Calibration Report: Pyranometer

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Calibration date: 2001 June 02
Next Calibration due: 2003 June 02

Calibrations of pyranometers have been completed. The most recently preformed calibrations appear in this box, earlier calibrations appear below in the CALIBRATION HISTORIES section. 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	9.214 ± 1.013%
CM22-000030	8.40 ± 1.316%
CM31-000507	11.769 ± 0.739%
CM31-000508	11.866 ± 0.932%
PSP-29472F3	8.57 ± 2.63%
PSP-30806F3	8.95 ± 1.22%

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

Pyranometer: Kipp and Zonen CM22-000024

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2001 Jun 18	9.214	1.013	Forgan’s alternate
2000	9.16	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM22-000030

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

Pyranometer: Kipp and Zonen CM31-990004

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2000 Nov 28	12.132	0.876	Forgan's alternate
1999 Nov 11	12.133	0.739	Forgan's alternate
1999	?	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-990005

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2000 Nov 28	11.852	0.963	Forgan's alternate
1999 Nov 11	11.748	0.753	Forgan's alternate
1999	?	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-000507

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2001 Jun 18	11.769	0.739	Forgan's alternate
2000	11.70	5.00	manufacturers original

Pyranometer: Kipp and Zonen CM31-000508

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2001 Jun 18	11.866	0.932	Forgan's alternate
2000	?	5.00	manufacturers original

Pyranometer: Eppley PSP-29472F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2001 Jun 18	8.57	2.63	Forgan's alternate
1999 Feb 12	8.49	4.51	Forgan's alternate
1998	8.68	1.22	Forgan's alternate
?	8.76	5.00	manufacturers original

Pyranometer: Eppley PSP-30676F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
1999 Feb 12	8.49	2.98	Forgan's alternate
1998	8.66	1.06	Forgan's alternate
?	8.74	5.00	manufacturers original

Pyranometer: Eppley PSP-30798F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type

1999 Feb 12	8.45	5.23	Forgan’s alternate
1998	8.82	1.28	Forgan’s alternate
?	9.01	5.00	manufacturers original

Pyranometer: Eppley PSP-30803F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
1999 Feb 12	9.26	4.35	Forgan’s alternate
1998	9.55	1.17	Forgan’s alternate
1996	9.362	3.2	Forgan’s alternate
?	9.46	5.00	manufacturers original

Pyranometer: Eppley PSP-30806F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
2001 Jun 18	8.95	1.22	Forgan’s alternate
1999 Feb 12	8.72	5.47	Forgan’s alternate
1998	9.07	0.90	Forgan’s alternate
?	9.22	5.00	manufacturers original

Pyranometer: Eppley PSP-30847F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
1999 Sep 24	8.37	3.24	Forgan’s alternate
1999 Feb 12	8.75	3.14	Forgan’s alternate
1998	8.80	1.19	Forgan’s alternate
?	8.96	5.00	manufacturers original

Pyranometer: Eppley PSP-30851F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
1999 Feb 12	8.37	1.61	Forgan’s alternate
1998	8.48	0.93	Forgan’s alternate
1996	8.257	3.3	Forgan’s alternate
?	9.68	5.00	manufacturers original

Pyranometer: Eppley PSP-31560F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
1999 Sep 23	8.85	9.07	Forgan’s alternate (poor)
1999 Feb 12	9.23	4.20	Forgan’s alternate
1998	9.53	0.98	Forgan’s alternate
?	9.51	5.00	manufacturers original

Pyranometer: Eppley PSP-31561F3

date	S ($\mu V/W/m^2$)	U95 (%)	calibration type
1999 Feb 12	8.42	1.84	Forgan's alternate
?	8.52	5.00	manufacturers original

ABSTRACT

Data have been collected for the purpose of calibrating pyranometers at various times and at various sites. Data collection sites have included the Chesapeake Ocean Validation Experiment site located at the Chesapeake Light Station, approximately 20km off the shore of Virginia Beach, Virginia, NASA Langley, and the Mauna Loa Observatory Hawaii. These calibrations are performed to be in compliance with standards set in the Baseline Surface Radiation Network Operations Manual V1.0, 1997. Calibrated sensors have included Kipp & Zonen CM-31 and CM-22 pyranometers, and Eppley Laboratory Inc. Precision Spectral Pyranometers. An Eppley Laboratory, Inc. Hickey-Frieden Absolute Cavity Radiometer is used as the radiometric reference in these calibrations. The current pyranometer calibration coefficients are compared to all available previous values. An uncertainty analysis is preformed and included with the results of the pyranometer calibrations.

1. Introduction

Calibration data are collected for pyranometers. An Eppley Laboratory, Inc. Absolute Cavity Radiometer (ACR) was used as the standard in this calibration. The calibration technique followed is described in the Baseline Surface Radiation Network, (BSRN) Operations Manual, V1.0, 1997. The BSRN document recommends the calibration technique described by Forgan.

2. Preliminary Uncertainty Analysis

A preliminary Uncertainty Analysis was performed to determine the reasonable range in which the pyranometer calibration values should lie. A discussion of this preliminary uncertainty analysis is contained in the November 1999 pyranometer calibration document, which is accessible at http://www-svg.larc.nasa.gov/cal/.

