Calibration Report: Pyrheliometers

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SUMMARY

Calibration date: 2008 February 01.
Next calibration due: 2010 February 01.
Application period: 2008 February 01 through 2010 February 01.
Reference standard: AHF-31041.

The calibration coefficients and their associated uncertainties (U95%) have been determined for two pyrheliometers. The unit of the calibration coefficients (S) is $\mu V/(W/m^2)$. 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	CH1-960133	10.72	+/- 0.60%
Kipp and Zonen	CH1-010254	10.64	+/- 0.60%

Application

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

Where: I = the irradiance measured by the pyrheliometer
(μV 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 serial number AHF31041 with its associated Agilent 34970A control unit. The cavity is traceable to the World Standard Group (WSG) of pyrheliometers at the Physikalisch-Meteorologisches Observatorium in Davos, Switzerland.

Test Instrumentation

The two test pyrheliometers were Kipp and Zonen CH1-960133 and CH1-010254. Each was connected to a Campbell Scientific Inc. 23X data logger. CH1-960133 was connected to data logger 3135, while CH1-010254 was connected to logger 2216. Both were wired for differential measurements.

FIGURES

Figure 1 shows an example of cavity measured solar irradiance. Figure 2 is an example of the millivolt measurements obtained by a test pyrheliometer. Figure 3 shows one second calibration values obtained using cavity and test pyrheliometer data. Figure 4 shows calibration values for each cavity measurement interval, approximately 30 minutes, and a final value, which is a mean of the grouped measurements. Figure 5 is the calibration history, Figures 4 and 5 are for pyrheliometer CH1-010254. Figures 6 and 7 are the same as 4 and 5 but for pyrheliometer CH1-960133.

DATA

Data used to determine these calibration values were collected on the dates indicated on figures 4 and 6.

