/A	N/A	N/A	7.3504	2.23	278.32
34	N/A	N/A	N/A	8.1560	0.67	227.60	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1495	0.64	128.60	8.1130	0.66	238.76	82	7.6192	3.50	81.82	7.0304	3.66	281.41
38	8.1326	0.65	124.77	8.1134	0.66	241.84	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1320	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0719	0.68	250.08	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31156F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

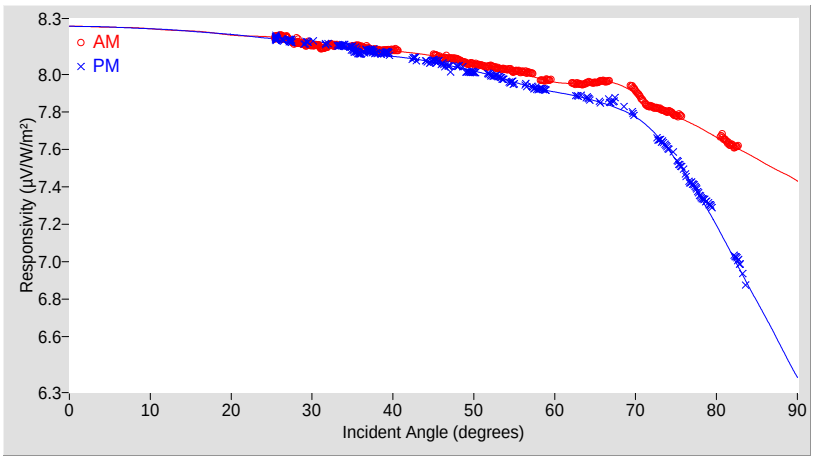


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.84	±1.84
Valid incidence angle range	25.5° to 82.7°	25.5° to 83.6°
R^2	0.9999997	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2548	*	8.2546	*	8.2547	*
9-18	8.2369	*	8.2367	*	8.2368	*
18-27	8.2068	*	8.2052	*	8.2060	*
27-36	8.1599	±1.86	8.1671	±1.88	8.1635	±1.91
36-45	8.1266	±1.86	8.0969	±1.87	8.1117	±1.96
45-54	8.0674	±1.89	8.0255	±1.92	8.0465	±2.13
54-63	7.9828	±1.90	7.9257	±1.92	7.9542	±2.24
63-72	7.9352	±1.96	7.8200	±2.10	7.8776	±2.90
72-81	7.7496	±2.22	7.4515	±4.12	7.6005	±6.93
81-90	7.5374	*	6.7470	*	7.1422	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

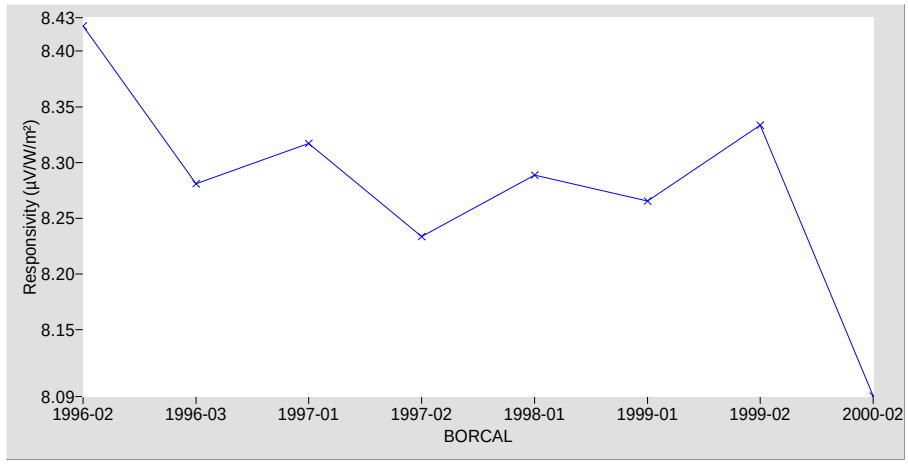
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0906	+1.61 / -2.81 [1]
45° - 55°	8.0392	±2.04 [2]
Composite	8.1109	+2.13 / -14.96 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.7°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



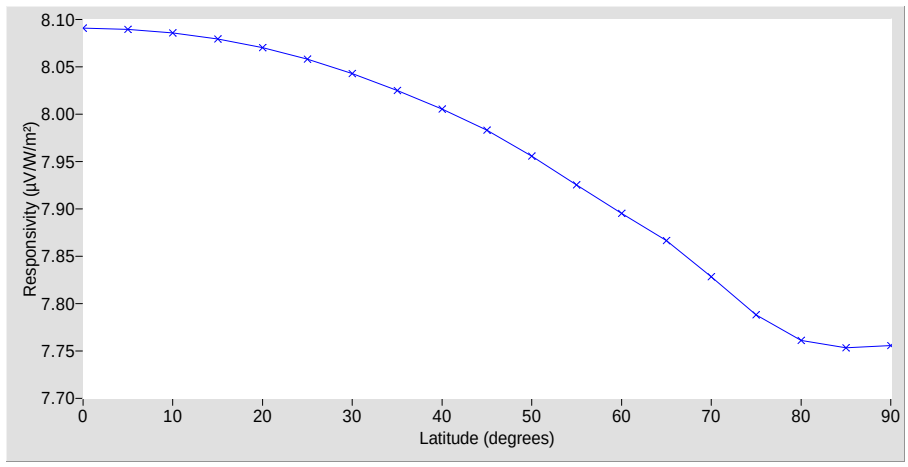
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0907	+2.78 / -20.24
5	8.0896	+2.79 / -20.23
10	8.0858	+2.83 / -20.19
15	8.0793	+2.89 / -20.12
20	8.0701	+2.98 / -20.03
25	8.0579	+3.10 / -19.91
30	8.0429	+3.19 / -19.76
35	8.0251	+3.29 / -19.59
40	8.0055	+3.37 / -19.39
45	7.9831	+3.40 / -19.17
50	7.9558	+3.53 / -18.89
55	7.9255	+3.64 / -18.58
60	7.8954	+3.69 / -18.27
65	7.8666	+3.74 / -17.97
70	7.8283	+3.84 / -17.57
75	7.7882	+3.89 / -17.15
80	7.7611	+3.66 / -16.86
85	7.7534	+3.28 / -16.78
90	7.7557	+3.26 / -16.81

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31157F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31157F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

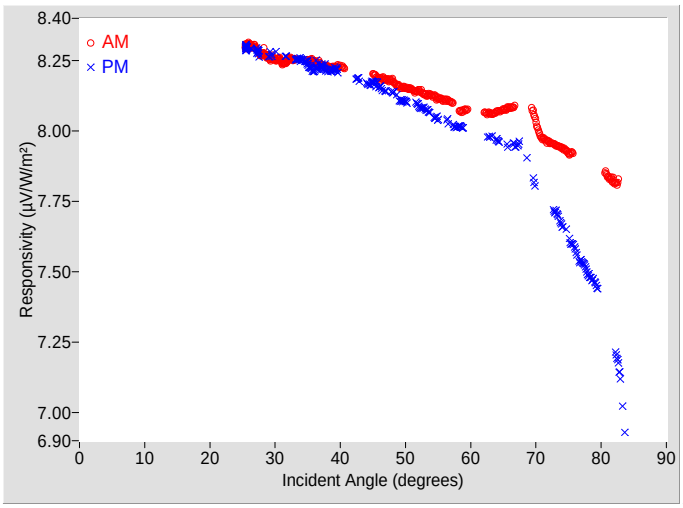


Figure 2. Responsivity vs Local Standard Time

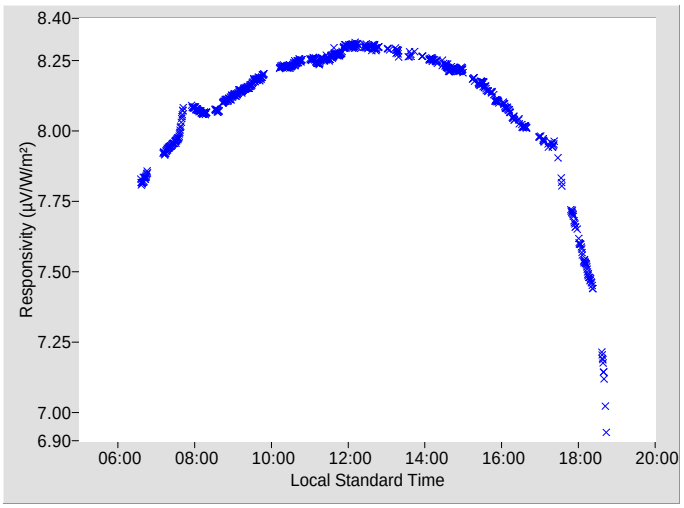


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.1870	+1.65 / -2.84	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1860	0.72	113.03	8.1555	0.72	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1777	0.73	110.65	8.1379	0.70	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1536	0.74	108.51	8.1043	0.72	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1423	0.77	106.38	8.0900	0.75	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1262	0.79	104.45	8.0647	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1095	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0712	N/A	100.08	8.0149	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0668	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0683	1.03	95.31	7.9671	0.96	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0825	1.10	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0314	1.45	90.67	7.8042	N/A	272.42
26	8.3035	0.63	166.67	8.2920	N/A	196.24	72	7.9602	1.44	89.21	N/A	N/A	N/A
28	8.2735	0.63	153.52	N/A	N/A	N/A	74	7.9388	1.62	87.71	7.6649	1.60	275.39
30	8.2529	0.62	144.92	8.2813	N/A	216.88	76	N/A	N/A	N/A	7.5783	1.88	276.88
32	8.2522	0.63	138.40	8.2663	N/A	221.87	78	N/A	N/A	N/A	7.4896	2.17	278.33
34	N/A	N/A	N/A	8.2534	0.66	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2452	0.64	128.62	8.2213	0.68	237.25	82	7.8194	3.47	81.83	7.2145	N/A	281.37
38	8.2291	0.64	124.79	8.2135	0.65	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2285	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.1682	0.67	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31157F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

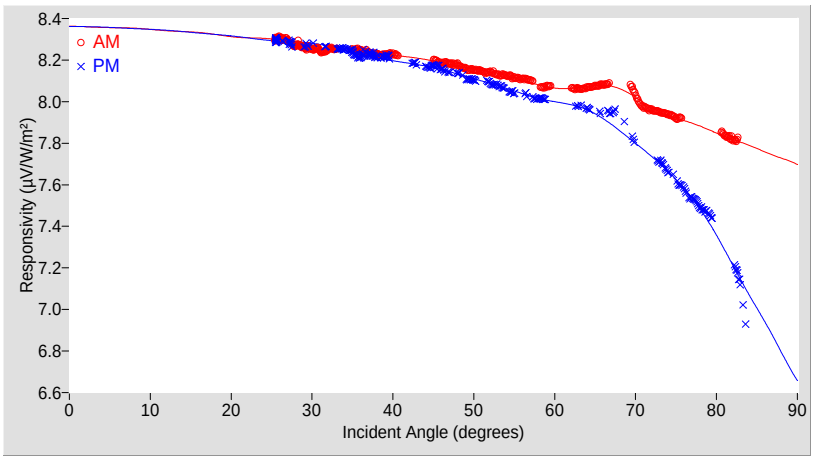


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.57	±1.57
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.6°
R^2	0.9999998	0.9999999

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.3576	*	8.3575	*	8.3575	*
9-18	8.3390	*	8.3388	*	8.3389	*
18-27	8.3076	*	8.3062	*	8.3069	*
27-36	8.2575	±1.58	8.2685	±1.60	8.2630	±1.64
36-45	8.2228	±1.59	8.1964	±1.61	8.2096	±1.70
45-54	8.1632	±1.62	8.1185	±1.67	8.1408	±1.91
54-63	8.0848	±1.61	8.0178	±1.65	8.0513	±2.02
63-72	8.0526	±1.68	7.8765	±2.11	7.9646	±3.41
72-81	7.9046	±1.77	7.5554	±3.15	7.7300	±6.32
81-90	7.7663	*	6.9708	*	7.3685	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

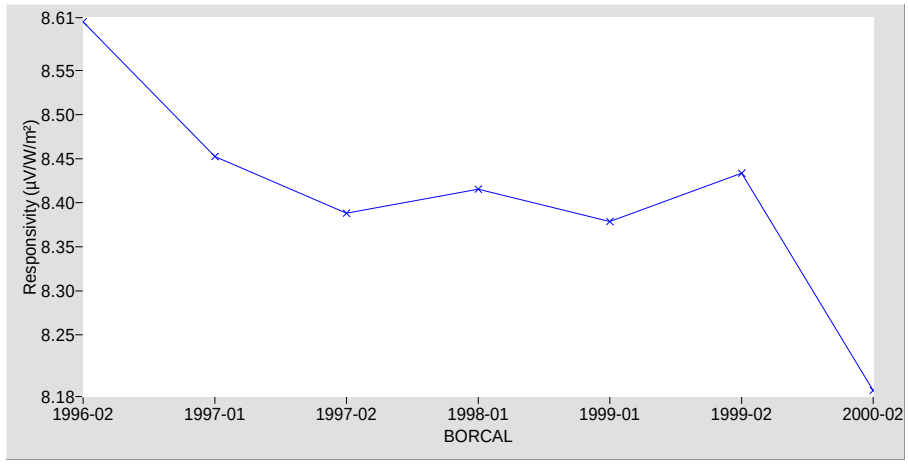
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1870	+1.65 / -2.84 [1]
45° - 55°	8.1335	±1.80 [2]
Composite	8.2122	+1.89 / -13.55 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



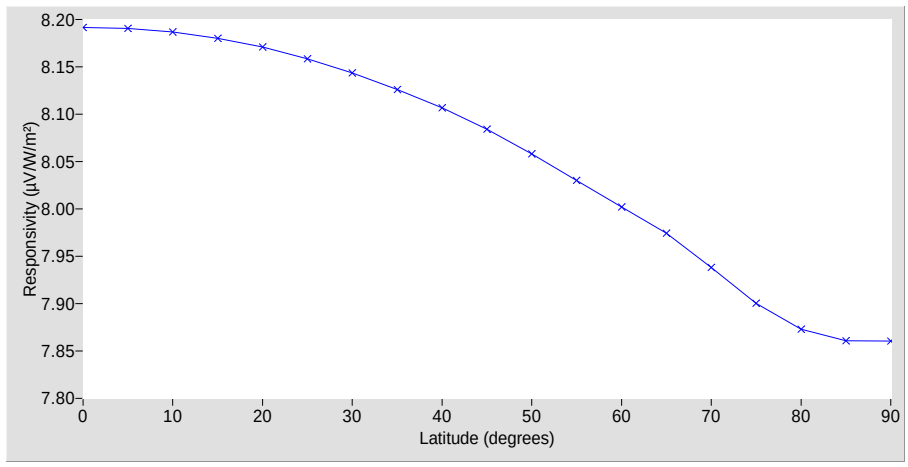
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.1917	+2.61 / -17.99
5	8.1906	+2.62 / -17.98
10	8.1867	+2.66 / -17.95
15	8.1802	+2.73 / -17.88
20	8.1709	+2.82 / -17.79
25	8.1586	+2.94 / -17.66
30	8.1436	+3.04 / -17.51
35	8.1259	+3.13 / -17.33
40	8.1066	+3.20 / -17.14
45	8.0843	+3.22 / -16.91
50	8.0580	+3.33 / -16.64
55	8.0301	+3.43 / -16.35
60	8.0019	+3.41 / -16.06
65	7.9743	+3.45 / -15.77
70	7.9381	+3.51 / -15.38
75	7.9004	+3.53 / -14.98
80	7.8729	+3.32 / -14.69
85	7.8608	+3.19 / -14.56
90	7.8604	+3.19 / -14.55

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31158F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31158F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

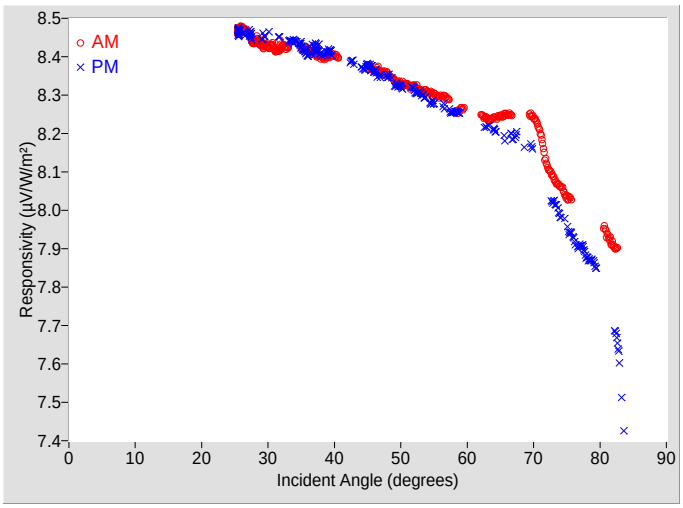


Figure 2. Responsivity vs Local Standard Time

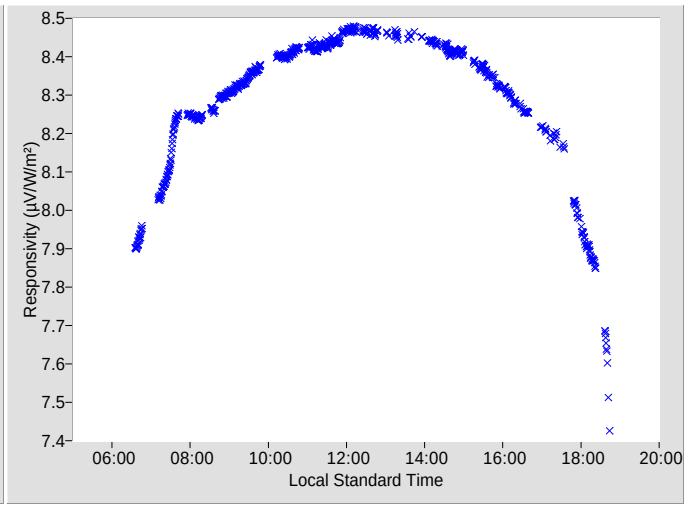


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3774	+1.56 / -2.17	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3639	0.71	113.03	8.3613	0.71	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3550	0.73	110.65	8.3496	0.70	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3322	0.74	108.51	8.3212	0.72	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3233	0.77	106.38	8.3140	0.74	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3092	0.79	104.45	8.2947	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2956	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2593	N/A	100.08	8.2561	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2489	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2409	1.02	95.31	8.2091	0.95	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2498	1.09	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2414	1.31	90.67	8.1597	N/A	272.42
26	8.4714	0.63	166.67	8.4644	N/A	196.24	72	8.1204	1.58	89.21	N/A	N/A	N/A
28	8.4397	0.61	153.52	N/A	N/A	N/A	74	8.0628	1.64	87.71	7.9871	1.56	275.39
30	8.4249	0.61	144.92	8.4653	N/A	216.88	76	N/A	N/A	N/A	7.9255	1.81	276.88
32	8.4273	0.63	138.33	8.4517	N/A	221.87	78	N/A	N/A	N/A	7.8766	2.13	278.33
34	N/A	N/A	N/A	8.4399	0.66	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4178	0.63	128.62	8.4085	0.65	237.89	82	7.9088	3.47	81.83	7.6864	N/A	281.37
38	8.4005	0.64	124.79	8.4066	0.66	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4025	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3717	0.67	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31158F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

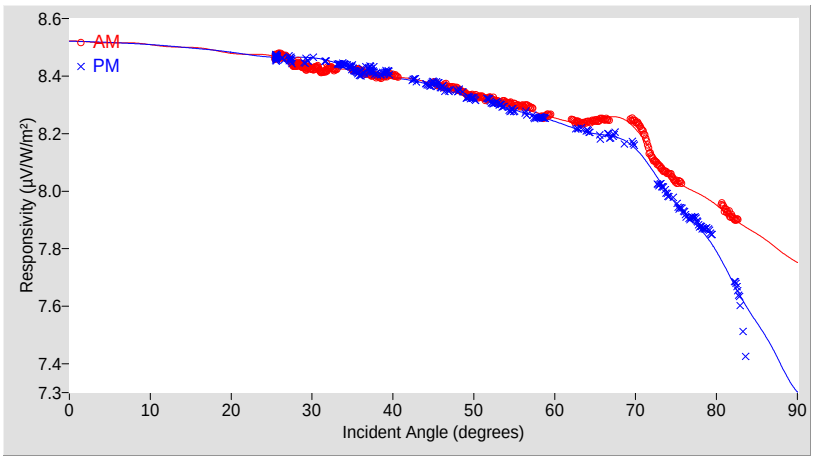


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.56	±1.56
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.6°
R^2	0.9999995	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.5173	*	8.5172	*	8.5173	*
9-18	8.5020	*	8.5018	*	8.5019	*
18-27	8.4756	*	8.4752	*	8.4754	*
27-36	8.4295	±1.58	8.4520	±1.59	8.4408	±1.61
36-45	8.3968	±1.58	8.3929	±1.59	8.3949	±1.61
45-54	8.3421	±1.60	8.3339	±1.62	8.3380	±1.69
54-63	8.2698	±1.62	8.2560	±1.63	8.2629	±1.74
63-72	8.2346	±1.67	8.1768	±1.72	8.2057	±2.15
72-81	8.0237	±1.99	7.9211	±2.51	7.9724	±3.68
81-90	7.8396	*	7.5172	*	7.6784	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

