

Broadband Outdoor Radiometer Calibration Longwave

BORCAL-LW 2017-01

Customer

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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

02/08/2017 to 03/14/2017

Report Date

March 14, 2017

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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 Infrared Standard Group (WISG).

This report includes these sections:

- Control Instruments - a group of instruments included in each BORCAL event that provides a measure of process consistency.
- Results Summary - a table of all instruments included in this report summarizing their calibration results and uncertainty.
- Instrument Details - the calibration certificates and application notes for each instrument.
- Environmental and Sky Conditions - meteorological conditions and reference irradiance during the calibration event.

Control Instrument History

Figure 1. Eppley PIR Control Instrument History (K0 Coefficient)

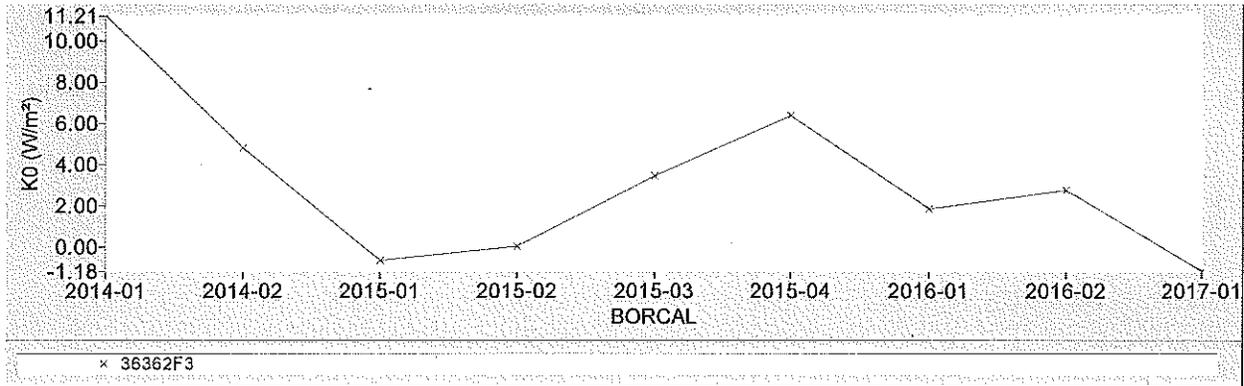


Figure 2. Eppley PIR Control Instrument History (K1 Coefficient)

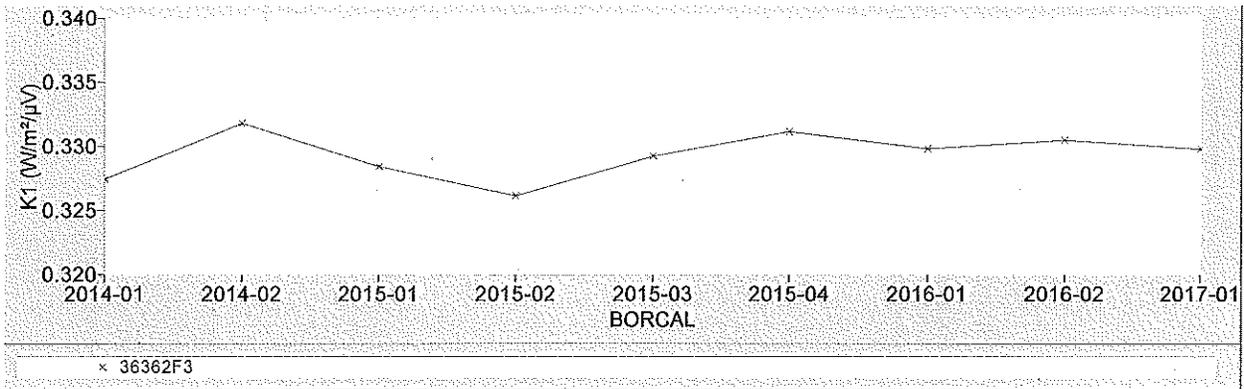


Figure 3. Eppley PIR Control Instrument History (K2 Coefficient)

