Calibration Report: Pyranometer

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Calibration date: 2005 June 15.
Next calibration: 2006 December 15.

Two radiometers were calibrated at the Chesapeake Ocean Validation site (COVE). The results of these Calibrations are included in this box. Earlier calibrations appear below in the CALIBRATION HISTORIES section. The reference standard used in this calibration was the Eppley Laboratories Inc. cavity radiometer AHF-31041. The unit of the sensitivity factors, S, is $\mu V/(W/m^{2})$. The sensitivity factors and their associated uncertainties (95%) are as follows:

Sensor	S ($\mu V/(W/m^2)$) ± U95%	Method
CM31-990004	12.22 ± 0.90%	relative
CM31-990005	11.87 ± 0.85%	shade/unshade

Application

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

Where: I = the irradiance measured by the pyranometer
(μV output) = microvolt output of the pyranometer
S = calibration coefficient of the pyranometer
U95% = the 95 % confidence level

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) serial number 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

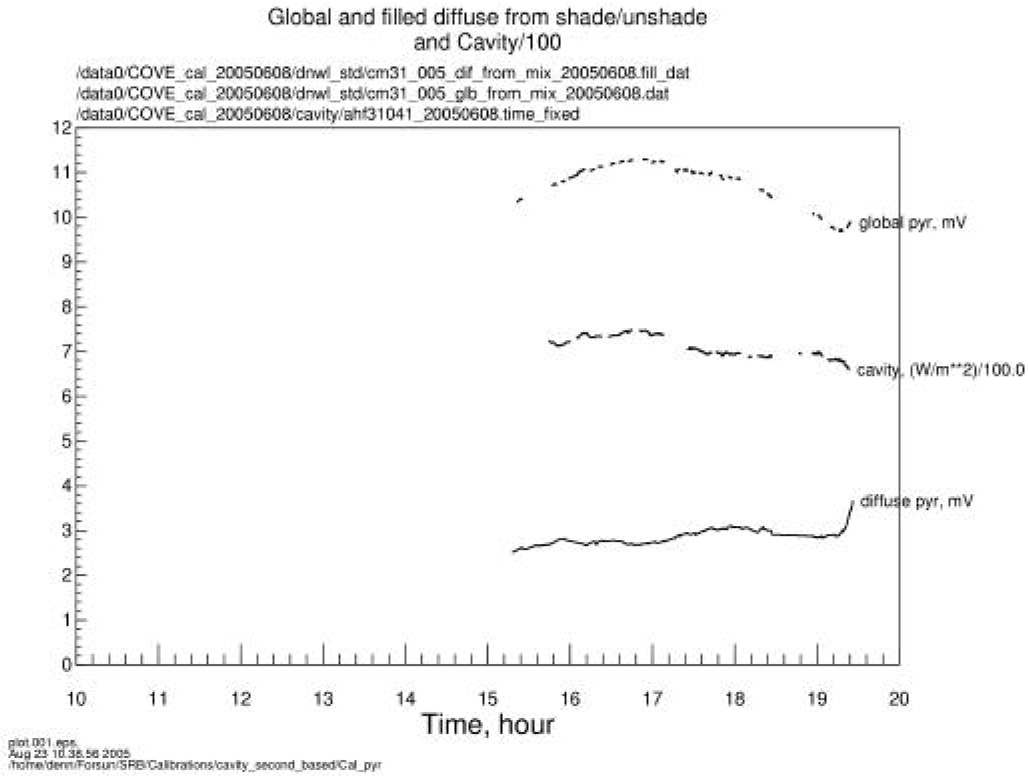
The test pyranometers were Kipp and Zonen serial numbers CM31-990004 and CM31-990004 which were connected to a Campbell Scientific Inc. 23X data logger serial number 2216. The pyranometers were wired for differential measurements.

FIGURES

Data are presented for two measurement periods, June 08 and June 15.

Figures 1 through 4 are for CM31-990005 calibrated using the shade/unshade method.
Figure 1, shows cavity measured solar and the pyranometer measured voltages.
Figure 2, displays the grouped calibration coefficients.
Figure 3, distribution of the calibration coefficients about the mean.
Figure 4, the data is grouped by cavity run and final calibration values have been determined.

Figures 5 through 7 are for CM31-990004 calibrated relative to CM31-990004.
Figure5, shows the ratio of voltages measured by the two pyranometers. Cavity runs separated by vertical red lines.
Figure 6, distribution of the ratios about there mean.
Figure 7, the data is grouped by cavity run and final calibration values have been determined.