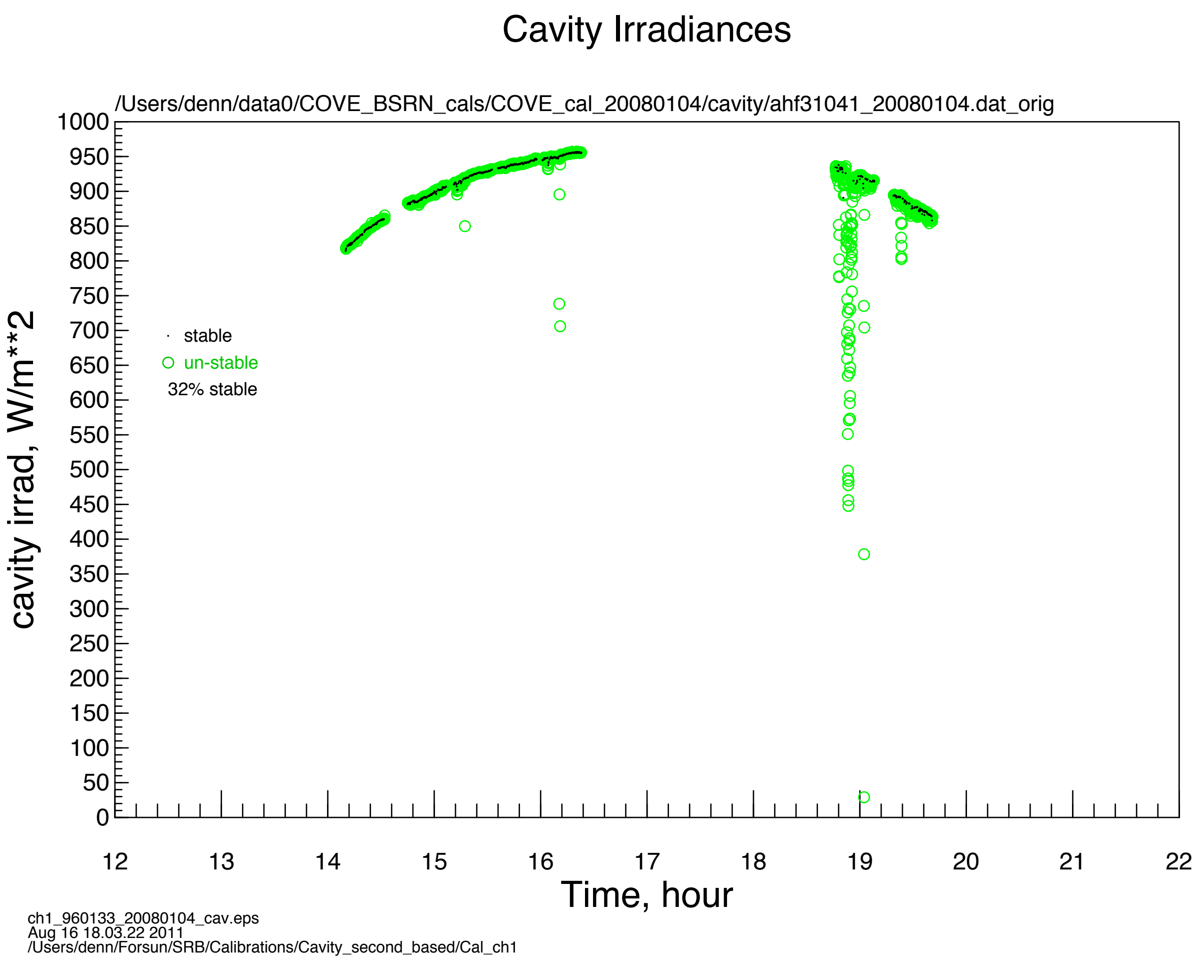

Figure 1. An Example of Irradiance measured by ACR AHF-31041. Note the gaps at approximately half hour intervals. The data gaps occur while the cavity system is doing its self calibration. Each set of data points between the gaps is considered to be a cavity run. The date is contained in the line at the top of the plot.

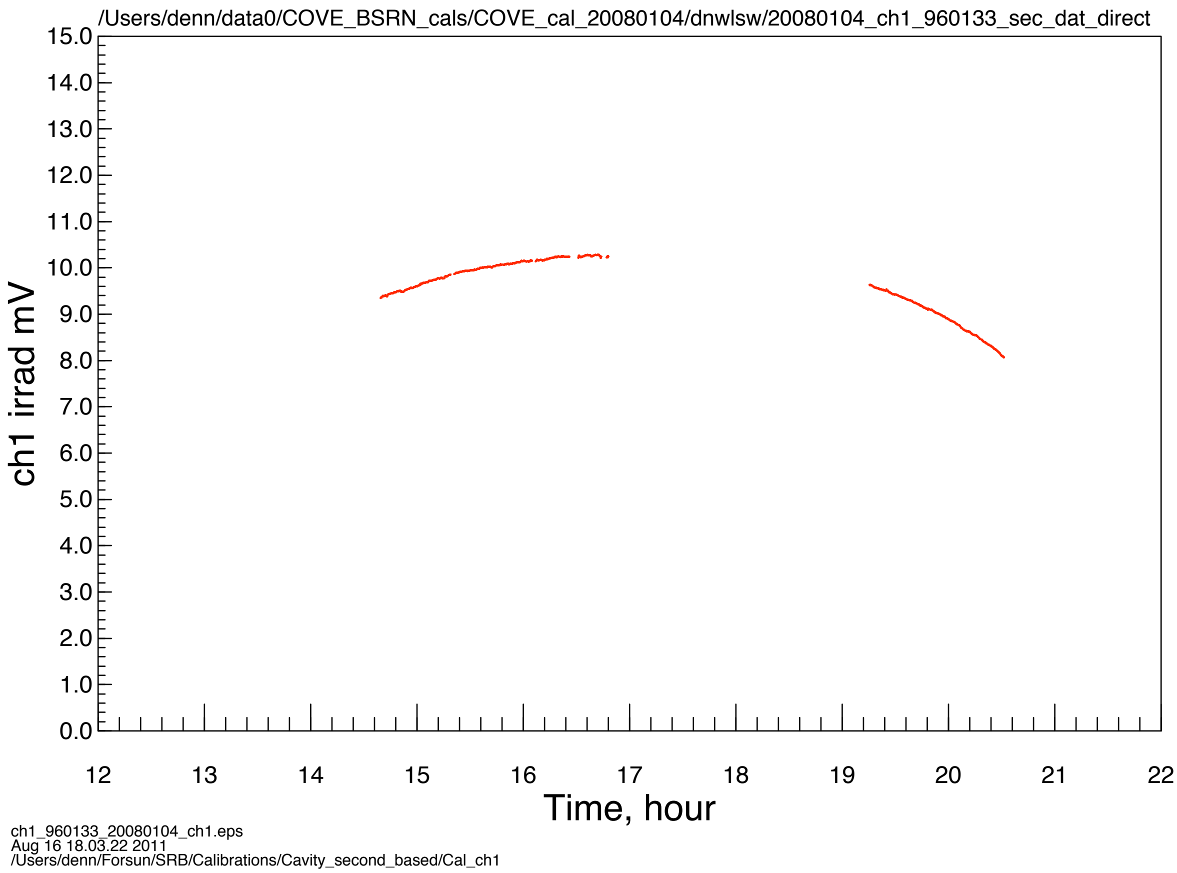

Figure 2. An example of millivolt measurements obtained by pyrheliometers CH1-960133. The date is in the line at the top of the plot and in the form yyyymmdd.

