Calibration Report: Pyrheliometers

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SUMMARY

Calibration date: 2005 June 15.
Next calibration due: 2006 July 15.

The calibration coefficient and its associated uncertainty (U95%) has been determined for a pyrheliometer. The unit of the calibration coefficients (S) are $\mu V/(W/m^2)$. This calibration coefficient can be traced to the World Radiation Reference determined by the World Standard Group kept at the Physikalisch-Meteorologisches Observatorium in Davos Switzerland. The sensitivity factor and its associated uncertainty (95%) are as follows:

Manufacturer	Serial Number	S $\mu V/(W/m^2)$	U95
Kipp and Zonen	CH1-010254	10.63	+/- 0.58%

Application

$$I = (\text{mV output})/S \pm \text{sqrt}(2)*U95\%$$

Where: I = the irradiance measured by the pyrheliometer
(mV output) = microvolt output of the pyrheliometer
S = calibration coefficient of the pyrheliometer
U95% = the 95 % confidence level of a field measurement.

INTRODUCTION

The following sections contain: a hardware description; a set of figures; a summary of past calibrations; and a description of the calibration process.

HARDWARE

Reference Standard

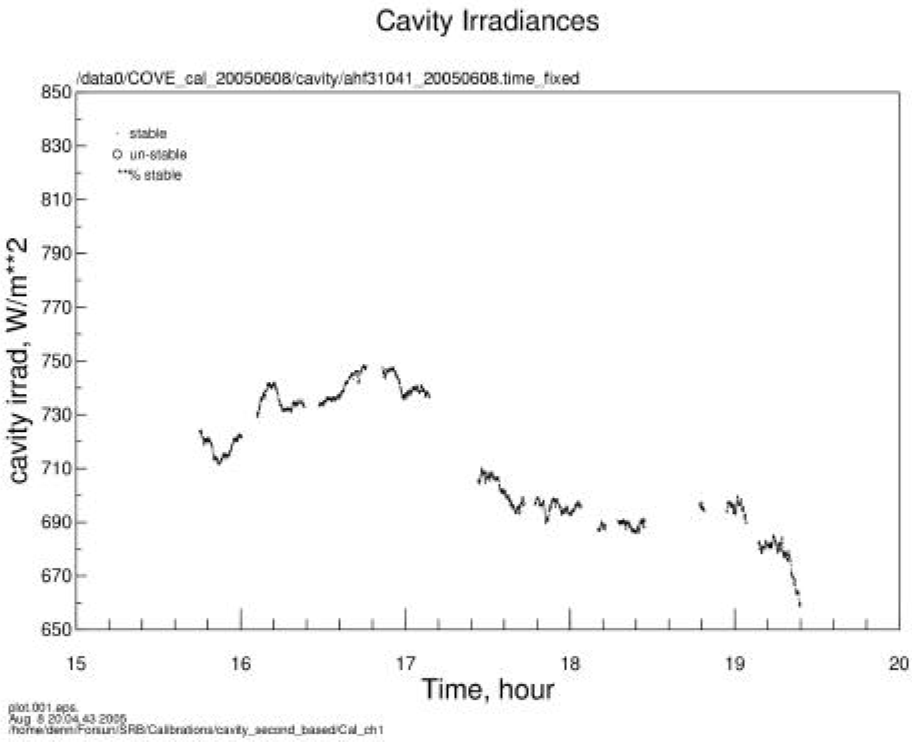
The reference pyrheliometer was the Eppley Laboratories Inc. Absolute Cavity Radiometer (ACR) sn AHF31041 with its associated Agilent 34970A control unit. The Agilent 34970A contains the following 3 optional boards: 34901A 20 channel multiplexer; 34904A matrix switch; and a 34907A multi function module. It is operated with a Windows computer using a LabView based program supplied by Ibrahim Reda of The National Renewable Energy Laboratory (NREL) located in Golden Colorado.

