Broadband Outdoor Radiometer Calibration

BORCAL
2002-02

Customer:

Calibration System

Calibration Facility:

Solar Radiation Research Laboratory

Latitude: 39.740°N
Longitude: 105.180°W
Elevation: 1829.0 meters AMSL
Avg. Station Pressure: 812.0 mBar
Time Zone: -7.0

Calibration date
06/05/2002 to 06/06/2002

Report Date
December 4, 2002

NOTICE

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

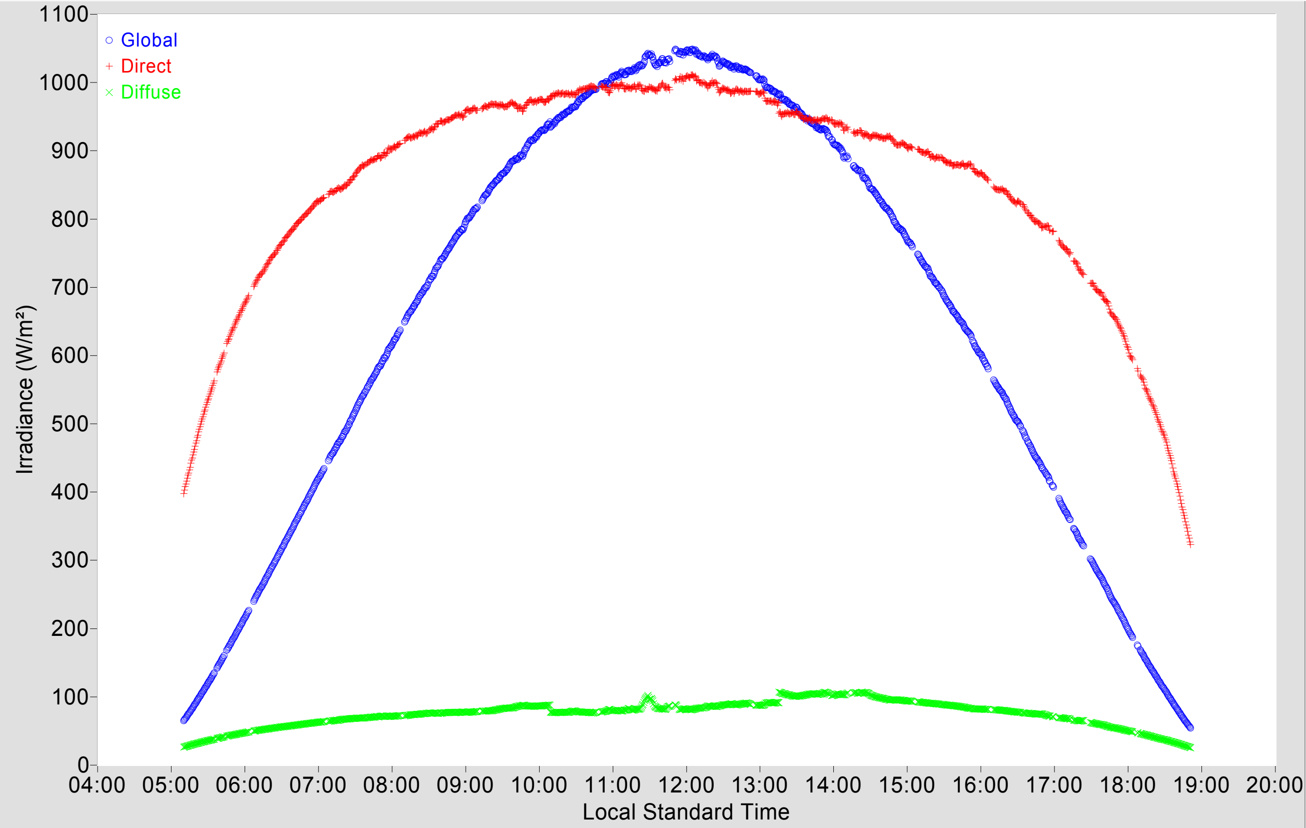
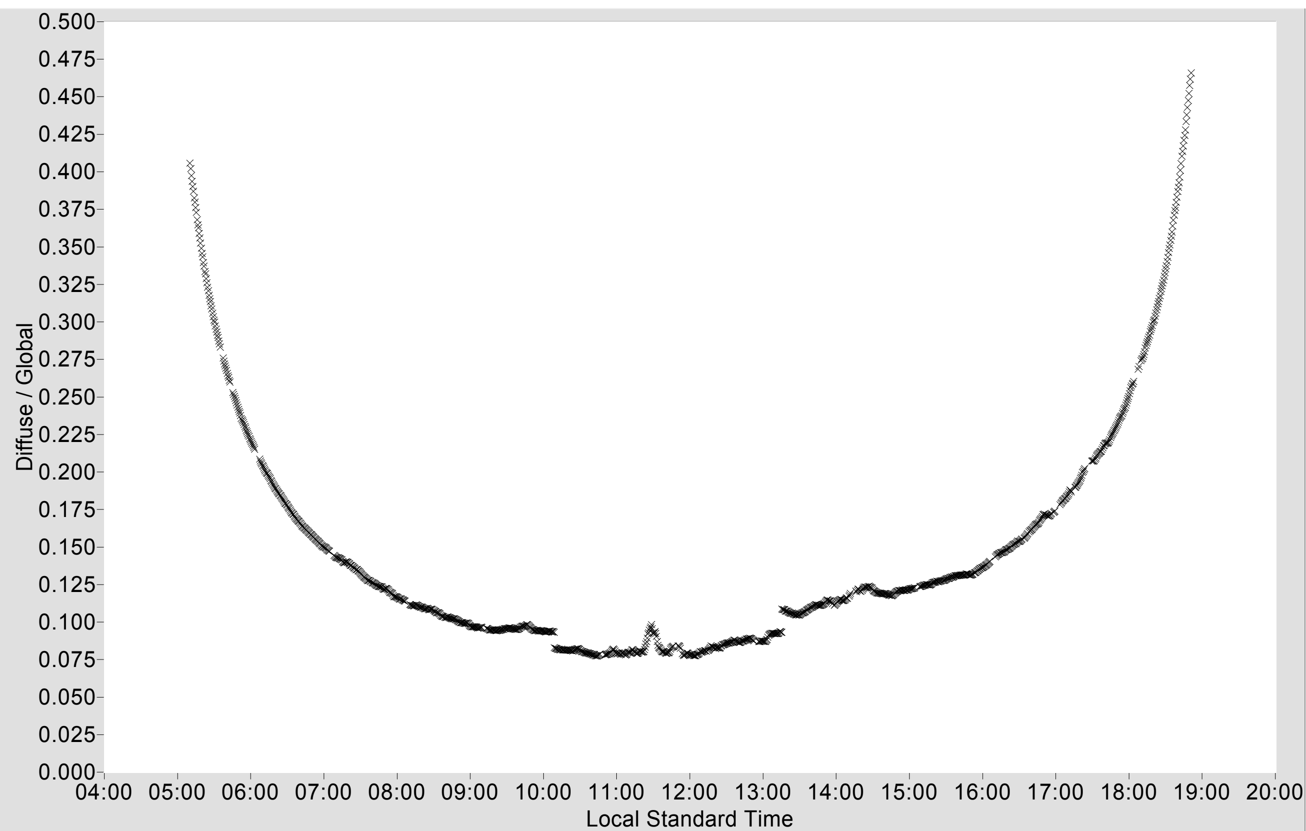