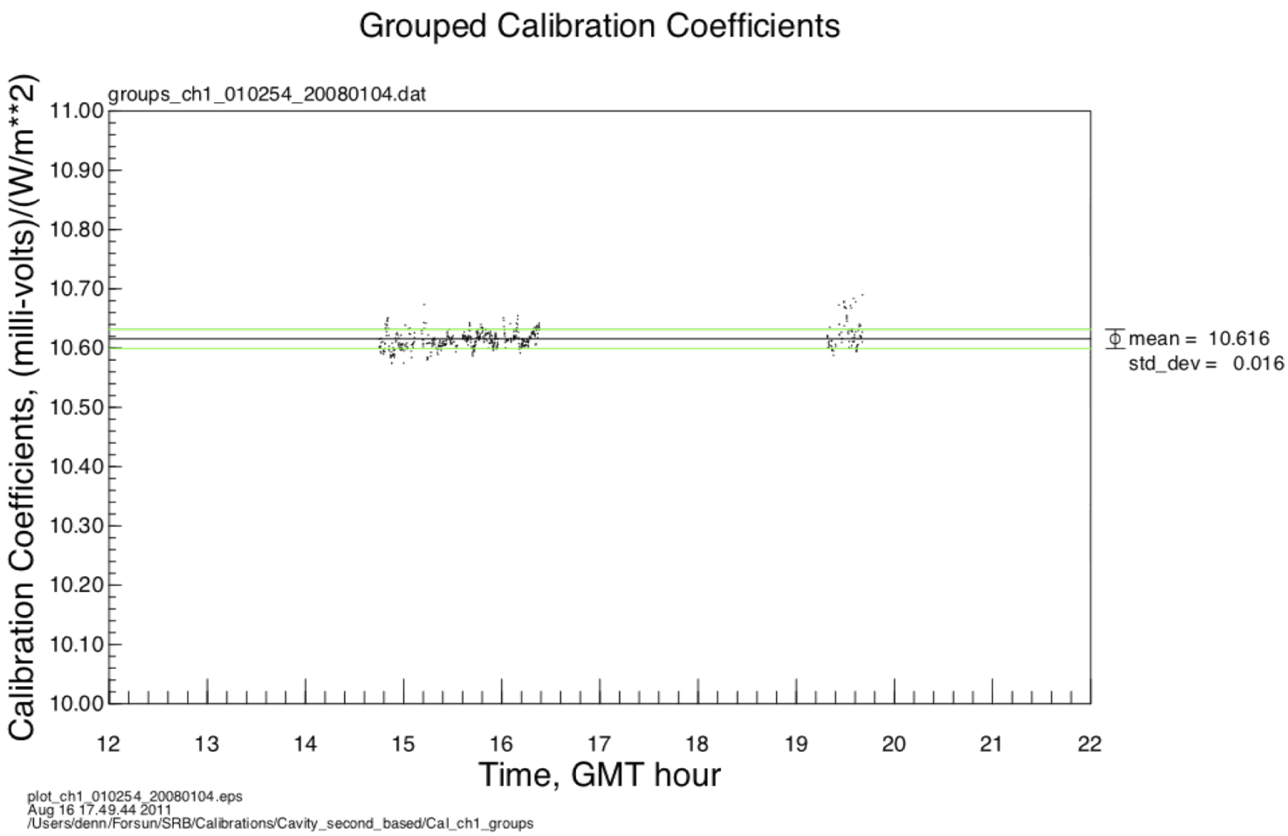

Figure 3. An example of selected calibration coefficients for CH1-010254, The data gaps occur while the cavity is self calibrating. The date between each gap will be combined into a single measurement. The date is on the top left of the plot.