Test Instrumentation

The test pyrheliometer was a Kipp and Zonen CH1 sn CH1-010254 which was connected to a Campbell Scientific Inc. 23X data logger sn 3151. The pyrheliometer was wired for differential measurement, low was not jumpered to ground.

FIGURES

Figure 1 shows cavity measured solar irradiance for the measurement periods. Figure 2 shows the milli-volt measurements obtained by the test pyrheliometer. Figure 3 shows the calibration values obtained using a grouped subset of the data presented in Figures 1 and 2. Figure 4 displays the distribution of the calibration values about their means. Figure 5 shows the calibration coefficients for both days of data grouped by cavity run.



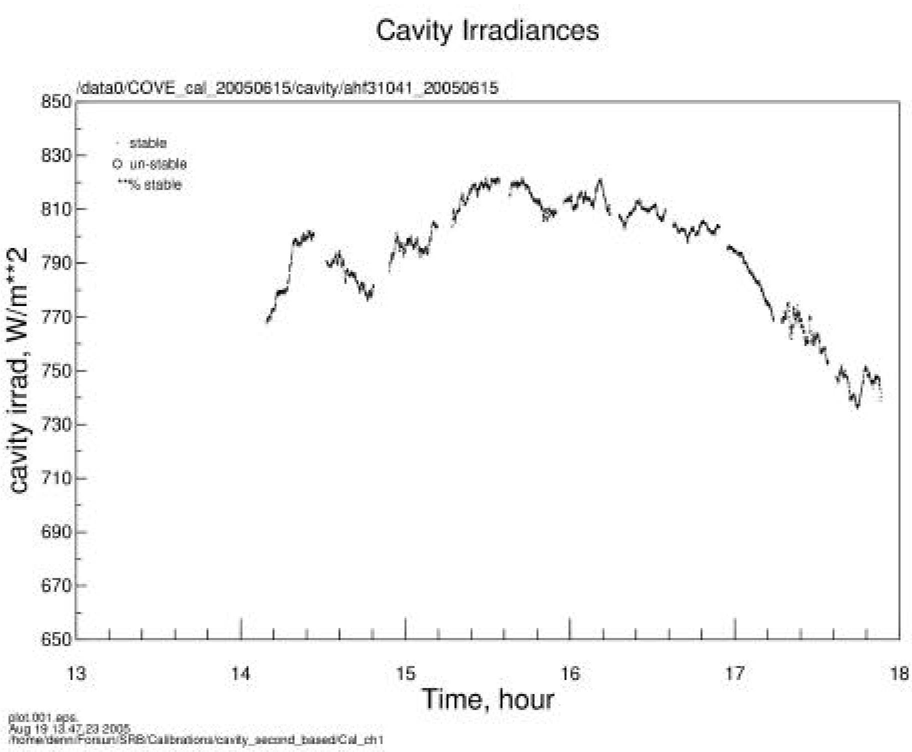
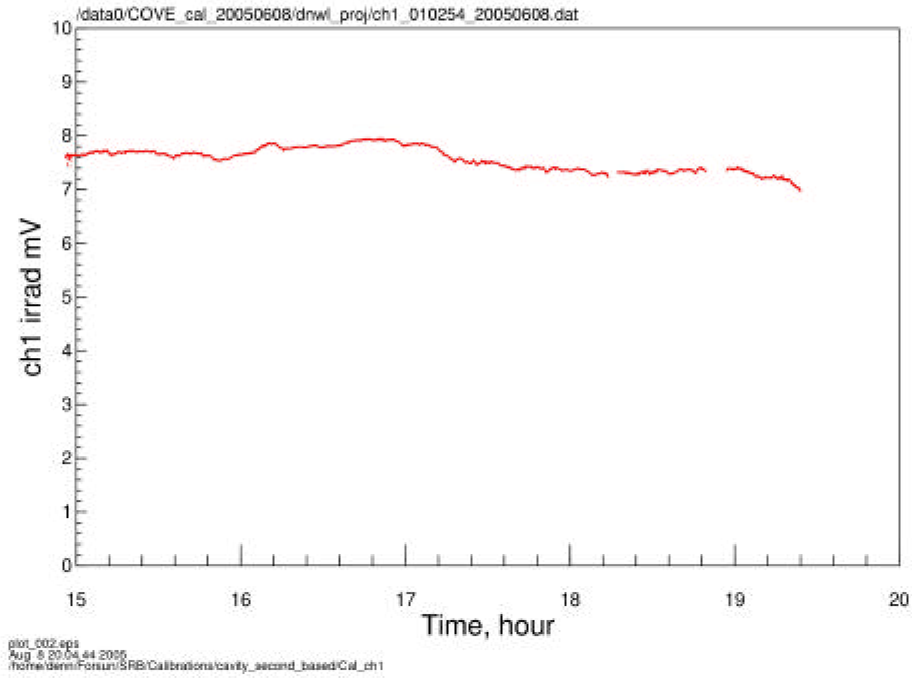


