Broadband Outdoor Radiometer Calibration

BORCAL
2001-05

Customer:
Tom Stoffel

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
09/04/2001

Report Date
November 8, 2002

NOTICE

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

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

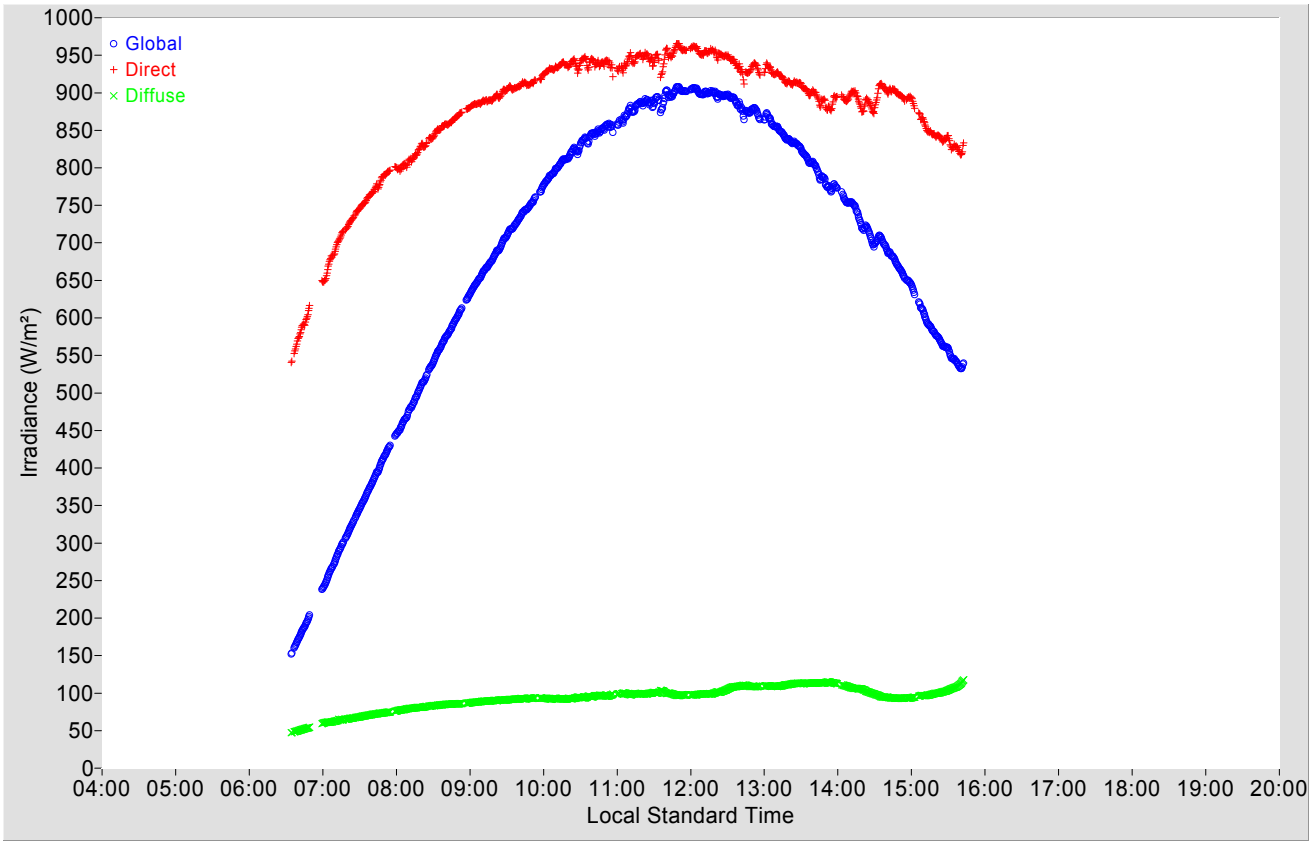
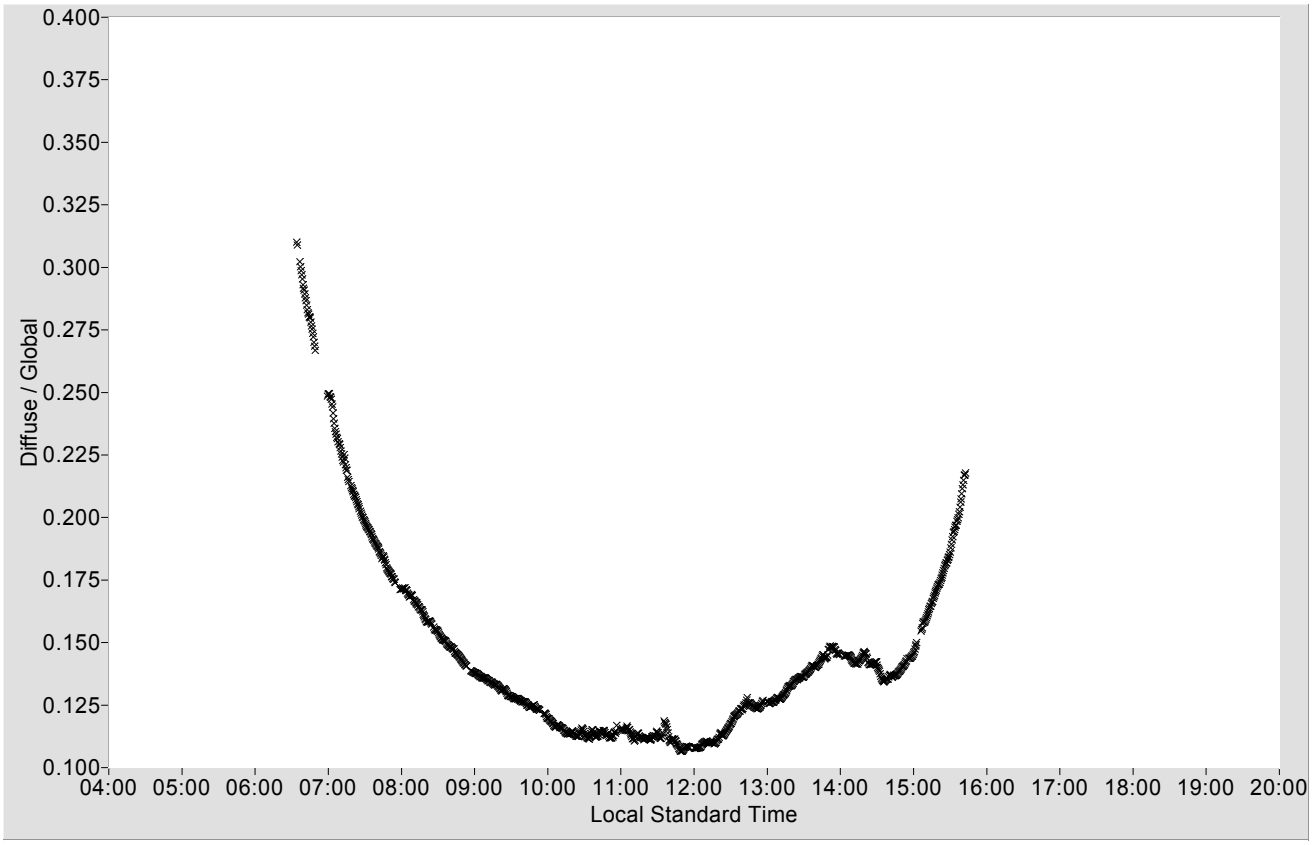