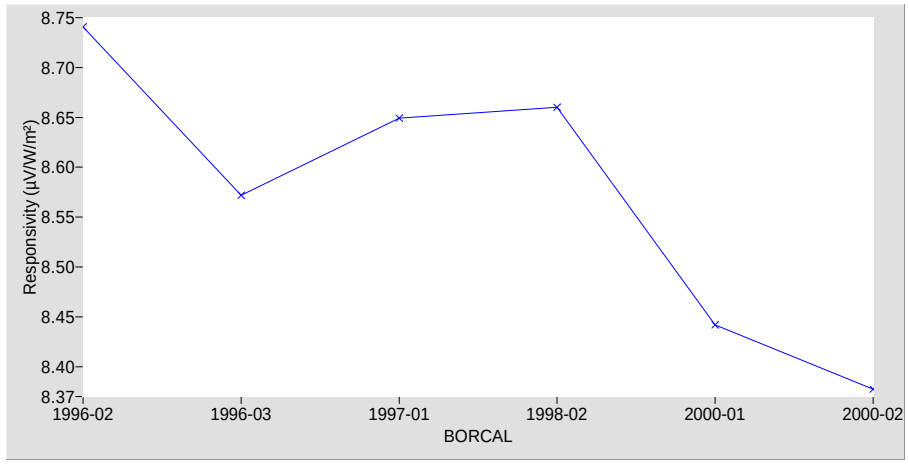
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3774	+1.56 / -2.17 [1]
45° - 55°	8.3318	±1.65 [2]
Composite	8.3967	+1.78 / -9.52 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



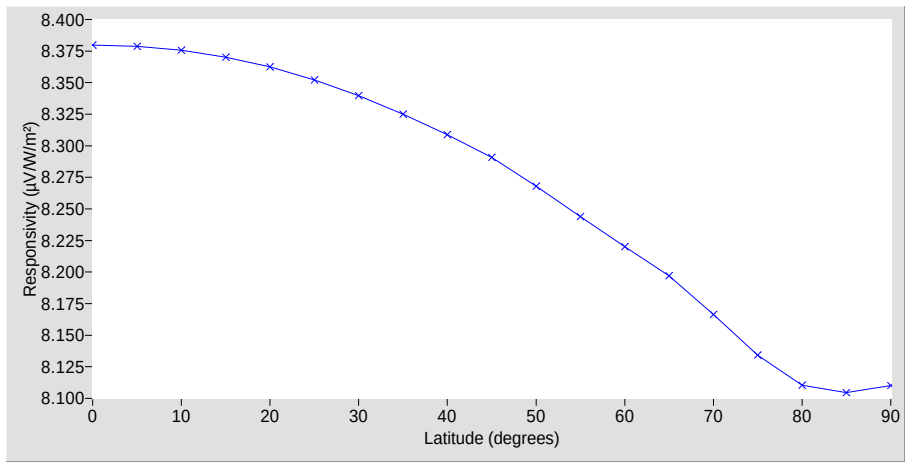
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.3797	+2.31 / -12.48
5	8.3788	+2.32 / -12.47
10	8.3757	+2.35 / -12.44
15	8.3701	+2.40 / -12.38
20	8.3624	+2.47 / -12.30
25	8.3522	+2.56 / -12.20
30	8.3397	+2.63 / -12.07
35	8.3251	+2.69 / -11.91
40	8.3088	+2.76 / -11.74
45	8.2908	+2.76 / -11.55
50	8.2680	+2.85 / -11.31
55	8.2439	+3.05 / -11.05
60	8.2201	+2.85 / -10.80
65	8.1972	+2.88 / -10.55
70	8.1665	+2.87 / -10.22
75	8.1343	+2.90 / -9.87
80	8.1104	+2.68 / -9.60
85	8.1046	+2.46 / -9.54
90	8.1101	+2.41 / -9.60

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31159F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31159F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

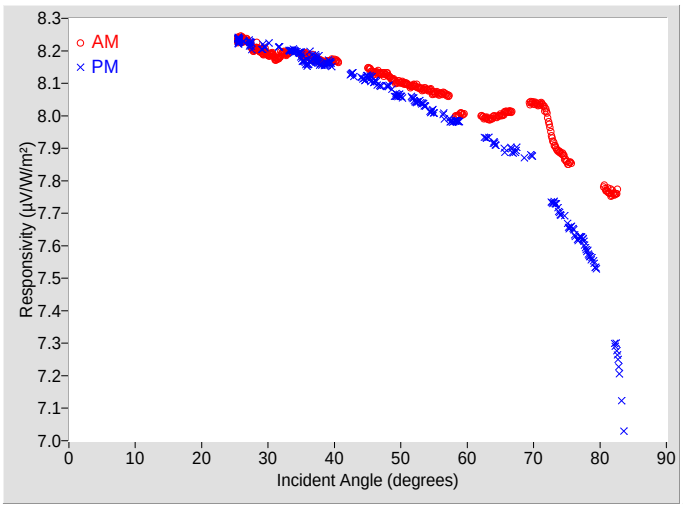


Figure 2. Responsivity vs Local Standard Time

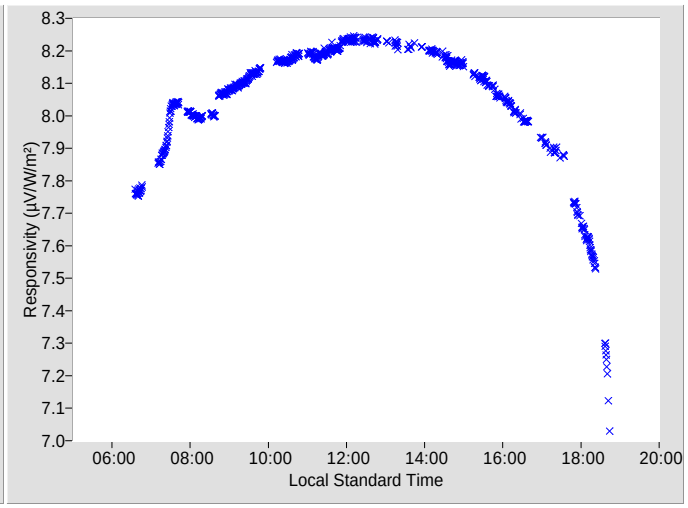


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.1333	+1.66 / -2.57	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1328	0.71	113.03	8.1053	0.71	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1261	0.73	110.65	8.0917	0.70	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1035	0.74	108.51	8.0602	0.72	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0929	0.76	106.38	8.0493	0.74	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0804	0.79	104.45	8.0288	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0674	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9993	N/A	100.08	7.9825	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0004	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9970	1.03	95.31	7.9154	0.96	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0121	1.10	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0397	1.29	90.67	7.8760	N/A	272.42
26	8.2351	0.63	166.67	8.2300	N/A	196.24	72	8.0057	1.61	89.21	N/A	N/A	N/A
28	8.2066	0.62	153.52	N/A	N/A	N/A	74	7.8875	1.65	87.71	7.6991	1.57	275.39
30	8.1876	0.62	144.92	8.2241	N/A	216.88	76	N/A	N/A	N/A	7.6447	1.82	276.88
32	8.1890	0.63	138.40	8.2127	N/A	221.87	78	N/A	N/A	N/A	7.5846	2.17	278.33
34	N/A	N/A	N/A	8.1989	0.66	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1839	0.64	128.62	8.1665	0.69	237.25	82	7.7604	3.47	81.83	7.2990	N/A	281.37
38	8.1683	0.65	124.79	8.1575	0.67	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1696	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.1168	0.67	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31159F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

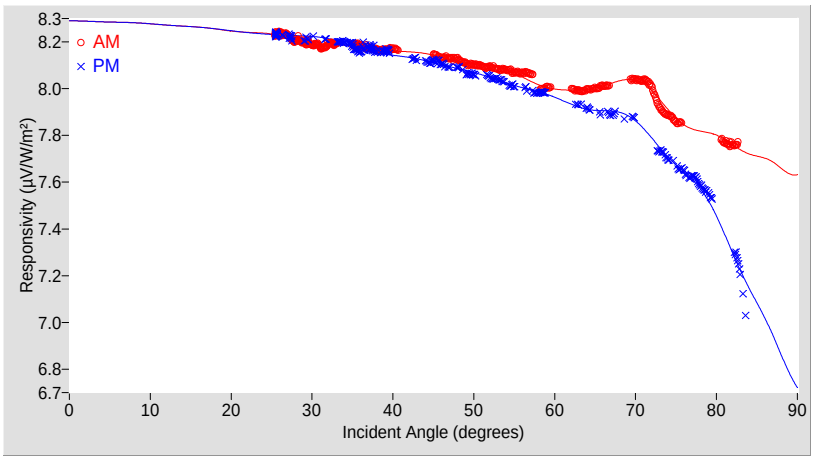


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.57	±1.57
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.6°
R^2	0.9999993	0.9999996

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2860	*	8.2859	*	8.2860	*
9-18	8.2694	*	8.2693	*	8.2693	*
18-27	8.2408	*	8.2405	*	8.2407	*
27-36	8.1933	±1.59	8.2123	±1.60	8.2028	±1.63
36-45	8.1645	±1.59	8.1423	±1.61	8.1534	±1.68
45-54	8.1130	±1.61	8.0737	±1.65	8.0934	±1.86
54-63	8.0241	±1.66	7.9801	±1.69	8.0021	±2.08
63-72	8.0179	±1.60	7.8883	±1.72	7.9531	±2.63
72-81	7.8644	±2.01	7.6247	±2.90	7.7446	±5.52
81-90	7.7026	*	7.0452	*	7.3739	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

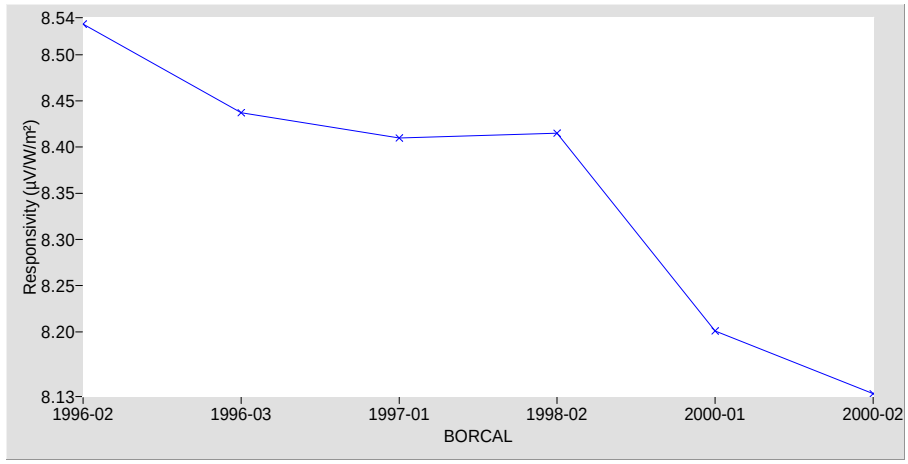
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.1333	+1.66 / -2.57 [1]
45° - 55°	8.0867	±1.76 [2]
Composite	8.1570	+1.82 / -12.04 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



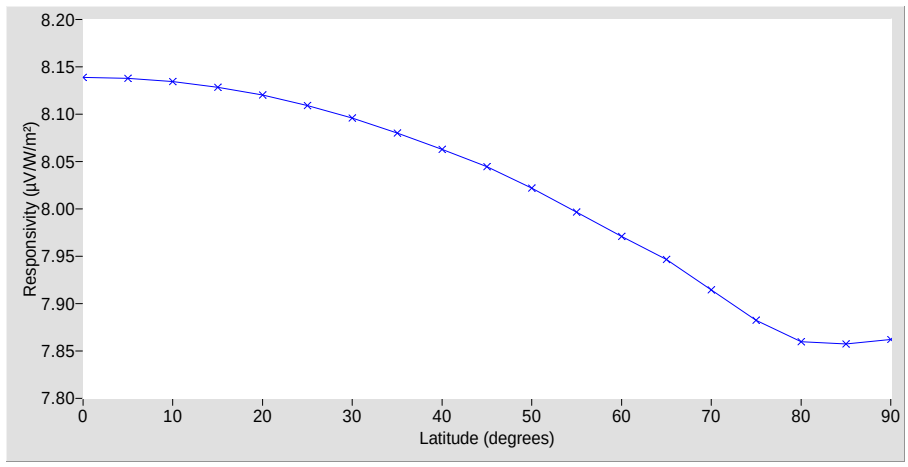
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.1387	+2.44 / -16.72
5	8.1377	+2.45 / -16.71
10	8.1344	+2.48 / -16.67
15	8.1284	+2.54 / -16.61
20	8.1202	+2.62 / -16.53
25	8.1093	+2.73 / -16.42
30	8.0959	+2.81 / -16.28
35	8.0800	+2.88 / -16.11
40	8.0628	+2.94 / -15.94
45	8.0446	+2.93 / -15.75
50	8.0220	+3.03 / -15.51
55	7.9967	+3.20 / -15.24
60	7.9710	+3.10 / -14.97
65	7.9466	+3.11 / -14.71
70	7.9147	+3.19 / -14.37
75	7.8825	+3.21 / -14.02
80	7.8599	+2.88 / -13.78
85	7.8573	+2.80 / -13.75
90	7.8623	+2.75 / -13.80

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31160F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31160F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

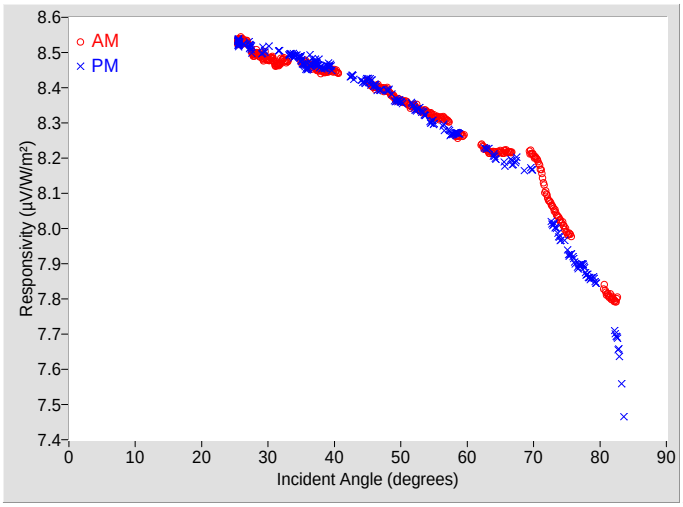


Figure 2. Responsivity vs Local Standard Time

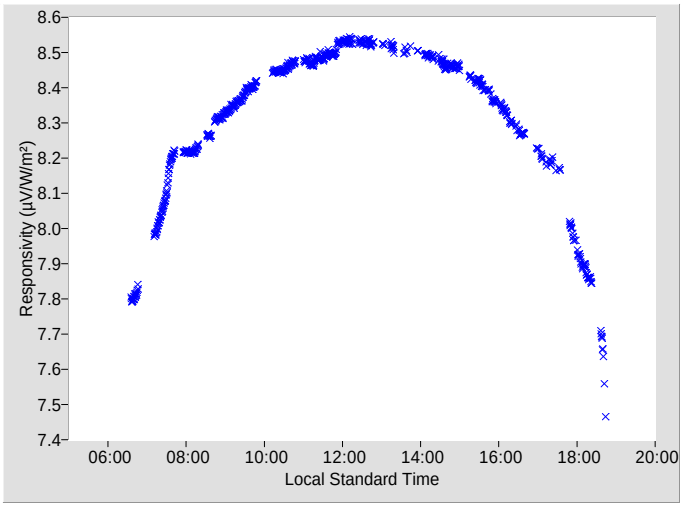


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4203	+1.69 / -2.63	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4017	0.71	113.03	8.4058	0.71	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3929	0.73	110.65	8.3929	0.70	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3635	0.74	108.51	8.3597	0.72	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3482	0.77	106.38	8.3447	0.74	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3299	0.79	104.45	8.3211	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3133	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2643	N/A	100.08	8.2700	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2388	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2172	1.02	95.31	8.2056	0.97	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2188	1.09	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2071	1.31	90.67	8.1666	N/A	272.42
26	8.5329	0.63	166.67	8.5245	N/A	196.24	72	8.0950	1.57	89.21	N/A	N/A	N/A
28	8.4961	0.63	153.74	N/A	N/A	N/A	74	8.0229	1.66	87.71	7.9708	1.57	275.39
30	8.4797	0.63	144.92	8.5186	N/A	216.88	76	N/A	N/A	N/A	7.9131	1.81	276.88
32	8.4759	0.62	138.40	8.5053	N/A	221.87	78	N/A	N/A	N/A	7.8683	2.13	278.33
34	N/A	N/A	N/A	8.4911	0.66	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4670	0.64	128.62	8.4628	0.68	237.25	82	7.7989	3.47	81.83	7.7103	N/A	281.37
38	8.4489	0.65	124.79	8.4575	0.65	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4470	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4187	0.67	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31160F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

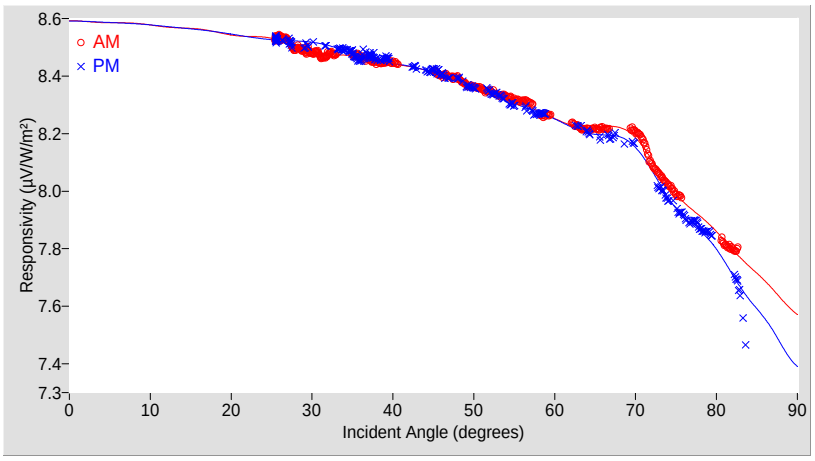


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.56	±1.56
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.6°
R^2	0.9999995	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.5871	*	8.5870	*	8.5870	*
9-18	8.5690	*	8.5688	*	8.5689	*
18-27	8.5378	*	8.5372	*	8.5375	*
27-36	8.4818	±1.58	8.5060	±1.59	8.4939	±1.63
36-45	8.4414	±1.59	8.4425	±1.59	8.4420	±1.62
45-54	8.3745	±1.63	8.3726	±1.65	8.3736	±1.73
54-63	8.2748	±1.68	8.2693	±1.68	8.2721	±1.83
63-72	8.2055	±1.66	8.1780	±1.72	8.1917	±2.00
72-81	7.9639	±2.28	7.9138	±2.43	7.9388	±3.35
81-90	7.6985	*	7.5695	*	7.6340	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

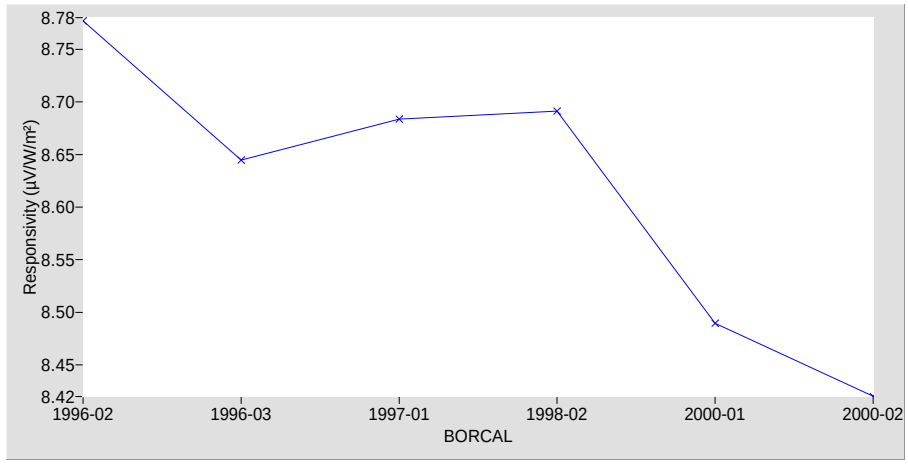
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4203	+1.69 / -2.63 [1]
45° - 55°	8.3654	±1.69 [2]
Composite	8.4413	+1.87 / -9.57 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



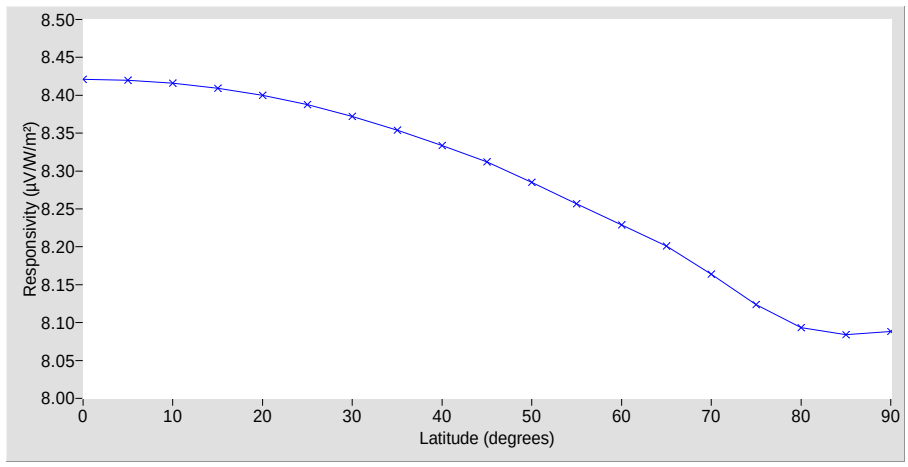
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.4209	+2.57 / -11.96
5	8.4198	+2.58 / -11.95
10	8.4159	+2.62 / -11.91
15	8.4093	+2.68 / -11.84
20	8.4000	+2.77 / -11.74
25	8.3876	+2.89 / -11.61
30	8.3721	+2.98 / -11.45
35	8.3540	+3.07 / -11.26
40	8.3338	+3.17 / -11.05
45	8.3120	+3.17 / -10.82
50	8.2852	+3.28 / -10.53
55	8.2569	+3.47 / -10.23
60	8.2289	+3.30 / -9.93
65	8.2010	+3.30 / -9.62
70	8.1638	+3.33 / -9.22
75	8.1238	+3.31 / -8.78
80	8.0934	+3.02 / -8.44
85	8.0839	+2.48 / -8.33
90	8.0883	+2.30 / -8.38