Figure 1. Irradiance measured by ACR AHF-31041 on June 6 (top) and June 15 (bottom).



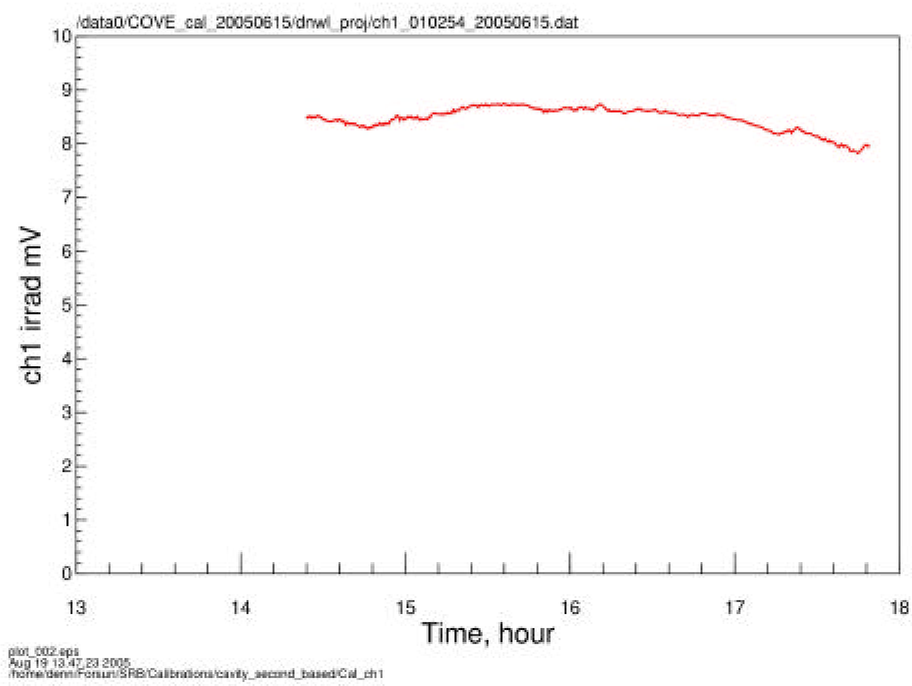
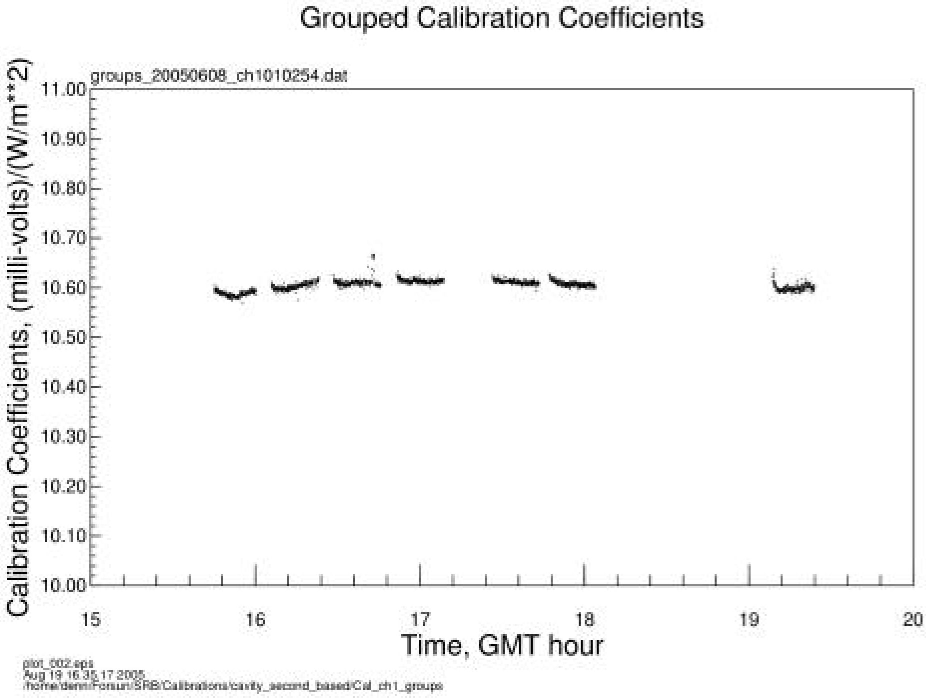