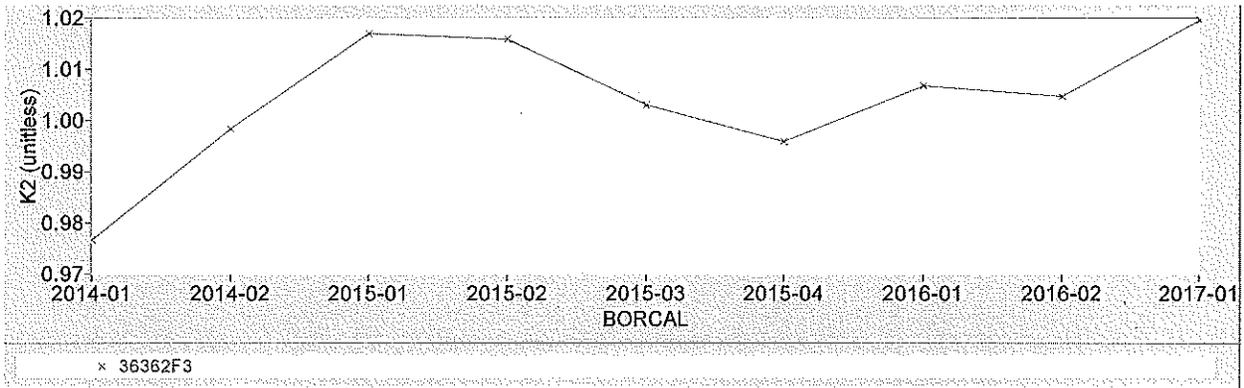
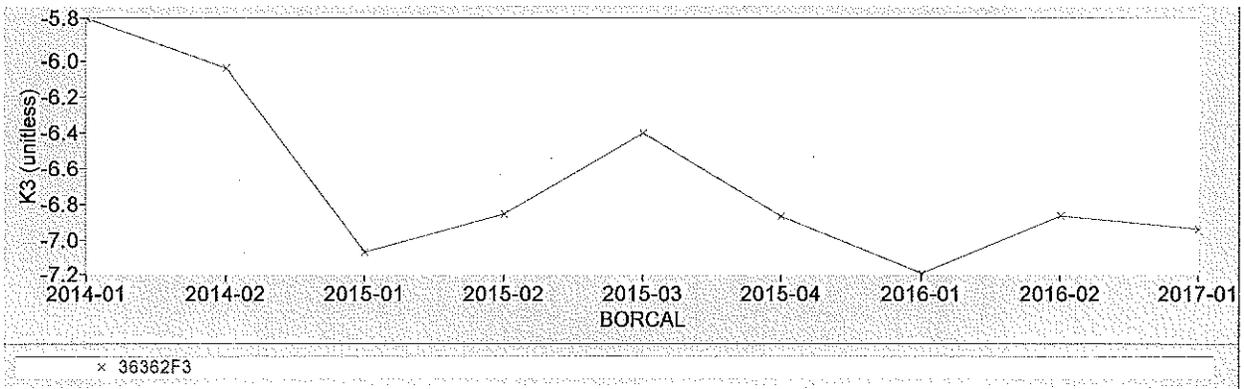


Figure 4. Eppley PIR Control Instrument History (K3 Coefficient)



Results Summary

Table 1. Results Summary

Instrument	K0 (W/m ²)	K1 (W/m ² /μV)	K2	K3	Kr * (K/μV)	U95 (W/m ²)	Page
26181F3 Eppley PIR	-9.0832	0.26708	1.0298	-4.9369	7.044e-4	±2.0	A1-2

Note: Environmental Conditions for BORCAL starts on page A1-5.

* Kr used to derive K0, K1, K2, and K3

2017-02-08

2017-03-14

Appendix 1

Instrument Details

Calibration Certificates: 3 pages for each radiometer (4 including Environmental Conditions)

Environmental Conditions for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.



National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory
Calibration Certificate

Test Instrument:	Downwelling Pyrgeometer	Manufacturer:	Eppley
Model:	PIR	Serial Number:	26181F3
Calibration Date:	3/14/2017	Due Date:	3/14/2018
Customer:	Bryan Fabbri	Environmental Conditions:	see page 4
Test Dates:	2/8-28, 3/1-14		

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 World Infrared Standard Group (WISG).

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 than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	03/31/2015	03/31/2017
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	03/31/2015	03/31/2017
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30557F3	01/29/2015	01/29/2020

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-LW-P00-Calibration and QA Procedure; available upon request.