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31387E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31387E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

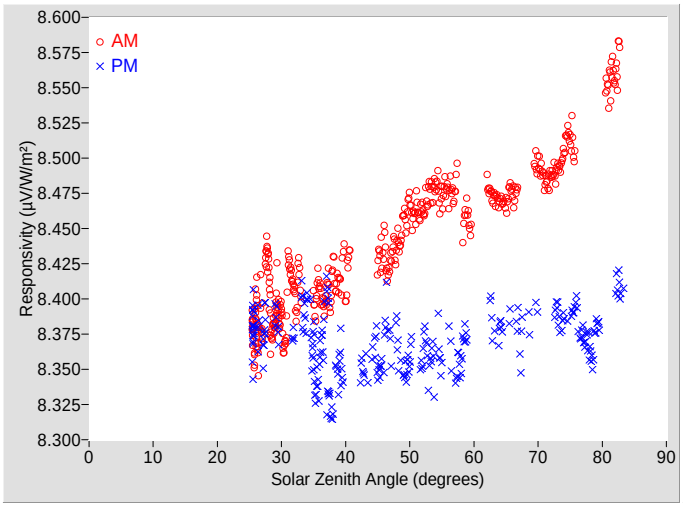


Figure 2. Responsivity vs Local Standard Time

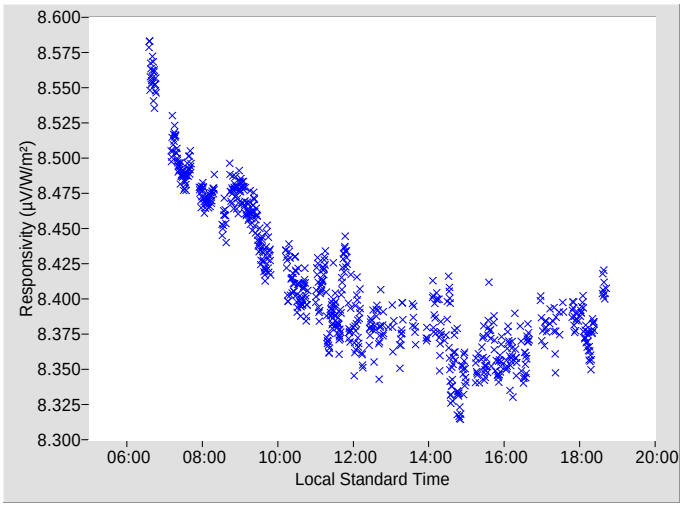


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3931	+1.66 / -1.37	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4362	0.49	112.98	8.3716	0.60	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4364	0.48	110.72	8.3709	0.50	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4687	0.47	108.46	8.3594	0.47	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4634	0.46	106.43	8.3602	0.51	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4808	0.47	104.46	8.3302	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4761	0.46	102.63	8.3806	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4401	N/A	100.03	8.3560	0.50	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4815	0.46	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4700	0.45	95.32	8.3788	0.45	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4744	0.47	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4947	0.49	90.67	8.3908	N/A	272.46
26	8.3806	0.61	166.57	8.3837	0.57	192.79	72	8.4867	0.48	89.17	N/A	N/A	N/A
28	8.4182	0.66	153.70	N/A	N/A	N/A	74	8.5047	0.51	87.71	8.3846	0.48	275.35
30	8.3828	0.57	144.94	N/A	N/A	N/A	76	8.5052	N/A	86.44	8.3926	0.51	276.91
32	8.4031	0.52	138.30	8.3741	0.44	222.24	78	N/A	N/A	N/A	8.3635	0.51	278.33
34	N/A	N/A	N/A	8.3948	0.58	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4075	0.48	128.63	8.3579	0.61	237.13	82	8.5588	0.65	81.83	8.4109	0.58	281.36
38	8.4159	0.49	124.80	8.3177	0.75	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4131	0.50	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3615	0.50	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31387E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

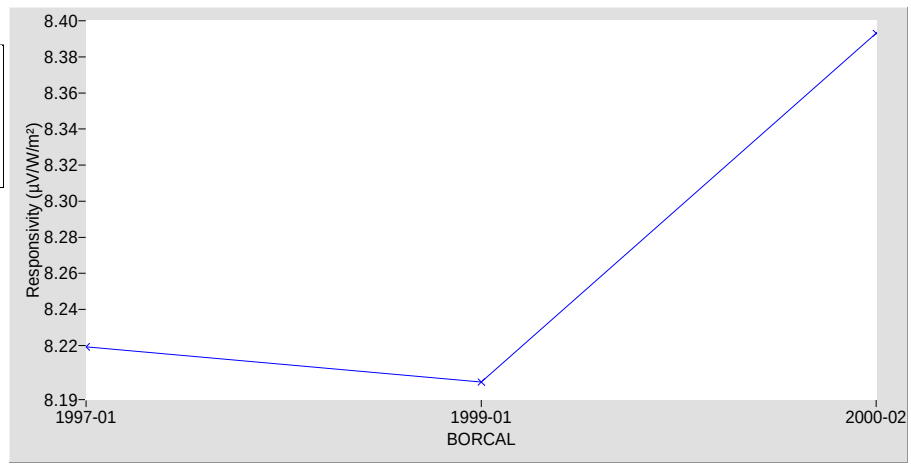
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3931	+1.66 / -1.37 †
Average	8.4144	+2.38 / -1.89 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 31388E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

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Number of pages of certificate: 3

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Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31388E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

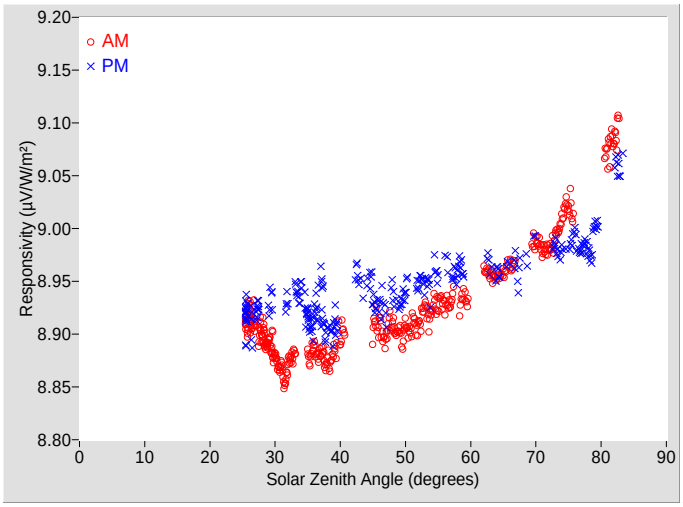


Figure 2. Responsivity vs Local Standard Time

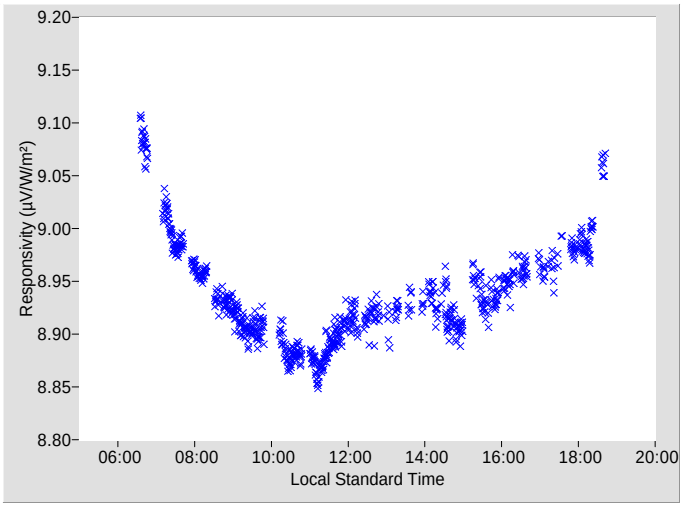


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9226	+1.02 / -1.16	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9073	0.49	112.98	8.9244	0.47	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9081	0.46	110.72	8.9388	0.50	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9076	0.46	108.46	8.9426	0.46	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9086	0.46	106.43	8.9483	0.44	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9211	0.48	104.46	8.9250	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9278	0.45	102.63	8.9746	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9171	N/A	100.03	8.9589	0.46	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9606	0.45	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9540	0.45	95.32	8.9588	0.44	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9654	0.46	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.9867	0.47	90.67	8.9929	N/A	272.46
26	8.9156	0.47	166.57	8.9189	0.51	192.79	72	8.9811	0.47	89.17	N/A	N/A	N/A
28	8.9028	0.46	153.70	N/A	N/A	N/A	74	9.0102	0.51	87.71	8.9783	0.47	275.35
30	8.8780	0.48	144.94	N/A	N/A	N/A	76	9.0142	N/A	86.44	8.9927	0.48	276.91
32	8.8707	0.48	138.30	8.9319	0.44	222.24	78	N/A	N/A	N/A	8.9780	0.52	278.33
34	N/A	N/A	N/A	8.9429	0.49	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8865	0.45	128.63	8.9182	0.52	237.13	82	9.0846	0.64	81.83	9.0627	0.56	281.36
38	8.8730	0.45	124.80	8.9014	0.60	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8997	0.48	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.9494	0.46	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31388E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

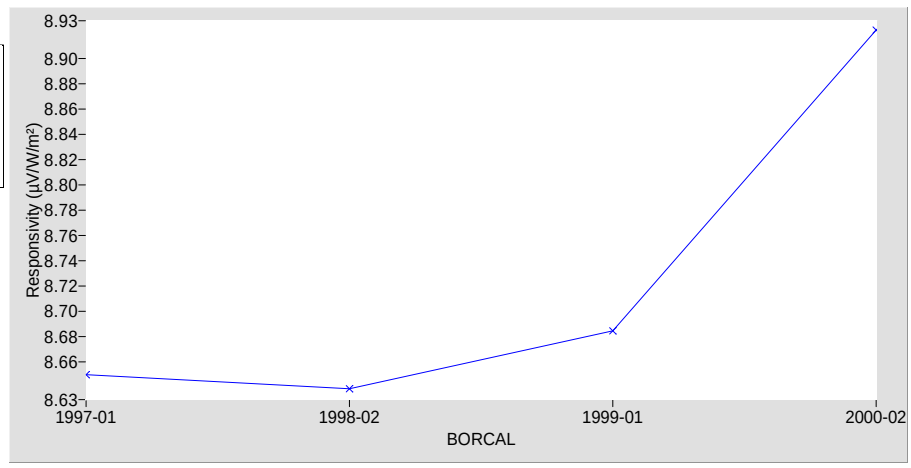
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9226	+1.02 / -1.16 †
Average	8.9457	+2.20 / -1.31 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

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:** 31629F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31629F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

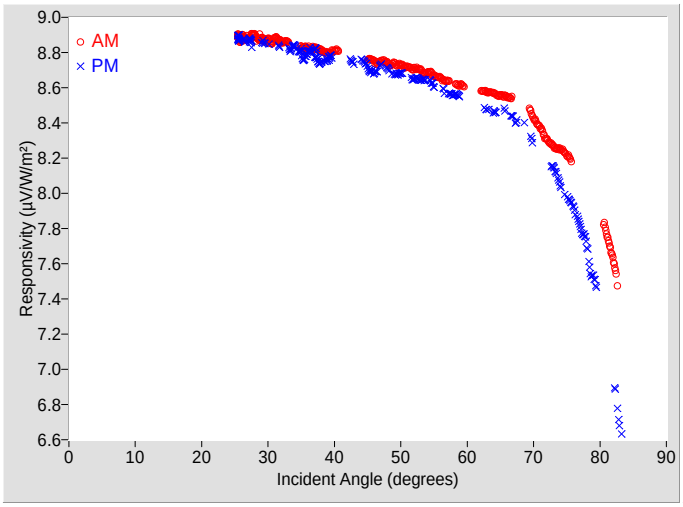


Figure 2. Responsivity vs Local Standard Time

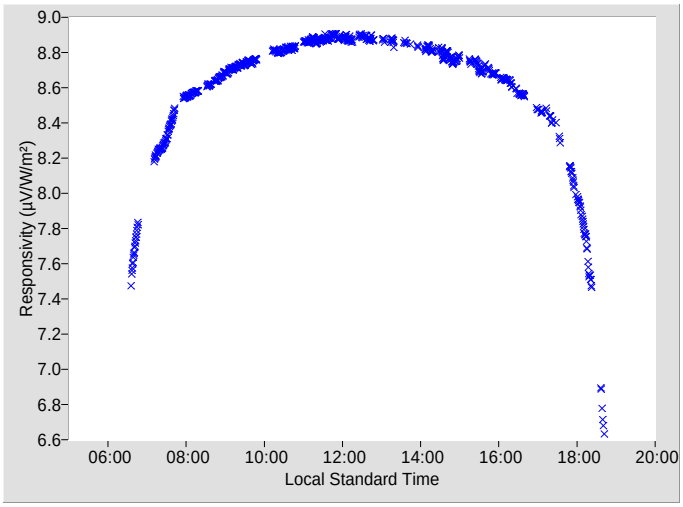


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.7392	+2.39 / -2.80	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7509	0.72	113.03	8.6876	0.74	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7396	0.74	110.65	8.7071	0.76	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7318	0.75	108.51	8.6820	0.71	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7070	0.76	106.38	8.6502	0.73	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6861	0.80	104.45	8.6445	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6546	0.83	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6223	N/A	100.08	8.5596	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5827	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5706	1.02	95.31	8.4619	0.95	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5484	1.10	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4265	1.42	90.67	8.2878	N/A	272.42
26	8.8784	0.67	166.67	8.8716	N/A	196.24	72	8.3064	1.54	89.21	N/A	N/A	N/A
28	8.8937	0.64	153.52	N/A	N/A	N/A	74	8.2513	1.62	87.71	8.0530	1.80	275.39
30	8.8749	0.63	144.92	8.8469	N/A	216.88	76	N/A	N/A	N/A	7.9150	2.03	276.88
32	8.8624	0.64	138.33	8.8296	N/A	221.87	78	N/A	N/A	N/A	7.7129	2.80	278.29
34	N/A	N/A	N/A	8.8378	0.68	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8246	0.64	128.62	8.8058	0.76	237.25	82	7.6209	3.92	81.83	6.8941	N/A	281.37
38	8.8145	0.66	124.79	8.7404	0.83	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8101	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.7583	0.70	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31629F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

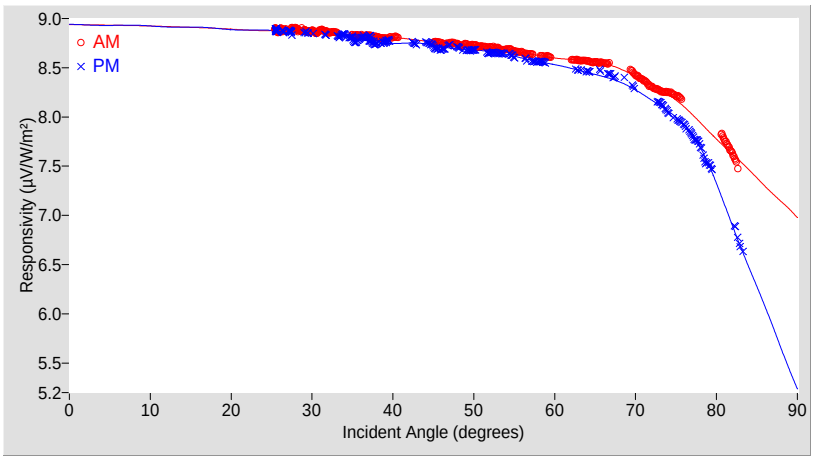


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.78	±1.78
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.3°
R²	0.9999996	0.9999987

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.9331	*	8.9333	*	8.9332	*
9-18	8.9150	*	8.9154	*	8.9152	*
18-27	8.8855	*	8.8838	*	8.8846	*
27-36	8.8646	±1.81	8.8405	±1.81	8.8525	±1.90
36-45	8.8013	±1.82	8.7541	±1.81	8.7777	±1.92
45-54	8.7303	±1.83	8.6849	±1.85	8.7076	±2.01
54-63	8.6256	±1.88	8.5603	±1.99	8.5930	±2.44
63-72	8.4950	±2.23	8.3617	±2.43	8.4284	±3.73
72-81	8.0623	±4.09	7.8190	±6.34	7.9407	±10.47
81-90	7.3406	*	6.1685	*	6.7546	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

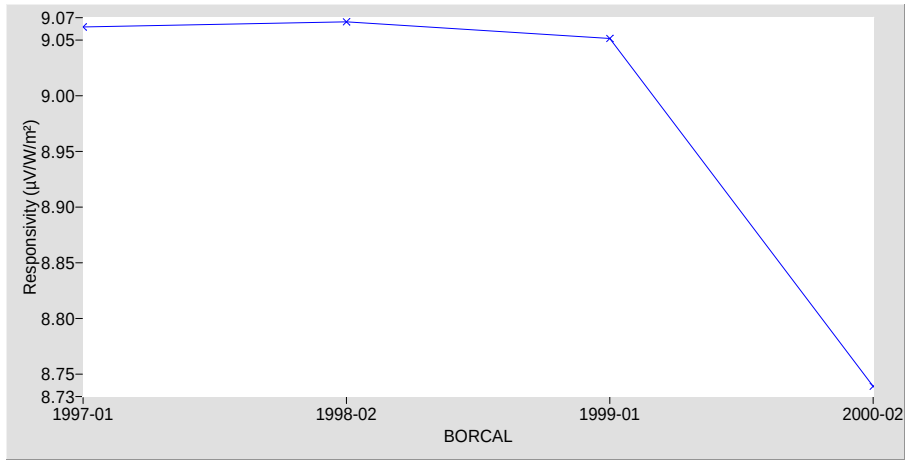
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.7392	+2.39 / -2.80 [1]
45° - 55°	8.6997	±1.96 [2]
Composite	8.7533	+2.34 / -23.79 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



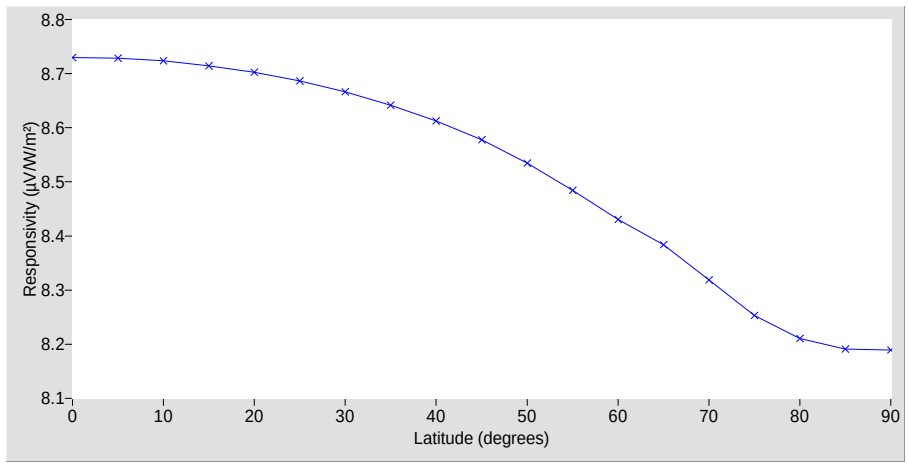
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.7298	+3.00 / -37.77
5	8.7286	+3.01 / -37.77
10	8.7237	+3.06 / -37.73
15	8.7146	+3.15 / -37.66
20	8.7025	+3.26 / -37.58
25	8.6864	+3.41 / -37.46
30	8.6664	+3.55 / -37.32
35	8.6415	+3.70 / -37.14
40	8.6123	+3.91 / -36.93
45	8.5774	+4.02 / -36.67
50	8.5347	+4.49 / -36.35
55	8.4842	+4.92 / -35.97
60	8.4307	+5.00 / -35.57
65	8.3839	+5.28 / -35.21
70	8.3190	+5.51 / -34.70
75	8.2529	+5.93 / -34.18
80	8.2106	+5.70 / -33.84
85	8.1910	+5.19 / -33.68
90	8.1891	+4.71 / -33.67

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31630F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31630F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