Figure 2. Diffuse / Global



Meteorological Observations

Table 1. Meteorological Observations

Observations	Mean
Temperature (°C)	29.53
Humidity (%)	15.94
Pressure (mBar)	N/A
Est. Aerosol Optical Depth (BB)	0.1037

Figure 3. Temperature

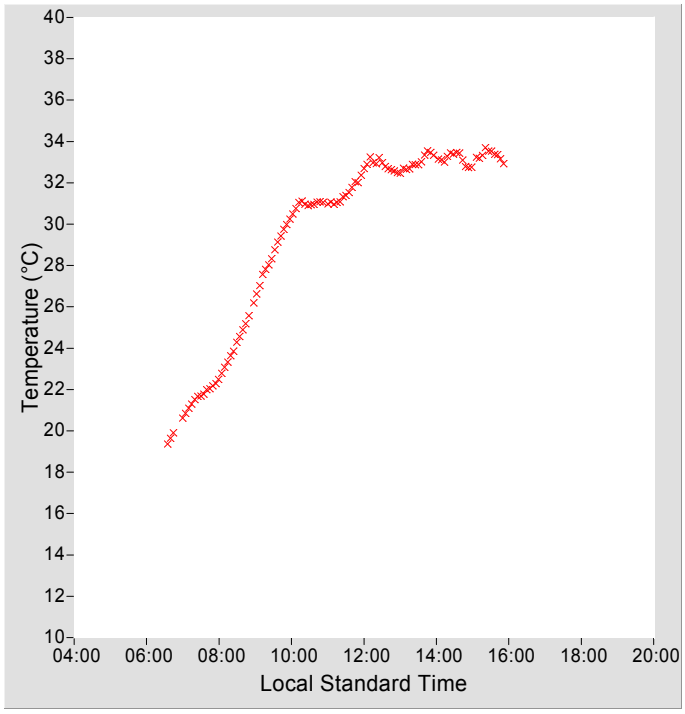


Figure 4. Humidity

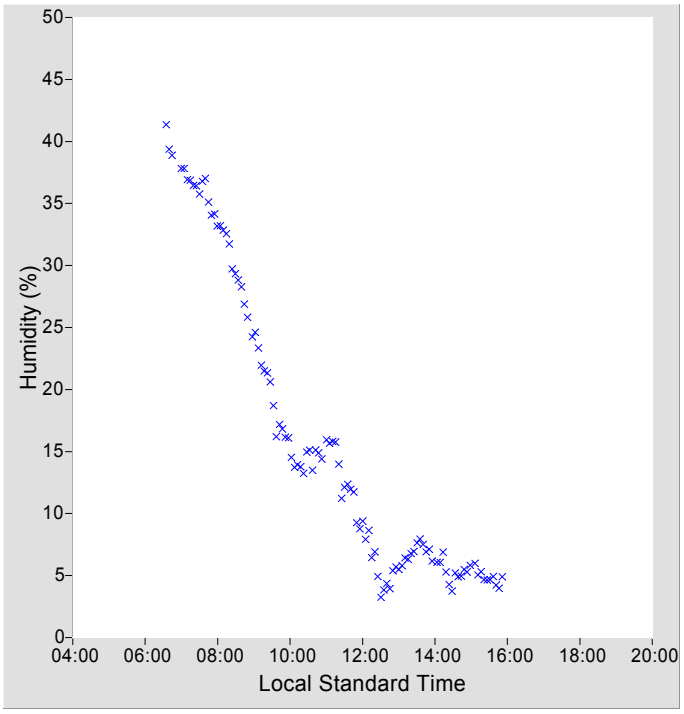


Figure 5. Pressure

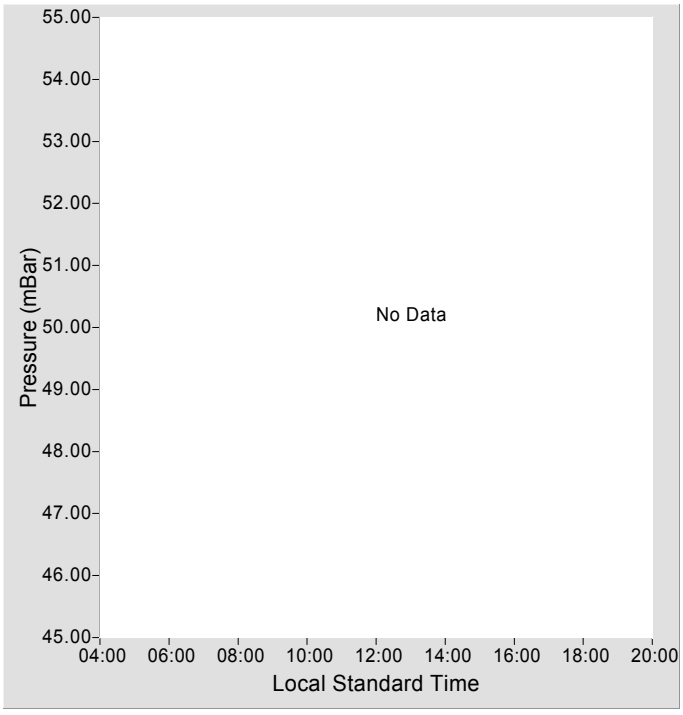
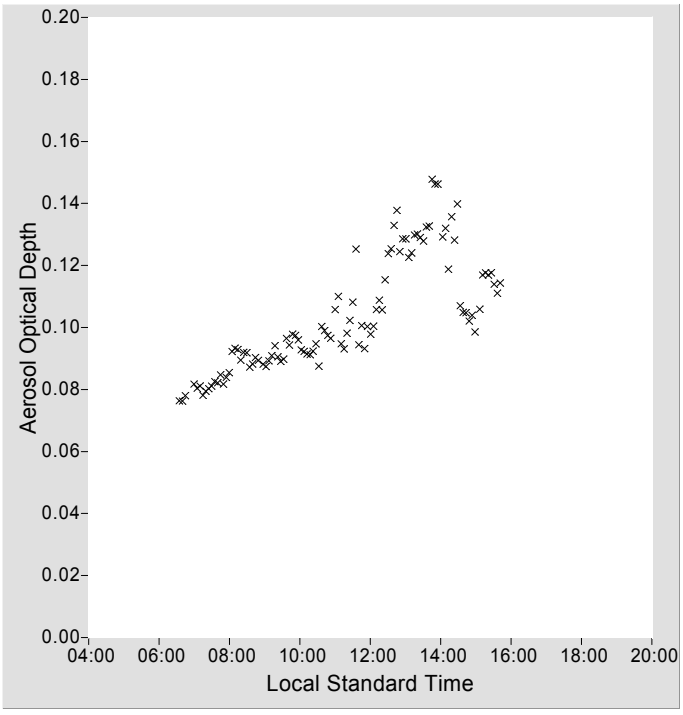