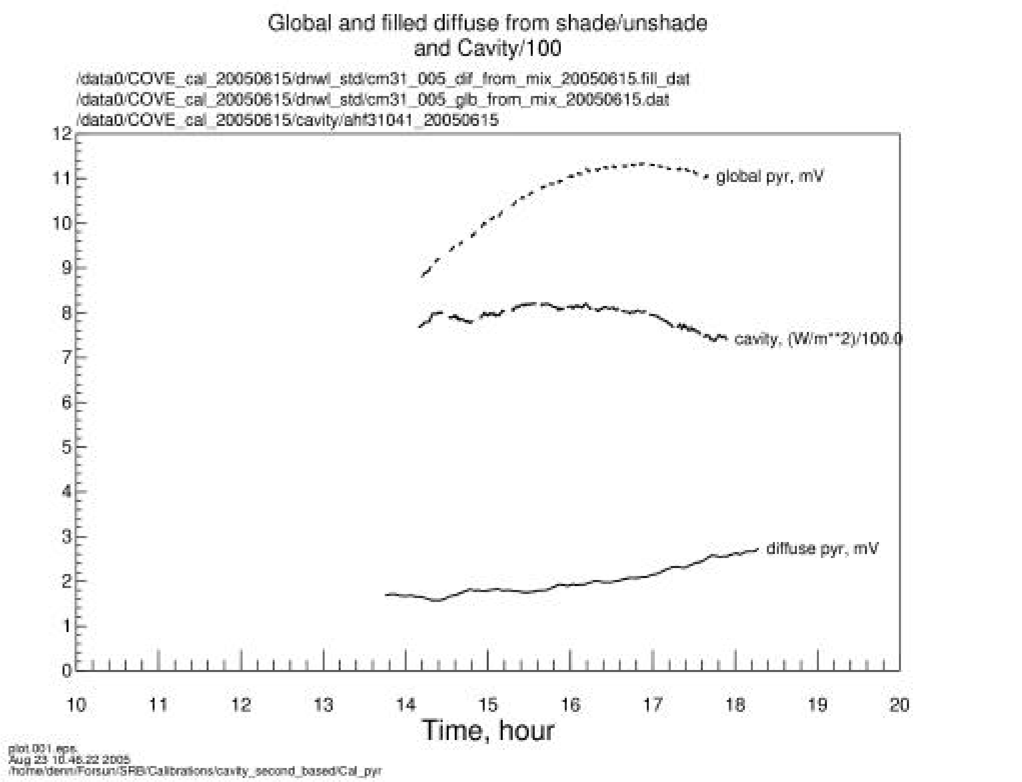


Figure 1. Calibration measurements for pyranometer CM31-990005 are presented. Cavity, and global and diffuse pyranometer measurements are presented separately. The diffuse measurements have been interpolated over their missing data periods. The top is for June 8, while the bottom is for June 15.