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

Calibrated by: Afshin Andreas

Ibrahim Reda, Technical Manager

3/14/17

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

26181F3 Eppley PIR

The incoming irradiance (W_{in} , W/m^2) of the test instrument during calibration is calculated using this Measurement Equation:

$$W_{in} = K_0 + K_1 \cdot V + K_2 \cdot W_r + K_3 \cdot (W_d - W_r) \quad [1]$$

where,

K_0, K_1, K_2, K_3 = calibration coefficients,
 V = thermopile output voltage (μV),
 $W_d = \sigma \cdot T_d^4$ = dome irradiance (W/m^2),
 where, T_d = dome temperature (K),

$W_r = \sigma \cdot T_r^4$ = receiver irradiance (W/m^2),
 where, $\sigma = 5.6704e-8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 $T_r = T_c + K_r \cdot V$ = receiver temperature (K),
 T_c = case temperature (K),
 K_r = efficiency coefficient (K/ μV).

Figure 1. Residuals for calc. vs ref. irradiance using $K_0 \neq 0$ Coefficients

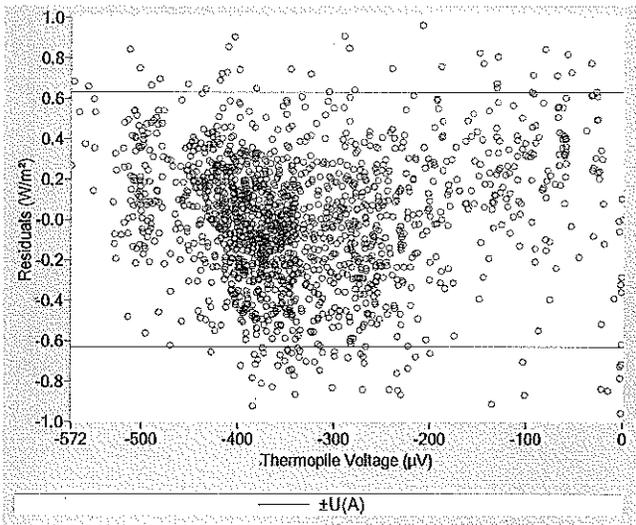


Figure 2. Residuals for calc. vs ref. irradiance using $K_0 = 0$ Coefficients

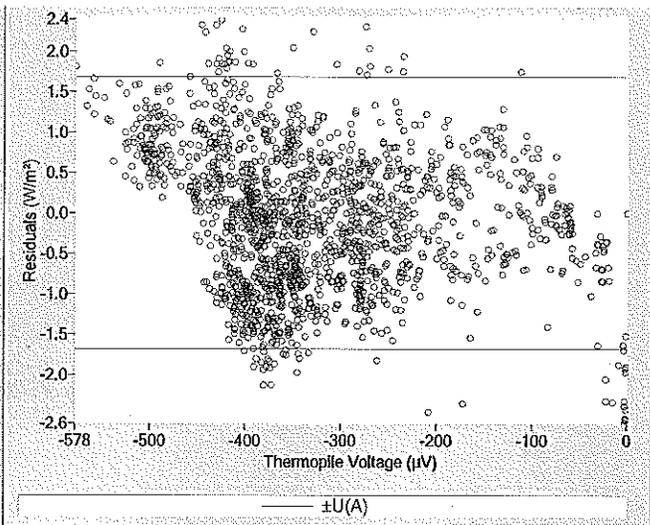


Table 2. Calibration Coefficients for $K_0 \neq 0$

K_0	-9.0832
K_1	0.26708
K_2	1.0298
K_3	-4.9369
K_r used to derive coefficients	0.00070440

Table 3. Calibration Coefficients for $K_0 = 0$

K_0	0
K_1	0.26610
K_2	1.0019
K_3	-4.5184
K_r used to derive coefficients	0.00070440

Table 4. Uncertainty using $K_0 \neq 0$ Coefficients

Type-B Standard Uncertainty, $u(B)$ (W/m^2)	± 0.96
Type-A Standard Uncertainty, $u(A)$ (W/m^2)	± 0.32
Combined Standard Uncertainty, $u(c)$ (W/m^2)	± 1.0
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (W/m^2)	± 2.0

Table 5. Uncertainty using $K_0 = 0$ Coefficients

Type-B Standard Uncertainty, $u(B)$ (W/m^2)	± 0.96
Type-A Standard Uncertainty, $u(A)$ (W/m^2)	± 0.86
Combined Standard Uncertainty, $u(c)$ (W/m^2)	± 1.3
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, U_{95} (W/m^2)	± 2.5

