Broadband Outdoor Radiometer Calibration
Shortwave Shade/Unshade

BORCAL-SW
2018-01

Generated by

Radiometer Calibration and Characterization

Calibration Facility

Solar Radiation Research Laboratory

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

Calibration date
04/11/2018

Report Date
April 13, 2018

NREL

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 International System (SI) Units of Measurement.

This report includes these sections:

- Results Summary - a table of all instruments included in this report summarizing their calibration results and uncertainty.
- Instrument Details - the calibration certificates for each instrument.
- Environmental and Sky Conditions - meteorological conditions and reference irradiance during the calibration event.

Results Summary

Table 1. Results Summary

Instrument	Customer	R@45 [1] (µV/W/m²)	U [2] (%)	Rnet [3] (µV/W/m²)	Page
2530	NREL-SRRL-BMS	11.038	±1.1	N/A	A1-2
2541	NREL-RCC	9.6314	±1.4	N/A	A1-4

[1] CF = 1000 / R [2] See certificate for valid zenith angle range [3] Instrument's Effective Net IR Response

Note: Environmental Conditions for BORCAL starts on page A1-6.

Appendix 1
Instrument Details

Calibration Certificates: 2 pages for each radiometer (3 including Environmental Conditions)
Environmental Conditions for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2530
Calibration Date:	4/11/2018	**Due Date:**	4/11/2019
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 3
Test Dates:	4/11		

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

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

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

Table 1. Traceability

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

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 3

Calibration Procedure: NREL/TP-1900-68999; http://www.nrel.gov/docs/fy17osti/68999.pdf

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.

Calibrated by: RCC

_____ _____
Ibrahim Reda, Technical Manager Date

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

Calibration Results

2530 Hukseflux SR25

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

$$R = (Vu - Vs) / N * COS(Z) \quad [1]$$

where,

Vu = radiometer unshaded output voltage (microvolts),
Vs = radiometer shaded output voltage (microvolts),
N = reference direct irradiance (W/m²),
Z = zenith angle (degrees).

