Calibration Report: Pyranometer

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Calibration date: 2004 July 15.
Next calibration: 2005 November 30.

Several 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
CM31-000507	11.79 ± 0.74%	shade/unshade
CM31-000508	11.86 ± 0.91%	relative

Application

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

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

The following sections contain a plot of the cavity measured irradiance, figure 1. Plots of calibration coefficients for each pyranometer appear in parts A of figures 2-5, while the distributions of the calibration coefficients about the means are shown in parts B. Next a table of historical calibration coefficients then appears. The last section is a discussion of the measurement and data analysis methodologies.

PLOTS

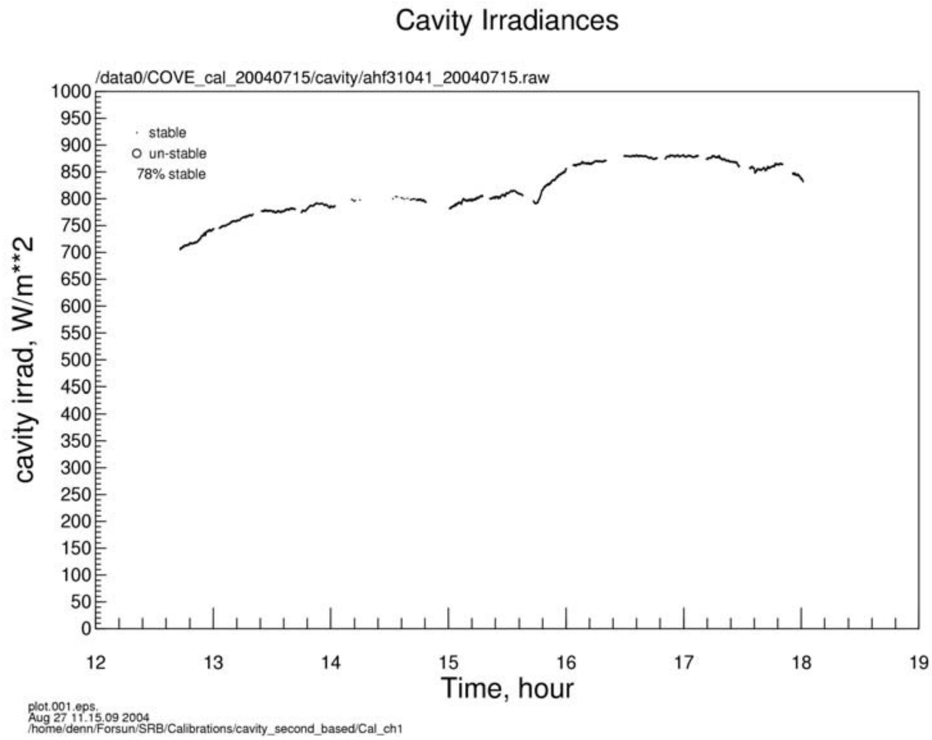

Figure 1. Plot of the irradiance measured by ACR AHF31041 on the day of the calibration.