Figure 2. Milli-volt measurements obtained by the test pyrheliometer on June 6 (top) and June 15 (bottom).



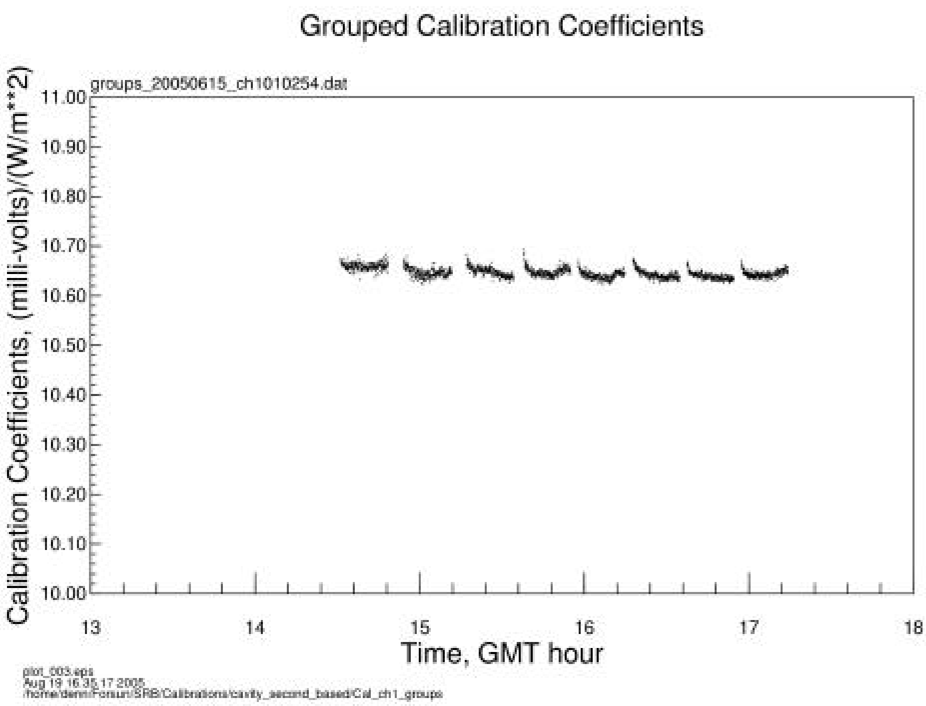
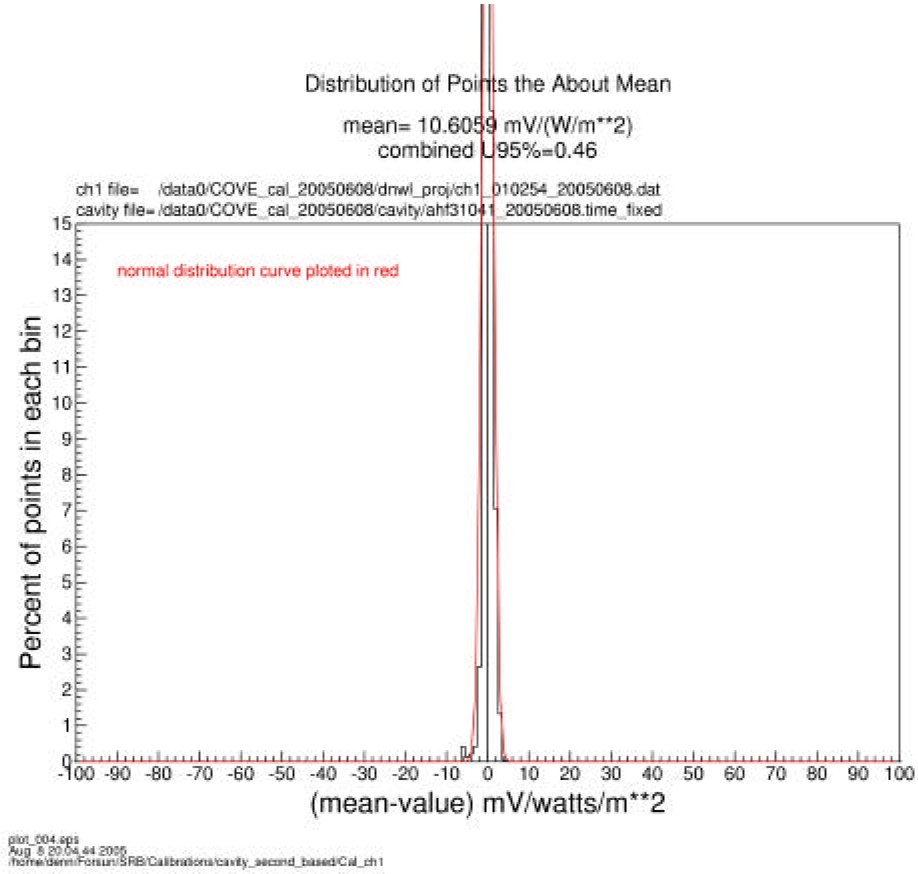


Figure 3. Selected calibration coefficients, grouped by cavity run, are shown for June 6 (top) and June 15 (bottom).