Figure 1. Average Responsivity vs Zenith Angle

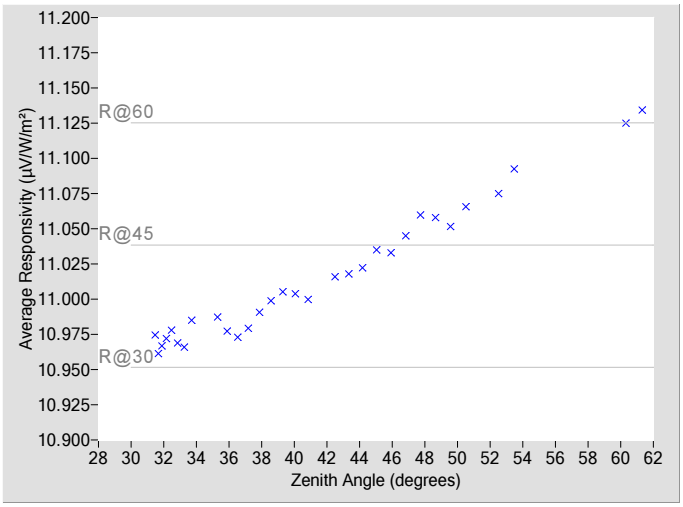


Figure 2. Shaded Voltage Ratio (Test/Control) vs Zenith Angle

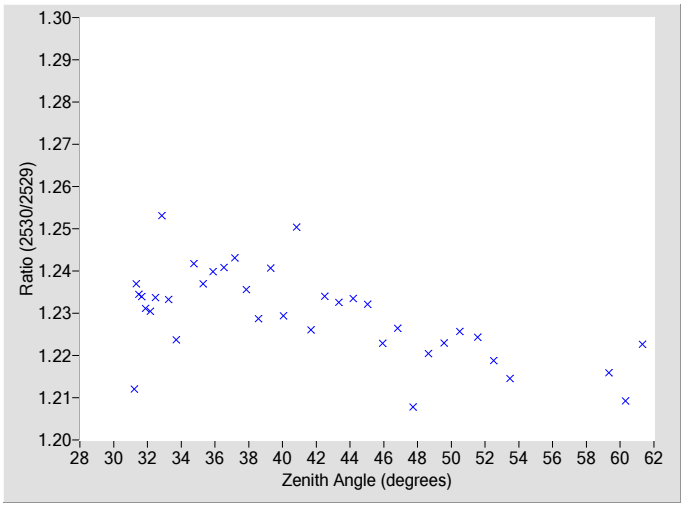
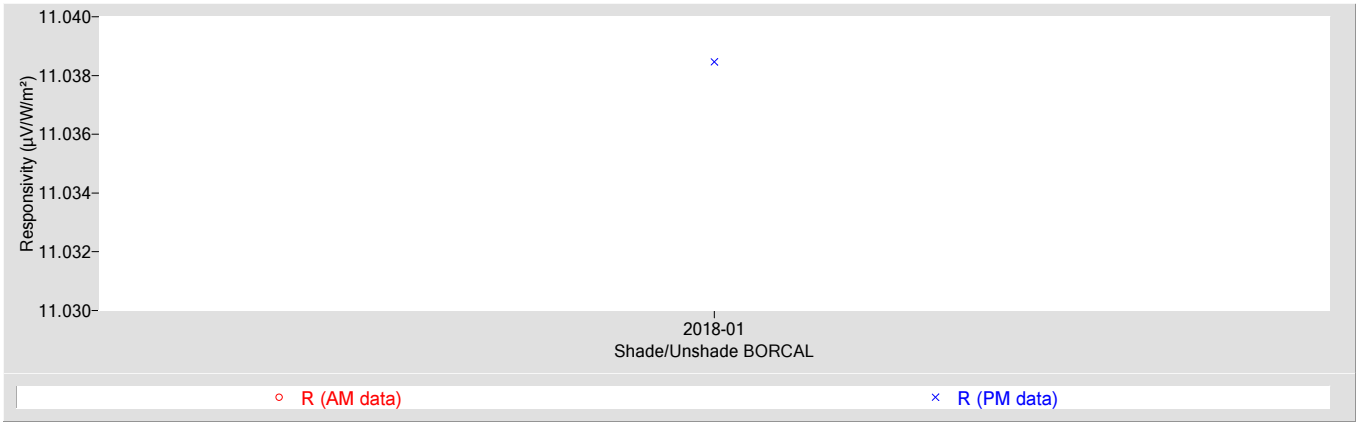


Table 2. Calibration Result and Uncertainty

R @ 45° (µV/W/m²)	11.038
Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Standard Uncertainty, u(A) (%)	±0.072
Standard Uncertainty of range, u(R) (%)	±0.45
Std. Uncertainty of sensor non-linearity, u(NL) (%)	±0.12
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
Thermal Offset (W/m²)	0.5
Valid zenith angle range	31.4° to 61.7°

Figure 3. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Andreas A. (2017). Calibration Procedure of a Modified Hukseflux SR25 as an Example to Establish the Diffuse Reference for the Broadband Outdoor Radiometer Calibration; NREL/TP-1900-68999; http://www.nrel.gov/docs/fy17osti/68999.pdf.

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2541
Calibration Date:	4/11/2018	**Due Date:**	4/11/2019
Customer:	NREL-RCC	**Environmental Conditions:**	see page 3
Test Dates:	4/11		

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Calibration Procedure: NREL/TP-1900-68999; http://www.nrel.gov/docs/fy17osti/68999.pdf

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.

Calibrated by: RCC

_____ _____

Ibrahim Reda, Technical Manager Date

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

Calibration Results

2541 Hukseflux SR25

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

$$R = (Vu - Vs) / N * COS(Z) \quad [1]$$

where,

Vu = radiometer unshaded output voltage (microvolts),
Vs = radiometer shaded output voltage (microvolts),
N = reference direct irradiance (W/m²),
Z = zenith angle (degrees).