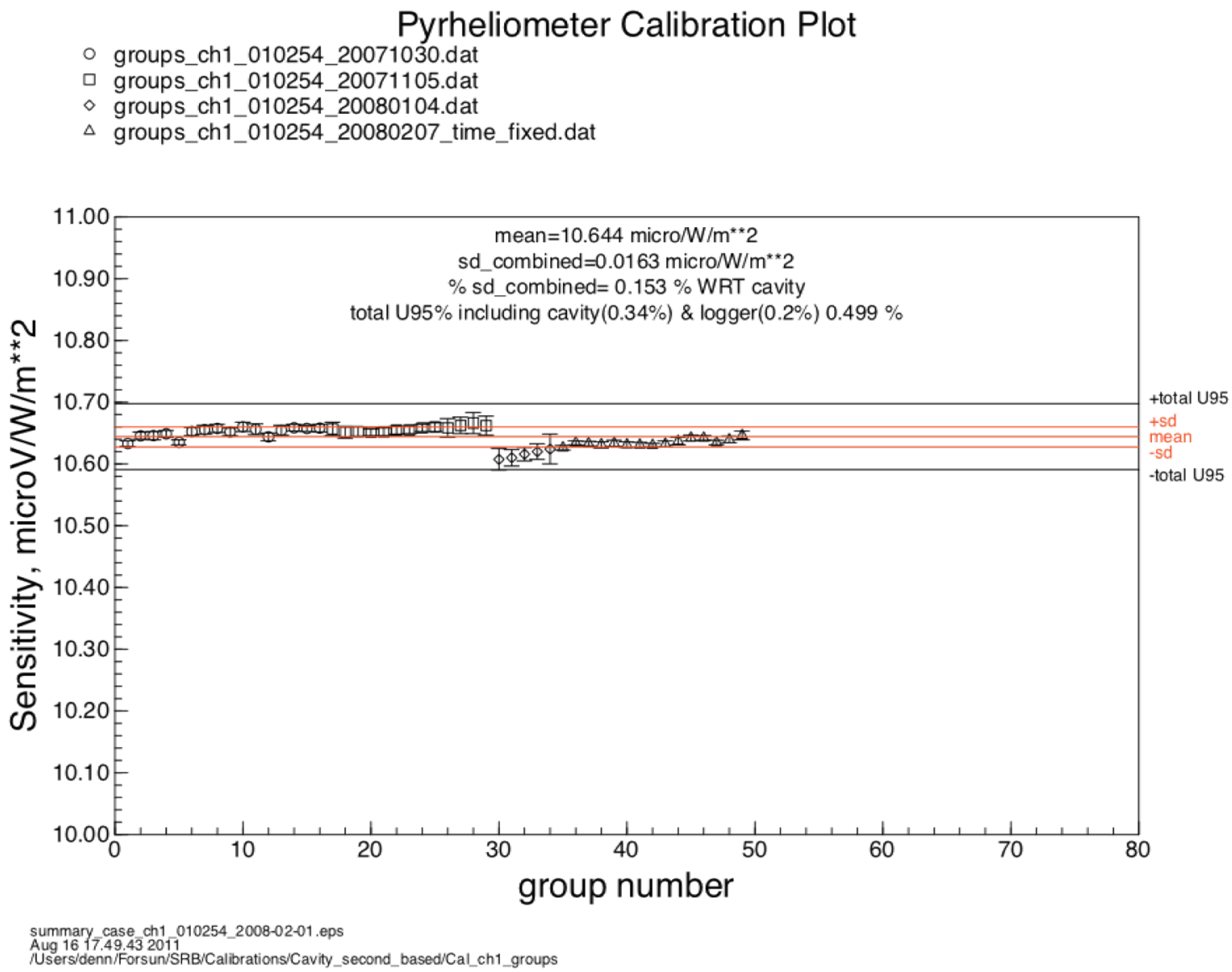

Figure 4. An example of data grouped according to cavity run. A group must contain 66% of the maximum number of points possible. Data for CH1-010254 collected on five different dates are displayed. The dates are listed on the plot.