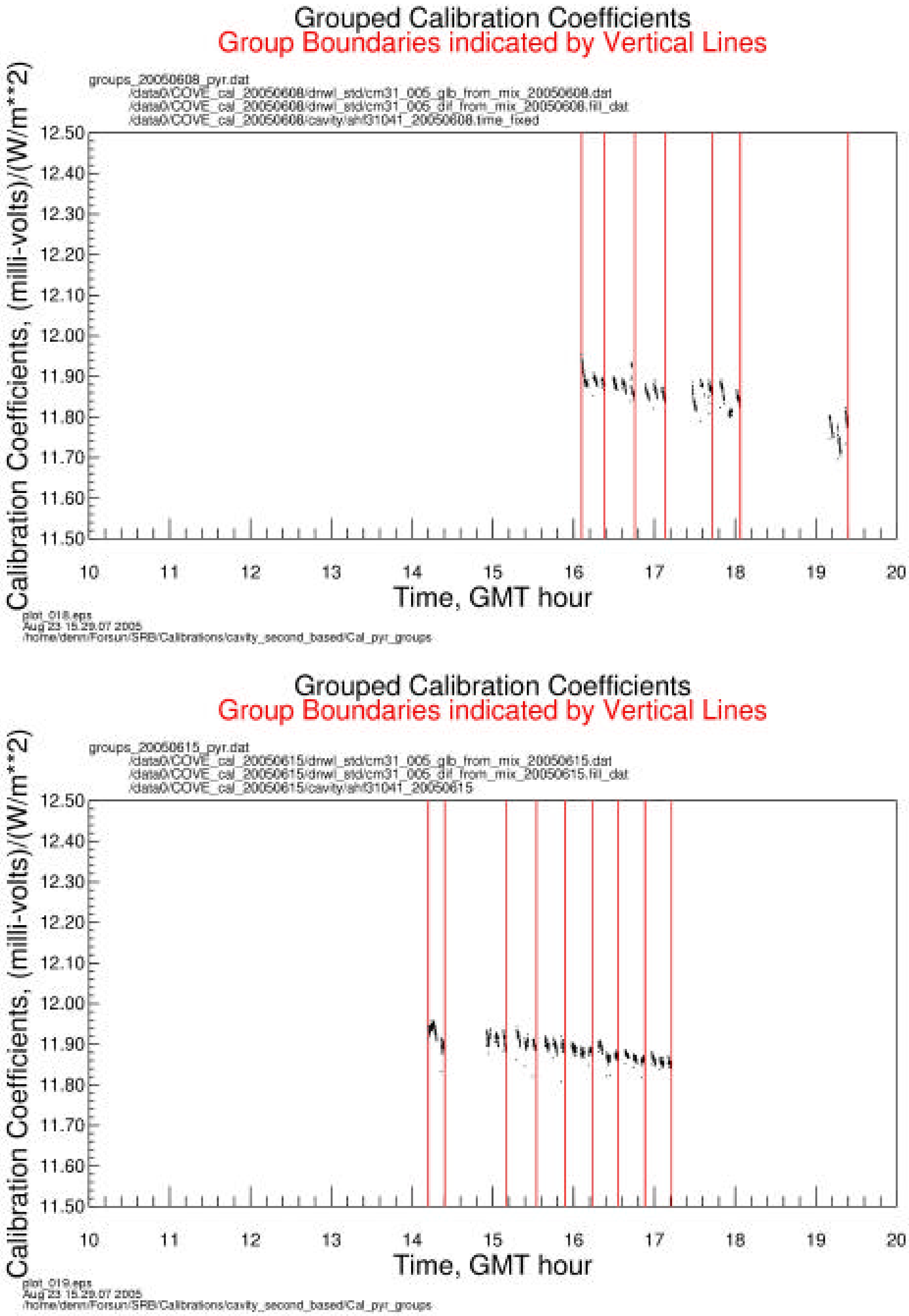


Figure 2. Newly determined calibration coefficients for pyranometer CM31-990005 grouped by cavity run. The data between any tow adjacent red lines if for one cavity run. The data are grouped by cavity run in the analysis. The top is for June 8 while the bottom is for June 15.

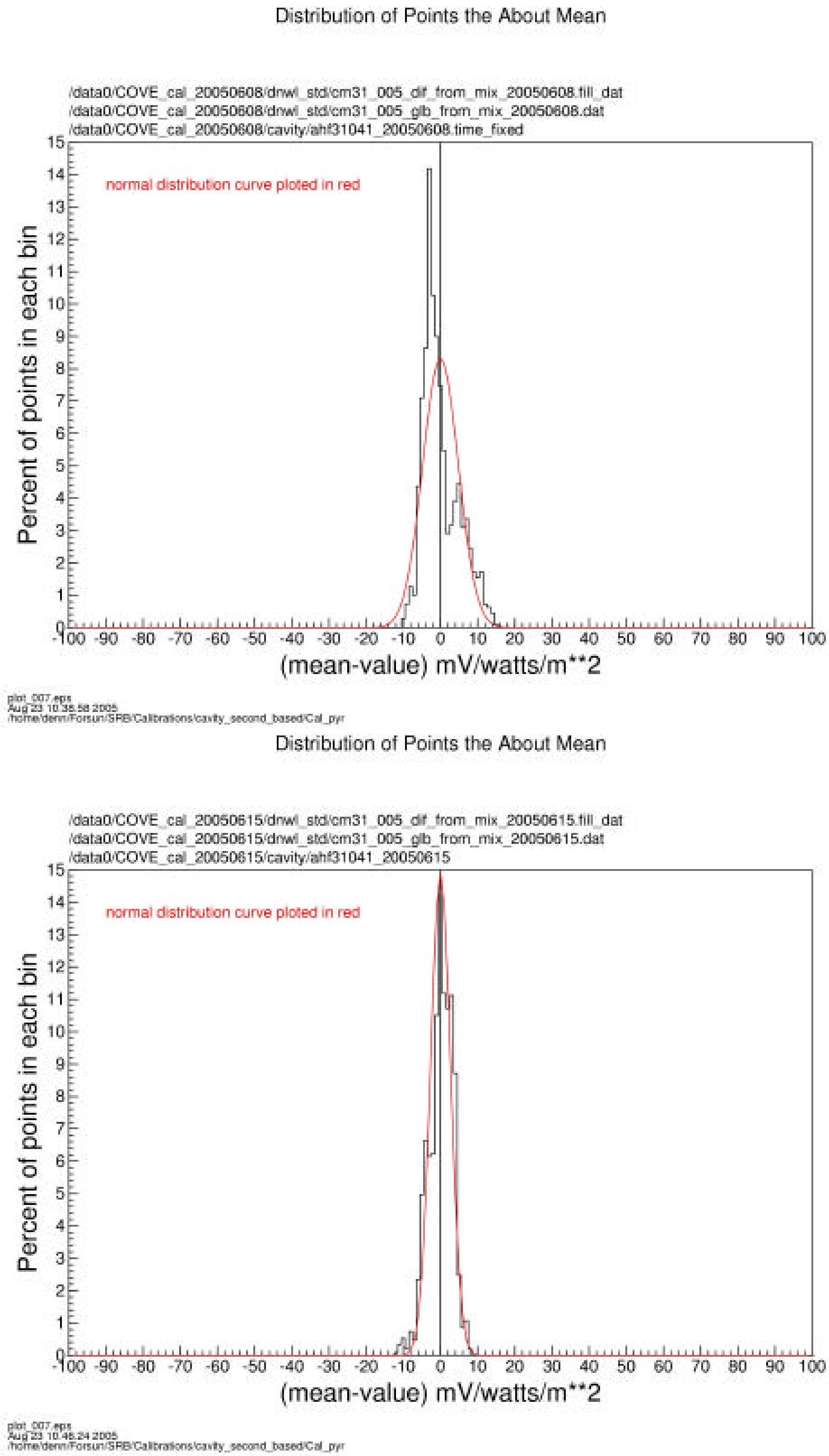


Figure 3. Histograms of the distributions of calibration values about the mean value. The expected normal distribution curve is plotted in red. These distributions approximate a normal curve quite well which is expected. The top is for June 8, while the bottom is for June 15.