3. Calibration Reference Sensor Uncertainty

The reference unit used in these pyranometer calibrations is an Eppley Laboratory Inc. ACR. The ACR calibration is linked by its World Radiation Reference (WRR) to the World Standard Group (WSG) at the Physikalisch-Meteorologisches Observatorium Davos. The LaRC ACR AHF31041 was linked to WSG through the National Renewable

Energy Laboratory (NREL) ACR standard group in 1997, 1998, 1999, 2001 and directly to the WSG in 2000. The NREL ACR standard group was linked to the WSG at the Eighth International Pyrheliometer Comparison (IPC-VIII) and at IPC-IX. The defined magnitude of the WRR standard uncertainty is 0.3, (U95% wrt SI units) reported at IPC-VIII. The WRR's obtained at these intercomparisons are displayed below:

WRR factors for cavity AHF31041 with Eppley 406 controller.

date	WRR	U95%	comparison
2000 Oct 13	0.99813	0.33	IPC-IX
1999 Oct 10	0.99827	0.39	NREL
1998 Oct 15	0.99833	0.37	NREL
1997 Oct 16	0.99961	0.42	NREL

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

4. Methodology

Bruce Forgan's alternate calibration method is used to calibrate these sensors is described in the BSRN Operations Manual V1.0, 1997. The basic principal of this technique is:

(global irradiance) = (diffuse irradiance) + cos(solzen angle) x (direct normal irradiance).

The technique of this calibration is to make coincident diffuse radiation measurements, global radiation measurements, and ACR direct beam measurements during clear sky conditions, over as wide a range of solar zenith angles as practical. For example sunrise to solar noon (A-period). Then exchange the global sensor with the diffuse sensor and collect another set of coincident measurements over an equivalent range of solar zenith angles (B-period). Then match the solar zenith angles during the two periods and solve for the calibration coefficients. This is described in a bit more detail in the data analysis section. The A-periods and B-periods can be on the same day or on different days. A single or several A-periods and B-periods may be used.

Measurements can be taken from several instruments at the same time. Global sensors are mounted with the signal connector pointed toward geometric north (+/- 5^o) and diffuse sensors are mounted with the signal connector pointed away from the sun (+/- 1^o). All sensors were leveled using the manufacturer installed bubble level (+/- 1^o). The desiccant in each sensor is checked and replaced as necessary before the calibration.

5. Data Analysis

The pyranometers are sampled at a frequency of 1 HZ, one-minute means and standard deviations are determined, and used in the uncertainty analysis.

$VA2(\theta) / R1 = Edir * COS(\theta) + VA1(\theta) / R2$

$VB1(\theta) / R1 = Edir * COS(\theta) + VB2(\theta) / R2$

Where:
R1: Calibration coefficient for pyranometer #1; $\mu V/W/m^2$
R2: Calibration coefficient for pyranometer #2; $\mu V/W/m^2$
θ : solar zenith angle; degrees
VA1: pyranometer #1 output during period A while shaded; Volts (Diffuse component)
VA2: pyranometer #2 output during period A while un-shaded; Volts (Global Component)
VB1: pyranometer #1 output during period B while un-shaded; Volts (Diffuse component)
VB2: pyranometer #2 output during period B while shaded; Volts (Global Component)
E_{dir}: ACR output during both periods A and B, W/m^2 (Direct Component)

Solve the two equations simultaneously for R1 and R2 at coincident solar zenith angles. Perform statistical analyses on the resulting calibration coefficients to determine the means and standard deviations of the calibration coefficients for each sensor.

Calibration results are presented in the summary at the beginning of this document.

6. Uncertainty Analysis

The uncertainty of the calibration factors is calculated with respect to SI units. For each set of pyranometer data, the one minute means and standard deviations of these one minute means are determined, additionally the mean of the standard deviations of the one minute data values are calculated for each calibration data set. The one minute means and the means of the standard deviations of the one minute means are used to determination the combined uncertainty.

The final uncertainty of a pyranometer calibration coefficient is a function of the ACR uncertainty and the uncertainties of the pyranometer measurements. To determine the U95 for the pyranometer calibration coefficients, the Expanded Uncertainty (two standard deviations) of each component is used. This combined experimental uncertainty (95%) is calculated using the following equation:

$$U95\% = sqrt[2(U95_{cav})^2 + (2\sigma_{GA})^2 + (2\sigma_{DA})^2 + (2\sigma_{GB})^2 + (2\sigma_{DB})^2 + (2\sigma_R)^2]$$

where:
$U95_{cav}$ ≡ U95% uncertainty of the ACR, used twice because two ACR measurements are used to determine a calibration coefficient.

σ_{GA} ≡ mean of the standard deviations of the global 1 minute means for period A
σ_{DA} ≡ mean of the standard deviations of the diffuse 1 minute means for period A
σ_{GB} ≡ mean of the standard deviations of the global 1 minute means for period B
σ_{DB} ≡ mean of the standard deviations of the diffuse 1 minute means for period B
σ_{R} ≡ standard deviations of the calibration coefficients for a given period.

7. **Discussion**

The calibration of pyranometers using the Alternate method has been completed. The sensor calibration coefficients and associated uncertainties resulting from the analysis of all sets of data are defined as the current calibration values. The manufacturers stated uncertainties are 5%.

For some of the sensors, a calibration coefficient, determined as a function of the solar zenith angle, would result in better irradiance values. Another method which might provide better overall calibration values would be to weight the individual calibration coefficients by the cosine of the solar zenith angle thereby giving more consideration to periods of greater incident energy.

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