Figure 3. History of instrument (K0 Coefficient)

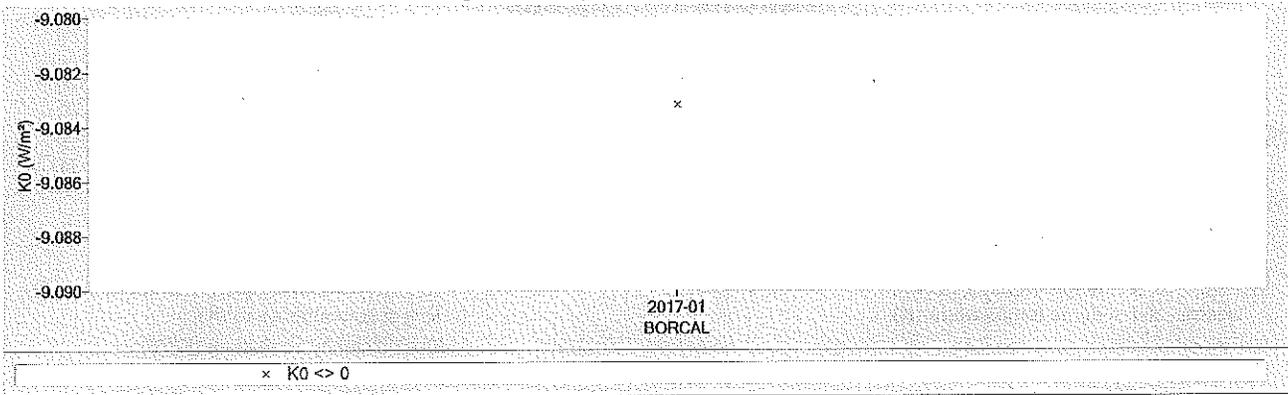


Figure 4. History of instrument (K1 Coefficient)

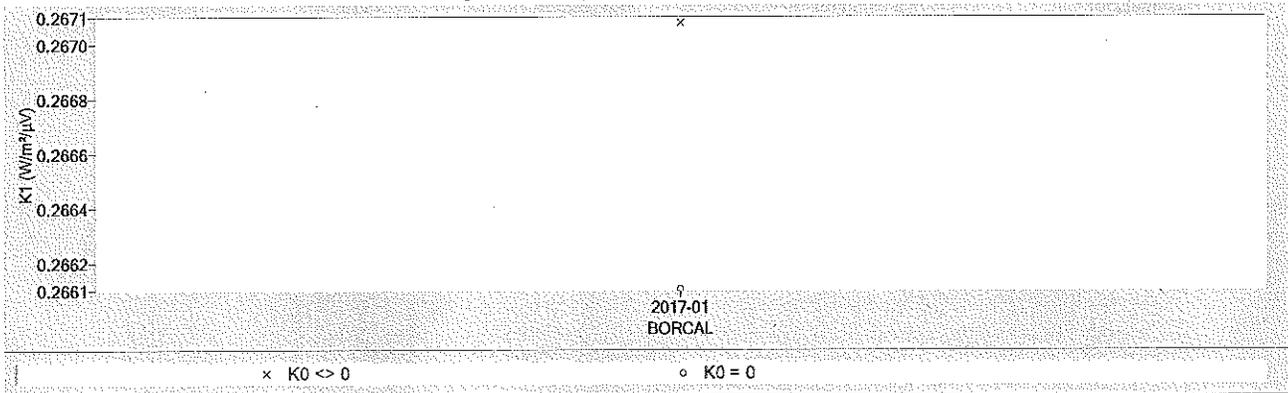


Figure 5. History of instrument (K2 Coefficient)