Figure 2. Diffuse / Global



Meteorological Observations

Table 1. Meteorological Observations

Observations	Mean
Temperature (°C)	24.03
Humidity (%)	28.59
Pressure (mBar)	819.4
Est. Aerosol Optical Depth (BB)	0.0759

Figure 3. Temperature

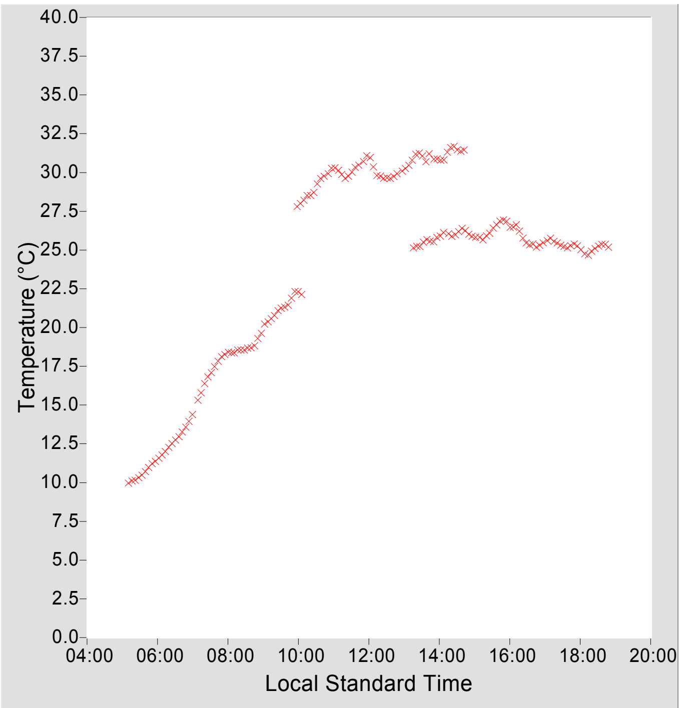


Figure 4. Humidity

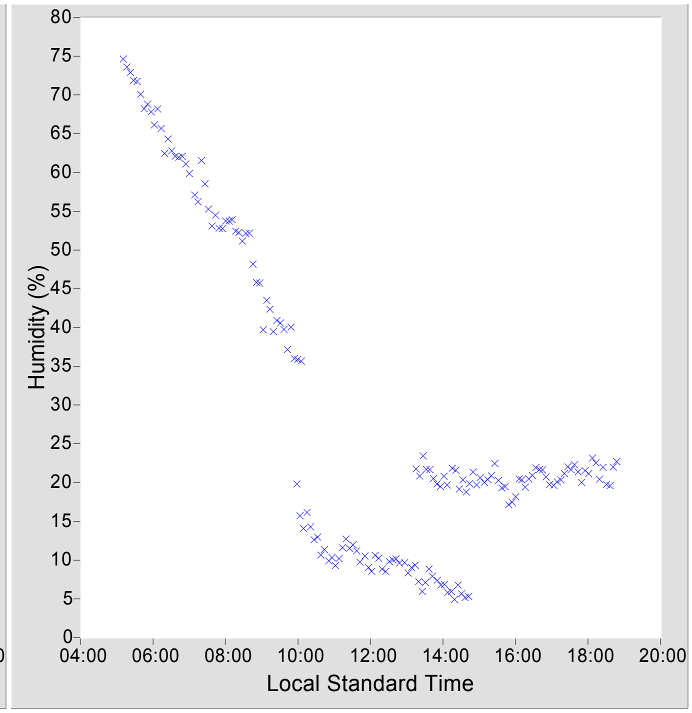


Figure 5. Pressure

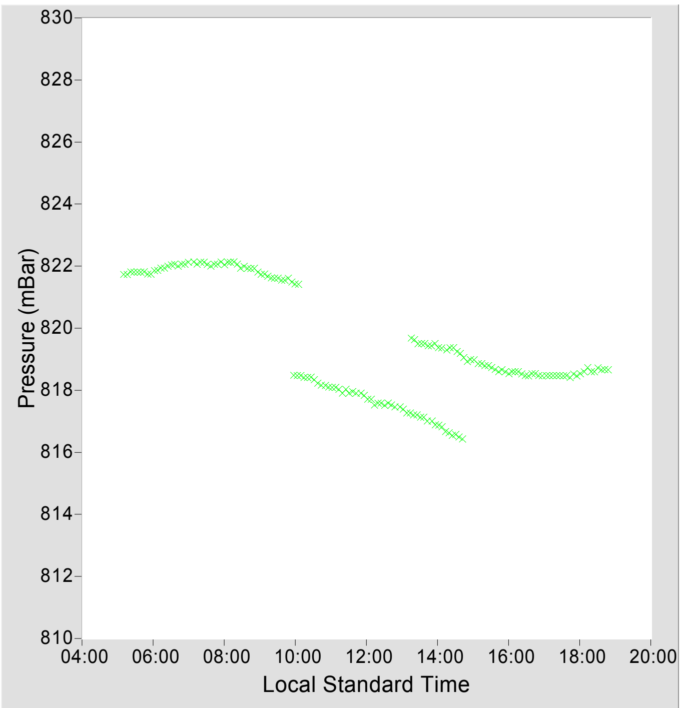
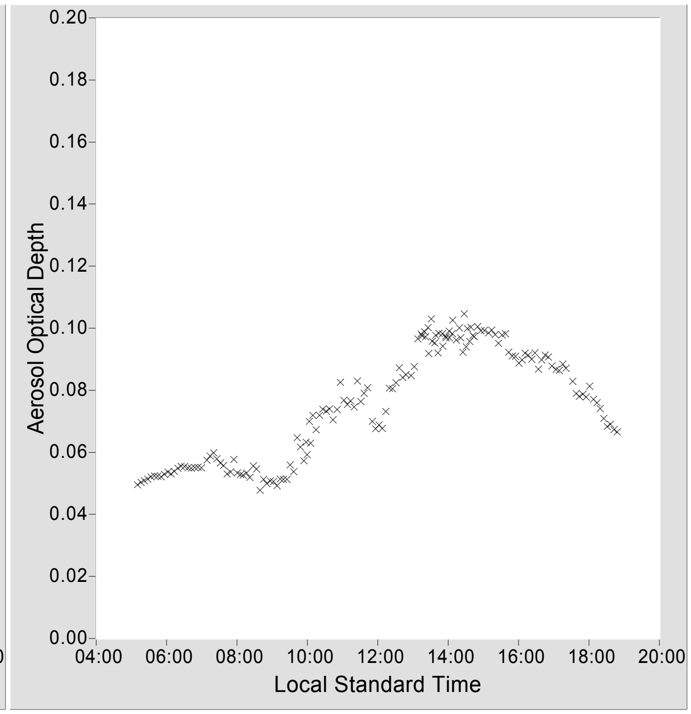