Figure 1. Average Responsivity vs Zenith Angle

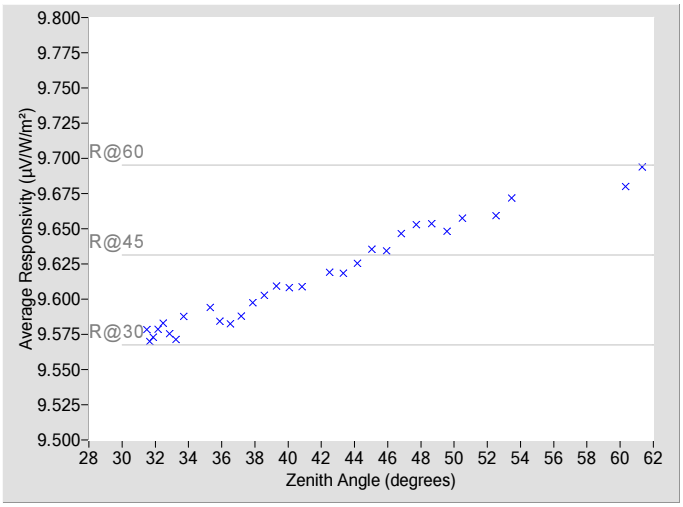


Figure 2. Shaded Voltage Ratio (Test/Control) vs Zenith Angle

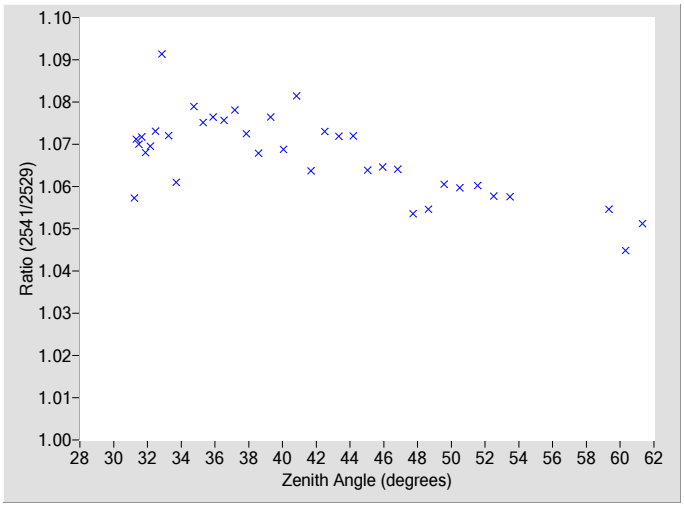
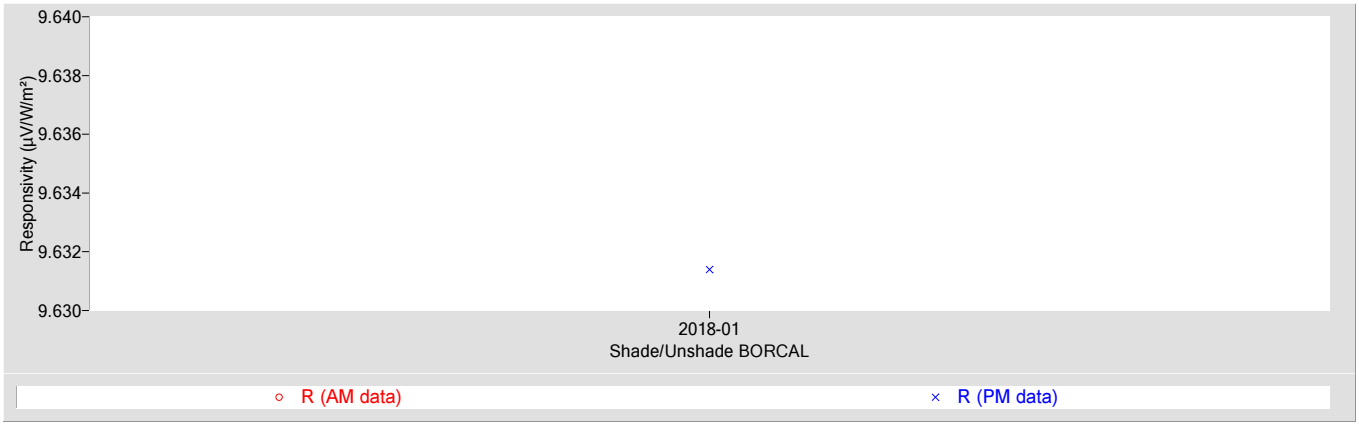


