Calibration Report: Pyranometer

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Calibration date: 2003 April 03.

Several radiometers were calibrated at the Chesapeake Ocean Validation site (COVE). The results of this Calibration are included in this box. Earlier calibrations appear below in the CALIBRATION HISTORIES section. The reference standard used in this calibration was the Eppley Lavatories Inc. cavity radiometer AHF-31105. 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%
CM22-000024	9.19 ± 1.16%
CM22-000025	9.29 ± 1.06%
CM31-990004	12.18 ± 0.92%
CM31-990005	11.83 ± 1.47%
CM31-000506	11.67 ± 1.64%
CM31-000507	11.72 ± 0.83%
CM31-000508	11.78 ± 1.88%
PSP-29472F3	8.53 ± 1.80%
PSP-30806F3	8.70 ± 2.92%
PSP-33028F3	8.53 ± 1.01%

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

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
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
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
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
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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 ($\mu V/W/m^2$)	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 intercomparing pyranometers in use during the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) experiment. These data were collected during 2002 March. Pyranometers included are those which measure global shortwave radiation, both upwelling and downwelling, on the aircraft and at the Chesapeake Ocean Validation Experiment (COVE) site, approximately 20 km off the shore of Virginia Beach, Virginia. Historical data has been collected at NASA Langley in Hampton Virginia Mauna Loa Observatory Hawaii, and COVE. The historical data is used to create a time history of calibration coefficients. The radiometric reference for this study is the derived global measured at COVE. The derived global is defined as Cosine of the solar zenith angle times direct normal incident irradiance, plus diffuse irradiance.

An uncertainty analysis is preformed and included with the results of the pyranometer calibrations.

New calibration coefficients were determined which were within the uncertainty range of the previously determined calibration coefficient, which were used during CLAMS. No changes in calibration need to be applied to the CLAMS data.

1. Introduction

Intercomparison data are collected for four pyranometers CM31-990004 (COVE global downwelling), CM31-000508 (COVE upwelling), PSP-29472F3 (aircraft downwelling), and PSP-30806F3 (aircraft upwelling). The Chesapeake Ocean Validation Experiment (COVE) derived global was used as the standard in this intercomparison. The derived global is defined as the cosine of the solar zenith angle times the direct normal plus diffuse irradiance. These data were collected during 2002 March. These components can be traced through an Eppley Laboratories Inc. Absolute Cavity Radiometer to the World Radiometric Reference (WRR).

2. Methodology

The measurements were taken at a frequency 1 Hz and averaged to 1 minute means, these 1 minute means are then used in the comparison. The Method used for the comparisons is to determine the straight line least squares relationship between the pyranometer measurements (microvolts), and the COVE derive global irradiance (W/m^2). The diffuse sensor is mounted on a sun tracker with the signal connector pointed away from the sun (+/- 1^o). The direct measurement is made with a normal incident pyrheliometer, mounted on a sun tracker, and aligned with the sun using its diopter alignment system. Global sensors are mounted with the signal connector pointed toward geometric north (+/- 5^o). All pyranometers were leveled using the manufacturer installed bubble level (+/- 1^o). The

desiccant in each sensor was checked and replaced as necessary before the intercomparison.

3. Data Analysis

The 1 minute mean data from the pyranometers (microvolts) are compared to the 1 minute mean derived global irradiance from COVE (W/m^2). A least squares straight line fit with the derived global irradiance on the horizontal axis and pyranometer microvolts on the vertical axis was determined, for each pyranometer. These fit lines define the relationship between the microvolt measurement for a given pyranometer and the COVE derived global irradiance. The slopes of these lines are the calibration coefficients for each pyranometer in $\mu V/W/m^2$. The intercomparison results are presented in the summary at the beginning of this document and in the calibration history section.

4. Uncertainty Analysis

The U95 uncertainty of the calibration factors were calculated with respect to SI units. First, the U95 of the derived global is determined as the root sum square of the U95 uncertainties in the direct normal irradiance and the diffuse irradiance. The U95 values used are the most recent ones available from previous calibrations, and are taken from the history section above. The root sum square method is presented below.

U95 for the derived global is determined as follows:

$$U95_{dg} = \mathrm{sqrt}((U95_{dir})^2 + (U95_{diff})^2)$$

Where: $U95_{dg}$ is the uncertainty in the derived global value (1.34%).

$U95_{dir}$ is the uncertainty in the direct measurement (0.81%, (from the 2001 Aug 2 calibration)).

$U95_{diff}$ is the uncertainty in the diffuse measurement (1.07%, from the calibration history above).

The root sum square method was again applied to determine the U95 for the individual pyranometers. The components were taken as the $U95_{dg}$ from above and the most recent U95 for each individual pyranometer (from the calibration history above). The results are displayed in the table below.

Sensor	previous U95	$U95_{dg}$	combined U95
CM31-990004	1.20%	1.34%	1.80%
CM31-000508	0.93%	1.34%	1.63%
PSP-29472F3	2.63%	1.34%	2.95%
PSP-30806F3	1.22%	1.34%	1.81%

These values are also presented in the summary box at the beginning of this document.

5. **Discussion**

An intercomparison of pyranometers has been completed. A set of calibration coefficients has been determined from data taken during 2002 March. These calibration coefficients with their uncertainties include the previous calibration coefficients for each pyranometer. The calibration coefficients used during CLAMS have been verified as appropriate for the duration of the CLAMS mission.

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.

McArthur, L.J.B., Baseline Surface Radiation Network (BSRN) Operations Manual V1.0, World Climate Research Programme, June 1997.

NREL, “Broadband Outdoor Radiometer Calibration Report”, BORCAL 96-2, 23 July 1996.

Pacific Northwest Radiometer Workshop, National Renewable Energy Laboratory, University of Oregon Solar Monitoring Lab, Eugene, Oregon, Aug 6-8 1997.

Pyrheliometer calibration document, 2001 Aug 2,
http://www-svg.larc.nasa.gov/cal/indes.html