Figure 6. Estimated Broadband Aerosol Optical Depth



Control Instrument History

Figure 7. Eppley NIP Control Instrument History

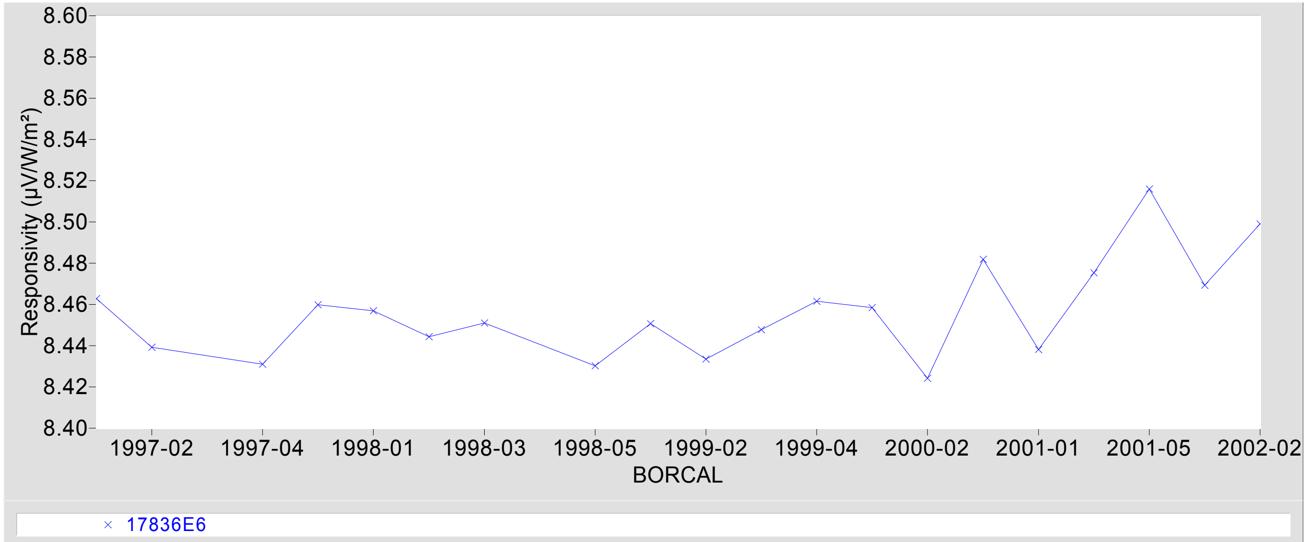
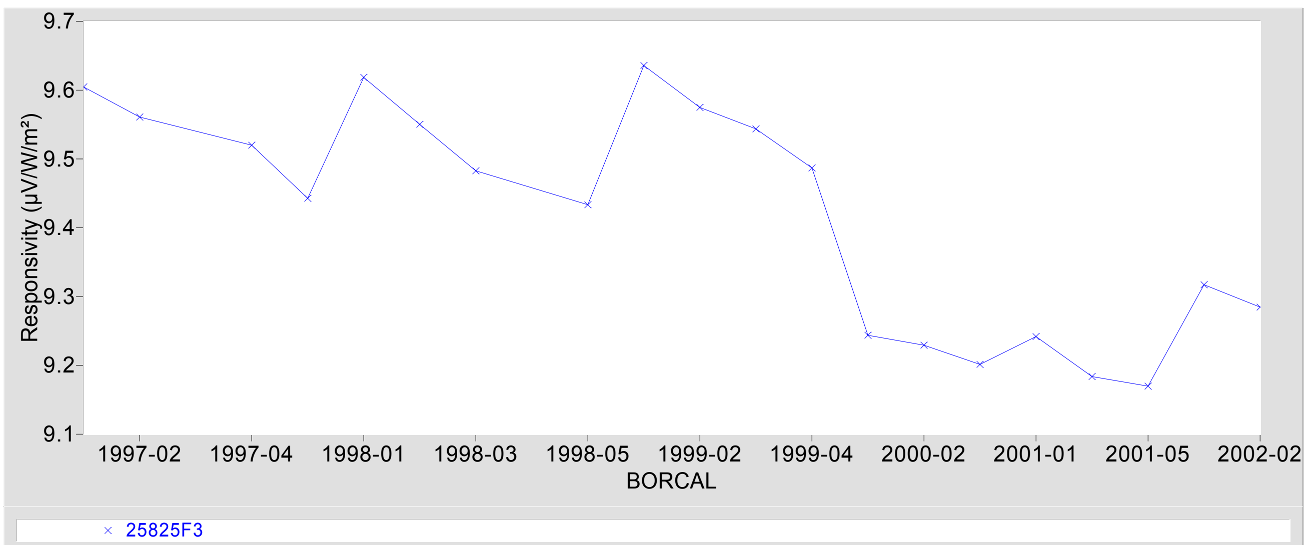


Figure 8. Eppley PSP Control Instrument History



Results Summary

Table 2. Results Summary

Instrument	Customer	Rs@45 (μV/W/m²)	U95 (%)	Page
17836E6	Calibration System	8.4990	+1.07 / -1.26	A1-2
18745FPP	Calibration System	0.68954	+2.99 / -5.26	A1-5
25825F3	Calibration System	9.2848	+2.11 / -3.72	A1-9

Note: Ancillary Data for BORCAL starts on page A1-13.

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.

National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 17836E6

Calibration Date: 6/6/2002

Due Date: 6/6/2003

Customer: Calibration System

Calibration Site Parameters: see page 3

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

Data Acquisition Dates: 6/5-6

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 31104	10/05/2001	10/05/2002
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32858	03/19/2002	03/19/2003
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32871	03/19/2002	03/19/2003
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6671000	04/02/2002	04/02/2003

† 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.

Calibrated by: Ibrahim Reda, Peter Gotseff, and Steve Wilcox

Certified by:

____

Ibrahim Reda

Title: Senior Research Engineer I

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Senior Scientist II

Date: __________________

Calibration Results
17836E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

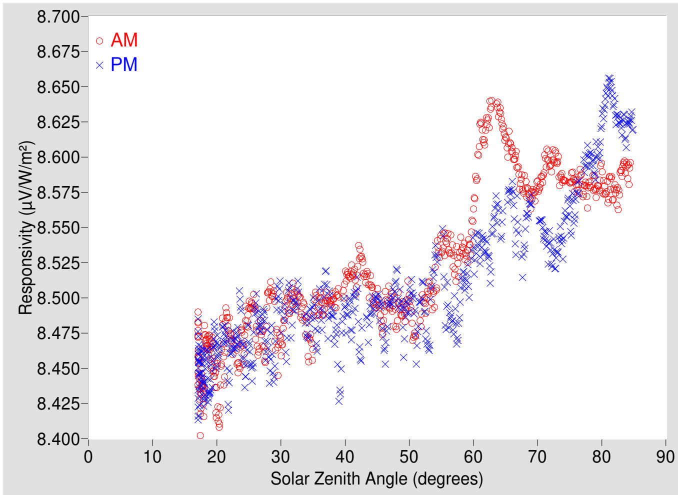


Figure 2. Responsivity vs Local Standard Time

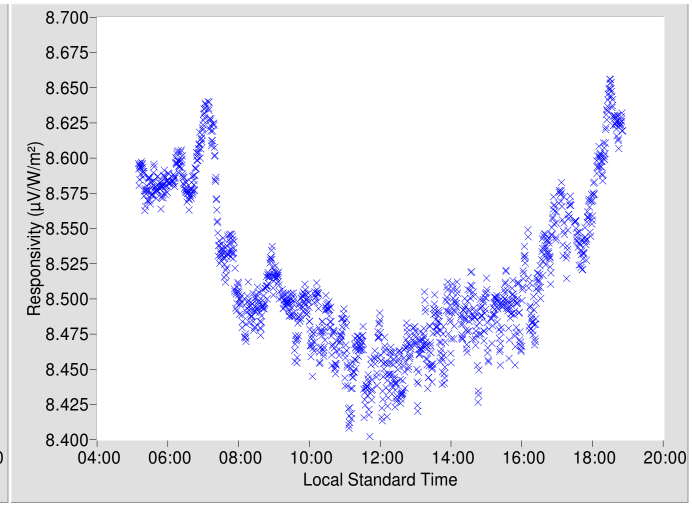


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
8.4990	+1.07 / -1.26	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	8.4852	0.45	96.27	8.4709	0.50	263.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4874	0.43	94.39	8.5124	0.44	265.66
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5006	0.48	92.63	8.4989	0.52	267.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4915	0.43	90.91	8.5063	0.53	269.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5059	0.51	89.25	8.5266	0.60	270.82
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5388	0.43	87.63	8.4910	0.60	272.43
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5349	0.45	86.00	8.5034	0.51	274.05
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5629	0.63	84.44	8.5312	0.49	275.61
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6211	0.45	82.90	8.5342	0.47	277.17
18	8.4490	0.66	159.59	8.4405	0.59	200.56	64	8.6336	0.44	81.38	8.5561	0.45	278.64
20	8.4309	0.61	144.83	8.4617	0.49	215.18	66	8.6046	0.44	79.82	8.5740	0.51	280.23
22	8.4758	0.52	135.99	8.4485	0.54	224.10	68	8.5782	0.43	78.28	8.5419	0.54	281.76
24	8.4682	0.49	129.35	8.4660	0.57	230.33	70	8.5787	0.43	76.79	8.5548	N/A	283.49
26	8.4832	0.48	124.00	8.4915	0.55	235.59	72	8.5946	0.42	75.20	8.5344	0.45	284.84
28	8.4984	0.53	119.67	8.4597	0.51	240.03	74	8.5843	0.43	73.67	8.5444	0.49	286.42
30	8.4677	0.53	116.17	8.4951	0.54	243.75	76	8.5807	0.43	72.11	8.5694	0.48	287.99
32	8.4994	0.42	112.82	8.4926	0.47	247.18	78	8.5776	0.44	70.43	8.6017	0.44	289.64
34	8.4768	0.48	109.89	8.4769	0.43	250.22	80	8.5867	0.46	68.83	8.6243	0.58	291.25
36	8.4954	0.42	107.19	8.4909	0.53	252.91	82	8.5761	0.47	67.12	8.6329	0.49	292.97
38	8.4987	0.41	104.68	8.4863	0.56	255.41	84	8.5905	0.47	65.39	8.6219	0.49	294.71
40	8.5105	0.42	102.36	8.4900	0.59	257.70	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5223	0.45	100.21	8.4893	0.54	259.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5083	0.43	98.17	8.4919	0.45	261.88	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

17836E6 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:

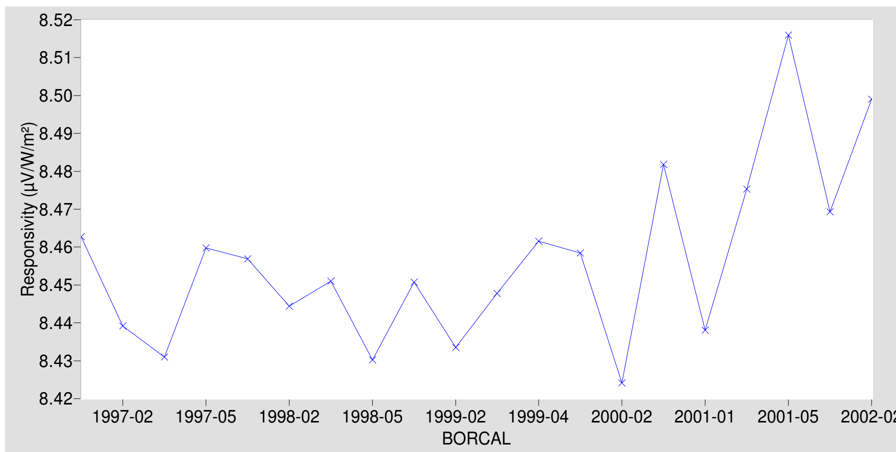
Table 1. Single Responsivities

Responsivity Characterization	RS (μV/W/m²)	U95 (%)
45°	8.4990	+1.07 / -1.26 †
Average	8.5237	+1.77 / -1.69 ‡

† Valid zenith angle range: 30.0° to 60.0°
‡ Valid zenith angle range: 17.0° to 84.5°

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

National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument:	Flat Plate Pyranometer	**Manufacturer:**	Eppley
Model:	FPP	**Serial Number:**	18745FPP
Calibration Date:	6/6/2002	**Due Date:**	6/6/2003
Customer:	Calibration System	**Calibration Site Parameters:**	see page 3

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

Data Acquisition Dates: 6/5-6

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 31104	10/05/2001	10/05/2002
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32858	03/19/2002	03/19/2003
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32871	03/19/2002	03/19/2003
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6671000	04/02/2002	04/02/2003

† 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.

Calibrated by: Ibrahim Reda, Peter Gotseff, and Steve Wilcox

Certified by:

____

Ibrahim Reda

Title: Senior Research Engineer I

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Senior Scientist II

Date: __________________

Calibration Results

18745FPP Eppley FPP

Figure 1. Responsivity vs Incident Angle

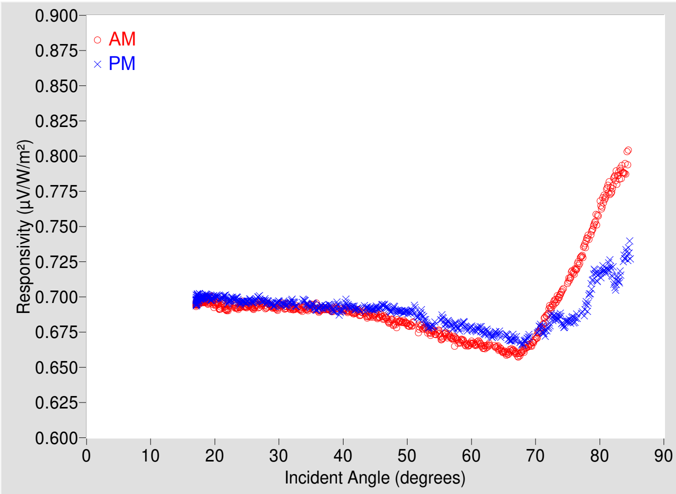


Figure 2. Responsivity vs Local Standard Time

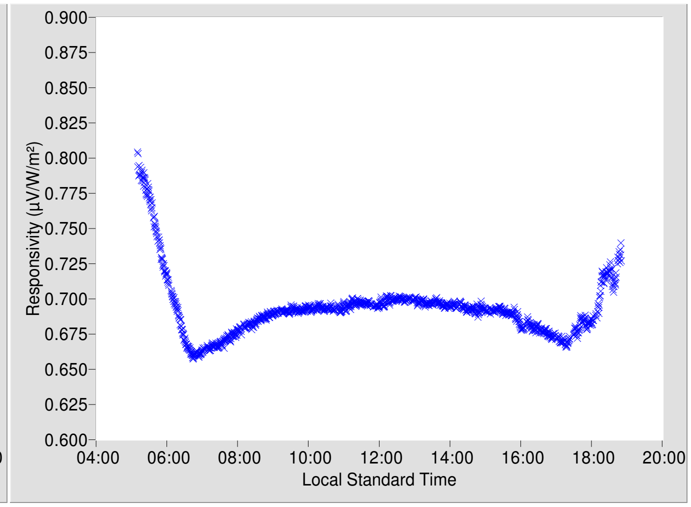


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
0.68954	+2.99 / -5.26	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	0.68616	1.74	96.26	0.69367	1.77	263.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	0.68080	1.85	94.38	0.69186	1.87	265.65
4	N/A	N/A	N/A	N/A	N/A	N/A	50	0.68054	1.91	92.62	0.68932	1.91	267.41
6	N/A	N/A	N/A	N/A	N/A	N/A	52	0.67837	2.05	90.90	0.68750	2.20	269.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	0.67516	2.14	89.24	0.67963	2.15	270.82
10	N/A	N/A	N/A	N/A	N/A	N/A	56	0.67320	2.24	87.62	0.68086	2.36	272.42
12	N/A	N/A	N/A	N/A	N/A	N/A	58	0.66850	2.41	86.04	0.67785	2.45	274.05
14	N/A	N/A	N/A	N/A	N/A	N/A	60	0.66735	2.56	84.44	0.67777	2.58	275.60
16	N/A	N/A	N/A	N/A	N/A	N/A	62	0.66420	2.76	82.90	0.67458	2.80	277.17
18	0.69698	1.33	159.56	0.69948	1.38	200.53	64	0.66404	2.96	81.37	0.67430	2.99	278.64
20	0.69524	1.42	144.81	0.70006	1.27	215.15	66	0.66156	3.23	79.82	0.66926	3.31	280.22
22	0.69155	1.39	135.97	0.69727	1.35	224.08	68	0.66170	3.59	78.28	0.66685	3.69	281.76
24	0.69400	1.35	129.34	0.69595	1.37	230.31	70	0.67006	4.00	76.78	0.67422	N/A	283.48
26	0.69208	1.34	124.10	0.69681	1.37	235.68	72	0.69006	4.49	75.19	0.67859	4.63	284.84
28	0.69354	1.38	119.65	0.69694	1.38	240.12	74	0.70303	4.88	73.66	0.68389	5.20	286.41
30	0.69357	1.41	116.16	0.69625	1.40	243.74	76	0.71813	5.60	72.11	0.68394	6.14	287.99
32	0.69169	1.42	112.81	0.69673	1.46	247.17	78	0.74036	6.56	70.47	0.69536	7.51	289.63
34	0.69255	1.46	109.88	0.69677	1.51	250.21	80	0.76325	8.05	68.78	0.71639	8.88	291.24
36	0.69239	1.53	107.18	0.69132	1.54	252.90	82	0.77901	10.29	67.11	0.71516	11.91	292.96
38	0.69064	1.51	104.67	0.69347	1.58	255.40	84	0.79225	14.51	65.41	0.72979	17.14	294.70
40	0.69109	1.55	102.35	0.69211	1.79	257.69	86	N/A	N/A	N/A	N/A	N/A	N/A
42	0.68934	1.62	100.20	0.69174	1.65	259.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	0.68609	1.70	98.16	0.69197	1.72	261.87	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

18745FPP Eppley FPP

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.

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

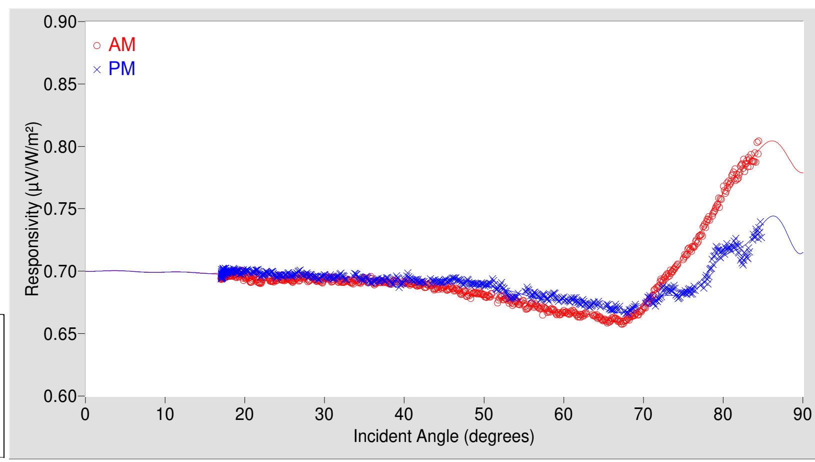
where the coefficients a_i and b_j are available upon request.

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

Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±7.15	±7.15
Valid incidence angle range	17.0° to 84.5°	17.0° to 84.8°
R^2	0.9999982	0.9999956

Figure 1. Responsivity Function



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	0.69990	*	0.69988	*	0.69989	*
9-18	0.69867	*	0.69887	*	0.69877	*
18-27	0.69373	±7.16	0.69770	±7.16	0.69572	±7.20
27-36	0.69272	±7.16	0.69620	±7.16	0.69446	±7.18
36-45	0.68999	±7.17	0.69236	±7.16	0.69118	±7.19
45-54	0.68102	±7.19	0.68969	±7.19	0.68535	±7.35
54-63	0.66951	±7.20	0.67840	±7.17	0.67395	±7.37
63-72	0.66626	±7.39	0.67171	±7.21	0.66898	±7.64
72-81	0.72454	±9.00	0.69152	±7.56	0.70803	±11.69
81-90	0.78983	*	0.72772	*	0.75878	*