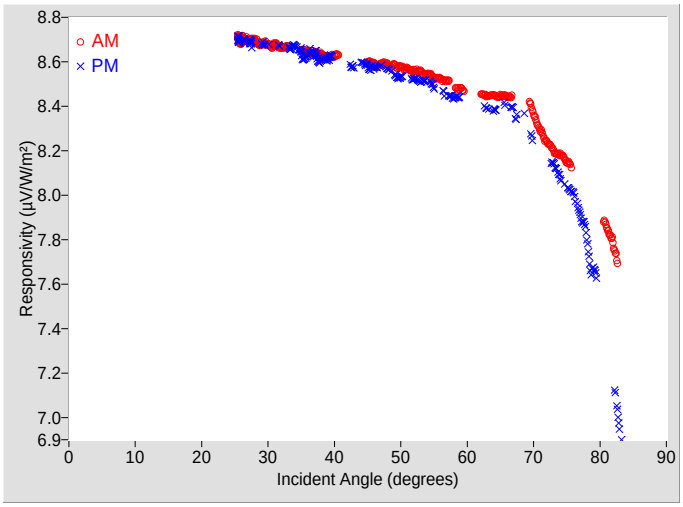


Figure 2. Responsivity vs Local Standard Time

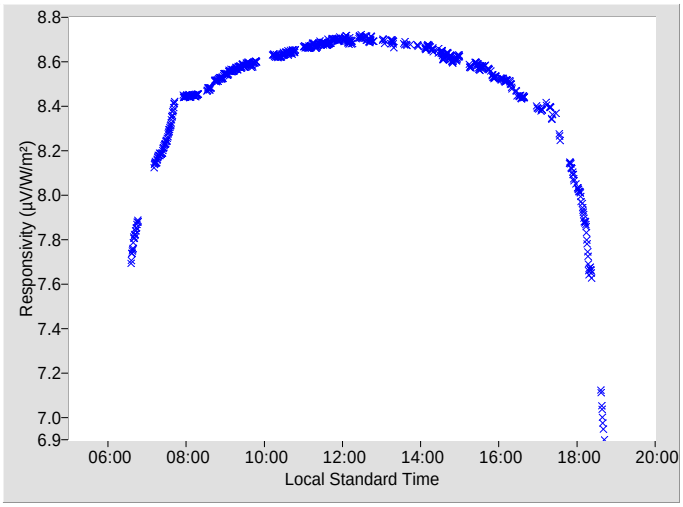


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.5896	+1.78 / -2.50	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5911	0.72	113.03	8.5760	0.69	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5870	0.73	110.65	8.5673	0.71	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5784	0.74	108.51	8.5322	0.72	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5595	0.76	106.38	8.5224	0.74	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5454	0.80	104.45	8.5161	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5225	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4840	N/A	100.08	8.4376	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4545	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4497	1.02	95.31	8.3841	0.95	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4436	1.09	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3646	1.48	90.67	8.2464	N/A	272.42
26	8.6973	0.66	166.67	8.6969	N/A	196.24	72	8.2398	1.52	89.21	N/A	N/A	N/A
28	8.6952	0.62	153.52	N/A	N/A	N/A	74	8.1822	1.64	87.71	8.0807	1.63	275.39
30	8.6782	0.62	144.92	8.6776	N/A	216.88	76	N/A	N/A	N/A	8.0012	1.91	276.88
32	8.6646	0.62	138.40	8.6696	N/A	221.87	78	N/A	N/A	N/A	7.8024	2.73	278.33
34	N/A	N/A	N/A	8.6717	0.67	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6419	0.64	128.62	8.6356	0.70	237.25	82	7.7783	3.62	81.83	7.1237	N/A	281.37
38	8.6349	0.65	124.79	8.6053	0.71	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6255	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.5972	0.67	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31630F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

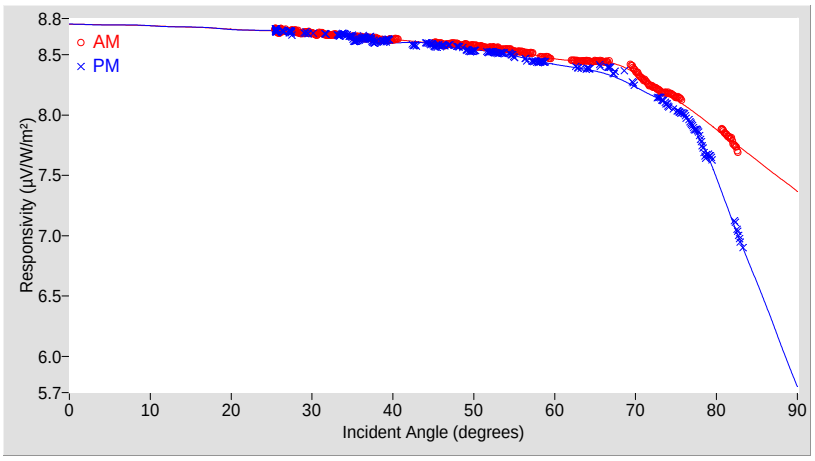


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.68	±1.68
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.3°
R^2	0.9999997	0.9999995

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.7482	*	8.7483	*	8.7483	*
9-18	8.7323	*	8.7325	*	8.7324	*
18-27	8.7054	*	8.7052	*	8.7053	*
27-36	8.6707	±1.71	8.6735	±1.70	8.6721	±1.74
36-45	8.6229	±1.70	8.6061	±1.70	8.6145	±1.73
45-54	8.5777	±1.71	8.5489	±1.74	8.5633	±1.83
54-63	8.4911	±1.77	8.4456	±1.81	8.4684	±2.10
63-72	8.4029	±1.96	8.3051	±2.10	8.3540	±2.92
72-81	8.0646	±3.03	7.8952	±5.18	7.9799	±8.35
81-90	7.5984	*	6.5220	*	7.0602	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

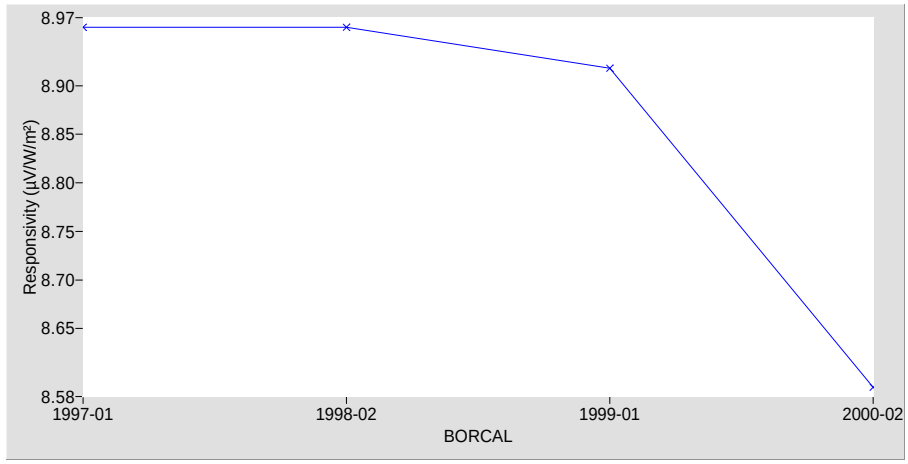
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.5896	+1.78 / -2.50 [1]
45° - 55°	8.5568	±1.79 [2]
Composite	8.6018	+2.02 / -19.35 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



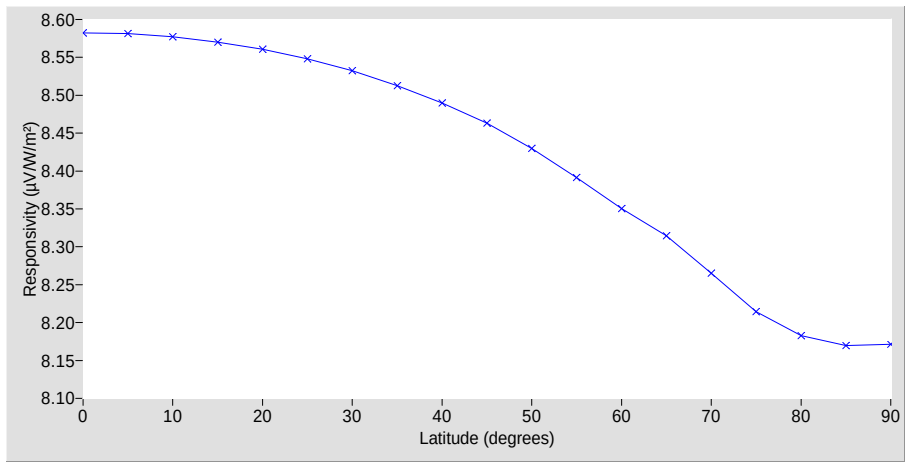
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.5822	+2.61 / -31.12
5	8.5812	+2.62 / -31.11
10	8.5772	+2.66 / -31.08
15	8.5702	+2.73 / -31.02
20	8.5607	+2.82 / -30.94
25	8.5482	+2.93 / -30.84
30	8.5324	+3.03 / -30.71
35	8.5127	+3.13 / -30.55
40	8.4900	+3.28 / -30.37
45	8.4631	+3.34 / -30.15
50	8.4299	+3.59 / -29.87
55	8.3913	+3.80 / -29.55
60	8.3503	+3.88 / -29.21
65	8.3146	+4.05 / -28.90
70	8.2650	+4.31 / -28.48
75	8.2143	+4.66 / -28.03
80	8.1828	+4.44 / -27.76
85	8.1698	+3.91 / -27.64
90	8.1715	+3.74 / -27.66

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:**	31631F3
Calibration Date:	8/24/2000	**Due Date:**	8/24/2001
Customer:	Dan Nelson	**Calibration Site Parameters:**	see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31631F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

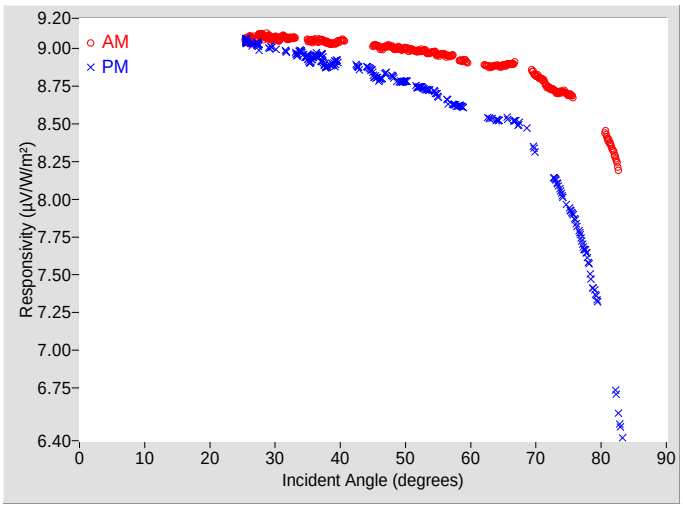


Figure 2. Responsivity vs Local Standard Time

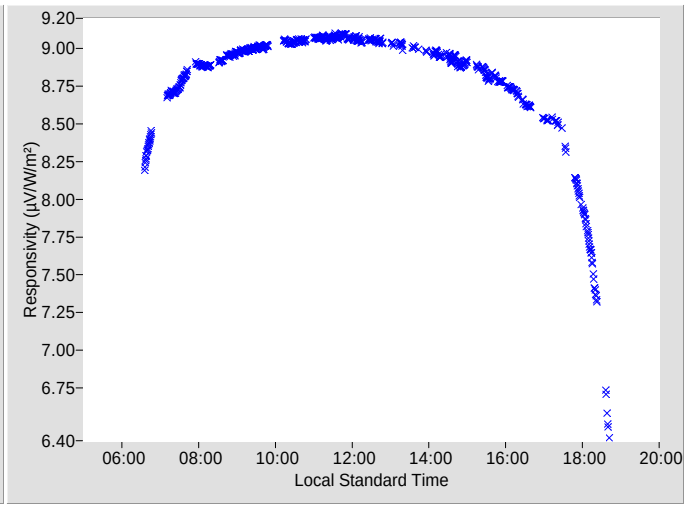


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9270	+2.47 / -4.21	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0099	0.72	113.03	8.7941	0.75	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0068	0.73	110.65	8.8149	0.77	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0014	0.74	108.51	8.7835	0.71	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9832	0.76	106.38	8.7435	0.74	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9753	0.80	104.45	8.7255	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9569	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9197	N/A	100.08	8.6187	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8911	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8885	1.02	95.31	8.5246	0.95	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8965	1.10	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.8215	1.33	90.67	8.3137	N/A	272.42
26	9.0607	0.67	166.67	9.0321	N/A	196.24	72	8.7400	1.48	89.21	N/A	N/A	N/A
28	9.0864	0.64	153.52	N/A	N/A	N/A	74	8.7132	1.61	87.71	8.0323	1.83	275.39
30	9.0745	0.63	144.92	8.9948	N/A	216.88	76	N/A	N/A	N/A	7.8582	2.18	276.88
32	9.0668	0.63	138.33	8.9748	N/A	221.87	78	N/A	N/A	N/A	7.6030	2.94	278.29
34	N/A	N/A	N/A	8.9816	0.74	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0508	0.64	128.62	8.9523	0.74	237.25	82	8.3023	3.65	81.83	6.7347	N/A	281.37
38	9.0428	0.66	124.79	8.8770	0.82	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0500	0.67	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.8781	0.70	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31631F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

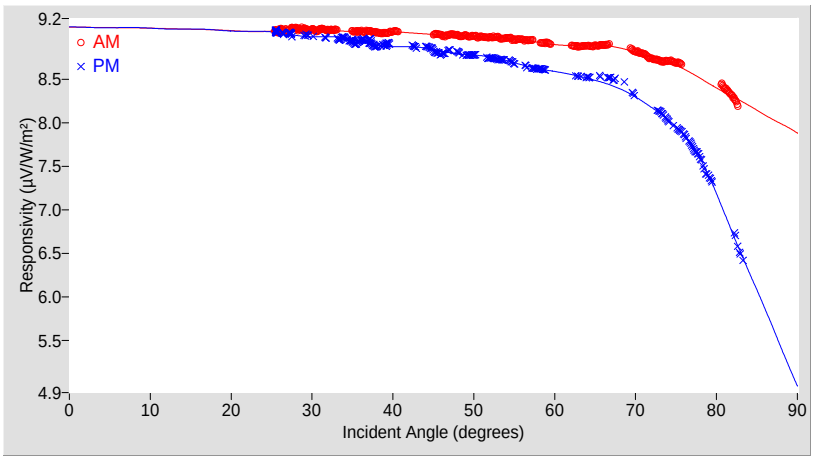


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.75	±1.75
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.3°
R^2	0.9999997	0.9999987

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.0968	*	9.0970	*	9.0969	*
9-18	9.0812	*	9.0814	*	9.0813	*
18-27	9.0578	*	9.0521	*	9.0549	*
27-36	9.0686	±1.76	8.9886	±1.80	9.0286	±2.05
36-45	9.0407	±1.76	8.8847	±1.82	8.9627	±2.35
45-54	8.9997	±1.77	8.7866	±1.87	8.8932	±2.89
54-63	8.9260	±1.82	8.6254	±2.02	8.7757	±3.87
63-72	8.8579	±1.89	8.4032	±2.63	8.6306	±6.04
72-81	8.5887	±2.83	7.7514	±7.32	8.1701	±15.31
81-90	8.1197	*	5.9655	*	7.0426	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

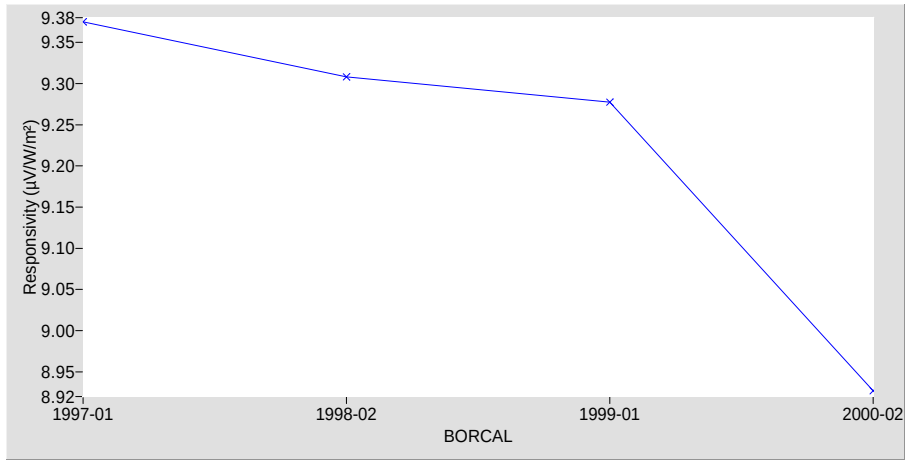
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9270	+2.47 / -4.21 [1]
45° - 55°	8.8852	±2.54 [2]
Composite	8.9323	+2.42 / -27.21 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



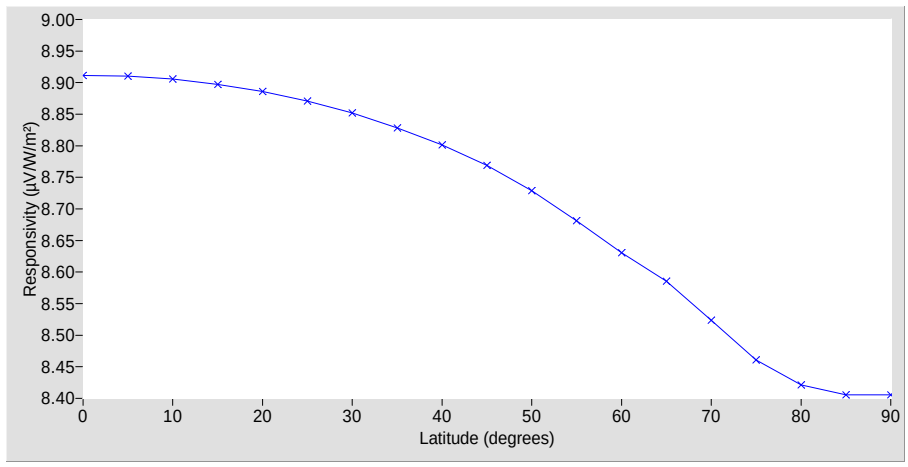
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.9112	+2.78 / -41.78
5	8.9101	+2.79 / -41.78
10	8.9056	+2.83 / -41.75
15	8.8972	+2.91 / -41.69
20	8.8859	+3.01 / -41.62
25	8.8707	+3.14 / -41.52
30	8.8519	+3.28 / -41.39
35	8.8283	+3.41 / -41.24
40	8.8011	+3.64 / -41.05
45	8.7688	+3.97 / -40.84
50	8.7289	+4.40 / -40.57
55	8.6813	+4.88 / -40.24
60	8.6305	+5.16 / -39.89
65	8.5856	+5.60 / -39.58
70	8.5237	+6.01 / -39.14
75	8.4609	+6.53 / -38.69
80	8.4214	+6.56 / -38.40
85	8.4054	+6.09 / -38.28
90	8.4054	+6.04 / -38.28

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31632F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31632F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

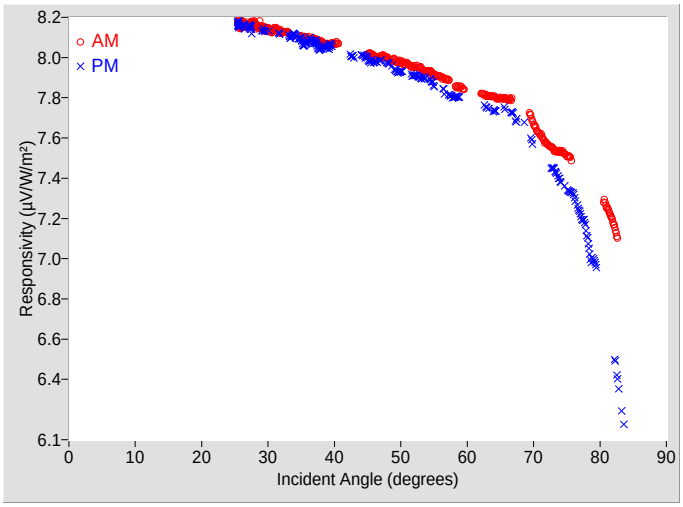


Figure 2. Responsivity vs Local Standard Time

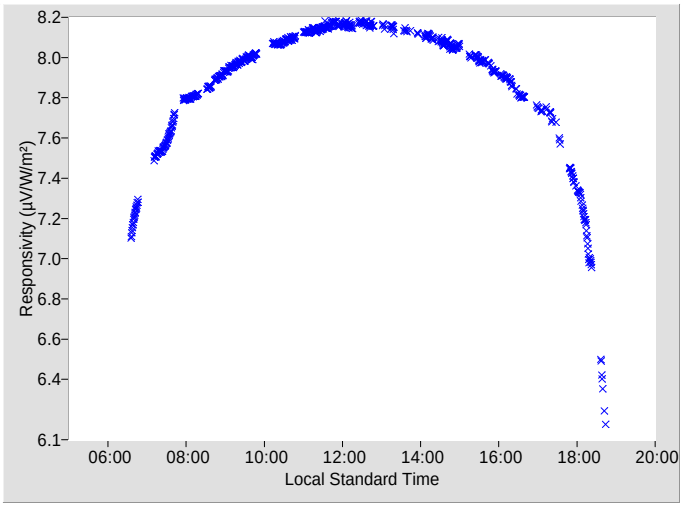


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.0067	+2.47 / -3.26	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0062	0.73	113.03	7.9798	0.69	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9949	0.74	110.65	7.9720	0.72	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9797	0.76	108.51	7.9301	0.72	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9538	0.77	106.38	7.9098	0.74	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9328	0.82	104.45	7.8972	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9034	0.83	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8581	N/A	100.08	7.8027	0.83	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8213	0.98	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8076	1.03	95.31	7.7350	0.96	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7936	1.10	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.6704	1.47	90.67	7.5700	N/A	272.42
26	8.1616	0.66	166.67	8.1590	N/A	196.24	72	7.5725	1.51	89.21	N/A	N/A	N/A
28	8.1673	0.64	153.52	N/A	N/A	N/A	74	7.5335	1.63	87.71	7.3894	1.66	275.39
30	8.1436	0.63	144.92	8.1324	N/A	216.88	76	N/A	N/A	N/A	7.3125	1.93	276.88
32	8.1281	0.63	138.33	8.1158	N/A	221.87	78	N/A	N/A	N/A	7.1196	2.74	278.33
34	N/A	N/A	N/A	8.1141	0.67	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0933	0.64	128.62	8.0818	0.68	237.25	82	7.1789	3.67	81.83	6.4988	N/A	281.37
38	8.0791	0.66	124.79	8.0420	0.71	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0686	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.0120	0.68	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31632F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