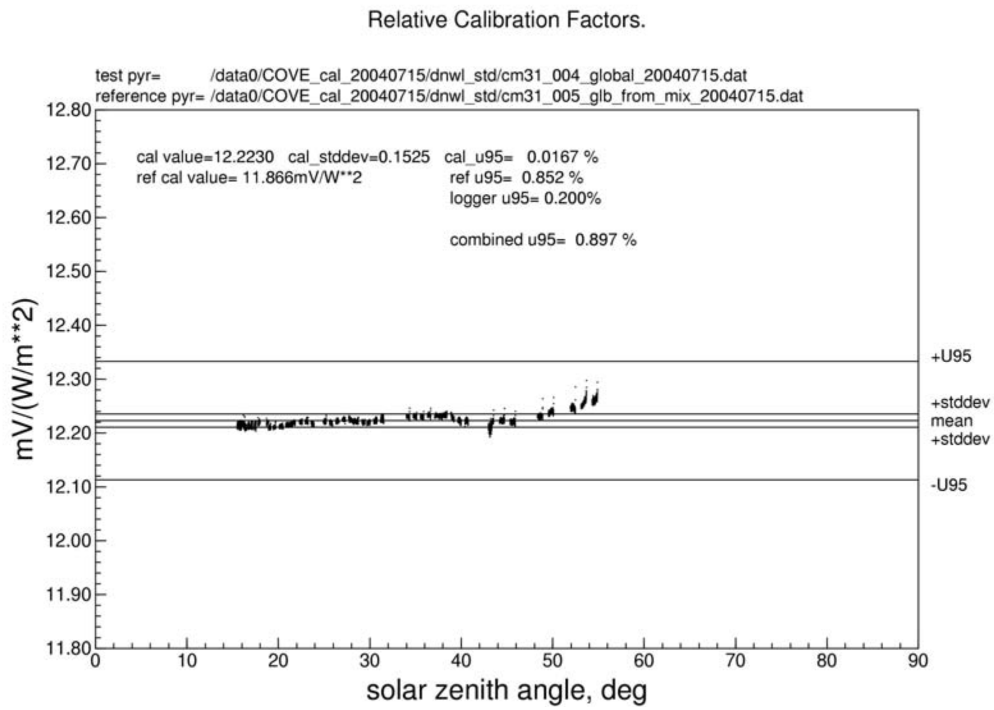

Figure 2A. The distribution of the 1Hz calibration values is shown for pyranometer CM31-990004. The mean, standard deviation, and the U95 limits are also shown. This calibration was preformed using the relative method. The reference pyranometer was CM31-990005.

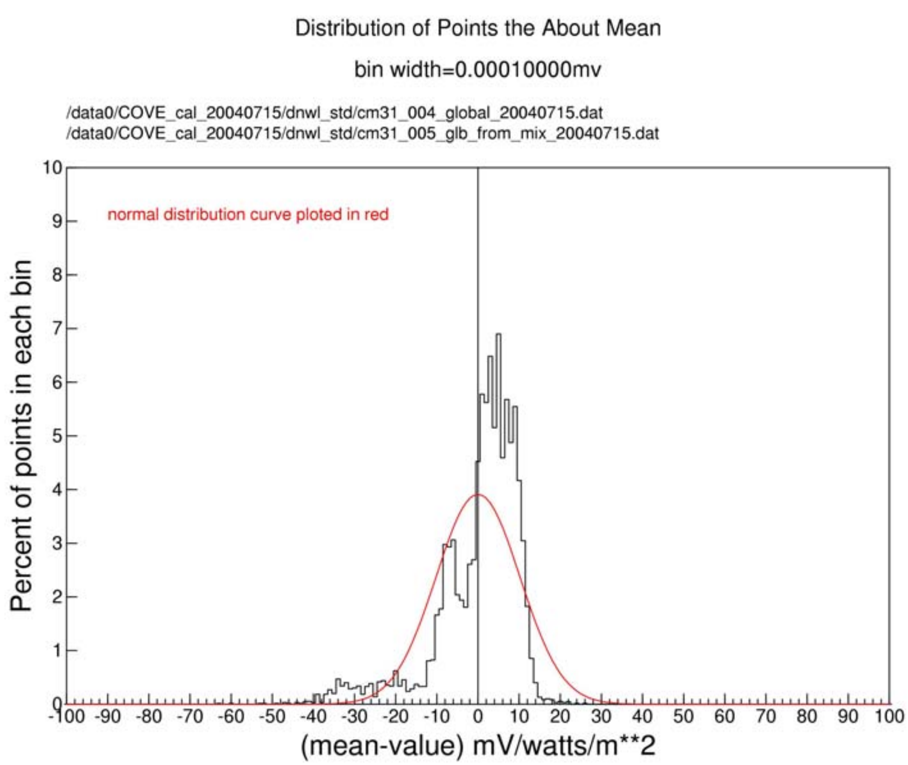

Figure 2B. A histogram of the distribution of the calibration points about the mean is shown for pyranometer CM-990004. The theoretical normal distribution curve is shown in red.