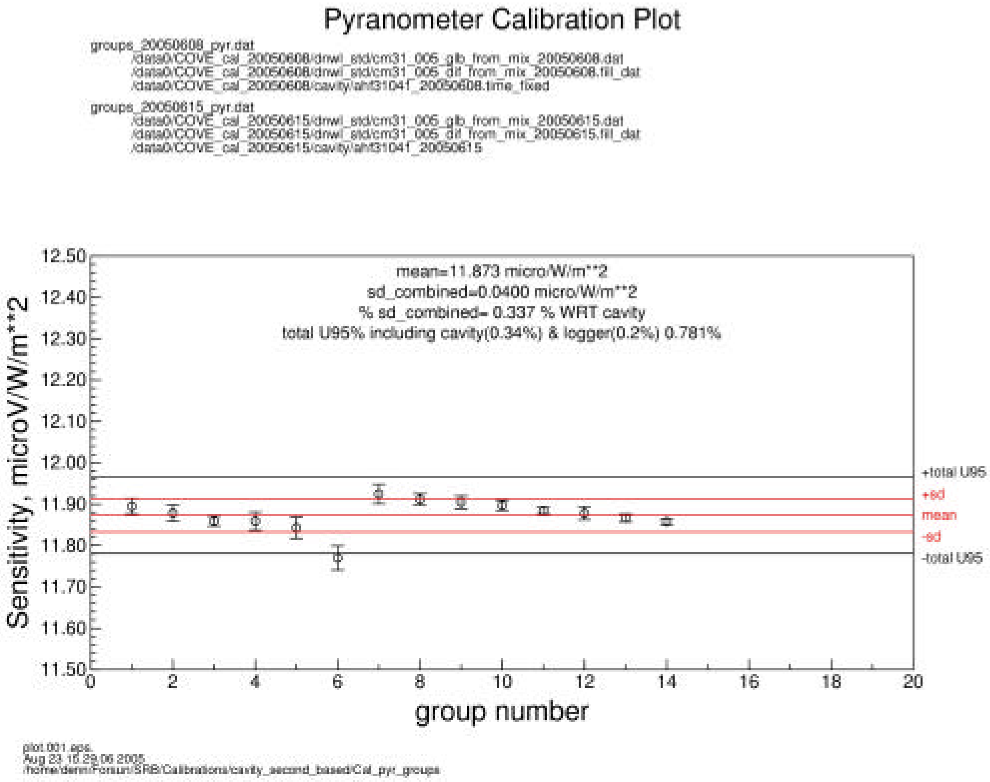
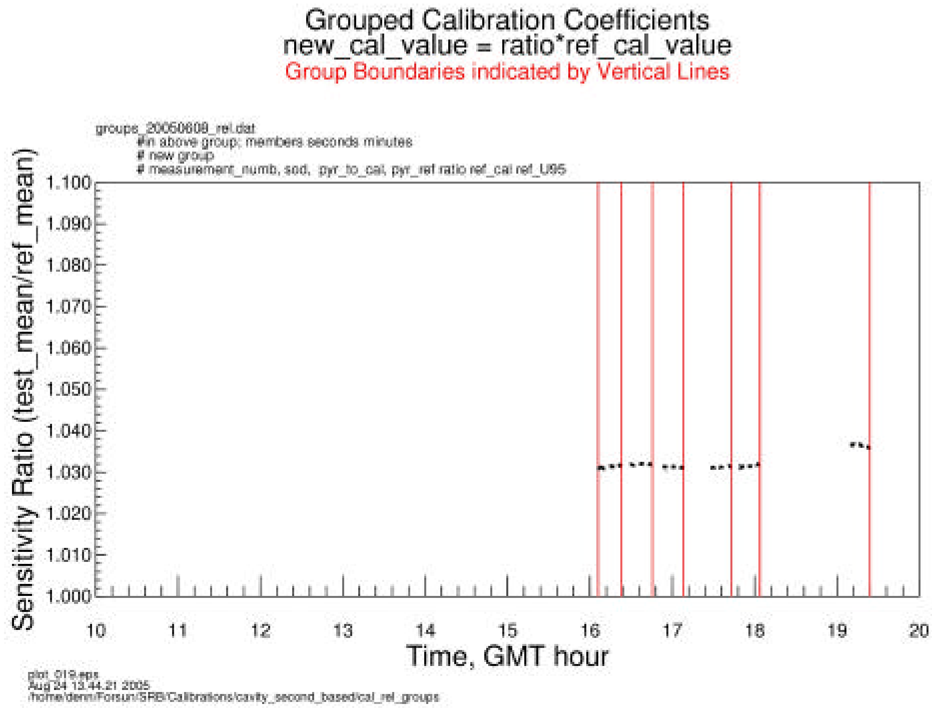


Figure 4. The grouped shade/unshade calibration data along with means and standard deviations is presented. This plot presents the new calibration coefficient and its associated U95 for CM31-990005. This data is for both June 8 and June 15.