Figure 6. Estimated Broadband Aerosol Optical Depth



Control Instrument History

Figure 7. Eppley NIP Control Instrument History

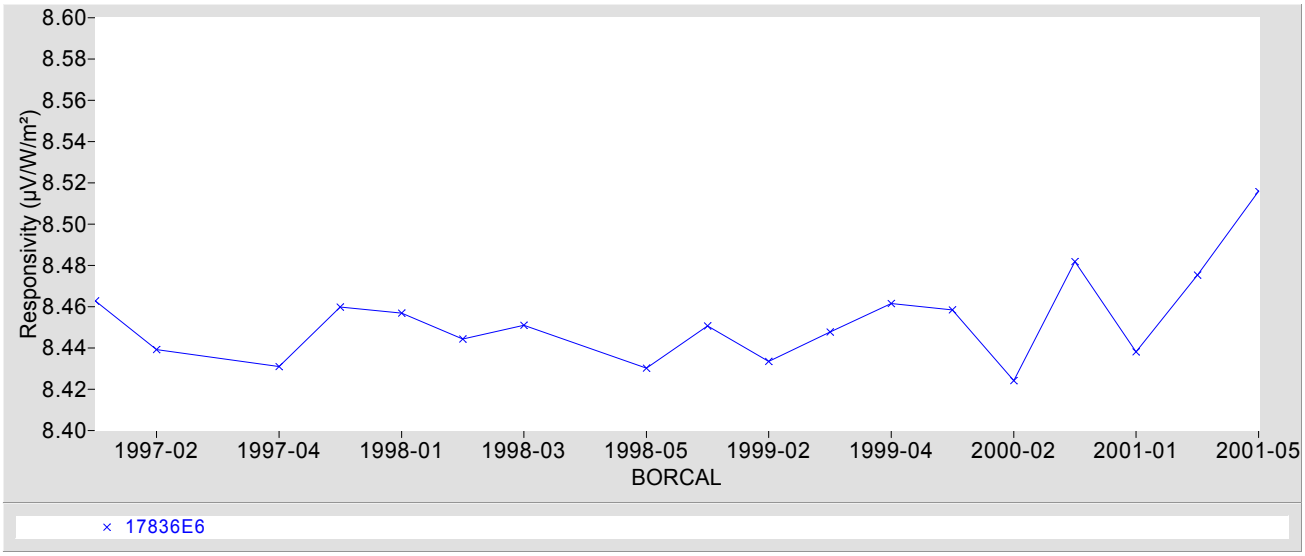
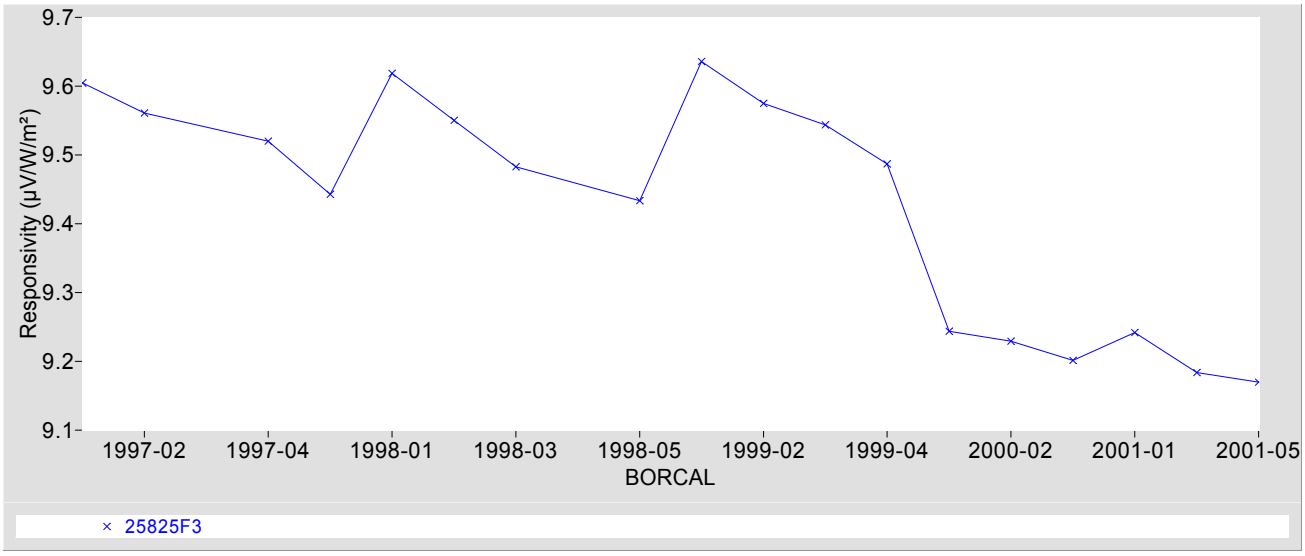


Figure 8. Eppley PSP Control Instrument History



Results Summary

Table 2. Results Summary

Instrument	Customer	Rs@45 (µV/W/m²)	U95 (%)	Page
19792E6	Tom Stoffel	9.0776	+1.12 / -1.27	A1-2

Note: Ancillary Data for BORCAL starts on page A1-5.