Table 2. Calibration Result and Uncertainty

R @ 45° (µV/W/m²)	9.6314
Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Standard Uncertainty, u(A) (%)	±0.063
Standard Uncertainty of range, u(R) (%)	±0.66
Std. Uncertainty of sensor non-linearity, u(NL) (%)	±0.12
Effective degrees of freedom, DF(c)	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
Thermal Offset (W/m²)	0.5
Valid zenith angle range	31.4° to 61.7°

Figure 3. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Andreas A. (2017). Calibration Procedure of a Modified Hukseflux SR25 as an Example to Establish the Diffuse Reference for the Broadband Outdoor Radiometer Calibration; NREL/TP-1900-68999; http://www.nrel.gov/docs/fy17osti/68999.pdf.

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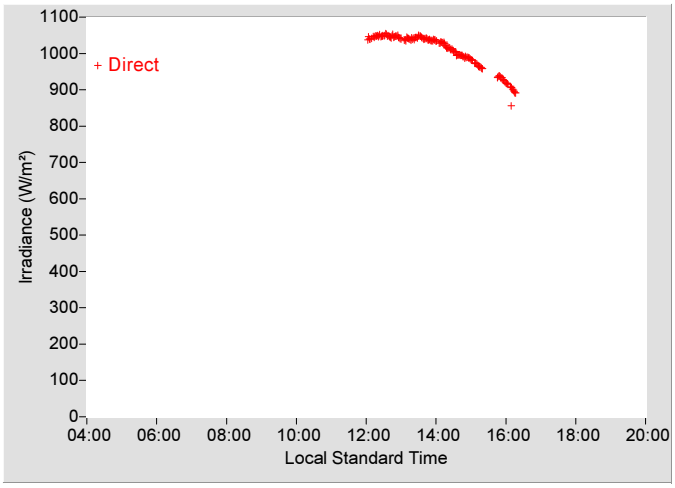
Environmental and Sky Conditions for BORCAL-SW 2018-01

Calibration Facility: Solar Radiation Research Laboratory

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

Reference Irradiance:

Figure 4. Reference Irradiance



Meteorological Observations:

Figure 5. Temperature

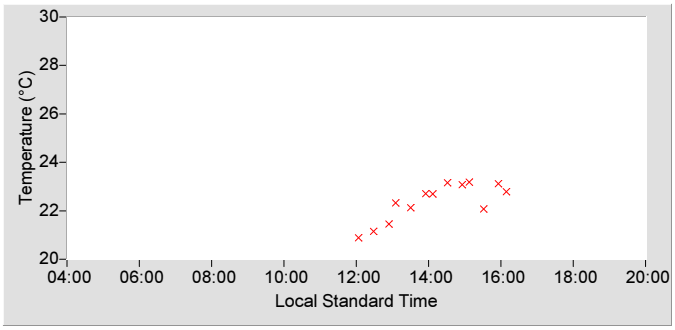


Figure 6. Humidity

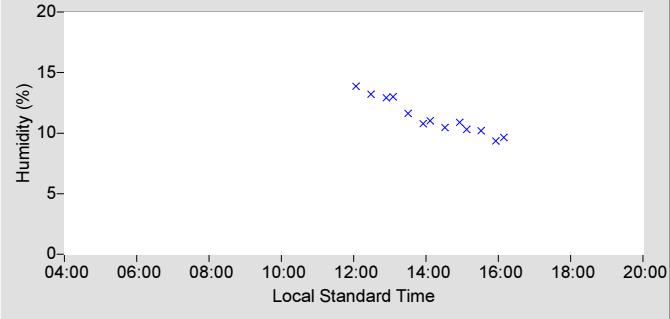


Figure 7. Pressure

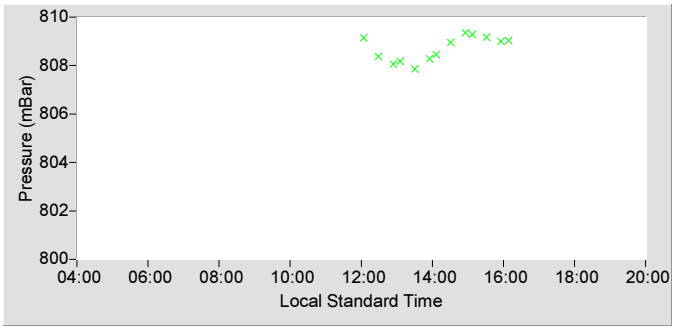


Figure 8. Estimated Broadband Aerosol Optical Depth

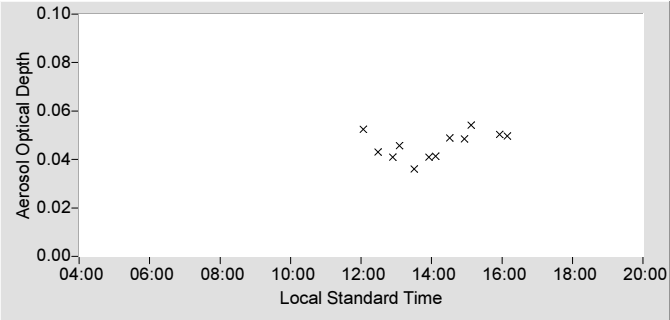


Table 3. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	22.36	20.88	23.18
Humidity (%)	11.33	9.35	13.86
Pressure (mBar)	808.7	807.9	809.4
Est. Aerosol Optical Depth (BB)	0.046	0.036	0.054

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

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Solar Radiation Research Laboratory
Comments:
Avg. Station Pressure & Temperature is for Denver, CO, which is used for the Solar Position Algorithm (SPA).

Operator: RCC
Comments:
Un-attended with no operator

Appendix 3
Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL 2018-01 Session Configuration Audit Report

LOCATION

Facility	Facility Abbrev.	Contact	Latitude	Longitude	Elevation (m)	Avg press (mbr)	Avg temp (C)	Time zone	ISO
Solar Radiation Research Laboratory	SRRL	Afshin M. Andreas	39.742	-105.180	1828.8	835.0	10.0	-7.0	

SYSTEM

% Error Thresholds

Cav1 / Cav2	1.0
Dif1 / Dif2	7.0
Global Ctrl / Ref	5.0
Direct Ctrl / Ref	5.0
Test(x) / Test(x-1)	3.0

Delta Thresholds

Temp(x) - Temp(x-1)	3.0
Hum(x) - Hum(x-1)	10.0
Bar(x) - Bar(x-1)	2.0
Thrm(x) - Thrm(x-1)	2.0
Thm (Dome-Case)	3.0
Case Thm (Inst-Pyrg)	5.0

Shade/Unshade

Enabled	☑
Port	2
Shaded Wait (s)	85
Unshaded Wait (s)	15

Scan Rate (sec)

Radiometers	10
Meteorological	180

ASR Setup

Scan Rate (s)	1
ASR Readings	2
Threshold 1 (Blue)	1.000
Threshold 2 (Green)	2.000
Threshold 3 (Brown)	3.000
Diffuse scaling factor	0.25

Clock

Reset Interval (m)	0
Warning Threshold (s)	1
Delta UT1	0.100

Uncertainty

Zenith Angle (deg)	0.003
Significant Figures	2
45° Offsets: -	-15.00 + 15.00
Min. Legal Direct	700
Max. Legal Diffuse	180
Max. Diffuse/Direct (%)	45.0