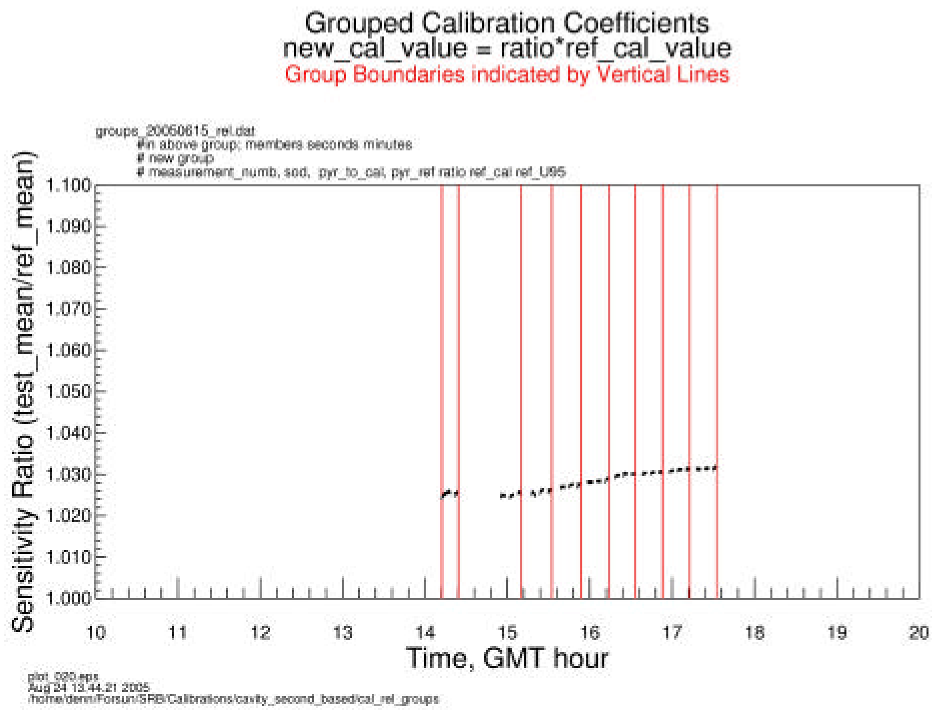


Figure 5. Grouped relative calibration data is presented CM31-990005 is the reference pyranometer and CM31-990004 is the pyranometer being calibrated. The top is for June 8, while the bottom is for June 15.