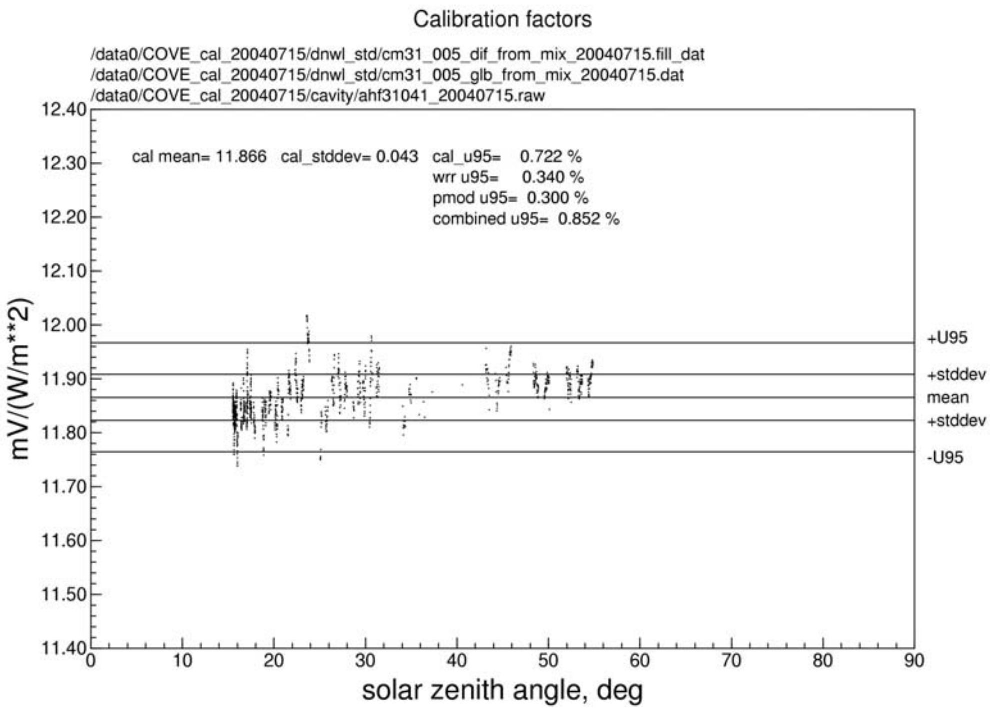

Figure 3A. The distribution of the 1Hz calibration values is shown for pyranometer CM31-990005. The mean, standard deviation, and the U95 limits are also shown in this figure. This calibration was preformed using the shade/unshade method. The reference is ACR AHF-31041.