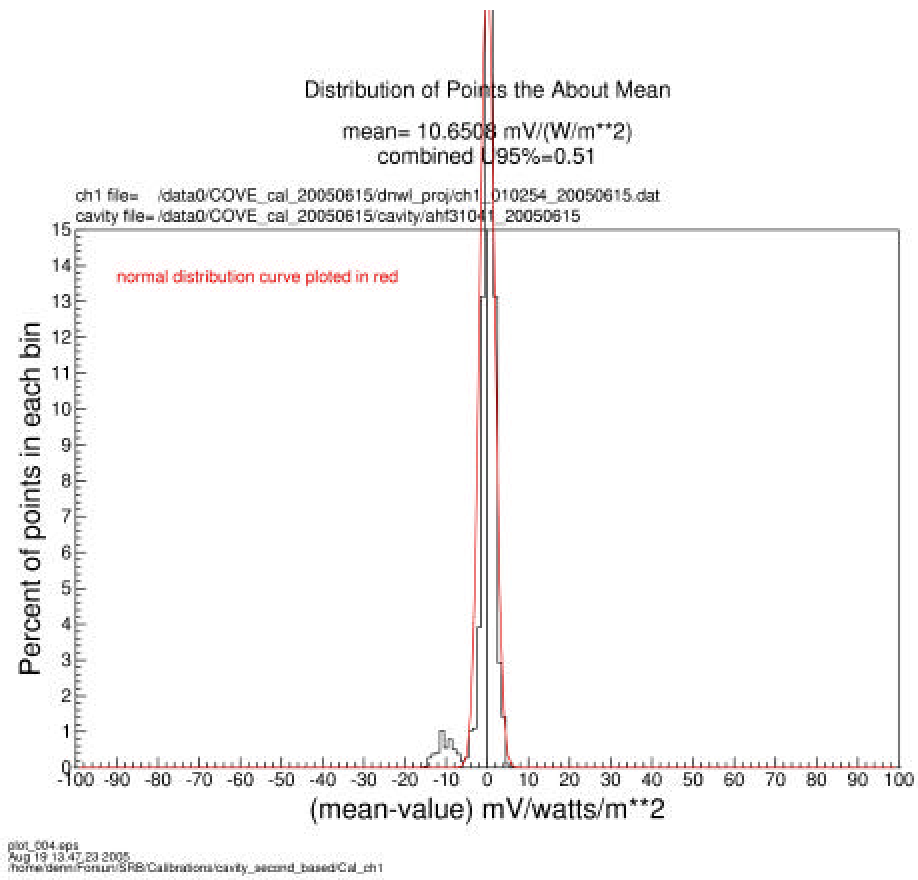


Figure 4. Histograms of the distribution of the calibration points about the mean are shown for pyrheliometer CH1-101254 for June 6 (top) and June 15 (bottom).

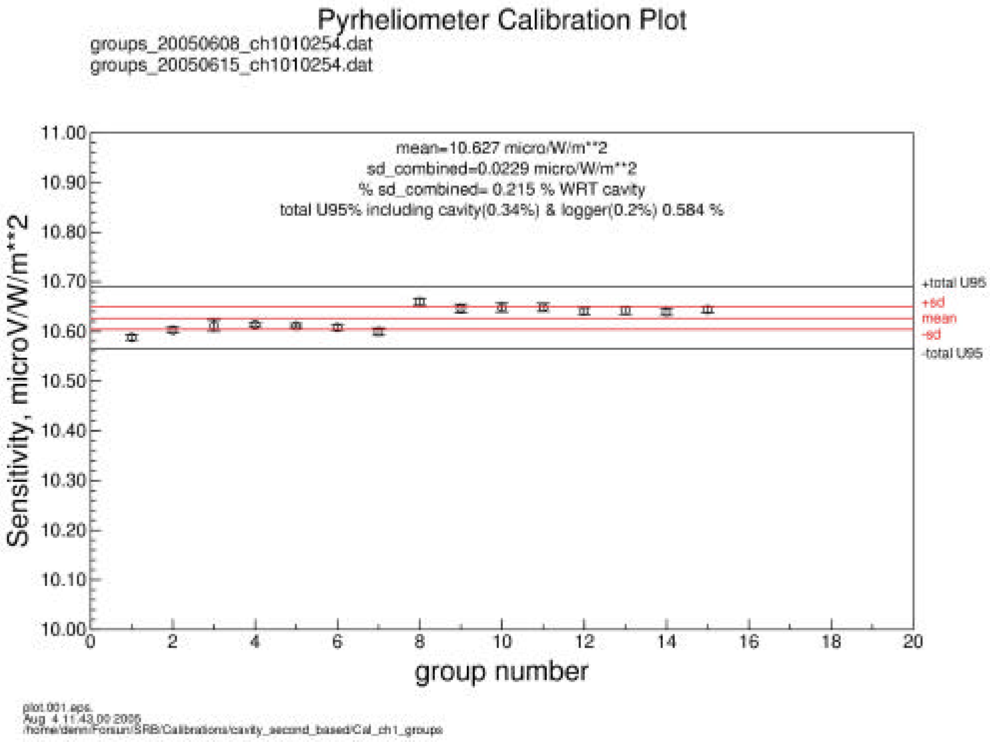


Figure 5. The data was grouped according to cavity run. A group must contain 75% of the maximum number of points possible. The means and the standard deviations of each data group are shown. The overall mean, standard deviation, and U95 are also shown.