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

4. The Single Responsivities:

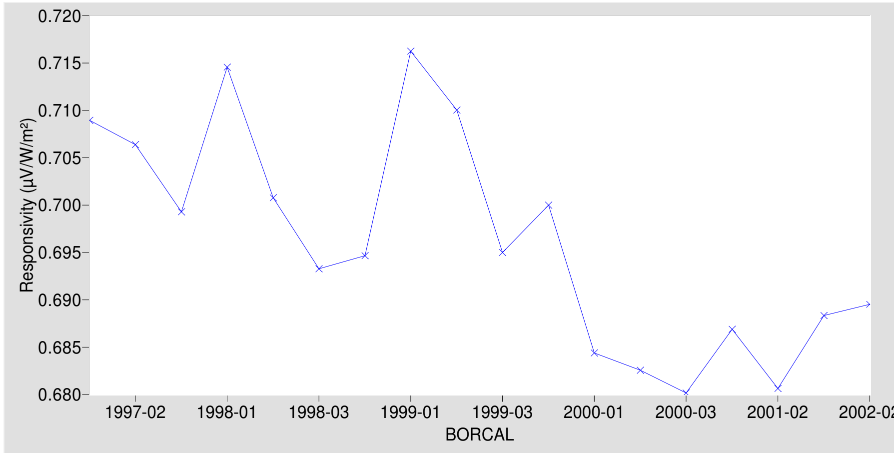
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	0.68954	+2.99 / -5.26 [1]
45° - 55°	0.68444	±7.29 [2]
Composite	0.69282	+16.68 / -8.62 [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: 17.0° to 84.5°

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°



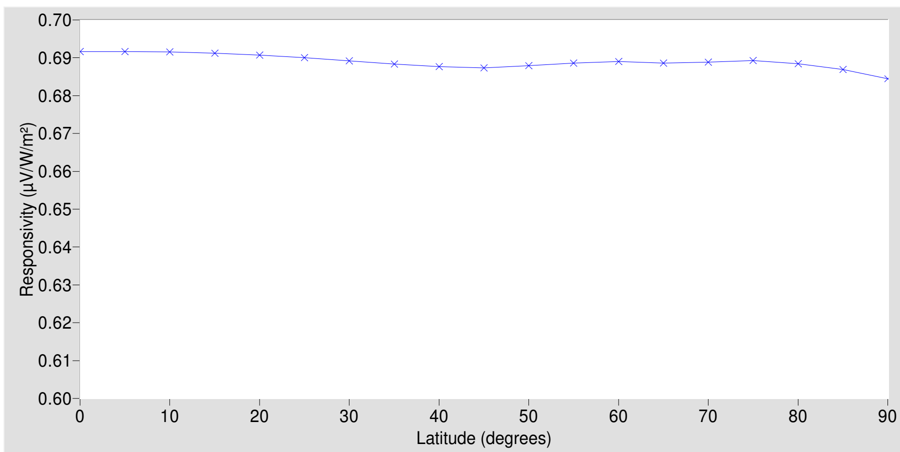
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	0.69164	+17.79 / -8.52
5	0.69167	+17.79 / -8.52
10	0.69152	+17.81 / -8.51
15	0.69120	+17.86 / -8.48
20	0.69072	+17.93 / -8.45
25	0.69007	+18.03 / -8.40
30	0.68923	+18.16 / -8.34
35	0.68834	+18.30 / -8.28
40	0.68767	+18.41 / -8.23
45	0.68731	+18.46 / -8.21
50	0.68791	+18.37 / -8.25
55	0.68863	+18.26 / -8.30
60	0.68901	+18.20 / -8.32
65	0.68860	+18.26 / -8.30
70	0.68883	+18.23 / -8.31
75	0.68926	+18.16 / -8.34
80	0.68840	+18.29 / -8.28
85	0.68691	+18.53 / -8.18
90	0.68449	+18.91 / -8.02

* 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.

National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 25825F3

Calibration Date: 6/6/2002

Due Date: 6/6/2003

Customer: Calibration System

Calibration Site Parameters: see page 3

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

Data Acquisition Dates: 6/5-6

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 31104	10/05/2001	10/05/2002
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32858	03/19/2002	03/19/2003
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32871	03/19/2002	03/19/2003
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6671000	04/02/2002	04/02/2003

† 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.

Calibrated by: Ibrahim Reda, Peter Gotseff, and Steve Wilcox

Certified by:

____

Ibrahim Reda

Title: Senior Research Engineer I

Date: __________________

Quality Assured by:

____

Thomas Stoffel

Title: Senior Scientist II

Date: __________________

Calibration Results

25825F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle

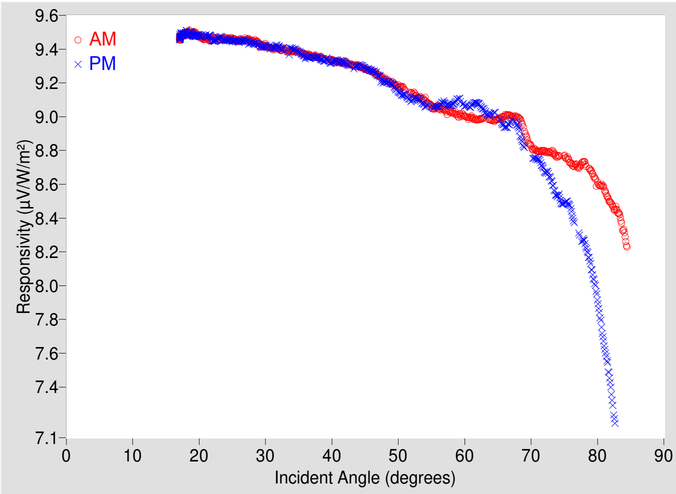


Figure 2. Responsivity vs Local Standard Time

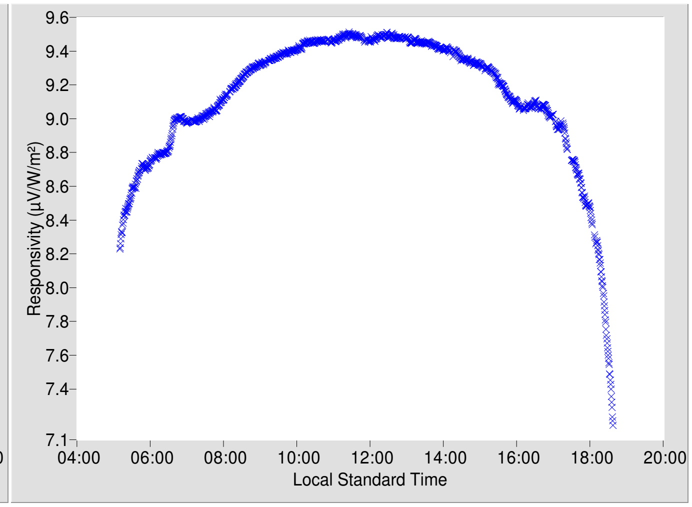


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
9.2848	+2.11 / -3.72	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	9.2699	0.63	96.23	9.2714	0.68	263.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2212	0.66	94.40	9.2066	0.70	265.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1808	0.67	92.64	9.1484	0.76	267.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1390	0.66	90.93	9.0964	0.70	269.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0998	0.71	89.26	9.0647	0.75	270.79
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0562	0.69	87.60	9.0618	0.76	272.44
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0282	0.73	86.01	9.0697	0.78	274.02
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0041	0.76	84.45	9.0655	0.83	275.62
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9836	0.77	82.91	9.0792	0.85	277.14
18	9.4933	0.61	159.64	9.4922	0.59	200.61	64	8.9809	0.80	81.34	9.0130	0.86	278.65
20	9.4776	0.56	144.88	9.4795	0.52	215.22	66	9.0046	0.85	79.84	8.9426	0.94	280.24
22	9.4597	0.52	136.03	9.4559	0.57	224.13	68	8.9954	0.97	78.29	8.9380	1.35	281.77
24	9.4609	0.51	129.39	9.4519	0.58	230.36	70	8.8229	1.16	76.76	8.7541	N/A	283.50
26	9.4526	0.52	124.03	9.4448	0.56	235.61	72	8.7963	1.05	75.21	8.6787	1.30	284.85
28	9.4476	0.53	119.69	9.4357	0.58	240.06	74	8.7666	1.18	73.63	8.5316	1.48	286.42
30	9.4213	0.56	116.19	9.4175	0.59	243.77	76	8.7226	1.35	72.08	8.4433	1.59	288.00
32	9.4012	0.55	112.84	9.4137	0.61	247.20	78	8.7269	1.52	70.44	8.2596	1.94	289.57
34	9.3869	0.55	109.84	9.4007	0.64	250.24	80	8.6057	1.86	68.83	7.9047	3.43	291.26
36	9.3693	0.57	107.13	9.3535	0.64	252.93	82	8.4889	2.31	67.13	7.4076	3.80	292.90
38	9.3514	0.56	104.70	9.3486	0.62	255.42	84	8.3082	3.22	65.40	N/A	N/A	N/A
40	9.3364	0.57	102.38	9.3220	0.63	257.72	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3226	0.59	100.17	9.3176	0.64	259.87	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2987	0.60	98.18	9.3021	0.64	261.90	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

25825F3 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

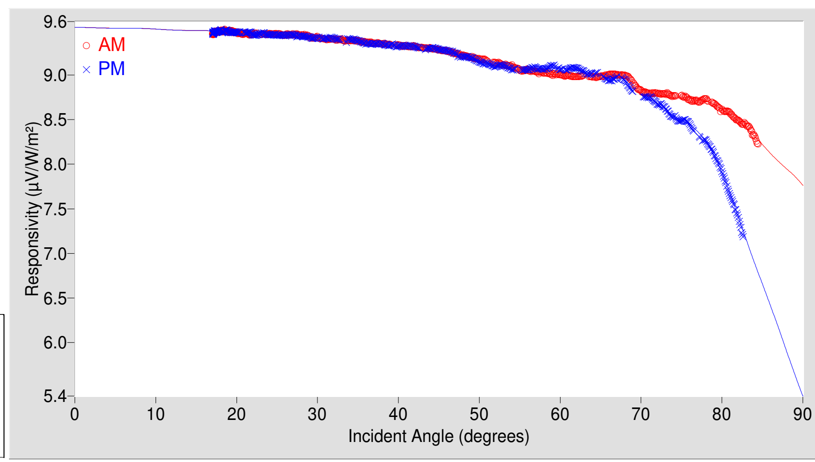


Table 1. Function Validity

	AM	PM
Uncertainty U95 (%)	±1.67	±1.67
Valid incidence angle range	17.0° to 84.4°	17.0° to 82.6°
R^2	0.9999987	0.9999986

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	9.5280	*	9.5280	*	9.5280	*
9-18	9.5045	*	9.5044	*	9.5045	*
18-27	9.4669	±1.69	9.4625	±1.69	9.4647	±1.71
27-36	9.4113	±1.73	9.4127	±1.71	9.4120	±1.77
36-45	9.3338	±1.72	9.3276	±1.72	9.3307	±1.77
45-54	9.1967	±1.93	9.1743	±2.05	9.1855	±2.37
54-63	9.0290	±1.79	9.0660	±1.68	9.0475	±1.91
63-72	8.9442	±2.04	8.9022	±2.58	8.9232	±3.37
72-81	8.7179	±2.02	8.3477	±5.45	8.5328	±9.32
81-90	8.1707	*	6.5306	*	7.3507	*

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

4. The Single Responsivities:

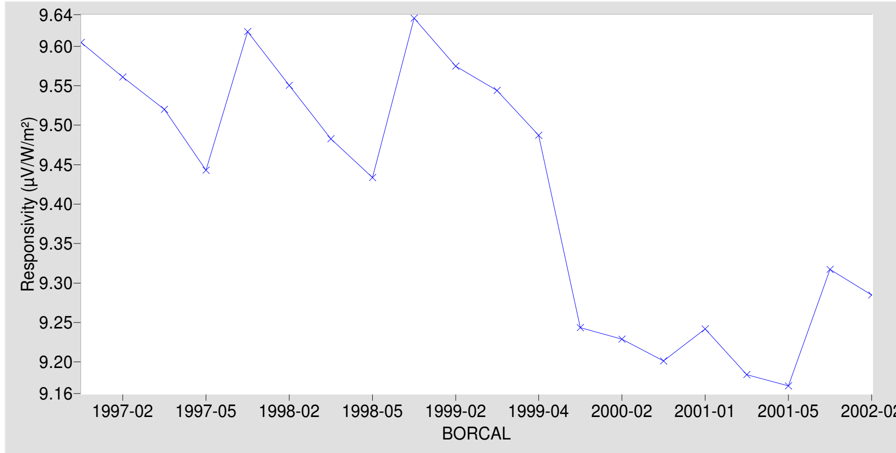
Table 3. Single Responsivities

Responsivity Characterization	RS (µV/W/m²)	U95 (%)
45°	9.2848	+2.11 / -3.72 [1]
45° - 55°	9.1696	±2.09 [2]
Composite	9.3060	+2.62 / -25.91 [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: 17.0° 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°



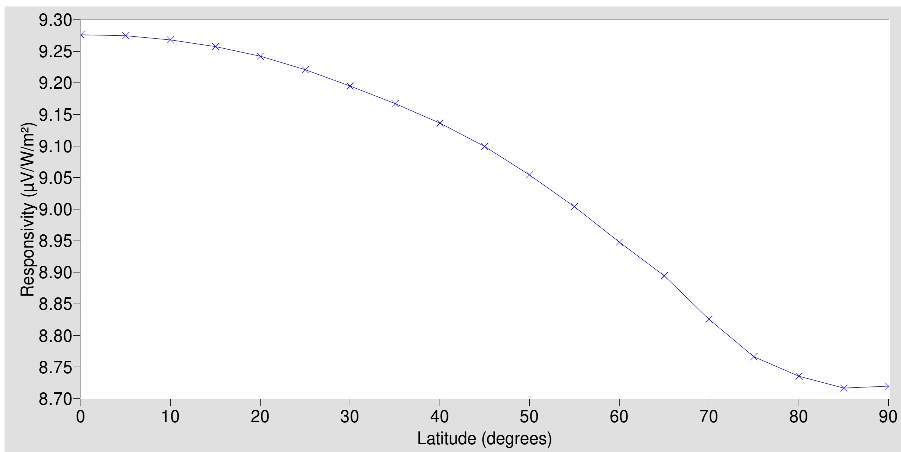
5. Latitude Optimized Responsivity:

Table 4. Latitude Optimized Responsivities

Latitude	RS (µV/W/m²)	Error estimate (%) *
0	9.2762	+3.26 / -39.21
5	9.2747	+3.27 / -39.20
10	9.2683	+3.33 / -39.16
15	9.2574	+3.44 / -39.09
20	9.2422	+3.59 / -38.99
25	9.2210	+3.79 / -38.85
30	9.1951	+3.96 / -38.67
35	9.1674	+4.10 / -38.49
40	9.1364	+4.30 / -38.28
45	9.0992	+4.39 / -38.03
50	9.0540	+4.73 / -37.72
55	9.0042	+4.89 / -37.37
60	8.9478	+4.98 / -36.98
65	8.8944	+5.18 / -36.60
70	8.8256	+5.27 / -36.11
75	8.7661	+4.76 / -35.67
80	8.7353	+4.26 / -35.45
85	8.7166	+4.40 / -35.31
90	8.7197	+3.67 / -35.33

* 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.

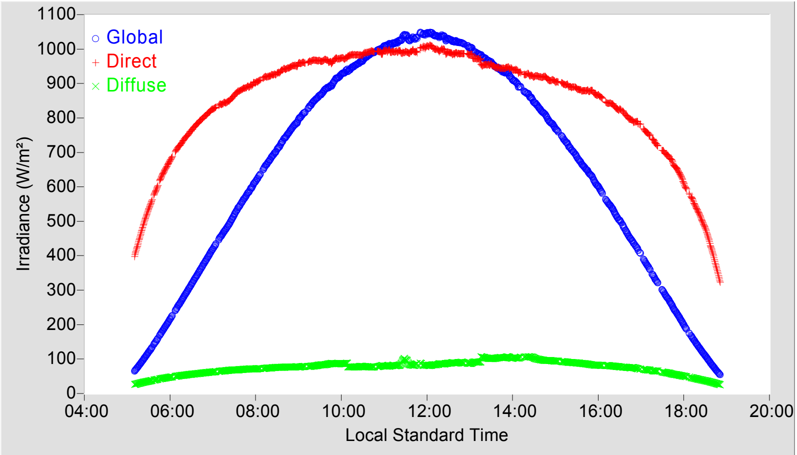
Ancillary Data for BORCAL 2002-02

Calibration Facility: Solar Radiation Research Laboratory

Latitude: 39.740°N   Longitude: 105.180°W   Elevation: 1829.0 meters AMSL   Avg. Station Pressure: 812.0 mBar   Time Zone: -7.0

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
31104	HF	1.00035

Table 5. Diffuse Irradiance (D)

Instrument	Model	Responsivity
32858	8-48	9.0940 μV/W/m²
32871	8-48	8.9610 μV/W/m²

Meteorological Observations:

Table 6. Meteorological Observations

Observations	Mean
Temperature (°C)	24.03
Humidity (%)	28.59
Pressure (mBar)	819.4
Est. Aerosol Optical Depth (BB)	0.0759

Figure 4. Temperature

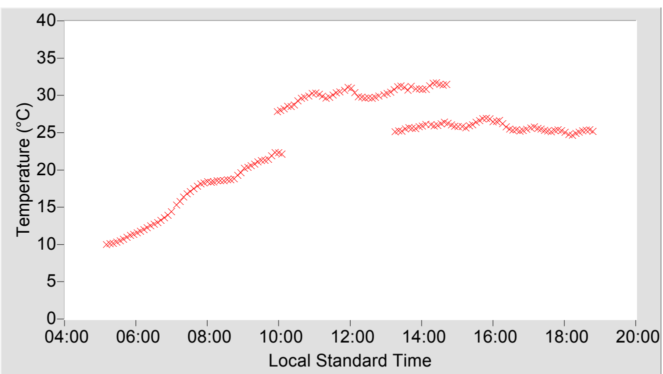


Figure 5. Humidity

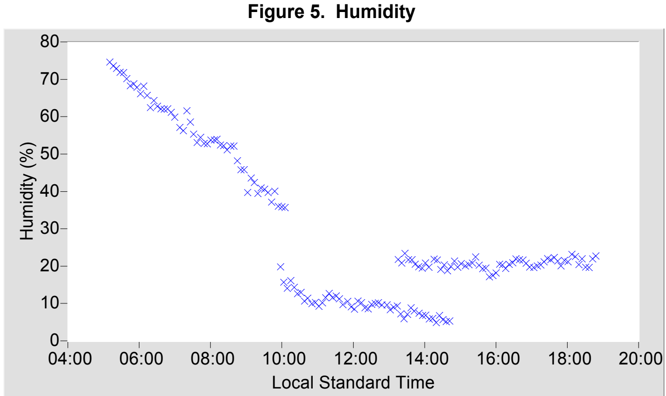


Figure 6. Pressure

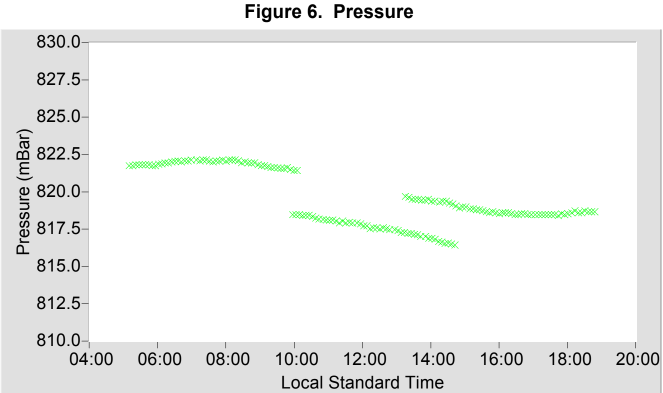
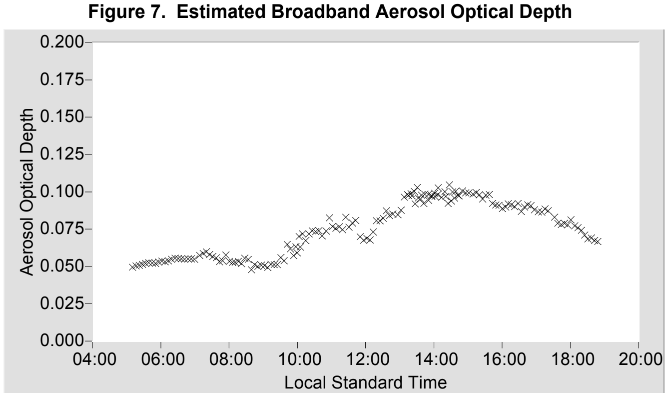


Figure 7. Estimated Broadband Aerosol Optical Depth



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

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

BORCAL: 2002-02
Comments:
The WRR number for cavity 31104 was incorrectly entered as 1.000249. The corrected number was entered for this report (1.00035). The difference between the two is approximatelyi 0.01% and would not significantly affect the results; hence data were not reprocessed with the corrected number.