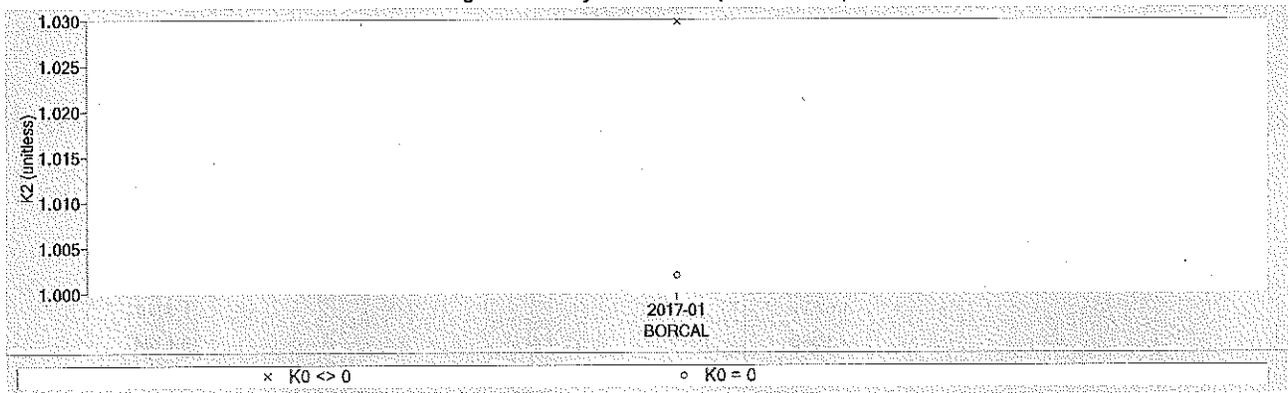
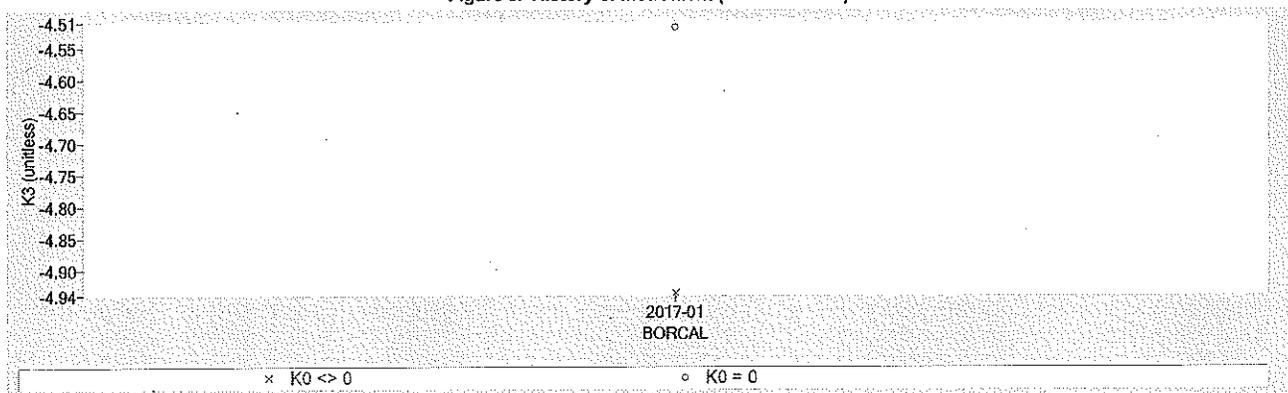


Figure 6. History of instrument (K3 Coefficient)



References:

- [1] Reda, I.; Stoffel, T. (2010), Pyreometer Calibration for DOE-Atmospheric System Research Program using NREL Method (Presentation). 9 pp.; NREL Report No. PR-3B0-47756; <http://www.nrel.gov/docs/fy10osti/47756.pdf>.