CALIBRATION HISTORIES

Pyrheliometer: Kipp and Zonen CH1-010254.

date	day of year	S ($\mu V/(W/m^2)$)	U95 (%)	
2005 Jun 15	197	10.63	0.58	(1 HZ grouped data)
2004 Jul 15	197	10.65	0.76	(1 HZ data)
2003 Apr 03	093	10.63	0.93	(minute data)
1002 Jun 01	182	10.63	5.00	(manufacturer calibration)

Pyrheliometer: Kipp and Zonen CH1-960132.

date	day of year	S ($\mu V/(W/m^2)$)	U95 (%)	
2001 Jun 01	152	damaged and removed from service		
2000 Nov 28	333	11.18	0.67	(minute data)
1999 Nov 19	323	11.19	0.71	(minute data)
1999 Feb 12	043	11.06	0.73	(minute data)
1996 Jun 30	182	11.06	5.00	(manufacturer calibration)

Pyrheliometer: Kipp and Zonen CH1-960133.

date	day of year	S ($\mu V/(W/m^2)$)	U95 (%)	
2005 Jun 15	197	Failed, sent in for repairs.		
2004 Jul 15	197	10.70	0.88	(1 HZ data)
2003 Apr 02	093	10.70	0.87	(minute data)
2001 Aug 02	214	10.65	0.81	(minute data)
2000 Nov 28	333	10.71	0.66	(minute data)
1999 Oct 09	282	10.66	0.78	(minute data)
1999 Feb 12	043	10.53	0.73	(minute data)
1996 Jun 30	182	10.65	5.00	(manufacturer calibration)

Pyrheliometer: Eppley PSP-31375E6.

date	day of year	S ($\mu V/(W/m^2)$)	U95 (%)	
1999 Feb 12	043	8.14	1.06	(minute data)
1998 Feb 16	047	8.21	0.83	(minute data)
unknown		8.24	5.00	(manufacturer calibration)

Pyrheliometer: Eppley PSP-31376E6.

date	day of year	S ($\mu V/(W/m^2)$)	U95 (%)	
1999 Feb 12	043	7.88	1.00	(minute data)
1998 Feb 16	047	7.92	1.24	(minute data)
unknown		8.00	5.00	(manufacturer calibration)

ABSTRACT

Calibration data from pyrheliometer sensors have been collected during several time periods. The data is typically collected at the Clouds and the Earth's Radiant Energy System (CERES) Ocean Validation Experiment (COVE) site located at the Chesapeake light station, in the Atlantic Ocean approximately 25km east of Virginia Beach, Virginia. Data collection sites have also included NASA Langley Research Center (LaRC), Hampton Virginia, and the Mauna Loa Observatory (MLO) Hawaii. Calibrated devices have included Eppley Laboratory, Inc. Normal Incident Pyrheliometers (NIP) and Kipp & Zonen, Inc. CH1 pyrheliometers. These sensors were calibrated using an Eppley Laboratory, Inc. Absolute Cavity Radiometer as the reference. These calibration data are analyzed to produce calibration coefficients with 95% uncertainty bounds (U95). Current and historical calibration coefficients are presented here.

1. Introduction

Calibrations of pyrheliometers are made periodically to maintain data quality and traceability to the World Radiometric Reference (WRR). The sensors are calibrated using an Eppley Laboratory, Inc. Absolute Cavity Radiometer (ACR) as the reference. The ACR is traceable to the WRR cavity pyrheliometers at the Physikalisch-Meteorologisches Observatorium Davos (PMOD) in Davos, Switzerland.