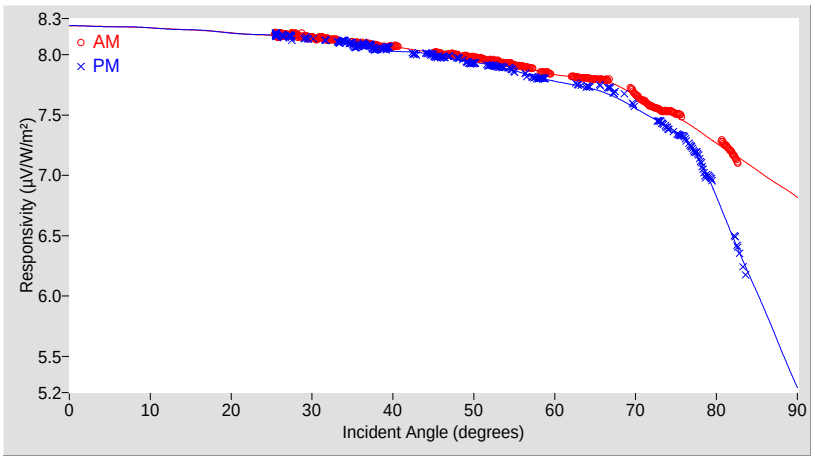


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.70	±1.70
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.6°
R^2	0.9999998	0.9999993

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.2343	*	8.2345	*	8.2344	*
9-18	8.2113	*	8.2115	*	8.2114	*
18-27	8.1728	*	8.1718	*	8.1723	*
27-36	8.1339	±1.75	8.1241	±1.74	8.1290	±1.82
36-45	8.0618	±1.75	8.0347	±1.76	8.0483	±1.86
45-54	7.9816	±1.77	7.9470	±1.82	7.9643	±2.02
54-63	7.8662	±1.85	7.8116	±1.92	7.8389	±2.37
63-72	7.7394	±2.18	7.6412	±2.33	7.6903	±3.44
72-81	7.4281	±2.87	7.2144	±5.38	7.3212	±8.87
81-90	7.0212	*	5.9484	*	6.4848	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

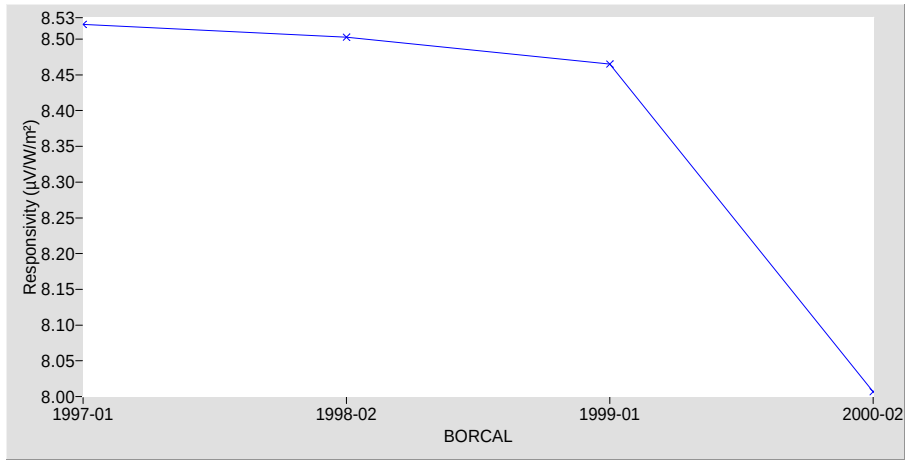
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.0067	+2.47 / -3.26 [1]
45° - 55°	7.9552	±1.94 [2]
Composite	8.0405	+2.28 / -22.24 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



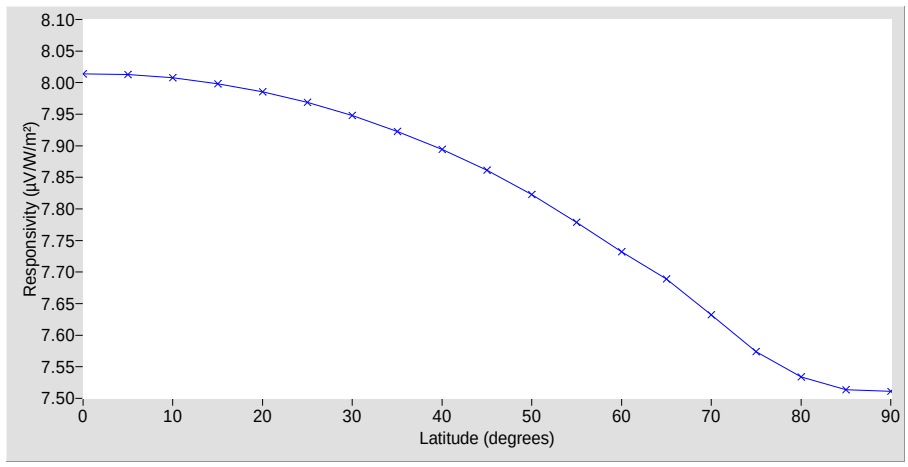
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.0140	+3.31 / -32.74
5	8.0128	+3.32 / -32.73
10	8.0076	+3.38 / -32.69
15	7.9982	+3.48 / -32.61
20	7.9854	+3.63 / -32.50
25	7.9686	+3.81 / -32.36
30	7.9479	+3.95 / -32.18
35	7.9228	+4.11 / -31.97
40	7.8944	+4.28 / -31.72
45	7.8614	+4.34 / -31.44
50	7.8226	+4.67 / -31.10
55	7.7785	+4.94 / -30.71
60	7.7319	+4.97 / -30.29
65	7.6891	+5.09 / -29.90
70	7.6324	+5.22 / -29.38
75	7.5740	+5.47 / -28.84
80	7.5340	+5.15 / -28.46
85	7.5135	+4.49 / -28.26
90	7.5113	+4.08 / -28.24

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31633F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31633F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

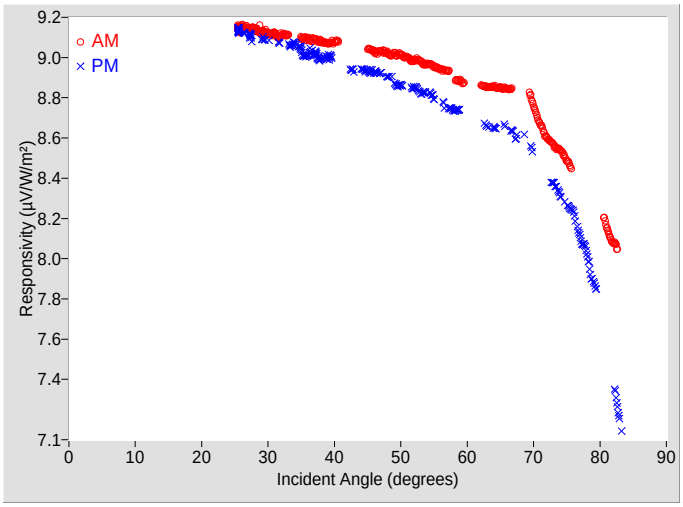


Figure 2. Responsivity vs Local Standard Time

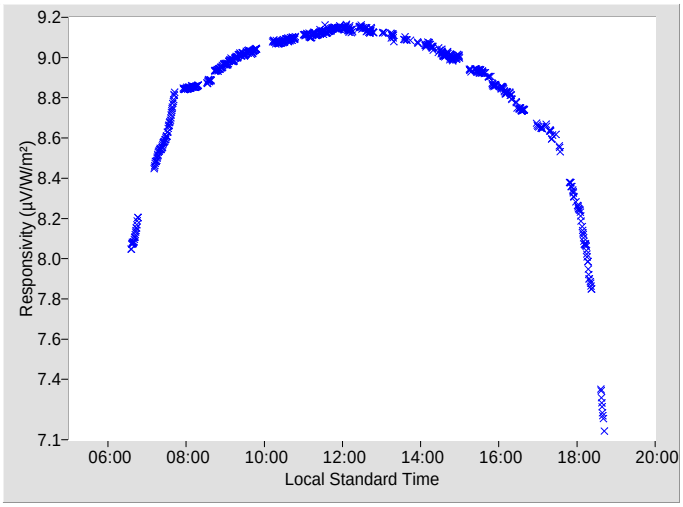


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9875	+2.23 / -3.50	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0297	0.71	113.03	8.9275	0.69	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0216	0.73	110.65	8.9043	0.70	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0159	0.74	108.51	8.8625	0.71	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9860	0.76	106.38	8.8498	0.75	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9684	0.79	104.45	8.8283	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9417	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8847	N/A	100.08	8.7364	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8628	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8564	1.02	95.31	8.6506	0.95	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8448	1.09	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.7584	1.54	90.67	8.5325	N/A	272.42
26	9.1428	0.65	166.67	9.1227	N/A	196.24	72	8.6028	1.51	89.21	N/A	N/A	N/A
28	9.1421	0.63	153.52	N/A	N/A	N/A	74	8.5405	1.66	87.71	8.3187	1.63	275.39
30	9.1206	0.62	144.92	9.0860	N/A	216.88	76	N/A	N/A	N/A	8.2226	1.98	276.88
32	9.1103	0.62	138.40	9.0705	N/A	221.87	78	N/A	N/A	N/A	8.0235	2.46	278.33
34	N/A	N/A	N/A	9.0703	0.67	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0921	0.64	128.62	9.0193	0.68	237.25	82	8.0806	3.52	81.83	7.3516	N/A	281.37
38	9.0826	0.65	124.79	8.9911	0.68	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0753	0.66	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.9425	0.67	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31633F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

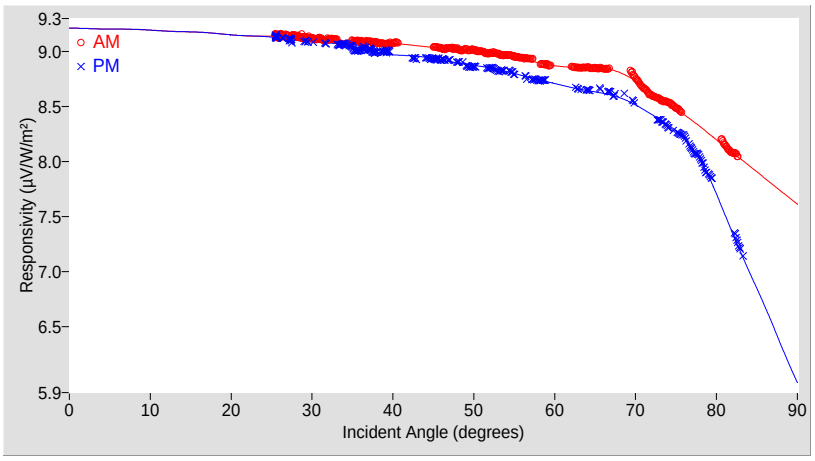


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.64	±1.64
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.3°
R^2	0.9999994	0.9999994

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.2059	*	9.2059	*	9.2059	*
9-18	9.1832	*	9.1832	*	9.1832	*
18-27	9.1464	*	9.1424	*	9.1444	*
27-36	9.1167	±1.66	9.0785	±1.70	9.0976	±1.84
36-45	9.0702	±1.67	8.9758	±1.71	9.0230	±2.02
45-54	9.0118	±1.68	8.8829	±1.75	8.9473	±2.34
54-63	8.9007	±1.75	8.7412	±1.86	8.8209	±2.91
63-72	8.7999	±2.00	8.5805	±2.04	8.6902	±3.74
72-81	8.4065	±3.21	8.1263	±5.25	8.2664	±9.16
81-90	7.8756	*	6.7558	*	7.3157	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

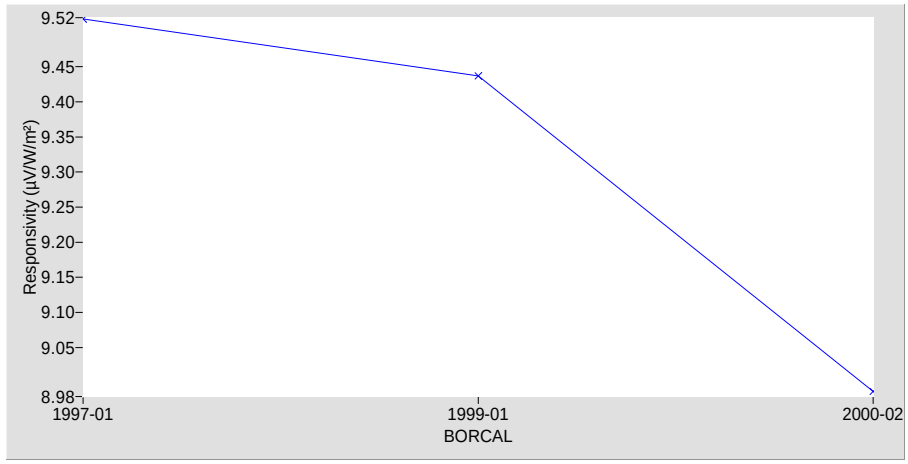
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9875	+2.23 / -3.50 [1]
45° - 55°	8.9383	±2.11 [2]
Composite	9.0135	+2.17 / -20.49 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



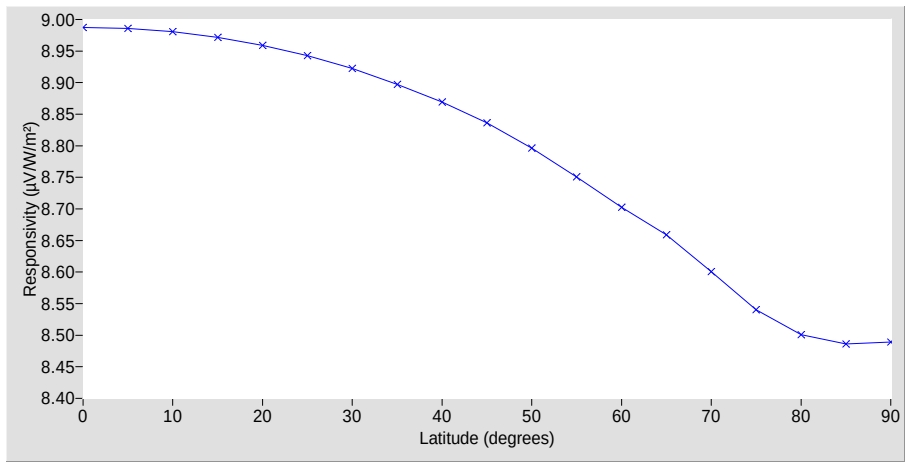
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.9872	+3.00 / -31.57
5	8.9858	+3.01 / -31.56
10	8.9807	+3.06 / -31.52
15	8.9717	+3.15 / -31.45
20	8.9592	+3.27 / -31.35
25	8.9429	+3.43 / -31.23
30	8.9224	+3.55 / -31.07
35	8.8974	+3.68 / -30.88
40	8.8690	+3.83 / -30.66
45	8.8364	+3.87 / -30.40
50	8.7963	+4.25 / -30.08
55	8.7505	+4.51 / -29.72
60	8.7025	+4.76 / -29.33
65	8.6591	+5.00 / -28.98
70	8.6007	+5.27 / -28.49
75	8.5403	+5.67 / -27.99
80	8.5011	+5.33 / -27.66
85	8.4864	+4.73 / -27.53
90	8.4893	+4.54 / -27.56

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31634F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31634F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

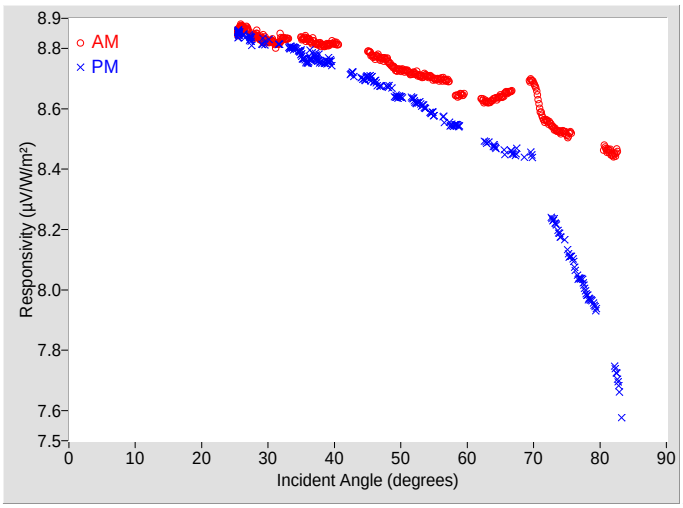


Figure 2. Responsivity vs Local Standard Time

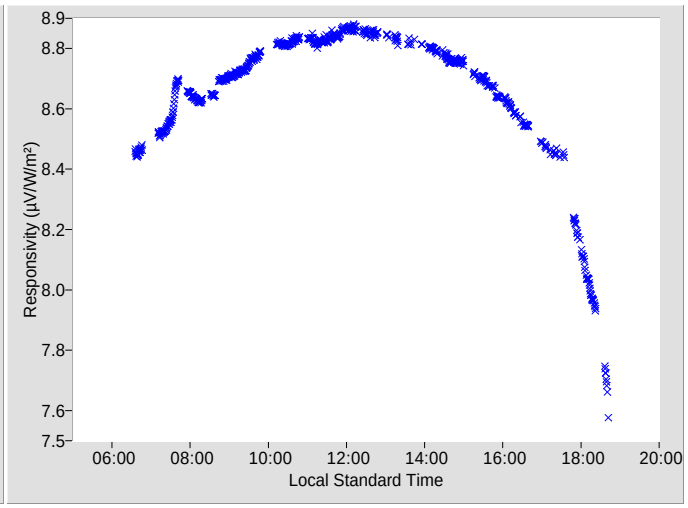


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.7478	+1.84 / -3.04	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7728	0.72	113.03	8.6903	0.71	252.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7594	0.74	110.65	8.6747	0.69	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7292	0.73	108.51	8.6390	0.71	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7180	0.76	106.38	8.6284	0.74	258.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7087	0.79	104.45	8.6009	N/A	259.73
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6969	0.81	102.56	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6442	N/A	100.08	8.5453	0.82	263.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6334	0.97	96.79	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6322	1.03	95.31	8.4757	0.95	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6546	1.10	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6850	1.40	90.67	8.4390	N/A	272.42
26	8.8670	0.65	166.67	8.8448	N/A	196.24	72	8.5580	1.44	89.21	N/A	N/A	N/A
28	8.8434	0.62	153.52	N/A	N/A	N/A	74	8.5230	1.60	87.71	8.1811	1.59	275.39
30	8.8229	0.62	144.92	8.8305	N/A	216.88	76	N/A	N/A	N/A	8.0894	1.88	276.88
32	8.8310	0.67	138.33	8.8144	N/A	221.87	78	N/A	N/A	N/A	7.9827	2.16	278.33
34	N/A	N/A	N/A	8.8011	0.66	227.61	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8299	0.64	128.62	8.7631	0.68	237.25	82	8.4480	3.44	81.83	7.7469	N/A	281.37
38	8.8140	0.64	124.79	8.7534	0.66	241.86	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8166	0.65	121.42	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.7012	0.67	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31634F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

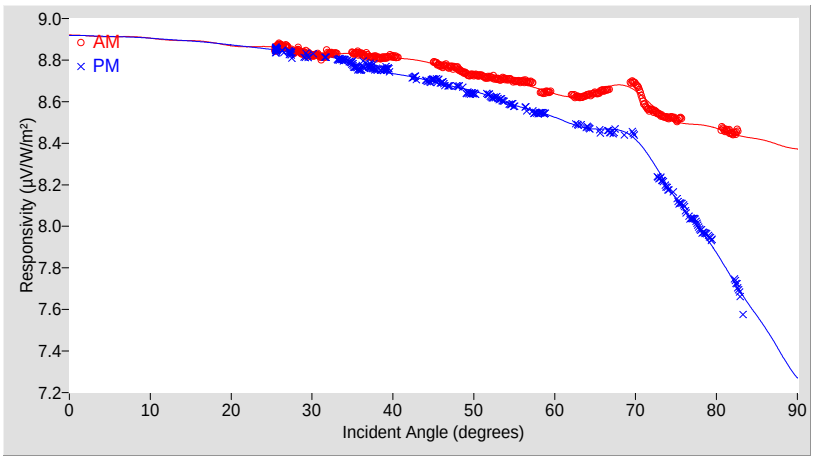


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.57	±1.57
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.3°
R^2	0.9999992	0.9999996

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.9147	*	8.9146	*	8.9147	*
9-18	8.8966	*	8.8963	*	8.8964	*
18-27	8.8667	*	8.8632	*	8.8650	*
27-36	8.8330	±1.57	8.8170	±1.61	8.8250	±1.69
36-45	8.8097	±1.58	8.7338	±1.62	8.7718	±1.88
45-54	8.7436	±1.62	8.6543	±1.65	8.6989	±2.13
54-63	8.6597	±1.64	8.5446	±1.69	8.6022	±2.38
63-72	8.6511	±1.63	8.4469	±1.75	8.5490	±3.22
72-81	8.5060	±1.71	8.0736	±3.34	8.2898	±6.66
81-90	8.4138	*	7.5374	*	7.9756	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

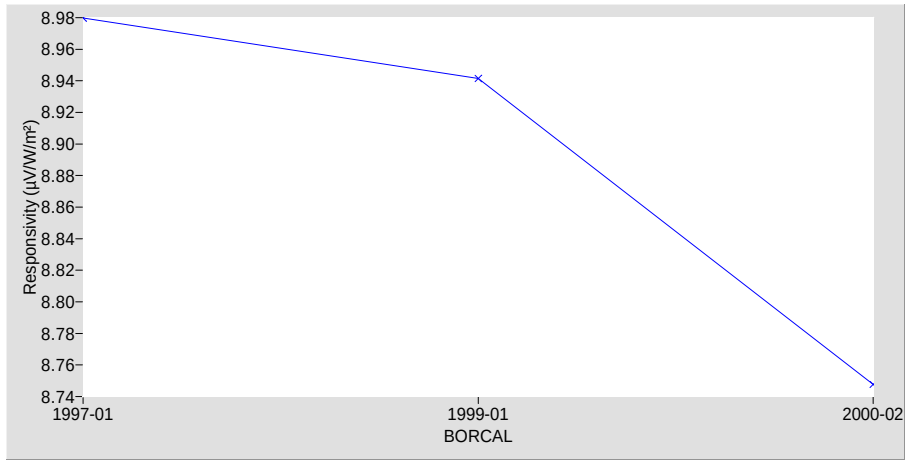
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.7478	+1.84 / -3.04 [1]
45° - 55°	8.6912	±1.94 [2]
Composite	8.7724	+1.87 / -12.53 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