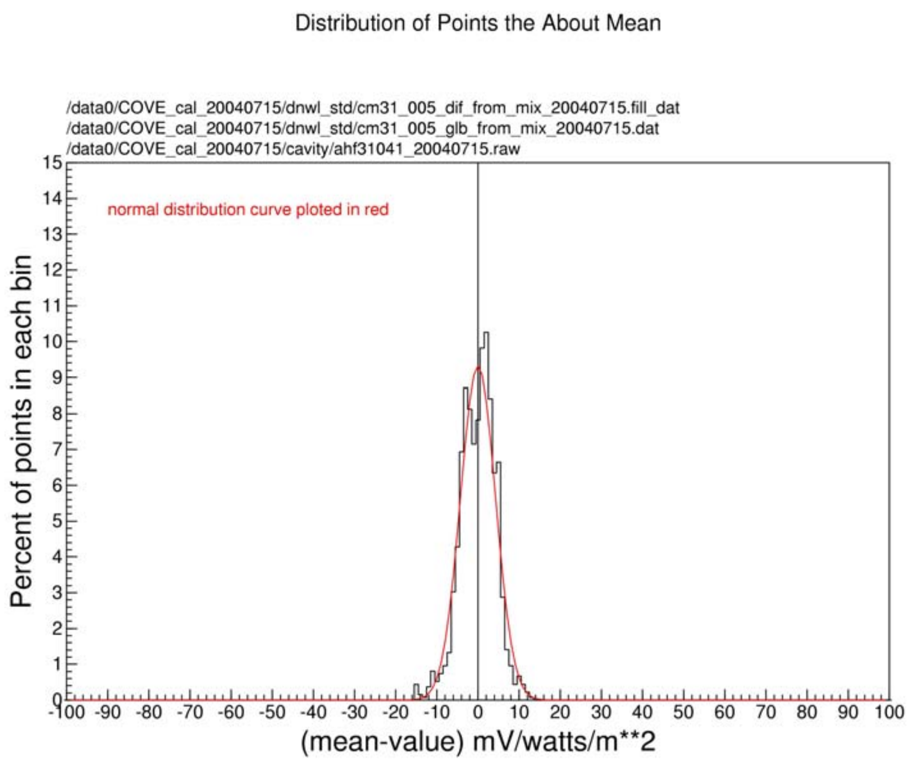

Figure 3B. A histogram of the distribution of the calibration points about the mean is shown for pyranometer CM-990005. The theoretical normal distribution curve is shown in red.

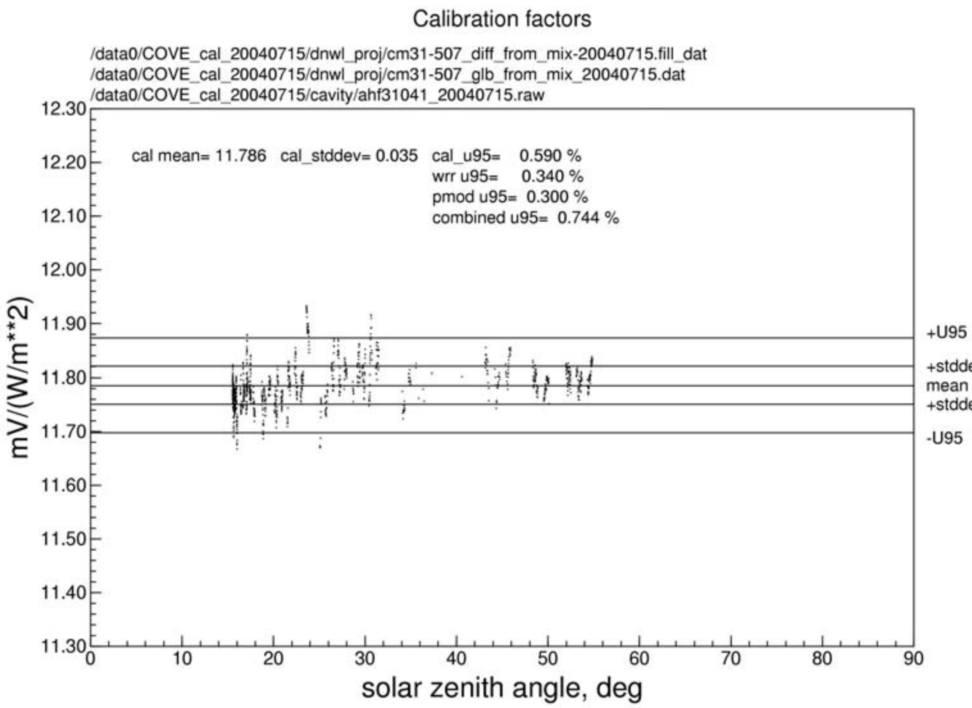

Figure 4A. The distribution of the 1Hz calibration values is shown for pyranometer CM31-990507. The mean, standard deviation and the U95 limits are also shown in this figure. This calibration was preformed using the shade/unshade method. The reference is ACR AHF-31041.