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:** 19792E6

Calibration Date: 9/4/2001 **Due Date:** 9/4/2002

Customer: Tom Stoffel **Calibration Site Parameters:** see page 3

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

Data Acquisition Dates: 9/4

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 31104	10/05/2000	10/05/2001
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32858	05/08/2001	05/08/2002
Diffuse Irradiance †	Eppley Pyranometer Model 8-48, S/N 32871	05/08/2001	05/08/2002
Data Acquisition ‡	Fluke Data Logger Model Helios 2287A, S/N 6671000	04/15/2001	04/15/2002

† 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

Certified by:

_____
Ibrahim Reda

Title: Senior Research Engineer I

Date: _____

Quality Controlled by:

_____
Thomas Stoffel

Title: Senior Scientist II

Date: _____

Calibration Results

19792E6 Eppley NIP

Figure 1. Responsivity vs Zenith Angle

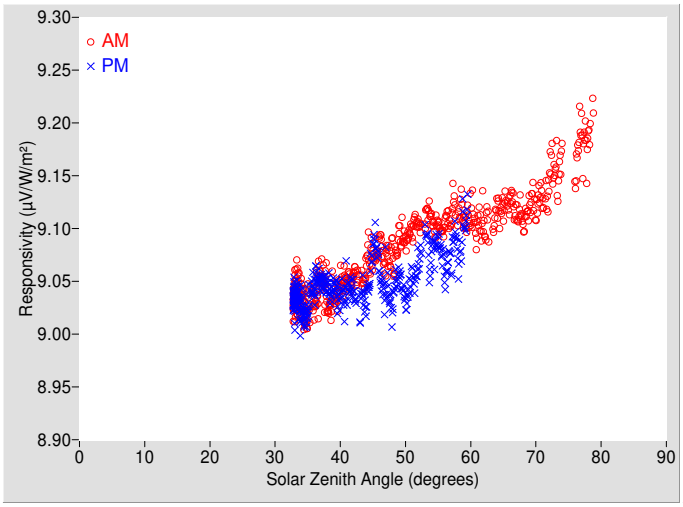


Figure 2. Responsivity vs Local Standard Time

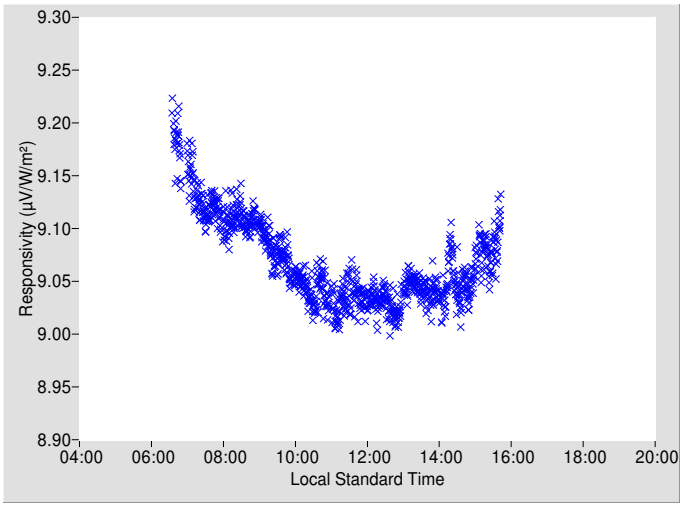


Table 2. Calibration Label Values

RS @ 45° (µV/W/m²)	U95 (%) †	Tilt / Azm
9.0776	+1.12 / -1.27	N/A

† Valid zenith angle range: 32.8° to 59.5°

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	9.0861	0.46	125.59	9.0589	0.63	234.22
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0711	0.48	122.34	9.0295	0.51	237.47
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0892	0.44	119.39	9.0306	0.46	240.48
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1032	0.43	116.65	9.0679	0.48	243.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1089	0.45	114.09	9.0749	0.51	245.72
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1038	0.43	111.64	9.0600	0.50	248.17
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1119	0.47	109.25	9.0776	0.58	250.41
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1142	0.51	107.24	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1050	0.49	105.20	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1198	0.45	103.23	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.1252	0.44	101.30	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.1050	0.45	99.47	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.1182	0.46	97.58	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	72	9.1435	0.54	95.86	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	74	9.1686	0.52	94.25	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	76	9.1496	0.60	92.36	N/A	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A	78	9.1780	0.61	90.74	N/A	N/A	N/A
34	9.0342	0.54	162.05	9.0236	0.50	197.76	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0304	0.52	151.11	9.0469	0.48	208.69	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0340	0.52	143.88	9.0462	0.44	215.92	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0492	0.47	138.19	9.0390	0.51	221.70	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0569	0.43	133.41	9.0399	0.47	226.40	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0647	0.50	129.33	9.0328	0.58	230.55	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 ‡