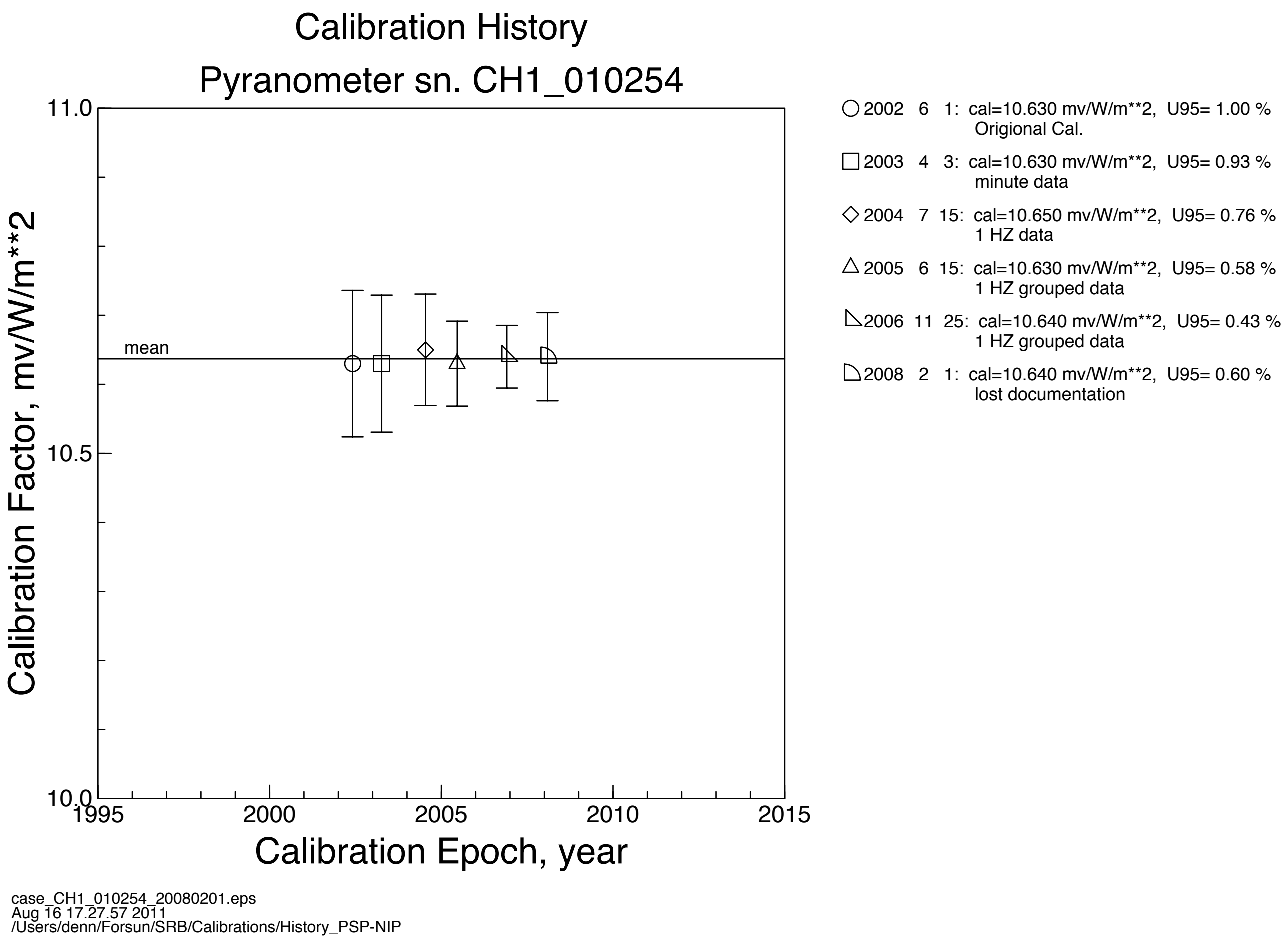

Figure 5. Calibration history for pyrheliometer CH1-010254 is presented. The solid horizontal line represents the mean value. The symbols and their error bars represent the mean and U95 of each calibration event. The column on the right presents numerical values for each calibration event and a brief description of the calibration method used.

NOTE: The unit on the axis should be micro-volts.