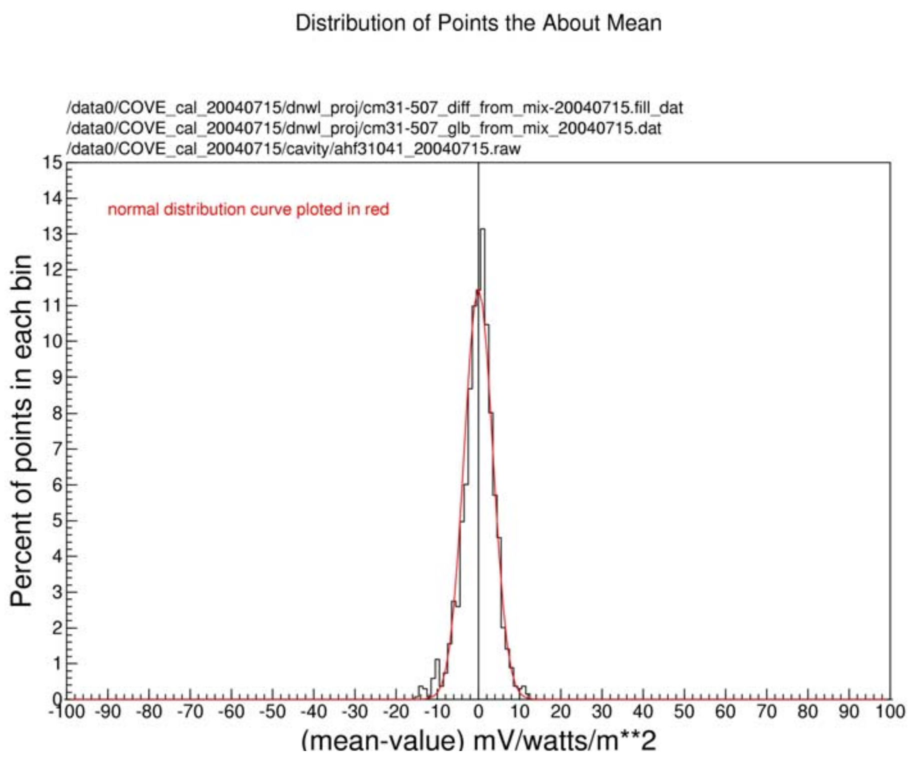

Figure 4B. A histogram of the distribution of the calibration points about the mean is shown for pyranometer CM-000507. The theoretical normal distribution curve is shown in red.

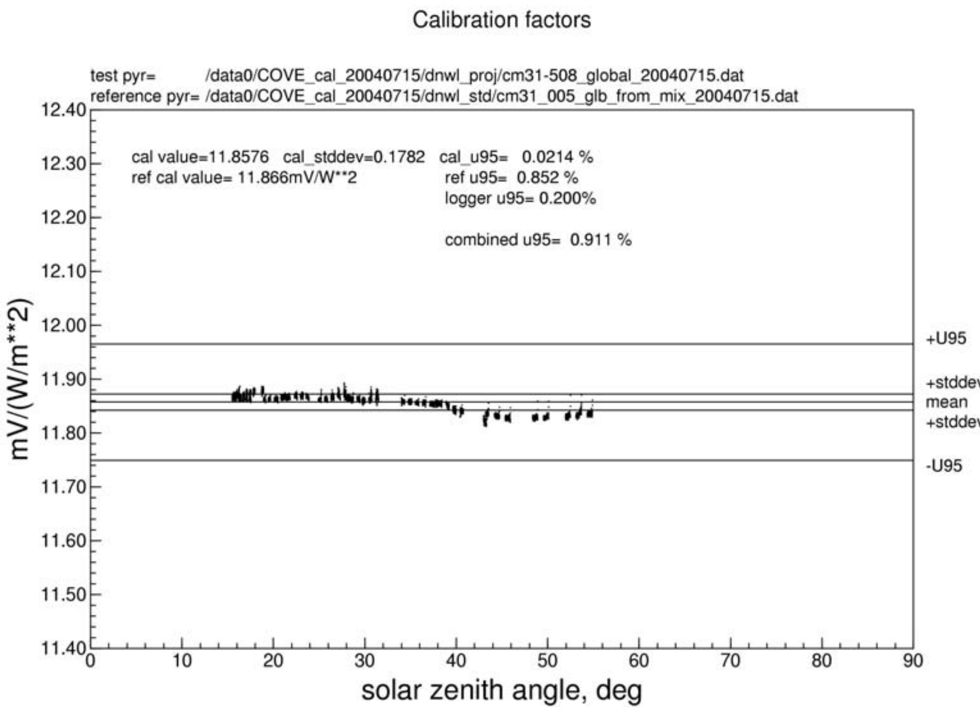

Figure 5A. The distribution of the 1Hz calibration values are shown for pyranometer CM31-000508. The mean, standard deviation, and the U95 limits are also shown in this figure. This calibration was preformed using the relative method. The reference pyranometer was CM31-990005.