19792E6 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:

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

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

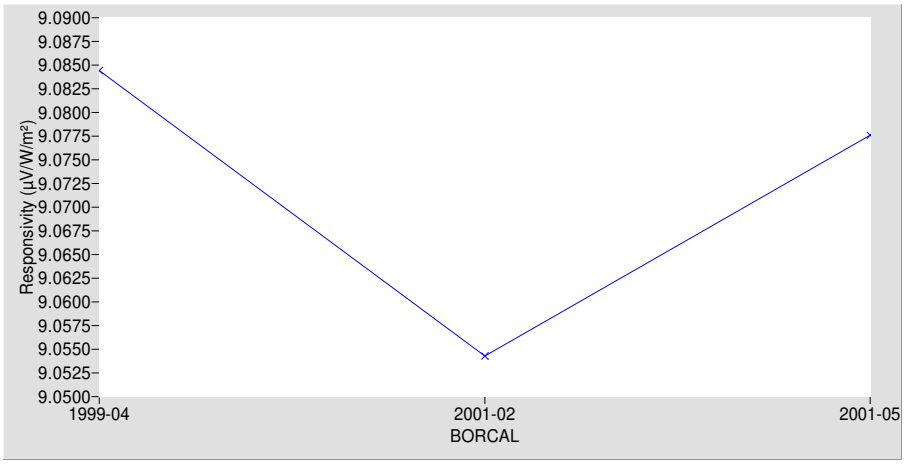
Responsivity Characterization	RS (μV/W/m²)	U95 (%)
45°	9.0776	+1.12 / -1.27 †
Average	9.0604	+1.04 / -0.90 ‡

† Valid zenith angle range: 32.8° to 59.5°

‡ Valid zenith angle range: 32.8° to 59.5°

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

‡ The incident angle range for this BORCAL may not adequately characterize this instrument.

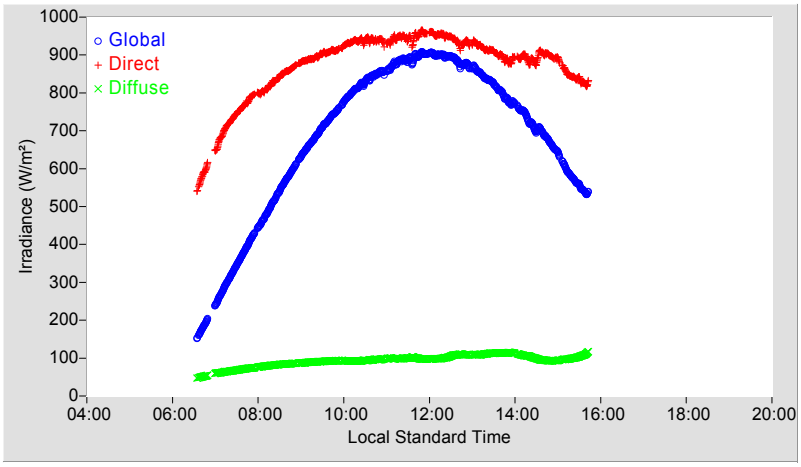
Ancillary Data for BORCAL 2001-05

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-corked solar incidence angle.