2. Methodology

Verify that the pyrheliometer desiccant was within the proper tolerance. Attach the ACR and pyrheliometers to the solar tracker. Verify instrument alignment with respect to the sun. Connect the ACR to the ACR controller and the controller to the PC. Attach the pyrheliometers to the Campbell Scientific Inc. data logger system. Clean the pyrheliometer windows. Verify that the ACR window and the ACR cover are off. Use a computer program, supplied by Ibrahim Reda of National Renewable Energy Laboratory (NREL) located in Golden Colorado, to operate the ACR system. Use the Campbell data logger system to record voltages produced by the pyrheliometers.

The ACR is calibrated, this takes about 3 minutes. The program is then instructed to take 300 measurements, one every 3 or 4 seconds, this is considered to be a run. The process is then repeated, about 3 runs an hour can be obtained this way. Runs are made as long as sky conditions permit. A maximum of about 150 matching points are obtained for each run. The resulting data are edited to remove periods of unstable sky conditions. For a run to be considered valid 75% of the maximum number of points are required (112). A mean and standard deviation are determined for each run. These run values and standard deviations are then used to calculate a calibration event mean and standard deviation. The calibration event mean is the mean of the run values. A standard deviation of these means is then calculated, as well as the mean of the individual standard deviations. These two standard deviations are then combined using the root sum square method to get a standard deviation for the calibration event.

3. Calibration Uncertainty

The reference unit used in these pyrheliometer calibrations is an Eppley Laboratory Inc. ACR. The ACR is linked through national reference group, at the NREL in Golden Colorado, which in turn is linked to the WRR determined by World Standard Group (WSG) at the Physikalisch-Meteorologisches Observatorium Davos. The LaRC ACR AHF-31041 was linked to WSG through the NREL ACR standard group in 1997, 1998, 1999, 2001, 2002, 2003 and 2004 and directly to the WSG in 2000. The NREL ACR standard group was linked to the WSG, in 1995 and 2000, at the Eighth and Ninth International Pyrheliometer Comparisons (IPC-VIII and IPC-IX). The determined uncertainty if the cavity is 0.36% (U95% with respect to SI units) reported at IPC-VIII. See the cavity calibration documents for greater detail. The cavity uncertainty determined at the 2004 National Pyrheliometer Comparison at NREL was 0.34%.

The U95% for any specific pyrheliometer conveys the expected statistical relationship between an individual measurement made by that pyrheliometer and a hypothetical collocated individual measurement made by the WSG. This relationship is conveyed by the U95% metric which allows investigators to determine the 95% confidence intervals of measurements made by their radiometers. The measurement and its associated U95 would span the WSG measurement 95% of the time.

The final uncertainty of the test pyrheliometer calibration factor is the root sum square of the U95s of the cavity with respect to the WRR, the test pyrheliometers with respect to the cavity, and the data logger.

$$U95_{total} = \mathrm{sqrt}\left((U95_{cavity})^2 + (U95_{measured})^2 + (U95_{logger})^2 \right)$$

Where:

$U95_{total}$ is the total U95 for the test pyrheliometers.

$U95_{cavity}$ is the U95 of the cavity with respect to the WRR

$U95_{measured}$ is the U95 of the test pyrheliometers with respect to the cavity.

$U95_{logger}$ is the expected U95 of the of the test pyrheliometer data logger.

USEFUL REFERENCES

American National Standard for Expressing Uncertainty-U.S. Guide to the Expression of Uncertainty in Measurement, ANSI/NCSL Z540-2-1997. Reprinted 16 February 1998.

Swiss Meteorological Institute, (May 1996). “International Pyrheliometer Comparison IPC-VIII.” Working Report No. 188, Davos and Zurich.

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