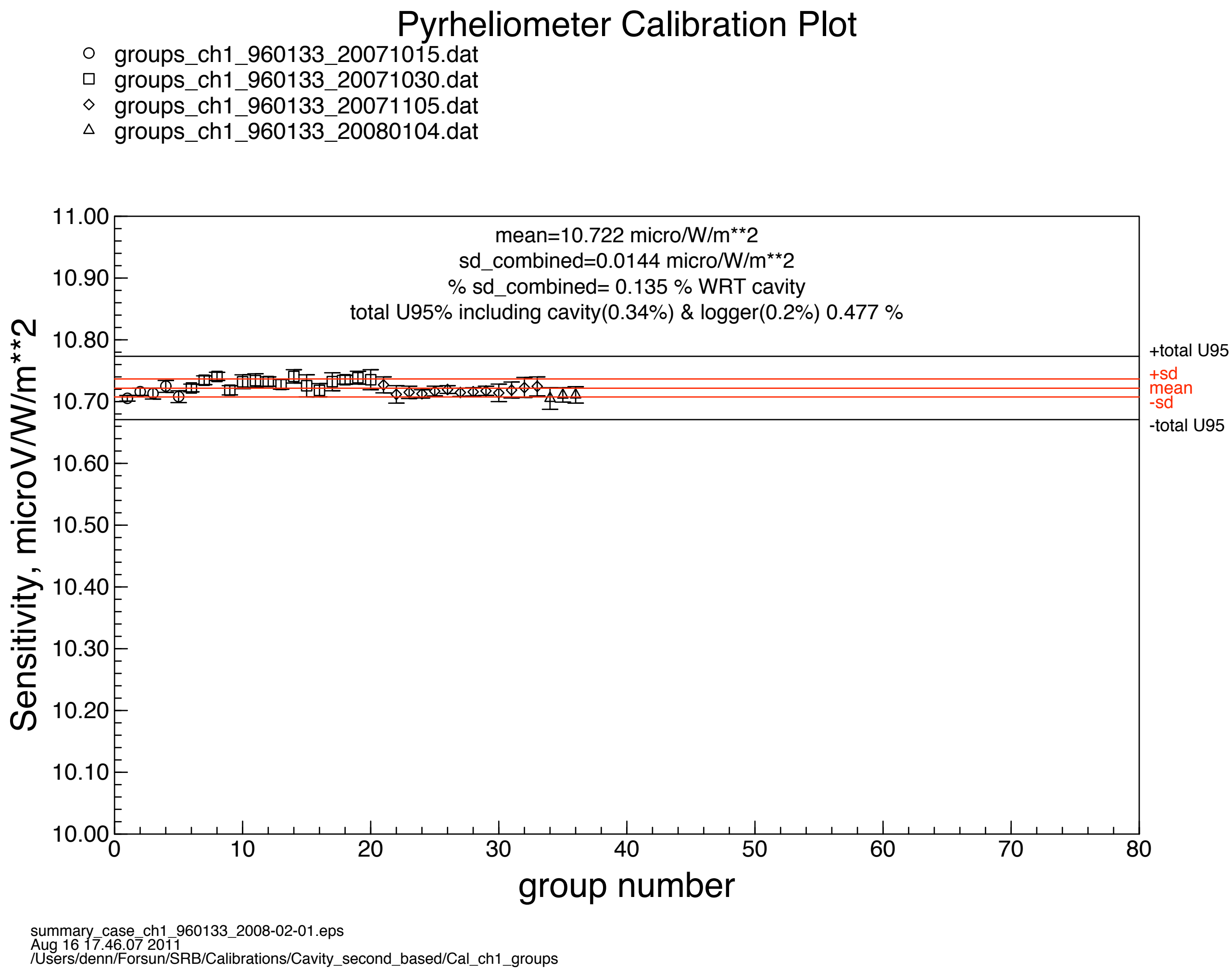

Figure 6. The data was grouped according to cavity run. A group must contain 66% of the maximum number of points possible. Data for CH1-960133 collected on five different dates are displayed. The dates are listed on the plot.

