Calibration Report: Pyrheliometers

F. M. Denn, and B. E. Fabbri

Analytical Services & Materials, Inc., Hampton, Virginia

SUMMARY

Calibration date: 2000 November 28.
Next calibration due: 2001 November 28.

Calibration measurements and analysis of pyrheliometer sensor(s) have been completed. The units of the sensitivity factors (S) are microV/W/m^2. The sensitivity factors and their associated uncertainties (95%) are as follows:

Manufacturer	serial Number	S ($\mu V/W/m^2$)	U95
Kipp and Zonen	CH1-960132	11.18	+/- 0.67%
Kipp and Zonen	CH1-960133	10.71	+/- 0.66%

Application

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

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

CALIBRATION HISTORIES

Pyrheliometer: Kipp and Zonen CH1-960132.

date	S ($\mu V/W/m^2$)	U95 (%)	
2000 Nov 28	11.18	0.67	
1999 Feb 12	10.06	0.73	
1996 Jun 30	11.06	5.00	(manufacturer calibration)

Pyrheliometer: Kipp and Zonen CH1-960133.

date	S ($\mu V/W/m^2$)	U95 (%)	
2000 Nov 28	10.71	0.66	
1999 Feb 12	10.53	0.73	
1996 Jun 30	10.65	5.00	(manufacturer calibration)

Pyrheliometer: Eppley PSP-31375E6.

date	S ($\mu V/W/m^2$)	U95 (%)	
1999 Feb 12	8.14	1.06	
1998 Feb 16	8.21	0.83	
unknown	8.24	5.00	(manufacturer calibration)

Pyrheliometer: Eppley PSP-31376E6.

date	S ($\mu V/W/m^2$)	U95 (%)	
1999 Feb 12	7.88	1.00	
1998 Feb 16	7.92	1.24	
unknown	8.00	5.00	(manufacturer calibration)

ABSTRACT

Calibration data from pyrheliometer sensors have been collected during several time periods. The data is typically collected at the Chesapeake Ocean Validation Experiment (COVE) site located at the Chesapeake light station, approximately 20km off the shore of Virginia Beach, Virginia. Data sites have also included NASA Langley (LaRC) and the Mauna Loa Observatory (MLO) Hawaii. Calibrated devices have included Eppley Laboratory, Inc. Normal Incident Pyrheliometers (NIP) and Kipp and Zonen, Inc. CH1 sensors. These sensors are calibrated using an Eppley Laboratory, Inc. Absolute Cavity Radiometer. These calibration data are analyzed to produce sensitivity coefficients with 95% uncertainty bounds (u95). These coefficients are compared to manufacturer provided values and to previously determined calibration values.

1. Introduction

Calibrations of pyrheliometers are made periodically to maintain data quality and traceability to the World Radiometric Reference (WRR). The sensors are calibrated using an Eppley Laboratory, Inc. Absolute Cavity Radiometer (ACR), which is traceable to the

WRR pyrheliometers kept at the Physikalisch-Meteorologisches Observatorium Davos (PMOD) in Davos, Switzerland.

2. Preliminary Uncertainty Analysis

A preliminary uncertainty analysis was preformed to determine a reasonable value for the uncertainty of pyrheliometer calibration values. See the 1999 pyrheliometer calibration document for a description of the preliminary uncertainty analysis.

3. Calibration Unit Uncertainty

The reference unit used in these pyrheliometer 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 Renewalble Energy Laboratory (NREL) ACR standard group in 1997, 1998, 1999, and 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 WRRs 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

Verify that the pyrheliometer desiccant was within the proper tolerance. Attach the ACR and pyrheliometers to the solar trackers. Align the trackers to geometric N-S. Align the ACR and pyrheliometer sensors to the solar tracker. Make all ground connections. Connect the ACR to the ACR controller and the controller to the PC. Attach the pyrheliometers to the Campbell Scientific Inc. data logger system. Clean the pyrheliometer windows. Verify that the ACR window and the ACR cover are off. Use a computer program (supplied by NREL, or written locally) to operate the ACR. Use the

Campbell data logger system to record voltages produced by the pyrheliometers. Use the manufacturer's initial as-manufactured sensitivity factors for both the ACR and pyrheliometer sensors in the data acquisition algorithms. Verify that sensor diopter alignments remain within tolerance throughout the data collection time period.

5. Data Analysis

ACR data is collected every two seconds, multiplied by the WRR factor, and averaged over a one-minute interval, for each one-minute interval a mean and a standard deviation are obtained. The mean of these standard deviations is then calculated for the entire data set ($\sigma_{ACR\text{-}m}$). The pyrheliometer measurements are collected every second and averaged over a one-minute interval, for each one-minute interval a mean and a standard deviation are obtained. The mean of these standard deviations is calculated for the entire data set ($\sigma_{P\text{-}m}$). All standard deviations were converted to percent of mean using the following equation:

$$\sigma\ \% = \frac{\sigma}{\text{WRRmean}} \times 100$$

Sensitivity factors for each pyrheliometer relative to the ACR are calculated by first dividing the voltage for each pyrheliometer by its respective as-manufactured sensitivity factor to obtain a pyrheliometer irradiance value. The ratio of the ACR WRR corrected irradiance divided by the pyrheliometer irradiance is calculated. Each pyrheliometer population means and standard deviations (σ_P) are calculated. These three standard deviations were used along with the ACR U95 values to obtain a combined U95 value for each pyrheliometer. All standard deviations are converted to percent of mean.

The final uncertainty of the pyrheliometer sensitivity factor is a function of the ACR uncertainty (95%), the standard deviation of the one-minute ACR data, the standard deviation of the one-minute pyrheliometer data, and the standard deviation of the ratio of the ACR/pyrheliometer (σ_r) for each data set. To determine the total uncertainty (U95) for each pyrheliometer, an expanded uncertainty for each measurement component must be determined. Since these errors result from random errors, two standard deviations of the measurements may be used to determine a 95-percent confidence interval. The combined experimental uncertainty (95%) was calculated using the following equation:

$$U95 = \text{sqrt}((U95_{cavity})^2 + (2\sigma_{p\text{-}m})^2 + (2\sigma_{ACR\text{-}m})^2 + (2\sigma_r)^2)$$

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.

Swiss Meteorological Institute, (May 2001). “International Pyrheliometer Comparison IPC-IX.” Working Report No. 197, Davos and Zurich.

Reda, I, Stoffel, T., Results of NREL Pyrheliometer Comparisons NPC1096, 1-5 October 1996, National Renewable Energy Laboratory, Golden, Colorado.

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.

Reda, I., Results of NREL Pyrheliometer Comparisons NPC1998, National Renewable Energy Laboratory, Center for Renewable Energy Resources, Measurements & Instrumentation Team, 11 November 1997.

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.