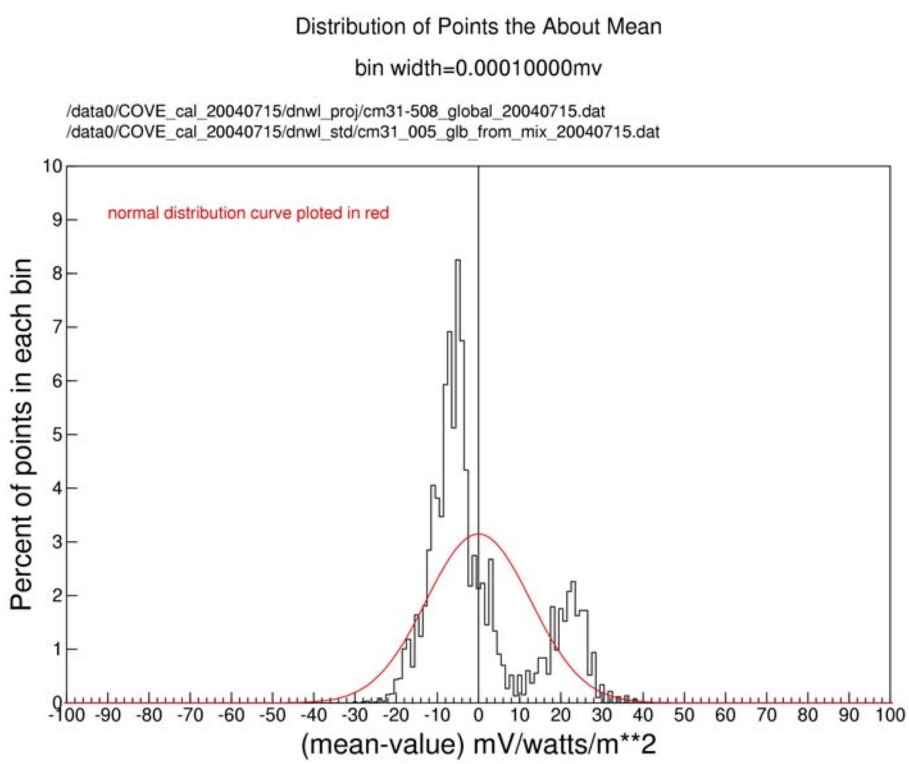

Figure 5B. A histogram of the distribution of the calibration points about the mean is shown for pyranometer CM-000508. The theoretical normal distribution curve is shown in red.

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
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 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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 July 2004 data were collected at the CERES Ocean Validation Experiment (COVE) site. COVE is located 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

Two pyranometers were mounted to measure global irradiance and two were mounted on a solar tracker and initially shaded by the shading apparatus. The pyranometers on the tracker were then operated alternately in the shaded (diffuse) configuration and them in the unshaded (global) configuration for periods of about 2 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 Campbell Scientific Inc. model 23x data loggers. The ACR measurements were taken at 3-4 Hz. All pyranometers were leveled using the manufacturer installed bubble level (+/- 1^o). The desiccant in each sensor was checked and replaced as necessary.

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 U95 uncertainties (twice the standard deviation) of the calibration factors, as a percent of the measurement, were calculated with respect to SI units. The root sum square method is used to determine a total uncertainty from component uncertainties. For the shade/unshade method four known component U95 uncertainties are: 1) twice the standard deviation of the calibration values over the calibration period; 2) the uncertainty if the ACR with respect to the WRR; 3) the uncertainty of the WRR; and 4) the uncertainty of the data logger. Known components of the uncertainty for the relative method are: 1) standard deviation of the relative measurements over the measurement period; and 2) the total uncertainty of the shade/unshade pyranometer. The uncertainty of the standard deviation of the mean calibration coefficient, number 1 in both cases above, is at least in part a function of solar zenith angle.

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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Bruce W. Forgan, “A New Method for Calibrating Reference and Field Pyranometers”, Journal of Atmospheric and Oceanic Technology, Volume 13, Pages 638-645.

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