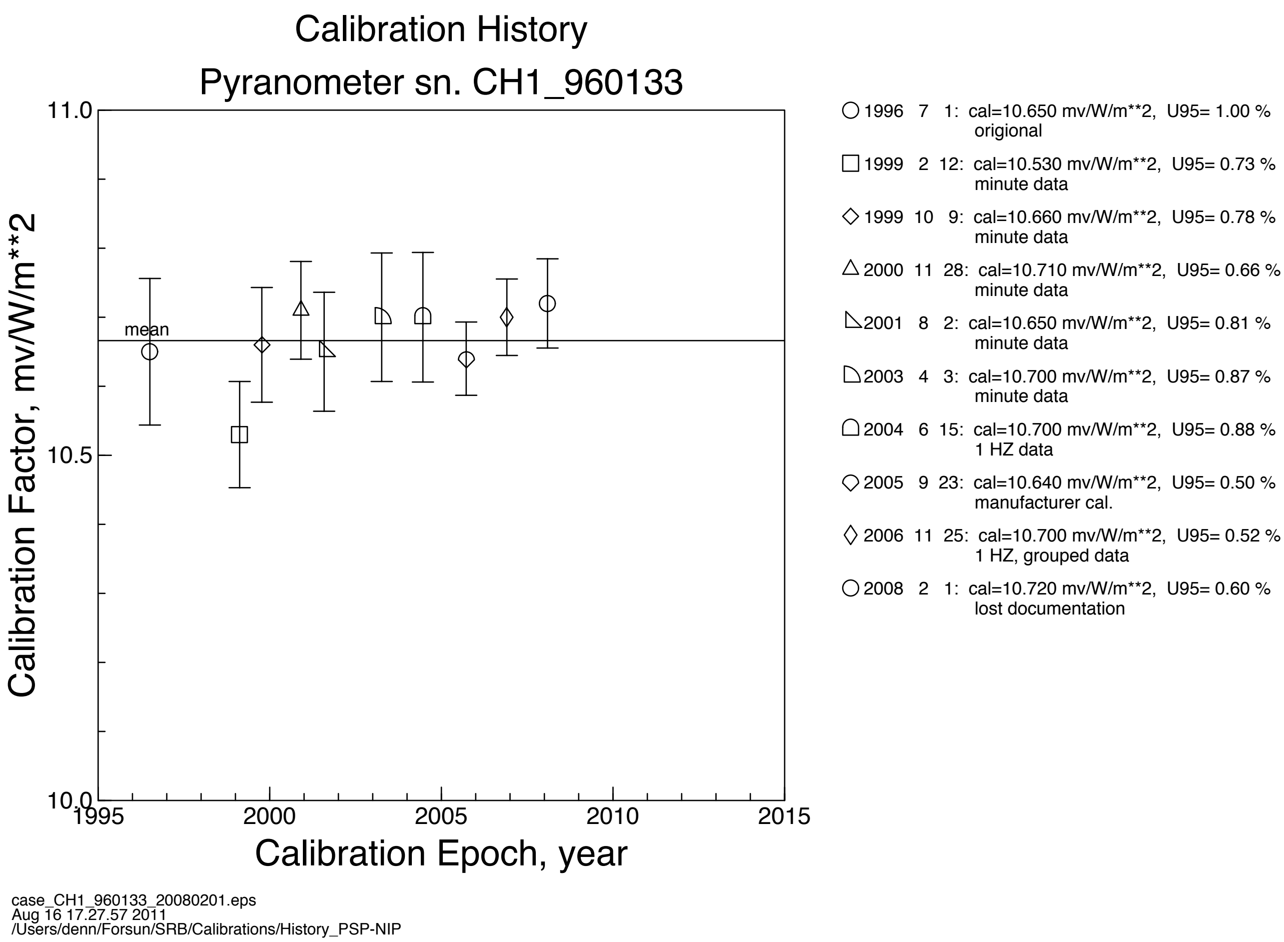

Figure 7. Calibration history for pyranometer CH1-960133 is presented. The solid horizontal line represents the mean value. The symbols and their error bars represent the mean and U95 of each calibration event. The column on the right presents numerical values for each calibration event and a brief description of the calibration method used.

NOTE: The unit on the axis should be micro-volts.

CALIBRATION HISTORIES

Pyrheliometer: Kipp and Zonen CH1-010254.

date	day of year	S (μV/(W/m^2))	U95 (%)	
2008 Feb 01	032	10.64	0.60	lost document
2006 Nov 25	329	10.64	0.58	(1 HZ grouped data)
2006 May 10	130			Setup error, no useable data.
2006 Jan 27	027			Setup error, no useable data.
2005 Jun 15	166	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)
2002 Jun 01	182	10.63	0.50	(manufacturer calibration)

Pyrheliometer: Kipp and Zonen CH1-960132.

date	day of year	S (μV/(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	0.50	(manufacturer calibration)

Pyrheliometer: Kipp and Zonen CH1-960133.

date	day of year	S (μV/(W/m^2))	U95 (%)	
2008 Feb 01	032	10.72	0.60	lost document
2006 Nov 25	329	10.70	0.58	(1 HZ grouped data)
2006 May 10	130			Setup error, no useable data.
2005 Sep 23	266	10.64	0.50	(manufacturer calibration)
2005 Jun 15	166	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	0.50	(manufacturer calibration)

Pyrheliometer: Eppley PSP-31375E6.

date	day of year	S (μV/(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 (μV/(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

Calibrations of pyrheliometers are made periodically to maintain data quality and traceability to the World Radiometric Reference (WRR). The radiometric reference used is an Eppley Laboratory, Inc. Absolute Cavity Radiometer (ACR). Calibration data from pyrheliometers have been collected periodically for the past several years. 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 25 km 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 (NIPs) and Kipp & Zonen, Inc. CH1 pyrheliometers. These calibration data are analyzed to produce calibration coefficients with 95% uncertainty bounds (U95). Current and historical calibration coefficients are presented here.