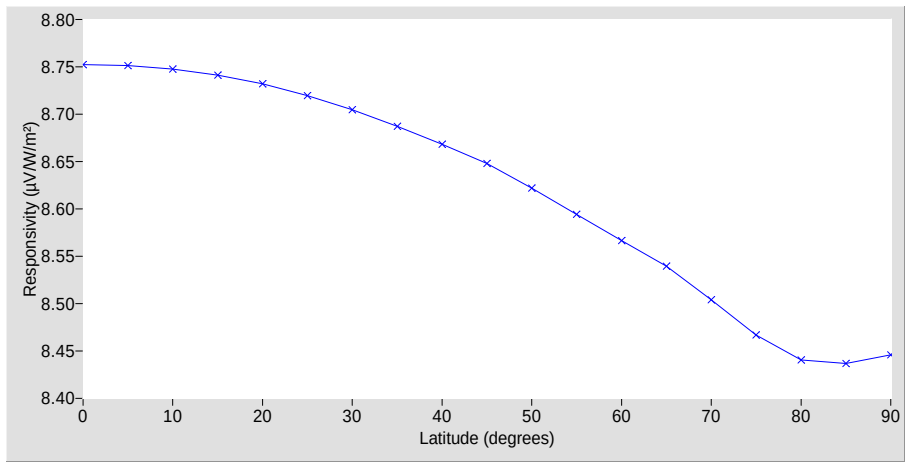
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.7524	+2.48 / -16.41
5	8.7514	+2.49 / -16.40
10	8.7477	+2.52 / -16.36
15	8.7412	+2.58 / -16.30
20	8.7319	+2.67 / -16.21
25	8.7196	+2.78 / -16.09
30	8.7047	+2.86 / -15.95
35	8.6873	+2.93 / -15.78
40	8.6682	+3.02 / -15.60
45	8.6481	+2.99 / -15.40
50	8.6221	+3.17 / -15.15
55	8.5942	+3.18 / -14.87
60	8.5665	+3.43 / -14.60
65	8.5394	+3.51 / -14.33
70	8.5040	+3.51 / -13.98
75	8.4670	+3.47 / -13.60
80	8.4405	+3.29 / -13.33
85	8.4367	+3.29 / -13.29
90	8.4460	+3.19 / -13.39

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31635F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31635F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

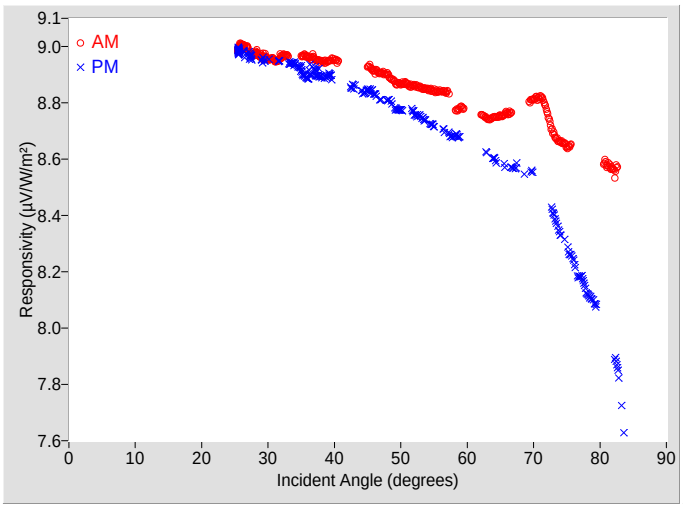


Figure 2. Responsivity vs Local Standard Time

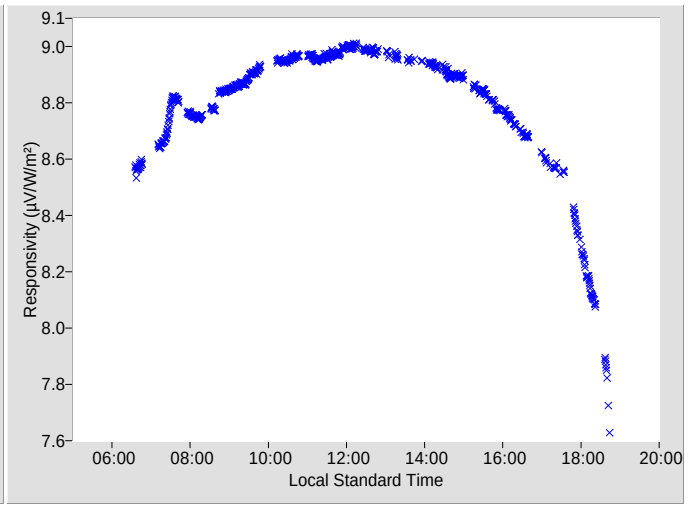


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.8881	+1.65 / -3.06	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9133	0.72	113.05	8.8293	0.71	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8998	0.74	110.67	8.8097	0.70	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8683	0.73	108.47	8.7744	0.71	256.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8616	0.76	106.39	8.7634	0.75	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8480	0.78	104.46	8.7391	N/A	259.74
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8408	0.81	102.57	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7742	N/A	100.09	8.6806	0.82	263.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7579	0.97	96.76	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7493	1.02	95.33	8.6019	0.95	268.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7626	1.09	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.8128	1.29	90.68	8.5572	1.23	272.38
26	9.0013	0.63	166.63	8.9851	N/A	196.28	72	8.7688	1.61	89.18	N/A	N/A	N/A
28	8.9752	0.61	153.40	N/A	N/A	N/A	74	8.6633	1.62	87.72	8.3371	1.63	275.40
30	8.9572	0.61	144.95	8.9540	N/A	216.90	76	N/A	N/A	N/A	8.2366	1.89	276.89
32	8.9630	0.63	138.35	8.9484	N/A	221.89	78	N/A	N/A	N/A	8.1250	2.17	278.33
34	N/A	N/A	N/A	8.9388	0.67	227.63	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9627	0.63	128.63	8.8925	0.69	237.90	82	8.5607	3.43	81.85	7.8885	N/A	281.38
38	8.9473	0.64	124.80	8.8924	0.67	241.88	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9530	0.65	121.43	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.8393	0.69	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31635F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

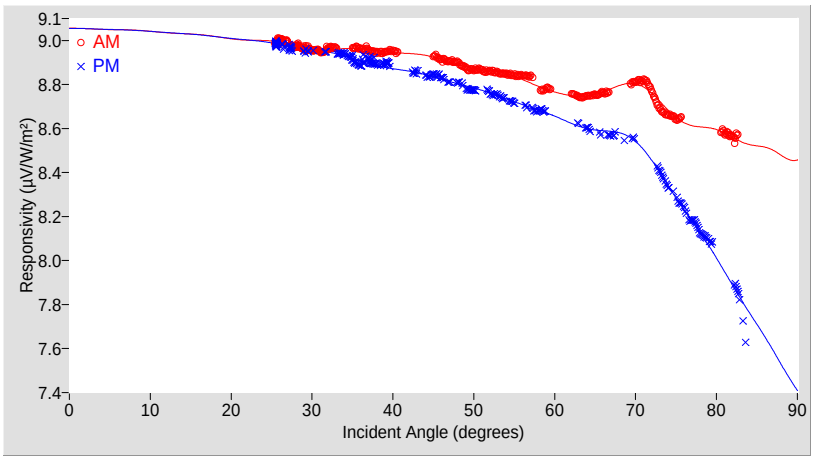


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.56	±1.56
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.6°
R^2	0.9999994	0.9999997

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	9.0512	*	9.0512	*	9.0512	*
9-18	9.0332	*	9.0331	*	9.0331	*
18-27	9.0032	*	9.0006	*	9.0019	*
27-36	8.9658	±1.57	8.9488	±1.60	8.9573	±1.67
36-45	8.9460	±1.57	8.8716	±1.60	8.9088	±1.84
45-54	8.8844	±1.61	8.7905	±1.65	8.8375	±2.14
54-63	8.7927	±1.66	8.6788	±1.70	8.7358	±2.45
63-72	8.7771	±1.59	8.5707	±1.73	8.6739	±3.11
72-81	8.6465	±1.85	8.2189	±3.28	8.4327	±6.80
81-90	8.5137	*	7.6788	*	8.0962	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

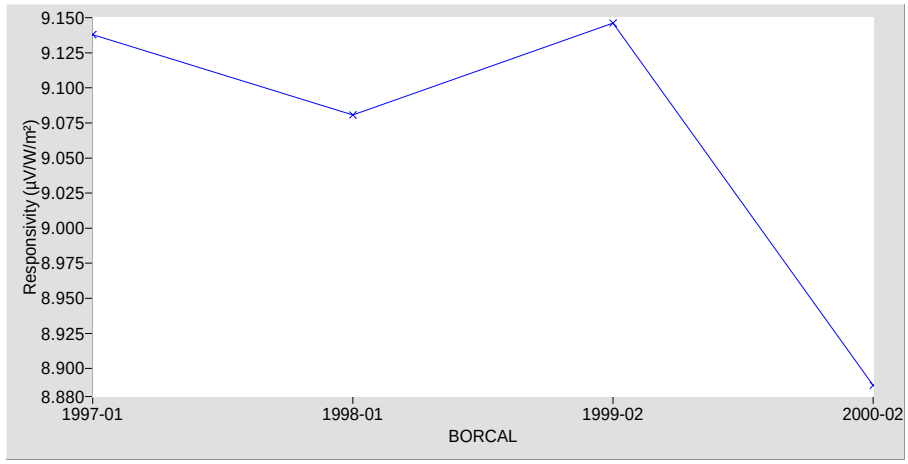
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.8881	+1.65 / -3.06 [1]
45° - 55°	8.8301	±1.94 [2]
Composite	8.9079	+1.85 / -12.58 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



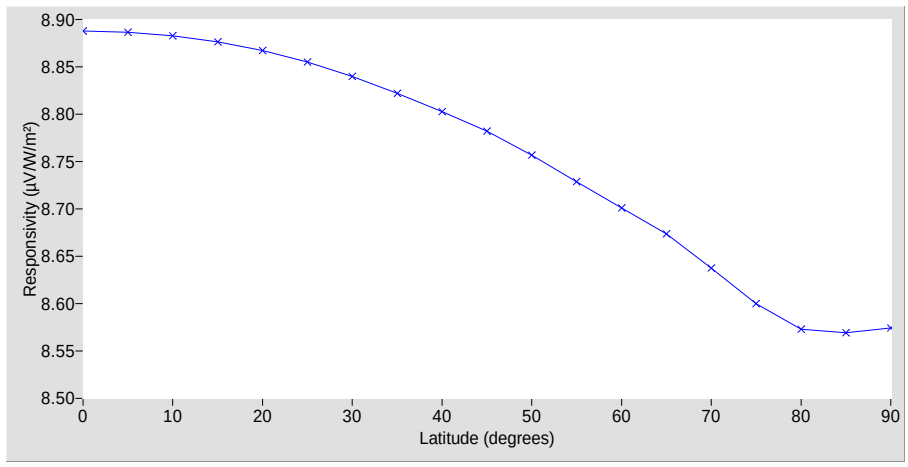
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.8877	+2.45 / -16.07
5	8.8866	+2.46 / -16.06
10	8.8828	+2.50 / -16.02
15	8.8764	+2.56 / -15.96
20	8.8673	+2.64 / -15.88
25	8.8549	+2.75 / -15.76
30	8.8399	+2.84 / -15.62
35	8.8221	+2.91 / -15.45
40	8.8025	+2.99 / -15.26
45	8.7822	+2.99 / -15.06
50	8.7568	+3.12 / -14.82
55	8.7287	+3.11 / -14.55
60	8.7010	+3.38 / -14.28
65	8.6737	+3.47 / -14.01
70	8.6375	+3.56 / -13.65
75	8.6001	+3.50 / -13.28
80	8.5731	+3.31 / -13.00
85	8.5692	+3.16 / -12.97
90	8.5743	+3.11 / -13.02

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31636F3

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31636F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

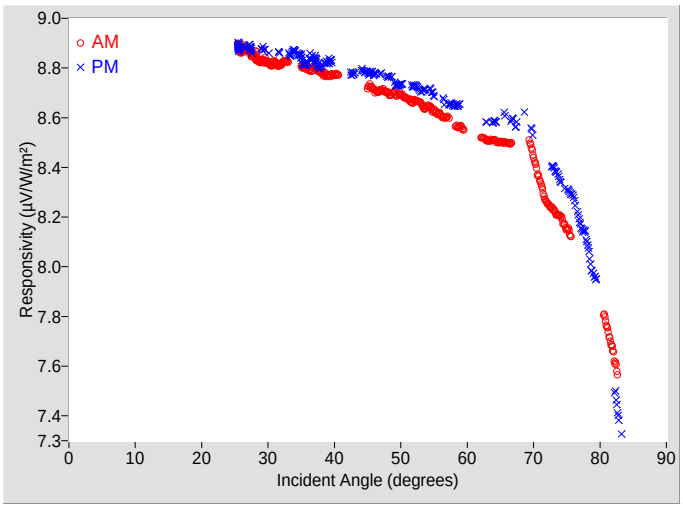


Figure 2. Responsivity vs Local Standard Time

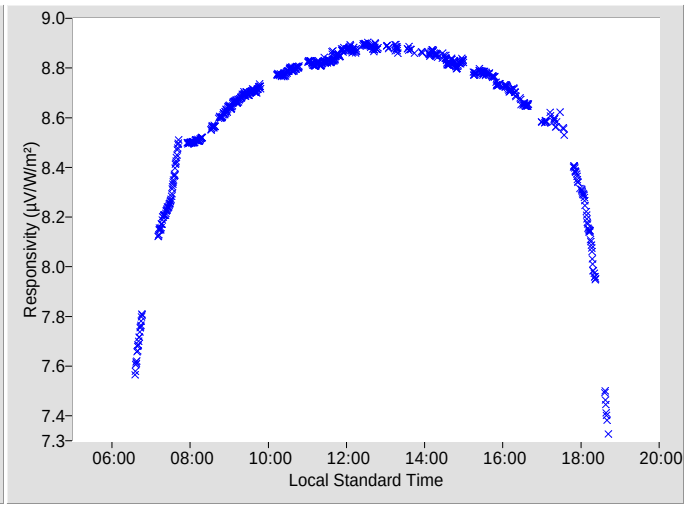


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.7533	+2.06 / -2.89	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7113	0.73	113.05	8.7758	0.69	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7000	0.73	110.67	8.7655	0.70	254.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6950	0.75	108.47	8.7348	0.71	256.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6657	0.76	106.39	8.7276	0.74	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6445	0.80	104.46	8.7142	N/A	259.74
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6117	0.83	102.57	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5646	N/A	100.09	8.6469	0.82	263.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5203	0.97	96.76	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5102	1.02	95.33	8.5842	0.95	268.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4994	1.09	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4411	1.60	90.68	8.5424	1.24	272.38
26	8.8752	0.65	166.63	8.8881	N/A	196.28	72	8.2589	1.58	89.18	N/A	N/A	N/A
28	8.8493	0.67	153.40	N/A	N/A	N/A	74	8.2052	1.68	87.72	8.3489	1.62	275.40
30	8.8236	0.63	144.95	8.8598	N/A	216.90	76	N/A	N/A	N/A	8.2743	1.95	276.89
32	8.8155	0.62	138.43	8.8597	N/A	221.89	78	N/A	N/A	N/A	8.1034	2.41	278.33
34	N/A	N/A	N/A	8.8693	0.67	227.63	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7963	0.64	128.63	8.8248	0.68	237.90	82	7.6528	3.69	81.85	7.4926	N/A	281.38
38	8.7836	0.67	124.80	8.8042	0.70	241.88	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7729	0.65	121.43	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.7919	0.67	250.11	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31636F3 Eppley PSP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

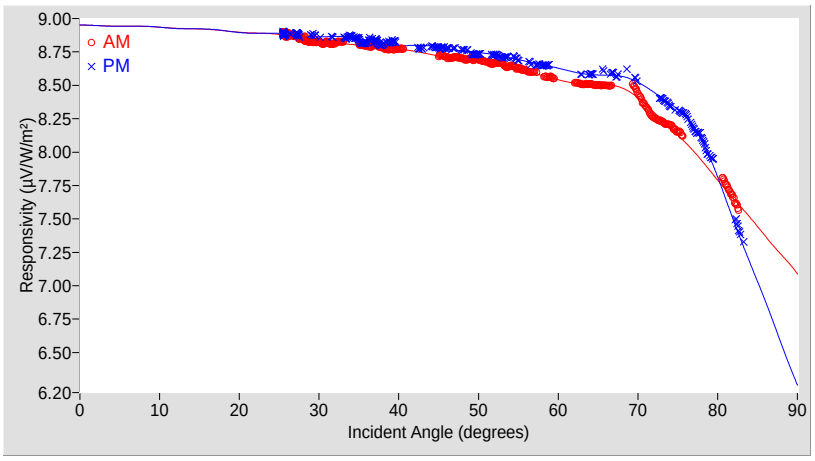


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.68	±1.68
Valid incidence angle range	25.5° to 82.6°	25.5° to 83.3°
R^2	0.9999990	0.9999993

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.9447	*	8.9448	*	8.9447	*
9-18	8.9251	*	8.9253	*	8.9252	*
18-27	8.8901	*	8.8926	*	8.8914	*
27-36	8.8229	±1.72	8.8627	±1.69	8.8428	±1.79
36-45	8.7661	±1.73	8.8025	±1.70	8.7843	±1.89
45-54	8.6911	±1.73	8.7494	±1.73	8.7203	±2.01
54-63	8.5713	±1.84	8.6501	±1.80	8.6107	±2.31
63-72	8.4635	±2.00	8.5547	±1.82	8.5091	±2.87
72-81	8.0416	±3.78	8.1866	±4.67	8.1141	±6.45
81-90	7.4068	*	6.9508	*	7.1788	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

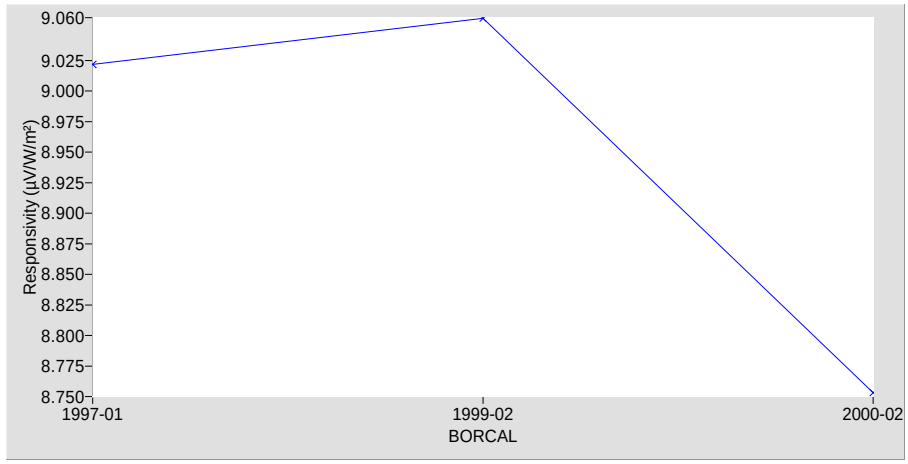
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.7533	+2.06 / -2.89 [1]
45° - 55°	8.7125	±1.92 [2]
Composite	8.7754	+2.11 / -16.57 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.6°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



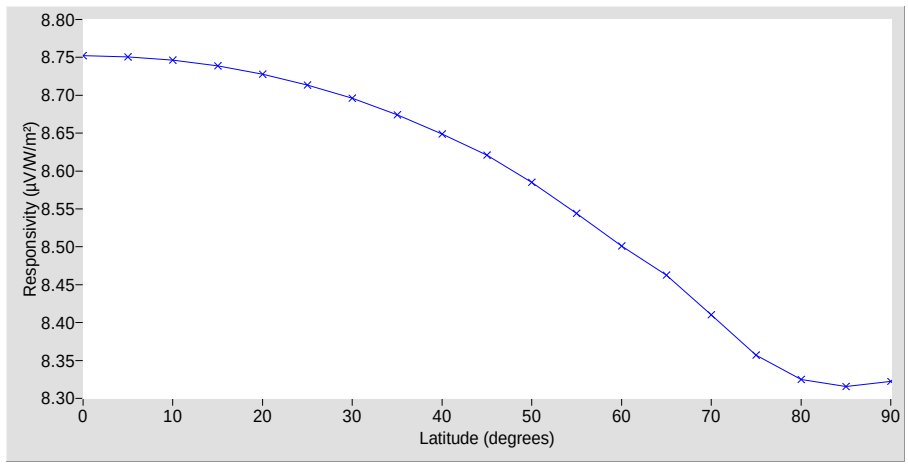
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.7521	+2.83 / -26.88
5	8.7507	+2.85 / -26.87
10	8.7463	+2.89 / -26.84
15	8.7386	+2.96 / -26.77
20	8.7279	+3.07 / -26.68
25	8.7136	+3.20 / -26.56
30	8.6959	+3.31 / -26.41
35	8.6740	+3.40 / -26.23
40	8.6490	+3.57 / -26.01
45	8.6208	+3.58 / -25.77
50	8.5849	+3.87 / -25.46
55	8.5441	+4.12 / -25.11
60	8.5008	+4.24 / -24.73
65	8.4624	+4.32 / -24.38
70	8.4102	+4.65 / -23.92
75	8.3571	+4.86 / -23.43
80	8.3249	+4.57 / -23.14
85	8.3157	+3.95 / -23.05
90	8.3222	+3.49 / -23.11