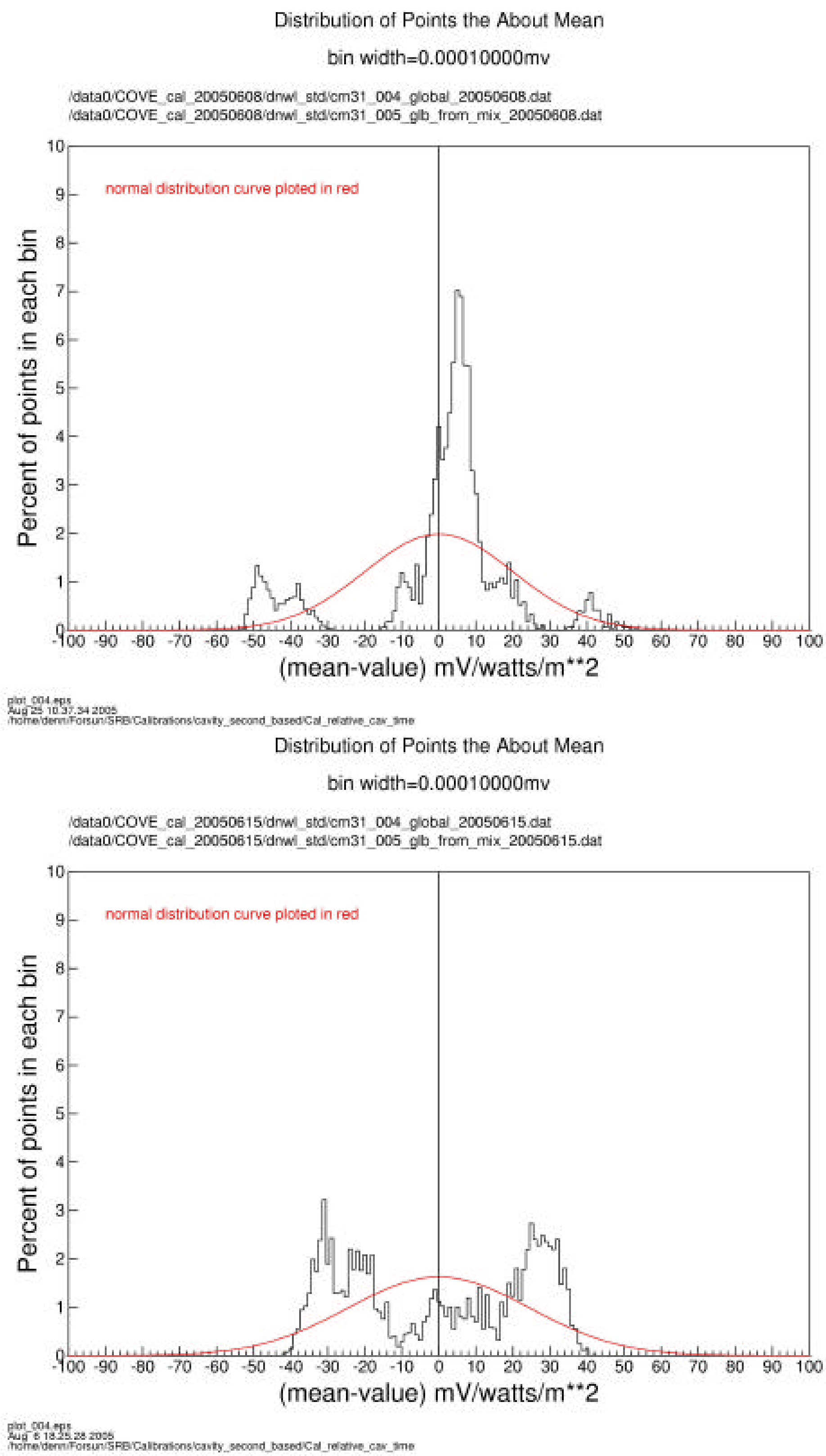


Figure 6. Histograms of the distributions of calibration values about the mean value. The expected normal distribution curve is plotted in red. The shape of the histogram indicated that the two pyranometers are equally level. The top is for June 8, while the bottom is for June 15.

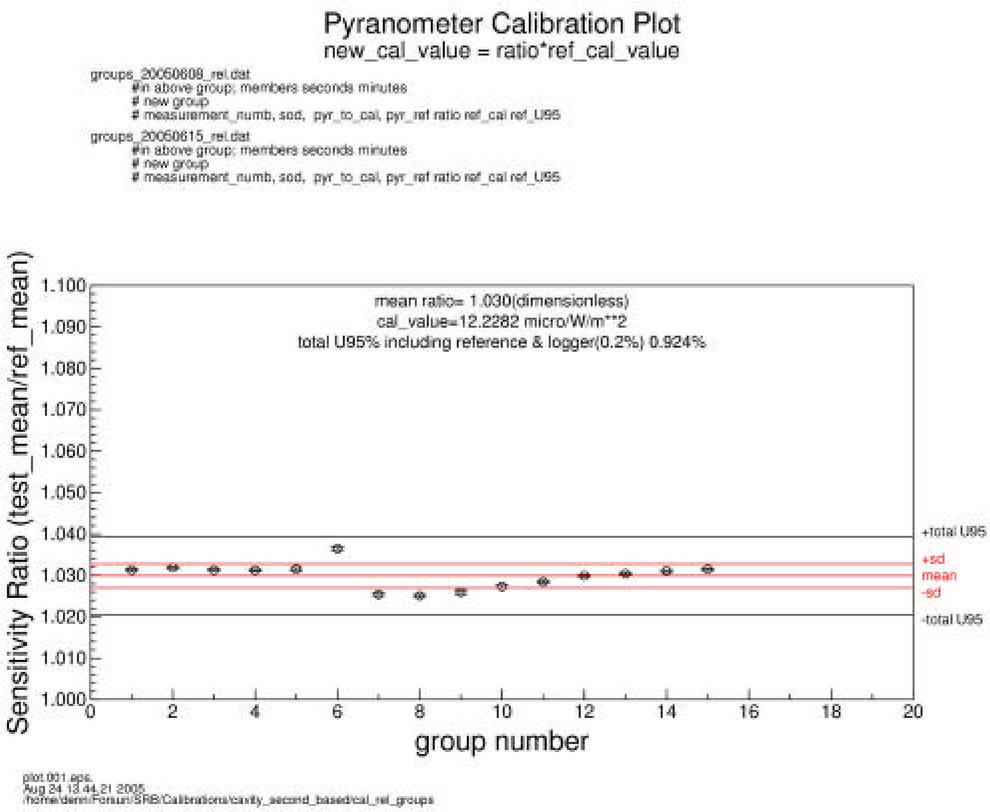


Figure 7. The grouped relative calibration data along with means and standard deviations is presented. This data is for both June 8 and June 15. This plot presents the new calibration coefficient and its associated U95 for CM31-990004. This data is for both June 8 and June 15.