Table 4. Beam Irradiance (B)

Instrument	Model	WRR Factor
31104	HF	1.00025

Table 5. Diffuse Irradiance (D)

Instrument	Model	Responsivity
32858	8-48	9.1541 µV/W/m²
32871	8-48	8.9238 µV/W/m²

Meteorological Observations:

Table 6. Meteorological Observations

Observations	Mean
Temperature (°C)	29.53
Humidity (%)	15.94
Pressure (mBar)	N/A
Est. Aerosol Optical Depth (BB)	0.1037

Figure 4. Temperature

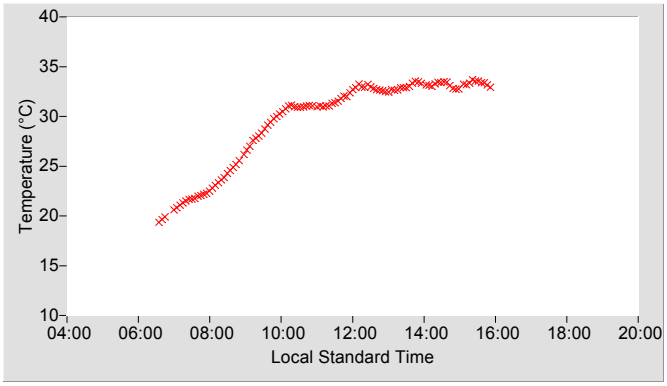


Figure 5. Humidity

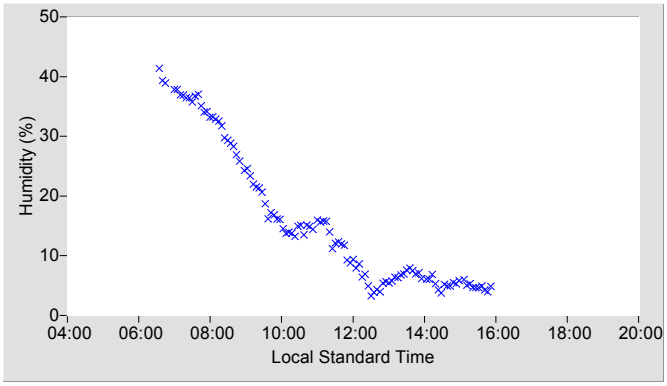


Figure 6. Pressure

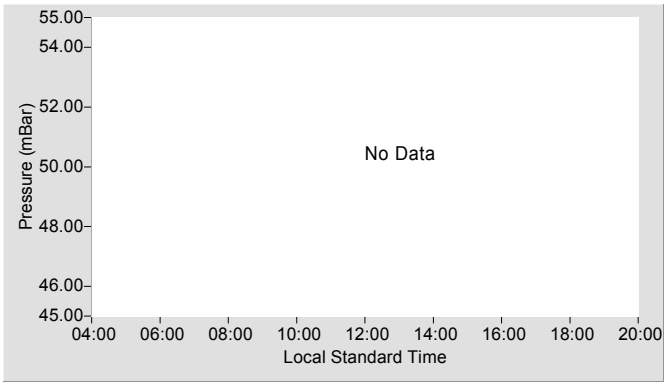
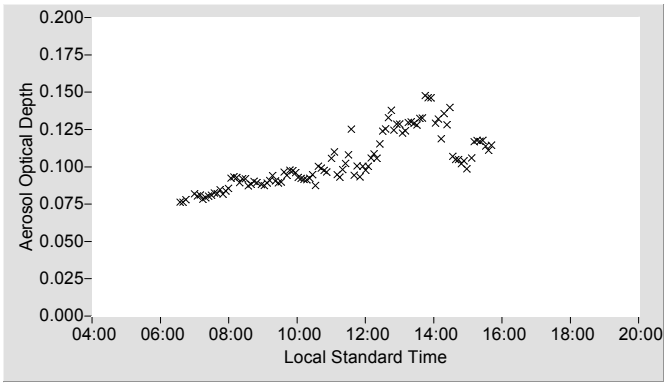


Figure 7. Estimated Broadband Aerosol Optical Depth



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: 2001-05
Comments:
A crossed signal and power line caused signal corruption for three pyrheliometers mounted on the Sunfollower II tracker. The signals were paralleled with the voltage, causing a bias in the results. Results for those insturments have been invalidated as noted in the individual instrument notes.