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

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:** 31747E6

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

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Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

31747E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

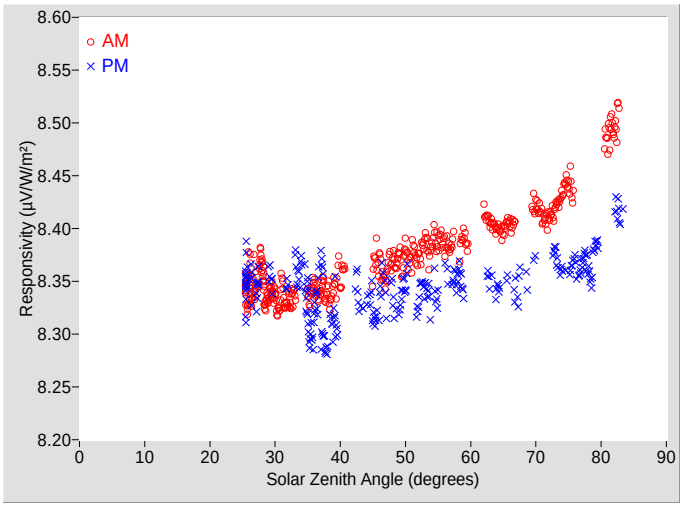


Figure 2. Responsivity vs Local Standard Time

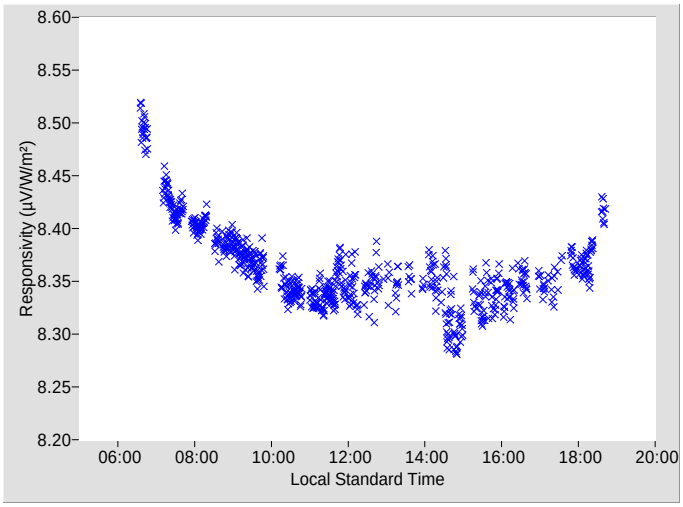


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.3441	+1.14 / -1.19	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3663	0.52	112.98	8.3334	0.56	252.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3691	0.47	110.72	8.3357	0.49	254.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3800	0.49	108.46	8.3499	0.50	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3730	0.46	106.43	8.3313	0.48	258.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3829	0.50	104.46	8.3136	N/A	259.78
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3849	0.46	102.63	8.3672	N/A	261.77
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3684	N/A	100.03	8.3538	0.49	263.35
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4153	0.46	96.80	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4001	0.46	95.32	8.3419	0.46	268.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4039	0.46	93.73	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4201	0.49	90.67	8.3744	N/A	272.46
26	8.3448	0.56	166.57	8.3549	0.63	192.79	72	8.4099	0.49	89.17	N/A	N/A	N/A
28	8.3630	0.56	153.70	N/A	N/A	N/A	74	8.4330	0.51	87.71	8.3601	0.49	275.35
30	8.3337	0.49	144.94	N/A	N/A	N/A	76	8.4359	N/A	86.44	8.3667	0.49	276.91
32	8.3303	0.46	138.30	8.3472	0.44	222.24	78	N/A	N/A	N/A	8.3609	0.54	278.33
34	N/A	N/A	N/A	8.3633	0.57	227.72	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3452	0.46	128.63	8.3178	0.64	237.13	82	8.4941	0.66	81.83	8.4229	0.59	281.36
38	8.3379	0.47	124.80	8.2847	0.73	241.78	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3544	0.50	121.32	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.3323	0.49	250.10	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

31747E6 Eppley NIP

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

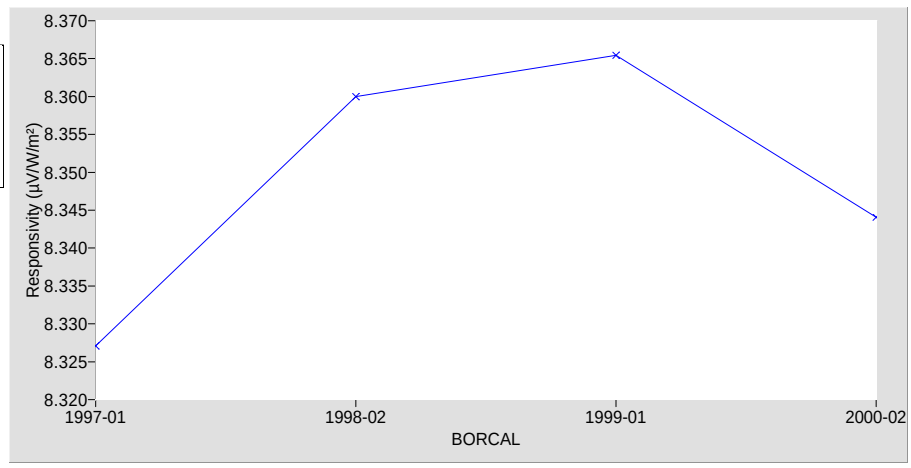
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.3441	+1.14 / -1.19 †
Average	8.3663	+2.19 / -1.70 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.7°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Silicon Pyrheliometer **Manufacturer:** Matrix

Model: MARK III **Serial Number:** 5034

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Calibration System **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

5034 Matrix MARK III

Figure 1. Responsivity vs Zenith Angle

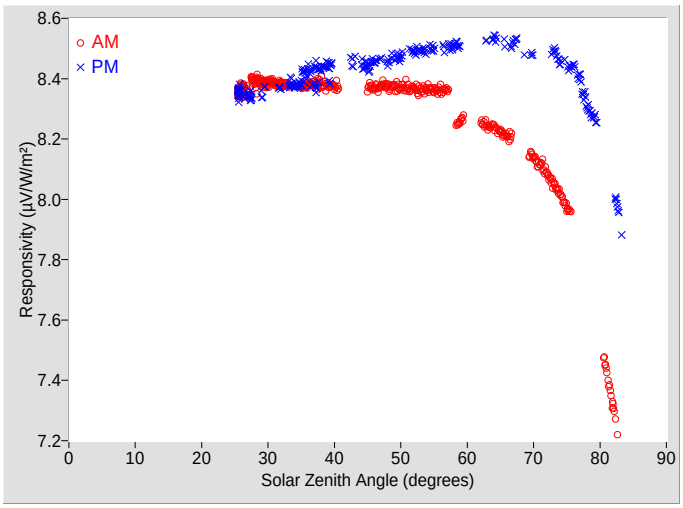


Figure 2. Responsivity vs Local Standard Time

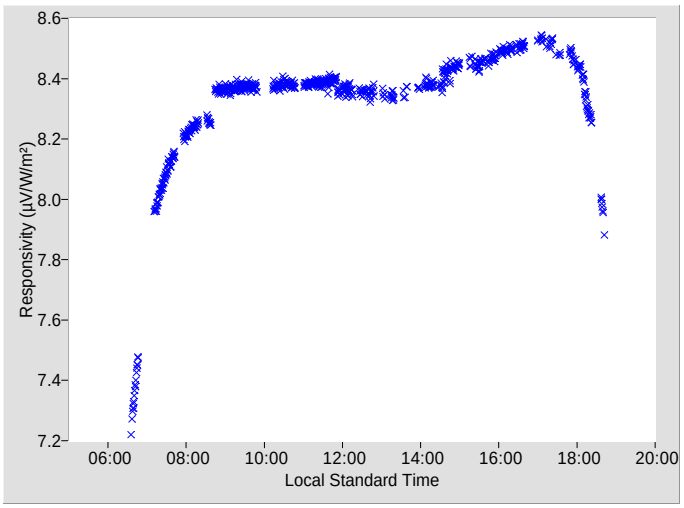


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4049	+1.84 / -2.33	N/A

† Valid zenith angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Zen. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3694	0.47	113.06	8.4552	0.51	252.24
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3736	0.49	110.67	8.4533	0.50	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3696	0.50	108.47	8.4727	0.47	256.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3704	0.49	106.39	8.4874	0.46	258.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3658	0.48	104.42	8.4813	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3643	0.48	102.58	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	8.5078	0.47	263.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2545	0.47	96.76	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2426	0.49	95.28	8.5334	0.46	268.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2075	0.51	93.74	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1412	0.56	90.68	8.4823	0.45	272.38
26	8.3638	0.52	166.65	8.3552	0.56	192.57	72	8.0895	0.76	89.19	N/A	N/A	N/A
28	8.3871	0.58	153.60	N/A	N/A	N/A	74	8.0188	0.69	87.73	8.4542	0.57	275.40
30	8.3850	0.46	144.96	N/A	N/A	N/A	76	N/A	N/A	N/A	8.4429	0.56	276.85
32	8.3828	0.45	138.44	8.3688	0.44	222.16	78	N/A	N/A	N/A	8.3121	0.99	278.34
34	N/A	N/A	N/A	8.3746	0.48	227.64	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3770	0.46	128.74	8.4237	0.62	238.73	82	7.3132	1.54	81.86	8.0003	N/A	281.44
38	8.3856	0.52	124.82	8.4334	0.76	241.90	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3777	0.47	121.35	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	8.4473	0.50	250.12	90	N/A	N/A	N/A	N/A	N/A	N/A

† Solar zenith angle (degrees)

‡ Average azimuth angle for ±0.3° of zenith angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

5034 Matrix MARK III

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. The Single Responsivities:

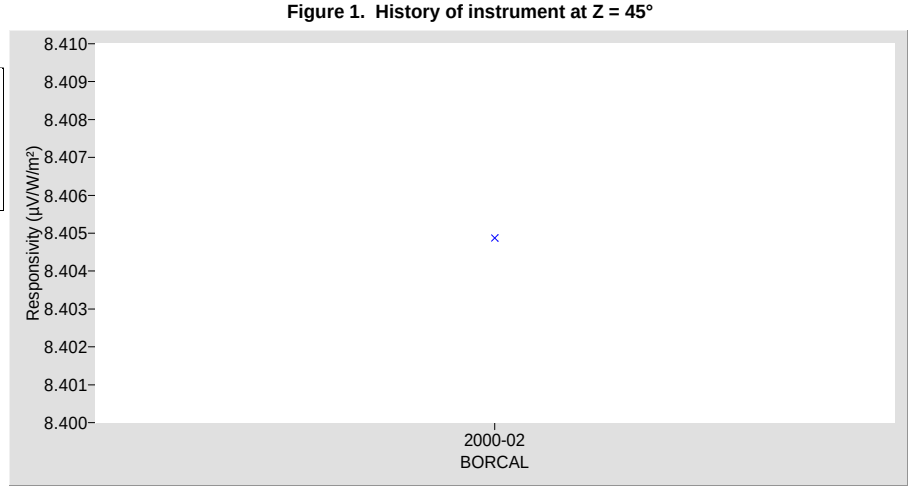
Table 1. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.4049	+1.84 / -2.33 †
Average	8.3260	+2.96 / -13.52 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 25.5° to 82.6°

The instrument responsivity at Z = 45° may be used to monitor instrument stability. The instrument's history at Z = 45° is shown in Figure 1.

Figure 1. History of instrument at Z = 45°



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Silicon Pyranometer **Manufacturer:** Licor

Model: LI200 **Serial Number:** PY22692

Calibration Date: 8/24/2000 **Due Date:** 8/24/2001

Customer: Dan Nelson **Calibration Site Parameters:** see page 3

Environmental Conditions: Outdoor, under natural sunlight (see page 3)

Data Acquisition Dates: 8/15, 8/23-24

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	05/05/2000	05/05/2001
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	06/05/2000	06/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32872	05/16/2000	05/16/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32873	05/16/2000	05/16/2001
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6294004	03/14/2000	03/14/2001

† Traceable to the World Radiometric Reference

‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3

Calibration Procedure: [1] Myers, D., Stoffel, T., Reda, I., Wilcox, S., and Andreas, A., 2002, "Recent Progress in Reducing the Uncertainty in and Improving Pyranometer Calibrations." Journal of Solar Energy Engineering, vol. 124, pp. 44-50. The American Society of Mechanical Engineers, Transactions of the ASME. [2] "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A., Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

Calibrated by: Craig Webb, Dan Nelson, and Rod Soper

Certified by:

_____

Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Assured by:

_____

Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

PY22692 Licor LI200

Figure 1. Responsivity vs Incident Angle

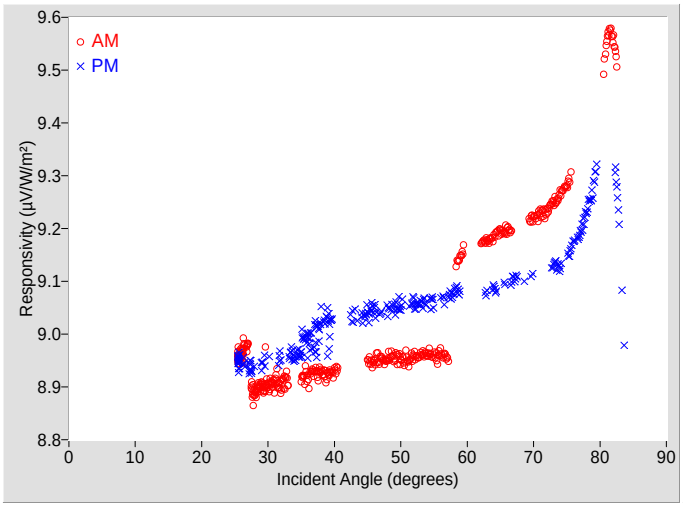


Figure 2. Responsivity vs Local Standard Time

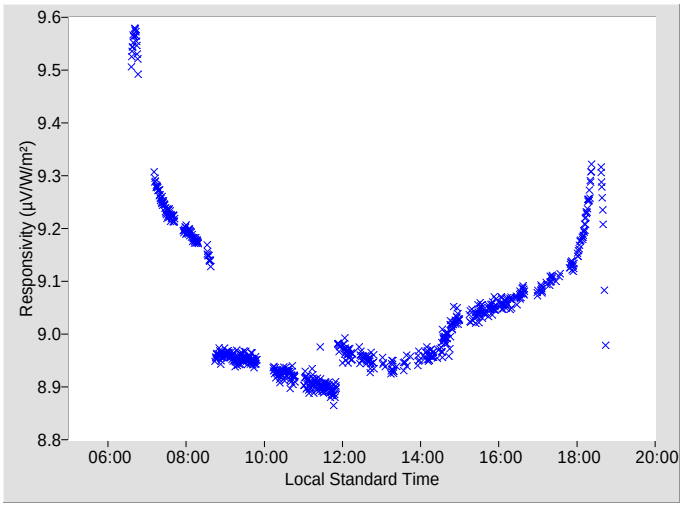


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.9950	+2.29 / -1.86	0.0° / 0.0°

† Valid incident angle range: 30.0° to 60.0°

Table 3. Instrument Responsivity (RS) and Calibration Uncertainty (U95)

	AM			PM				AM			PM		
Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	Inc. Angle†	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡	RS (µV/W/m²)	U95 ± (%)	Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9465	0.71	113.06	9.0444	0.71	252.25
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9537	0.73	110.68	9.0464	0.70	254.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9529	0.75	108.48	9.0559	0.73	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9576	0.77	106.40	9.0576	0.74	258.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9630	0.78	104.42	9.0551	N/A	259.75
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9646	0.82	102.59	9.0692	N/A	261.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	N/A	N/A	N/A	9.0774	0.82	263.34
14	N/A	N/A	N/A	N/A	N/A	N/A	60	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1729	0.96	96.77	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1846	1.02	95.29	9.0864	0.94	268.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.1980	1.09	93.75	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.2215	1.28	90.69	9.1143	N/A	272.43
26	8.9641	0.67	166.66	8.9451	0.65	192.60	72	9.2323	1.42	89.19	N/A	N/A	N/A
28	8.8879	0.64	154.04	8.9390	N/A	207.29	74	9.2659	1.60	87.73	9.1266	1.52	275.40
30	8.9026	0.77	144.98	8.9575	N/A	216.92	76	N/A	N/A	N/A	9.1747	1.76	276.86
32	8.9044	0.66	138.34	8.9559	0.66	222.18	78	N/A	N/A	N/A	9.2367	2.13	278.34
34	N/A	N/A	N/A	8.9535	0.66	227.74	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9158	0.67	128.75	8.9862	0.69	237.63	82	9.5557	3.40	81.84	9.3058	N/A	281.44
38	8.9299	0.65	124.83	9.0310	0.83	241.82	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9294	0.66	121.36	N/A	N/A	N/A	86	N/A	N/A	N/A	N/A	N/A	N/A
42	N/A	N/A	N/A	N/A	N/A	N/A	88	N/A	N/A	N/A	N/A	N/A	N/A
44	N/A	N/A	N/A	9.0314	0.69	250.12	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)

‡ Average azimuth angle for ±0.3° of incidence angle

N/A - Not Available

Suggested Methods of Applying Calibration Results

PY22692 Licor LI200

Listed below are the results for the methods documented in "Improved Methods for Broadband Outdoor Radiometer Calibration (BORCAL)," Wilcox, S., Andreas, A.,Reda, I., and Myers, D., Proceedings of the ARM Science Team Meeting, St. Petersburg, Florida, April 2002. Available upon request.

In all cases, the solar irradiance is calculated from the instrument responsivity using the equation:

$$IRR = V / RS \qquad [1]$$

where,

IRR = solar irradiance (Watts per square meter)
V = radiometer output voltage (microvolts)
RS = responsivity of the radiometer (µV/W/m²)

1. Two-degree Responsivities: Responsivities are obtained from Certificate Table 3. See Note 1 on next page.

2. AM and PM Responsivity Functions: See Note 1 on next page.

$$RS\ (am) = \sum_{i=0}^{n} a_i \bullet \cos^i(I) \qquad RS\ (pm) = \sum_{j=0}^{m} b_j \bullet \cos^j(I) \qquad [2]$$

where the coefficients a_i and b_j are available upon request.

The quality of the function fit to data is shown in Figure 1.

Figure 1. Responsivity Function

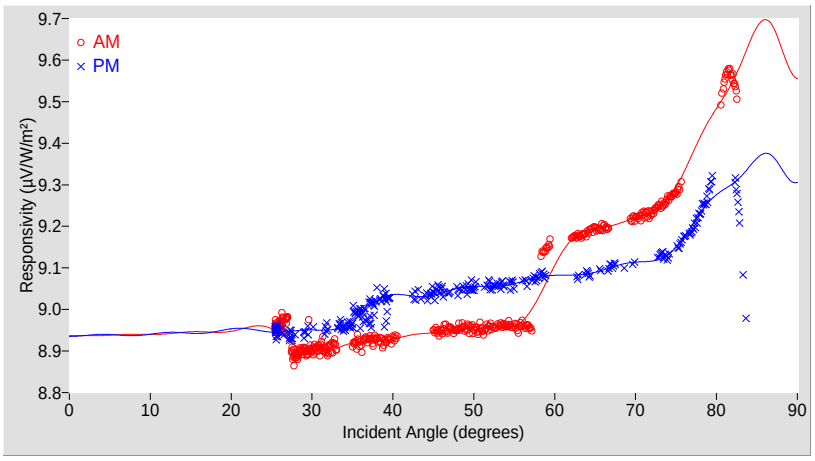


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.49	±1.49
Valid incidence angle range	25.5° to 82.5°	25.5° to 83.6°
R^2	0.9999995	0.9999998

3. Nine-degree Bin Responsivity: See Note 1 on next page.

Table 2. Nine-degree responsivities

Inc.	AM		PM		Combined	
Angle	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)	RS (µV/W/m²)	U95 (%)
0-9	8.9382	*	8.9379	*	8.9380	*
9-18	8.9433	*	8.9429	*	8.9431	*
18-27	8.9510	*	8.9498	*	8.9504	*
27-36	8.9069	±1.51	8.9551	±1.51	8.9310	±1.65
36-45	8.9312	±1.50	9.0252	±1.52	8.9782	±1.74
45-54	8.9527	±1.50	9.0503	±1.50	9.0015	±1.74
54-63	9.0496	±1.93	9.0746	±1.50	9.0621	±2.28
63-72	9.2056	±1.52	9.1012	±1.50	9.1534	±1.88
72-81	9.3520	±2.05	9.1894	±1.75	9.2707	±3.32
81-90	9.6156	*	9.3338	*	9.4747	*

* The responsivity is based on extrapolated data and the corresponding uncertainty is undefined.