Miscellaneous

PW: Slope	1.83	Intercept	1.00
Tilt: Zenith	0.00	Azimuth	0.00
W in: Min	150	Max	450
Zenith Angle (Auto Mode): Startup	70	Shutdown	70
Intervals (m): Cavity Calibration	60	Oper. Log	120
SPA: Atmos. Refraction	0.5667	Delta T	69.084

ASR RADIOMETERS

Channel	Junction Box	Cable	Location
ASR 1: 140310 Kipp & Zonen SP-LITE2			
26	08-02		Tbl-00-
ASR 2: None			

METEOROLOGICAL INSTRUMENTS

Channel	Junction Box	Cable	Location		
Temperature: E1220001-T Vaisala HMP155-T					
121	05-01	22-10	Deck		
				Scale 100	Offset -40
Humidity: E1220001-H Vaisala HMP155-H					
122	05-02	22-11	Deck		
				Scale 100	Offset 0
Barometer: Y0550020 Vaisala PTB101B					
120	05-00		Datalab		
				Scale 184	Offset 600

GPS TIME RECIEVER

GPS: None

Type	Port	Baud	Parity	Stop bits	Data bits
	0	0	0	0	0

DATALOGGER

	Logger/Relay	DMM
Unit 0	2005-998 NREL RAP-DAQ	SG42000600 Agilent 34420A
Unit 1	2005-999 NREL RAP-DAQ	SG42000530 Agilent 34420A
Unit 0	None	None
Unit 0	None	None

	Unit 0	Unit 1	Unit 0	Unit 0
Cal Date	04/12/2017	04/12/2017		
Cal Due Date	04/12/2019	04/12/2019		
System Offsets: Volts DC (µV)	2.44	2.44	0.00	0.00
2-Wire Res. (mOhms)	3640.00	3640.00	0.00	0.00
4-Wire Res. (mOhms)	0.06	0.06	0.00	0.00

Communications

	Unit	Type	Addr.	Board	Parity	Stop	Data
DMM	0	GPIB	21	0	0	0	0
Relay	0	GPIB	24	1	0	0	0
DMM	1	GPIB	22	0	0	0	0
Relay	1	GPIB	25	1	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0
	-1		0	0	0	0	0

CAVITIES, CONTROL UNITS, AND DIGITAL MULTI METERS

	Cavity 1	Cavity 2
Unwindowed WRR	1.000000	0.000000
Windowed WRR	1.061520	0.000000
Unwindowed Uncert (%)	0.40	0.00
Windowed Uncert (%)	0.40	0.00
Heater Resistance	153.40	0.00
Heater Lead Resistance	0.0660	0.0000
Mfg Calibration Factor	2.00090	0.00000
Default Sensitivity	0.01051	0.00000
Cal Date	09/25/2017	
Cal Due Date	09/25/2018	

	Unit 1	Unit 2
Cavity Head	29219 Eppley HF	None
Control Unit	03691C NREL Reda	None
Digital Multi Meter	MY44040325 Hewlett Packard 34970A	None
Cavity Location	South Patio	

	Control Unit 1	Control Unit 2
Current Shunt	1.000	0.000
Circuit Resist	2.600	0.000
Cal Date	09/26/2016	
Cal Due Date	09/26/2017	

Calibration Waits (Seconds)		
	TP-solar	0 / 0
	TP-heated	40 / 0
	TP-zero	60 / 0
	Dwell	0 / 0
	Active	☑ / ☐
	Window in Use	☑ / ☐

Communications

	Type	Port	Bd.	Parity	Stop bits	Data bits
Control Unit 1	GPIB	19	0	0	0	0
DMM 1		0	0	0	0	0
Control Unit 2		0	0	0	0	0
DMM 2		0	0	0	0	0

BORCAL 2018-01 Session Configuration Audit Report

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)	Max Out (mV)	Channel	J Box	Cable	Location	Tilt	Active
Diffuse 1: 2529 Hukseflux SR25														
9.253	05/04/2017	05/04/2018	6.2	70.3	5.0	1.50	0.0	25	116	15-08	04-07	BMS Tracker	☐	☑
Diffuse 1: Case 10K Temperature									n/a	n/a	n/a			
Diffuse 1: Dome 10K Temperature									n/a	n/a	n/a			