REFERENCE STANDARDS

The reference pyrheliometers are the Eppley Laboratories Inc. Absolute Cavity Radiometer (ACR) serial number AHF-31105 and AHF-31041 each with its associated Agilent 34970A control unit. These NASA Langley owned absolute cavity radiometers can be traced to the World Radiation Reference (WRR). Direct linkage was obtained at the ninth and tenth International Pyrheliometer Comparisons (IPC-IX and IPC-X) in October of 2000 and 2005 respectively. Other years starting in 1997 they were linked to the WRR through the National Standard Group (NSG) at the National Renewable Energy Laboratories in Golden, Colorado. The NSG is also linked to the WRR at the IPCs. The WRR is an average of the World Standard Group (WSG) of pyrheliometers which is kept at the Physikalisch-Meteorologisches Observatorium in Davos, Switzerland. The uncertainty of the WSG is 0.3% (U95% with respect to SI units). After each cavity intercomparison is completed, new WRR correction values and their U95 uncertainties, with respect to SI, are determined for each participant cavity. The raw irradiances as measured by a given ACR are multiplied by its WRR correction value to get the final ACR determined direct beam irradiance values. See the cavity calibration documents for greater detail.

The Agilent 34970As, used as cavity controllers, contain 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.

METHODOLOGY

Attach the ACR, and test pyrheliometers as necessary, to the solar tracker. Verify the instruments are aligned with the sun. Connect the ACR to the ACR controller and the controller to the PC. Verify that the ACR window and the ACR cover are off. Check the desiccant in each instrument and replaced as necessary. Clean the pyrheliometer windows. Verify the pyrheliometers are attached to the Campbell Scientific Inc. data logger system. Modify the data logger programs to store millivolt pyrheliometer 1 HZ data.

During a calibration session the following process is repeated as long as sky conditions permit. The ACR self calibration process is performed, this takes about 3 minutes. The program is then instructed to take 400 measurements, one every 4 seconds, this is considered to be a run. (Before January 2006, a run consisted of 300 measurements taken at intervals of 3-4 seconds). If pyranometers are being calibrated at the same time operate them in the shade/unshade mode. A run is about 30 minutes.

DATA ANALYSIS

The WRR factor is applied to the ACR measurements. The ACR and test pyrheliometer are matched to the nearest second. A calibration value is calculated for each ACR value. The data is edited to remove periods with unstable sky conditions. For a run to be considered valid 66% of the points must remain after removing bad data. For each run a run-mean and run-standard-deviation are determined. All of the runs for a calibration session are combined. The mean of the calibration values and the mean of the standard deviations of the run-means is then determined. These two standard deviations are used in the uncertainty analysis below. Ideally a calibration event would consist of data gathered on several days with varying sky but this is seldom possible because of poor site access.

UNCERTAINTY ANALYSIS

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 component U95 uncertainties listed below.

$$U95_{total} = sqrt((U95_{cavity})^2 + (U95_{mean})^2 + (U95_{sd})^2 + (U95_{logger})^2)$$

Where:
$U95_{total}$ = U95 for the test pyrheliometers.
$U95_{cavity}$ = U95 of the cavity with respect to the WRR.
$U95_{mean}$ = U95 of the calibration event mean.
$U95_{sd}$ = U95 of the calibration event standard deviation.
$U95_{logger}$ = U95 of the of the data logger (0.2%)

SUMMARY

Calibration of pyrheliometers has been completed. A set of calibration coefficients along with their associated U95 uncertainties have been determined. These values for each pyranometer are displayed at the beginning of this document. Historical calibration values are included for each pyranometer in the body of the document.

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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Reda, I., Stoffel, T., Treadwell, J., Results of NREL Pyrheliometer Comparisons NPC1997, National Renewable Energy Laboratory, Center for Renewable Energy Resources, Measurements & Instrumentation Team, 11 November 1997.

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Reda, I., Stoffel, Wilcox, S., Results of NREL Pyrheliometer Comparisons NPC1999, National Renewable Energy Laboratory, Center for Renewable Energy Resources, Measurements & Instrumentation Team, 21 September 1999.

International Pyrheliometer Comparison – 10 (IPC-X). IOM report No. 91. WMO/TD No. 1320. (Contact PMOD WRC for more information)