Environmental and Sky Conditions for BORCAL-LW 2017-01

Calibration Facility: Solar Radiation Research Laboratory

Latitude: 39.742°N

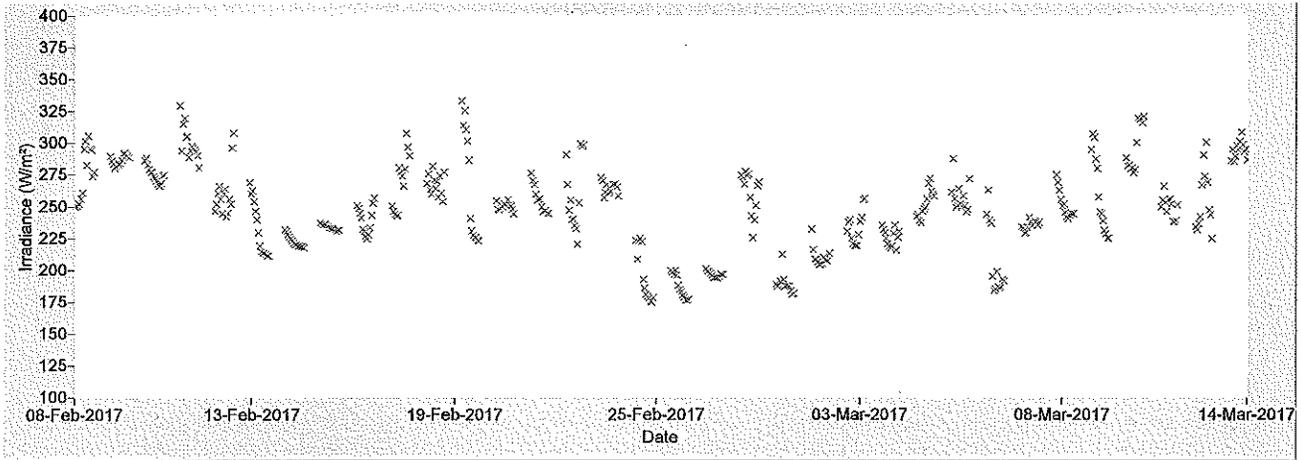
Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Reference Irradiance (hourly averages):

Figure 6. Reference Irradiance



Meteorological Observations (hourly averages):

Figure 7. Temperature

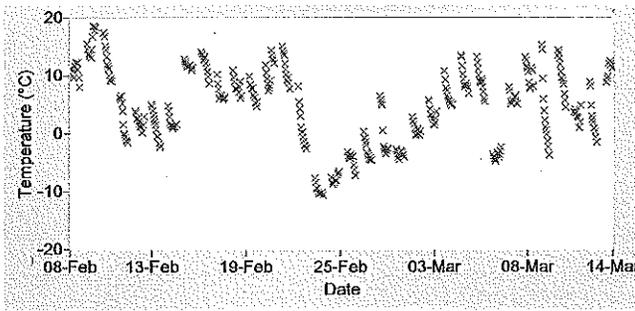


Figure 8. Humidity

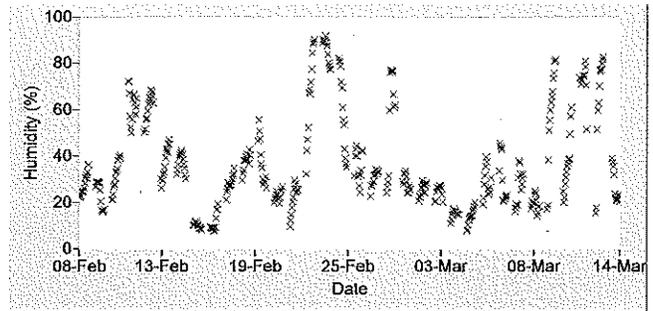


Figure 9. Pressure

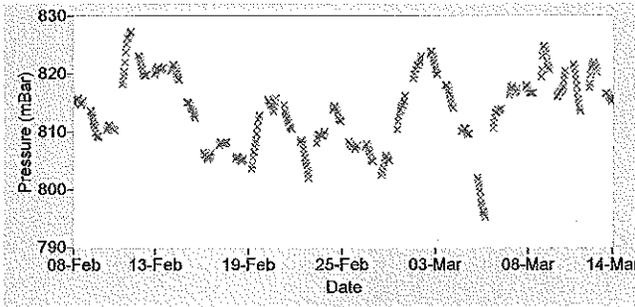


Figure 10. Estimated Precipitable Water Vapor (PWV)

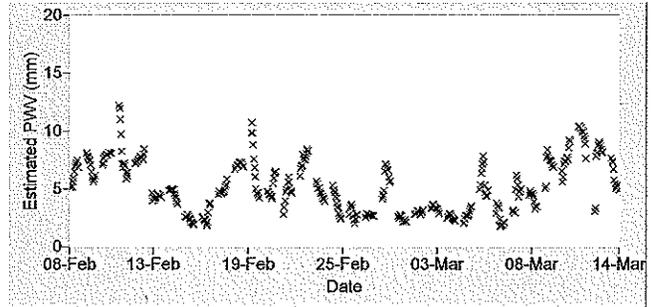


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	4.61	-10.77	19.55
Humidity (%)	36.86	6.39	92.87
Pressure (mBar)	813.5	795.1	827.4
Est. Precipitable Water Vapor (mm)	5.2	1.6	12.8

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