CALIBRATION HISTORIES
(doy = day of year)

Pyranometer: Kipp and Zonen CM22-000024

date	doy	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2003 Apr 03	093	9.19	1.16	Forgan's alternate
2001 Jun 18	169	9.214	1.013	Forgan's alternate
2000 Oct 01	275	9.16	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM22-000025

date	doy	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2003 Apr 03	093	9.29	1.06	Forgan's alternate
2000 Oct 01	275	9.18	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM22-000030

date	doy	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2001 Jun 18	169	8.40	1.316	Forgan's alternate
2000 Jan 01	001	8.40	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-990004

date	doy	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2005 June 15	165	12.23	0.99	relative
2004 Jul 15	197	12.22	0.90	relative
2003 Apr 03	093	12.18	0.92	Forgan's alternate
2002 Mar 31	90	12.26	1.80	Intercomparison (do not use)
2001 Aug 02	214	12.130	1.203	Forgan's alternate
2000 Nov 28	333	12.132	0.876	Forgan's alternate
1999 Nov 11	315	12.133	0.739	Forgan's alternate
1999 Jan 01	001	11.94	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-990005

date	doy	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2004 June 15	165	11.87	0.78	shade/unshade
2004 Jul 15	197	11.86	0.85	shade/unshade
2003 Apr 03	093	11.83	1.47	Forgan's alternate
2001 Aug 02	214	11.813	1.070	Forgan's alternate
2000 Nov 28	333	11.852	0.963	Forgan's alternate

1999 Nov 11	315	11.748	0.753	Forgan's alternate
1999 Jan 01	001	11.67	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-000506

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
2003 Apr 03	093	11.67	1.64	Forgan's alternate
2000 Sep 01	245	11.68	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-000507

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
2004 Jul 03	197	11.79	0.74	shade/unshade
2003 Apr 03	093	11.72	0.83	Forgan's alternate
2001 Jun 18	169	11.769	0.739	Forgan's alternate
2000 Jan 01	001	11.70	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-000508

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
2004 Jul 03	197	11.86	0.91	relative
2003 Apr 03	093	11.78	1.88	Forgan's alternate
2002 Mar 31	90	12.08	1.63	intercomparison (do not use)
2001 Aug 02	214	11.59	1.63	intercomparison[1] (do not use)
2001 Jun 18	169	11.866	0.932	Forgan's alternate
2000 Jan 01	001	11.81	5.00	manufacturers original

Pyranometer: Eppley PSP-29472F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
2003 Apr 03	093	8.53	1.80	Forgan's alternate
2002 Mar 31	90	8.52	2.95	intercomparison (do not use)
2001 Jun 18	169	8.57	2.63	Forgan's alternate
1999 Feb 12	043	8.49	4.51	Forgan's alternate
1998 Jun 03	154	8.68	1.22	Forgan's alternate
1993 Apr 16	106	8.76	5.00	manufacturers original

Pyranometer: Eppley PSP-30676F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
1999 Feb 12	043	8.49	2.98	Forgan's alternate
1998 Jun 03	154	8.66	1.06	Forgan's alternate
1995 Jun 16	167	8.74	5.00	manufacturers original

Pyranometer: Eppley PSP-30798F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
1999 Feb 12	043	8.45	5.23	Forgan's alternate
1998 Jun 03	154	8.82	1.28	Forgan's alternate
1995 Aug 07	219	9.01	5.00	manufacturers original

Pyranometer: Eppley PSP-30803F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
1999 Feb 12	043	9.26	4.35	Forgan's alternate
1998 Jun 03	154	9.55	1.17	Forgan's alternate
1996 Jul 23	205	9.362	3.2	BORCAL
1995 Aug 07	219	9.46	5.00	manufacturers original

Pyranometer: Eppley PSP-30806F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
2003 Apr 03	093	8.70	2.92	Forgan's alternate
2002 Mar 31	090	8.76	1.81	Intercomparison (do not use)
2001 Jun 18	169	8.95	1.22	Forgan's alternate
1999 Feb 12	043	8.72	5.47	Forgan's alternate
1998 Jun 03	154	9.07	0.90	Forgan's alternate
1995 Aug 07	219	9.22	5.00	manufacturers original

Pyranometer: Eppley PSP-30847F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
1999 Sep 24	267	8.37	3.24	Forgan's alternate
1999 Feb 12	043	8.75	3.14	Forgan's alternate
1998 Jun 03	154	8.80	1.19	Forgan's alternate
1995 Aug 07	219	8.96	5.00	manufacturers original

Pyranometer: Eppley PSP-30851F3

date		S (μV/W/m^2)	U95 (%)	calibration type
1999 Feb 12	043	8.37	1.61	Forgan's alternate
1998 Jun 03	154	8.48	0.93	Forgan's alternate
1996 Jul 23	205	8.257	3.3	BORCAL
1995 Aug 07	219	9.68	5.00	manufacturers original