PYRGEOMETER INSTRUMENTS

Cal Date	Cal Due Date	Calibration Coefficients K0	K1	K2	K3	Kr	Uncert. (W/m^2)	Max Out (mV)	Channel	J Box	Cable	Location	Active
Pyrgeometer 1: None													
		0.00000	0.00000	0.00000	0.00000	0.00000E+0	0.00	0					☐
Pyrgeometer 1: Case Thermistor									n/a	n/a	n/a		
Pyrgeometer 1: Dome Thermistor									n/a	n/a	n/a		

BORCAL 2018-01 Session Configuration Audit Report

INSTRUMENT GROUPS

Group	Calib. Type	Out (mV)	Instrument Type	Instrument Grouping Type	Correcting Pyrgeometer	Count
1	Global	25	Hukseflux SR25	Hukseflux SR25	none	2
Total						2

BORCAL 2018-01 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
2530	SR25	NREL-SRRL-BMS	1	1	14	07-02		Yes	Yes	No	TOT	Tkr-07-	12
2541	SR25	NREL-RCC	1	2	15	07-03		Yes	Yes	No	TOT	Tkr-07-	12

Appendix 4
Operator Session Logs

Operator session logs for the BORCAL

BORCAL 2018-01 Operator Session Log

Session: 1

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-10-2018	10:48:21	11:49:58	29219	7:00	959.1	957.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:09:05	33.76	Brown	988.3	14.9	Afshin Andreas

Comments:
Test of new SW SUN mode. Sky is poor.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:30:31	32.39	Green	985.6	15.2	Afshin Andreas

Comments: [None]

Session: 2

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-10-2018	11:49:58	12:51:39	29219	7:00	957.4	956.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:06:35	31.60	Red	868.4	24.2	Afshin Andreas

Comments: [None]

Session: 3

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-10-2018	12:51:39	13:04:53	29219	7:00	956.9	956.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:03:12	34.41	Red	236.6	67.5	Afshin Andreas

Comments: [None]

Session: 4

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-10-2018	13:05:18	13:36:48	29219	7:00	956.9	956.9

Observations: [None]

Session: 5

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	08:58:56	09:59:38	29219	0:00	956.1	956.4

Observations: [None]

Session: 6

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	09:59:38	11:00:45	29219	0:00	956.4	956.2

Observations: [None]

Session: 7

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	11:00:45	12:02:26	29219	0:00	956.2	956.2

Observations: [None]

Session: 8

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	12:02:26	13:04:10	29219	0:00	956.2	955.8

Observations: [None]

Session: 9

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	13:04:10	14:05:24	29219	0:00	955.8	955.8

Observations: [None]

Session: 10

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	14:05:24	15:06:11	29219	0:00	955.8	955.6

Observations: [None]

Session: 11

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	15:06:11	16:07:29	29219	0:00	955.6	955.6

Observations: [None]

Session: 12

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-11-2018	16:07:29	16:18:10	29219	0:00	955.6	955.6

Observations: [None]

Session: 13

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	07:46:07	08:47:11	29219	0:00	956.0	958.1

Observations: [None]

Session: 14

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	08:47:11	09:47:46	29219	0:00	958.1	959.0

Observations: [None]

Session: 15

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	09:47:46	10:48:50	29219	0:00	959.0	958.5

Observations: [None]

Session: 16

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	10:48:50	11:50:30	29219	0:00	958.5	957.9

Observations: [None]

Session: 17

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	11:50:30	12:52:20	29219	0:00	957.9	957.4

Observations: [None]

Session: 18

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	12:52:20	13:53:43	29219	0:00	957.4	956.4

Observations: [None]

Session: 19

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	13:53:43	14:54:42	29219	0:00	956.4	955.7

Observations: [None]

Session: 20

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-12-2018	14:54:42	15:37:54	29219	0:00	955.7	955.7

Observations: [None]