4. The Single Responsivities:

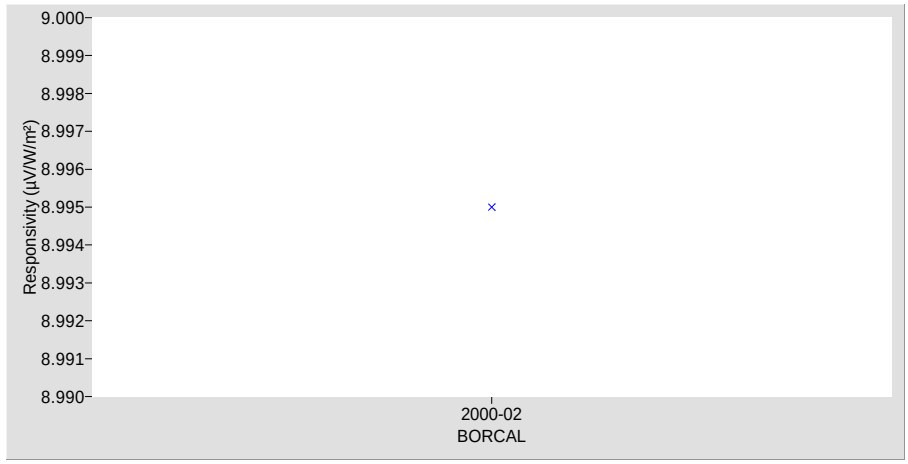
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	8.9950	+2.29 / -1.86 [1]
45° - 55°	9.0025	±1.63 [2]
Composite	8.9924	+7.07 / -1.86 [3]

[1] Valid incident angle range: 30.0° to 60.0°
[2] Valid incident angle range: 45.0° to 55.0°
[3] Valid incident angle range: 25.5° to 82.5°

The instrument responsivity at I = 45° may be used to monitor instrument stability. The instrument's history at I = 45° is shown in Figure 2.

Figure 2. History of instrument at I = 45°



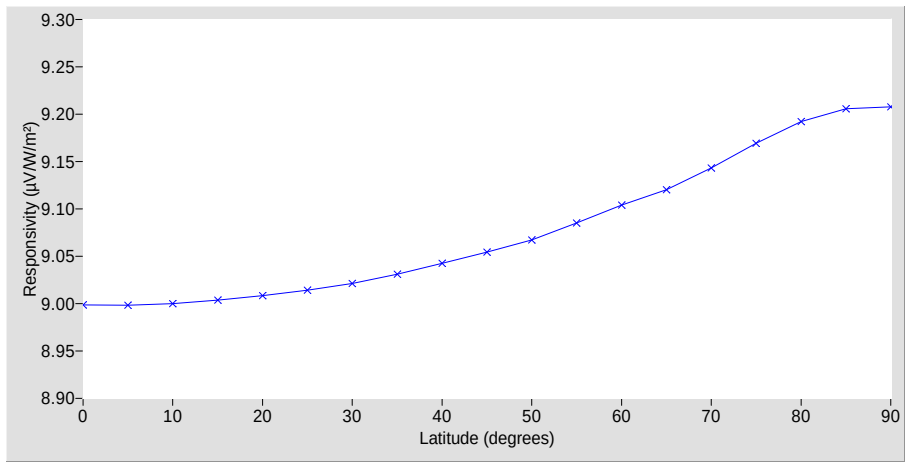
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	8.9986	+7.91 / -1.89
5	8.9984	+7.91 / -1.89
10	8.9999	+7.89 / -1.90
15	9.0037	+7.85 / -1.93
20	9.0084	+7.79 / -1.96
25	9.0142	+7.72 / -2.00
30	9.0212	+7.64 / -2.06
35	9.0309	+7.53 / -2.13
40	9.0427	+7.39 / -2.22
45	9.0543	+7.26 / -2.32
50	9.0671	+7.11 / -2.43
55	9.0851	+6.90 / -2.58
60	9.1042	+6.68 / -2.50
65	9.1204	+6.50 / -2.54
70	9.1432	+6.24 / -2.64
75	9.1691	+5.95 / -2.77
80	9.1922	+5.69 / -2.82
85	9.2056	+5.55 / -2.00
90	9.2077	+5.52 / -1.93

* Uncertainty is undefined

Figure 3. Latitude Optimized Responsivities



Application of the responsivities and uncertainties:

The responsivities above are applied according to equation [1]:

Example

Instrument responsivity (RS) = 7.34 µV/W/m² ±2.7%
Instrument output voltage (V) = 0.00624 V (6240 µV)
Irradiance (IRR) = V / RS = 6240 / 7.34 = 850.1 W/m² ±2.7%

Thus, at the 95% confidence level, the irradiance lies between 827.1 and 873.1 W/m²

Note 1: The data in methods 1, 2, and 3, in conjunction with knowledge of the sky irradiance distribution, may be used to compute the effective instrument responsivity.

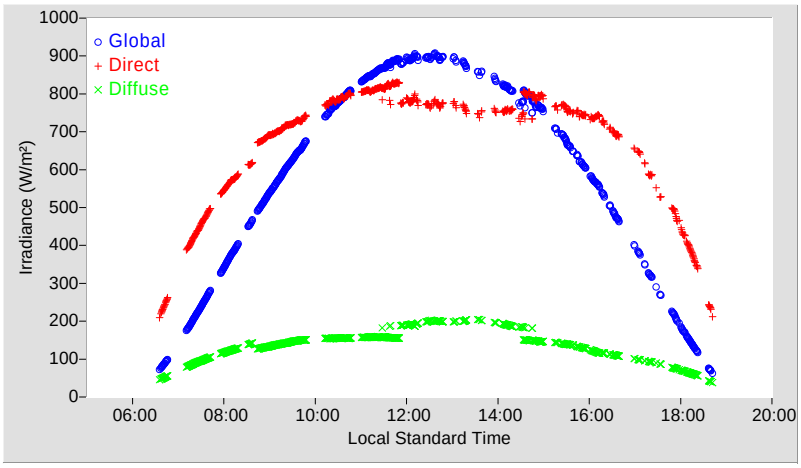
Ancillary Data for BORCAL 2000-02

Calibration Facility: Southern Great Plains

Latitude: 36.605°N Longitude: 97.488°W Elevation: 317.0 meters AMSL Avg. Station Pressure: 980.0 mBar Time Zone: -6.0

Reference Irradiance: 0.0° / 0.0° Tilt / Azm

Figure 3. Reference Irradiance



The reference global irradiance (G) is calculated using: G = B * Cos (I) + D,
where I is the refraction-corrected solar incidence angle.

Table 4. Beam Irradiance (B)

Instrument	Model	WRR Factor
29222	HF	1.05584 †
30495	HF	0.99838

† Windowed

Table 5. Diffuse Irradiance (D)

Instrument	Model	Responsivity
32872	8-48	9.4400 µV/W/m²
32873	8-48	8.5700 µV/W/m²

Meteorological Observations:

Table 6. Meteorological Observations

Observations	Mean
Temperature (°C)	36.95
Humidity (%)	41.23
Pressure (mBar)	N/A
Est. Aerosol Optical Depth (BB)	0.1919

Figure 4. Temperature

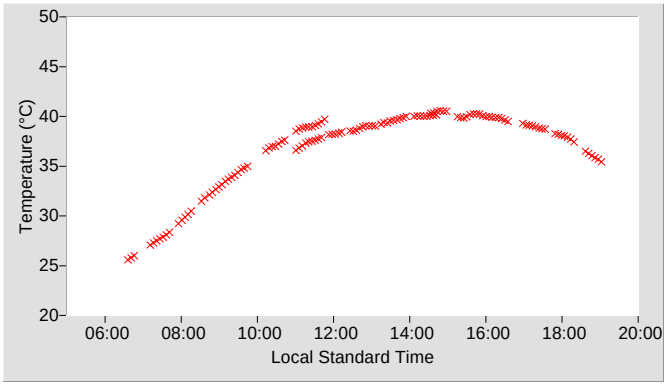


Figure 5. Humidity

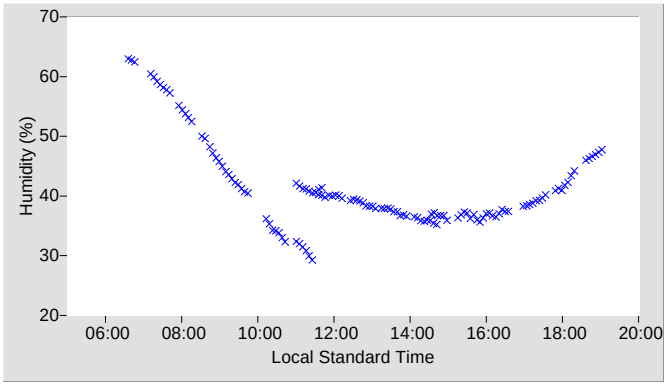


Figure 6. Pressure

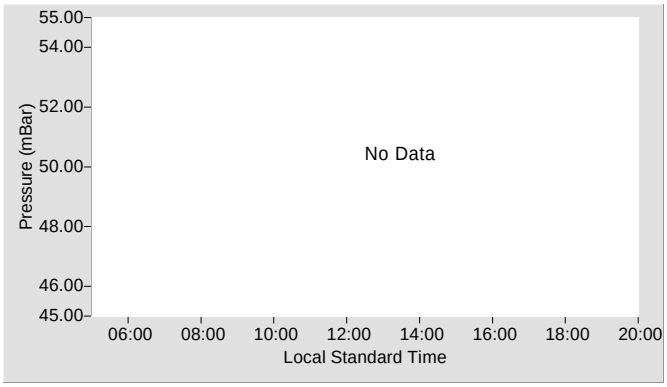
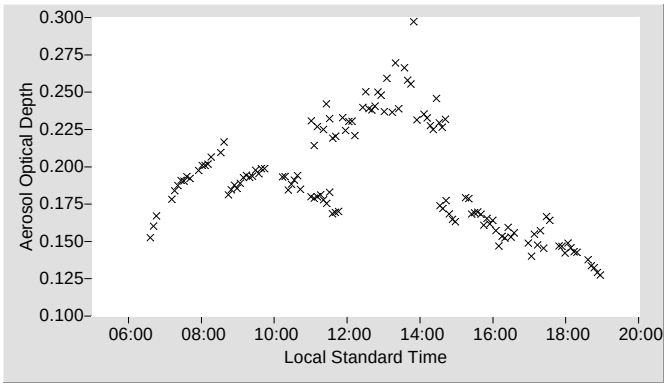


Figure 7. Estimated Broadband Aerosol Optical Depth



For other information about the calibration facility visit: http://www.arm.gov/docs/sites/sgp/sgp.html

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Calibration Data: 2000-02 29578E6 Eppley NIP
Comments:
Calibration data shows a strong disontinuity between two days of data. Although the results are consistent with the instrument's history, neither population is representaitve of the calibrated responsivity. Results invalidated.

29578E6 Eppley NIP
Comments:
NEW FACTORY CAL AS OF 6/7/01.

29738E6 Eppley NIP
Comments:
Sent back to Eppley for repair and the old cal factor was 7.72 uV/W/m^2 new one is 8.26uV/W/m^2.

29851E6 Eppley NIP
Comments:
Instrument returned to Eppley for repair on 5/8/2000. First calibration after repair is BORCAL 2000-02.

9881 Eppley 406
Comments:
Voltmeter S/N Unknown

9999 Analogic DP 100
Comments:
Voltmeter S/N Unknown

10151 Eppley 406
Comments:
Voltmeter S/N Unknown

Cavity Config: 29222 Eppley HF; Numbers: 1,2,3,4,5
Comments:
The improper window was in use for this cavity for this BORCAL. A special windowed WRR factor (1.05584) was derived using 30495 as a reference, and data were post-processed with the modified factor.

Appendix 3
Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL 2000-02 Session Configuration Audit Report

LOCATION

Facility	Facility Abbreviation	Contact	Latitude	Longitude	Elevation (m)	Avg press (mbr)	Time zone
Southern Great Plains	SGP	Dan Nelson	36.605	-97.488	317.0	980.0	-6.0

SYSTEM

% Error Thresholds

Cav1 / Cav2	1.0
Dif1 / Dif2	10.0
Global Ctrl / Ref	6.0
Direct Ctrl / Ref	6.0
Global ASR / Ref	18.0
Direct ASR / Ref	18.0
Test(x) / Test(x-1)	0.5

Delta Thresholds

Temp(x) - Temp(x-1)	3.0
Hum(x) - Hum(x-1)	7.0
Bar(x) - Bar(x-1)	10.0

Tilt Zenith	0.00
Tilt Azimuth	0.00
GPIB Board Number	0

Scan Rate (sec)

Radiometers	30
Meteorological	300
Thermistor	300

Clock

Reset Interval (m)	0
Warning Threshold (s)	0

Uncertainty

Decimal Precision	2
45° Neg. Offset	-15.00
45° Pos. Offset	15.00

Cavity Stability

Delta Threshold (%)	0.00
Scan Rate (s)	0
Stability Interval (s)	0

ASR Setup

Scan Rate (s)	1
Stability Interval (s)	60
Score Threshold 1	0.00
Score Threshold 2	0.00
Score Threshold 3	0.01
Weighting Dupes	5
Slope Weighting	2.00
Variability Weighting	1.00

PW Slope	1.23
PW Intercept	1.30
Cavity Calibration Interval (m)	0
Operator Log Interval (m)	0
Zenith Angle Uncertainty (deg)	0.03
Cal Due Interval (months)	12

ASR RADIOMETERS

Channel	Junction Box	Cable	Location
ASR 1: 5042 Matrix MARK III			
35			T-16
ASR 2: PY22693 Licor LI200			
134			2

METEOROLOGICAL INSTRUMENTS

Channel	Junction Box	Cable	Location
Temperature: B6077T Omega HX93T			
157			36
Humidity: B6077H Omega HX93H			
145			18
Pressure: None			

GPS TIME RECIEVER

GPS: None

Type	Port	Baud	Parity	Stop bits	Data bits
	0	0	0	0	0

DATALOGGER

Logger: 6294004 Fluke Helios 2287A

Cal Date 03/14/2000 Cal Due Date 03/14/2001

Communications

Type	Port	Baud	Parity	Stop bits	Data bits
RS232	1	9600	0	1	8

DIFFUSE REFERENCE INSTRUMENTS

	Responsivity	Cal Date	Cal Due Date	Shading Disk Diameter (cm)	Shading Disk Arm Length (cm)	Shading Disk Subtended Angle	Uncertainty Percent	Uncertainty Offset (W/m^2)	Channel	Junction Box	Cable	Location	Tilt	Active
Diffuse 1: 32872 Eppley 8-48	9.440	05/16/2000	05/16/2001	6.2	96.5	3.7	2.00	2.0	40			T-3	☐	☑
Diffuse 2: 32873 Eppley 8-48	8.570	05/16/2000	05/16/2001	6.2	96.5	3.7	2.00	2.0	41			T-4	☐	☑
Diffuse 3: None	0.000			0.0	0.0	0.0	0.00	0.0					☐	☐
Diffuse 4: None	0.000			0.0	0.0	0.0	0.00	0.0					☐	☐

CAVITIES, CONTROL UNITS, AND DIGITAL MULTI METERS

	Cavity 1	Cavity 2
Unwindowed WRR	1.00000	0.99838
Windowed WRR	1.05584	1.00000
Unwindowed Uncert (%)	0.41	0.41
Windowed Uncert (%)	0.41	0.41
Heater Resistance	153.90	154.40
Heater Lead Resistance	0.0660	0.0660
Mfg Calibration Factor	1.99000	1.99000
Default Sensitivity	0.01041	0.01050
Cal Date	05/05/2000	06/05/2000
Cal Due Date	05/05/2001	06/05/2001

	Unit 1	Unit 2
Cavity Head	29222 Eppley HF	30495 Eppley HF
Control Unit	9881 Eppley 406	10151 Eppley 406
Digital Multi Meter	9999 Analogic DP 100	9999 Analogic DP 100

	Control Unit 1	Control Unit 2
Current Shunt	10.000	10.000
Circuit Resist	3.700	2.200
Cal Date	05/05/2000	06/05/2000
Cal Due Date	05/05/2001	06/05/2001

Calibration Waits (Seconds)

TP-solar	0	0
TP-heated	45	45
TP-zero	60	60
Dwell	0	0
Active	☑	☑
Window in Use	☑	☐

Communications

	Type	Port	Baud	Parity	Stop bits	Data bits
Control Unit 1	RS232	5	9600	0	1	8
DMM 1	RS232	4	9600	0	1	8
Control Unit 2	RS232	3	9600	0	1	8
DMM 2	RS232	4	9600	0	1	8

BORCAL 2000-02 Session Configuration Audit Report

INSTRUMENT GROUPS

Group Number	Calibration Type	Instrument Type	Instrument Count
1	Global	Eppley PSP	10
2	Direct	Eppley NIP	10
3	Direct	Eppley NIP	9
4	Global	Eppley PSP	10
5	Global	Eppley PSP	10
6	Global	Eppley PSP	10
7	Global	Eppley PSP	10
8	Global	Eppley PSP	10
9	Global	Eppley PSP	3
10	Direct	Matrix MARK III	1
11	Global	Licor LI200	1
Total			84

BORCAL 2000-02 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Grp	Idx	Chn	Box	Cbl	TChn	TBox	TCbl	Location
20386F3	1	1	131			n/a	n/a	n/a	58
29554E6	2	1	80			n/a	n/a	n/a	T-7
29555E6	2	2	81			n/a	n/a	n/a	T-8
29578E6	2	3	43			n/a	n/a	n/a	T-13
29738E6	2	4	33			n/a	n/a	n/a	T-14
29740E6	2	5	34			n/a	n/a	n/a	T-15
29741E6	2	6	37			n/a	n/a	n/a	T-18
29847E6	2	7	38			n/a	n/a	n/a	T-19
29851E6	2	8	39			n/a	n/a	n/a	T-20
29856E6	2	9	88			n/a	n/a	n/a	T-21
29935E6	2	10	89			n/a	n/a	n/a	T-23
29936E6	3	1	90			n/a	n/a	n/a	T-24
30615F3	1	2	135			n/a	n/a	n/a	3
30617F3	1	3	126			n/a	n/a	n/a	65
30618F3	1	4	179			n/a	n/a	n/a	66
30619F3	1	5	136			n/a	n/a	n/a	4
30620F3	1	6	180			n/a	n/a	n/a	67
30652F3	1	7	181			n/a	n/a	n/a	68
30655F3	1	8	137			n/a	n/a	n/a	5
30663F3	1	9	138			n/a	n/a	n/a	6
30666F3	1	10	182			n/a	n/a	n/a	69
30667F3	4	1	139			n/a	n/a	n/a	7
30668F3	4	2	183			n/a	n/a	n/a	70
30670F3	4	3	127			n/a	n/a	n/a	74
30674F3	4	4	140			n/a	n/a	n/a	8
30677F3	9	3	139			n/a	n/a	n/a	7
30709F3	4	5	186			n/a	n/a	n/a	75
30719E6	3	2	91			n/a	n/a	n/a	T-25
30720E6	3	3	93			n/a	n/a	n/a	T-29
30775F3	4	6	187			n/a	n/a	n/a	76
30777F3	4	7	158			n/a	n/a	n/a	38
30791F3	4	8	159			n/a	n/a	n/a	39
30793F3	4	9	141			n/a	n/a	n/a	9
30796F3	4	10	160			n/a	n/a	n/a	40
30799F3	5	1	161			n/a	n/a	n/a	41
30811F3	5	2	55			n/a	n/a	n/a	12
30812F3	5	3	162			n/a	n/a	n/a	42
30813F3	5	4	163			n/a	n/a	n/a	43
30818F3	5	5	188			n/a	n/a	n/a	77
30820F3	5	6	189			n/a	n/a	n/a	78
30823F3	5	7	166			n/a	n/a	n/a	47
30890F3	5	8	167			n/a	n/a	n/a	48
30891F3	5	9	168			n/a	n/a	n/a	49
30894F3	5	10	169			n/a	n/a	n/a	50
30901F3	6	1	56			n/a	n/a	n/a	13
30948F3	6	2	146			n/a	n/a	n/a	20
30952F3	6	3	147			n/a	n/a	n/a	21
30957F3	6	4	148			n/a	n/a	n/a	22
30958F3	6	5	149			n/a	n/a	n/a	23
30961F3	6	6	150			n/a	n/a	n/a	24

BORCAL 2000-02 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Grp	Idx	Chn	Box	Cbl	TChn	TBox	TCbl	Location
31099F3†	6	7	123			103	-99	-99	64
31100F3†	6	8	124			104	-99	-99	73
31101F3†	6	9	125			105	-99	-99	82
31120E6†	3	4	42			62	-99	-99	T-12
31121E6	3	5	94			n/a	n/a	n/a	T-30
31122E6†	3	6	44			64	-99	-99	T-22
31146F3	6	10	128			n/a	n/a	n/a	83
31147F3	7	1	132			n/a	n/a	n/a	84
31148F3	7	2	133			n/a	n/a	n/a	85
31149F3†	7	3	120			100	-99	-99	37
31150F3†	7	4	121			101	-99	-99	46
31151F3†	7	5	122			102	-99	-99	55
31152F3†	7	6	51			71	-99	-99	19
31153F3†	7	7	52			72	-99	-99	28
31154F3†	7	8	53			73	-99	-99	29
31155F3	7	9	153			n/a	n/a	n/a	27
31156F3	7	10	54			n/a	n/a	n/a	30
31157F3	8	1	58			n/a	n/a	n/a	31
31158F3†	8	2	48			68	-99	-99	1
31159F3†	8	3	49			69	-99	-99	10
31160F3†	8	4	50			70	-99	-99	11
31387E6	3	7	95			n/a	n/a	n/a	T-31
31388E6	3	8	47			n/a	n/a	n/a	T-32
31629F3	8	5	190			n/a	n/a	n/a	79
31630F3	8	6	170			n/a	n/a	n/a	51
31631F3	8	7	191			n/a	n/a	n/a	80
31632F3	8	8	171			n/a	n/a	n/a	52
31633F3	8	9	129			n/a	n/a	n/a	56
31634F3	8	10	151			n/a	n/a	n/a	25
31635F3	9	1	152			n/a	n/a	n/a	26
31636F3	9	2	130			n/a	n/a	n/a	57
31747E6	3	9	96			n/a	n/a	n/a	T-33
5034	10	1	36			n/a	n/a	n/a	T-17
PY22692	11	1	57			n/a	n/a	n/a	14

† Standard Instrument

Appendix 4
Operator Session Logs

Operator session logs for the BORCAL