Pyranometer: Eppley PSP-31560F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
1999 Sep 24	267	8.85	9.07	Forgan's alternate (poor)
1999 Feb 12	043	9.23	4.20	Forgan's alternate
1998 Jun 03	154	9.53	0.98	Forgan's alternate
1997 May 05	125	9.51	5.00	manufacturers original

Pyranometer: Eppley PSP-31561F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
1999 Feb 12	043	8.42	1.84	Forgan's alternate
1997 May 05	125	8.52	5.00	manufacturers original

Pyranometer: Eppley PSP-33028F3

date	doy	S (μV/W/m^2)	U95 (%)	calibration type
2003 Apr 03	093	8.53	1.01	Forgan's alternate
2000 Jul 01	183	8.65	5.00	manufacturers original

1) The Pyranometer was mounted as a global sensor. An intercomparison with the COVE derived global irradiance was performed. The uncertainty was determined using the root sum square method and previously determined uncertainties for the 3 sensors, COVE direct, COVE diffuse, and the sensor being analyzed (CM31-000508).

ABSTRACT

Data have been collected for the purpose of calibrating pyranometers, The June 2005 data were collected at the CERES Ocean Validation Experiment (COVE) site. COVE is located at the Chesapeake Light Station approximately 25 km east of Virginia Beach, Virginia. Pyranometers included are those which measure global and diffuse downwelling shortwave radiation, and upwelling shortwave. In the past data have been collected at NASA Langley in Hampton, Virginia; Mauna Loa Observatory, Hawaii; and COVE. These historical data are used to create a time history of calibration coefficients. The radiometric reference used in these calibrations is the Eppley Laboratory Inc. absolute cavity radiometer serial number AHF-31041. For more information about the cavity radiometers see the Absolute Cavity Radiometer entries of the Calibration web site. An uncertainty analysis is preformed and included with the results of the pyranometer calibrations.

1. Introduction

During this calibration session data were collected for the pyranometers listed in the box at the beginning of the document. These calibration values can be traced through AHF-31041 to the National Standard group at the National Renewable Energy Laboratories in Golden Colorado to the World Radiometric Reference, at the Physikalisch-Meteorologisches Observatorium in Davos, Switzerland.

2. Measurement Configuration and Methodology.

One pyranometer was mounted to measure global irradiance and one was mounted on a solar tracker and initially shaded by the shading apparatus. The pyranometer on the tracker was then operated alternately in the shaded (diffuse) configuration and them in the unshaded (global) configuration for periods of about 3 minutes each, throughout the entire measurement period. This was accomplished by removing the nut from a pivot bolt in the shading system and rotating the shading balls around the zenith axes until they were well away from the sun. The ACR was mounted on the tracker and aligned with the sun. Pyranometer measurements were taken at 1Hz, by a Campbell Scientific Inc. model 23x data logger. All pyranometers were leveled using the manufacturer installed bubble level (+/- 1^o). The desiccant in each sensor was checked and replaced as necessary.

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. Data Analysis

The two calibration methods were here were shade/unshade and relative. In the shade/unshade method the data collected from a pyranometer during shaded and unshaded periods is separated into global and diffuse components. The missing periods of the diffuse component are filled in, in this case by linear interpolation. A pyranometer determined horizontal component of the direct beam irradiance, in millivolts, is calculated by taking the difference between the global and interpolated diffuse measurements for each second. ACR determined horizontal intensities of the direct beam irradiance, in watts/meter**2 are determined. This is done by multiplying the ACR measured irradiance by of the cosine of the solar zenith angle. The calibration coefficient, for each second of matching data, is then determined by dividing the pyranometer millivolt reading by the appropriate ACR determined irradiance. The Final result is then converted to microvolts/(W/m**2). The mean and standard deviation of the calibration coefficient was determined for the entire measurement period for each pyranometer.

In the relative comparison method the global pyranometer measuements and global component of shade/unshade pyranometer measurements were ratioed for each coincident measurement. A mean and standard deviation were then determined for this instrument pairing for the entire measurement period. This ratio was then applied to the calibration value previously determined for the shade/unshade pyranometer to obtain a new calibration coefficient for the global pyranometer.

4. Uncertainty Analysis

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 uncertainties presented here are the U95 values. The measured value with its U95 uncertainty have a 95% probability of including the ‘true value’. The U95 uncertainty is twice the standard deviation. Three uncertainties are used there to determine a resultant uncertainty they are, 1) the uncertainty of the reference standard, 2) the U95 (2.0*standard_deviation) of the measured data, and 3) the uncertainty of the data logger. The final uncertainty is taken to be the root sum square of the components.

$$U95_{total} = sqrt((U95_{reference})^2 + (U95_{measured})^2 + (U95_{logger})^2)$$

Where:
$U95_{total}$ is the total U95 for the test pyrheliometers.
$U95_{reference}$ is the U95 of the reference 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.

5. **Summary**

Calibration of pyranometers 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.

USEFULL REFERENCES

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

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