Calibration Report: Pyrheliometers

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SUMMARY

Calibration date: 2015 May 15.
Next calibration due: 2017 May 15.
Reference standard: AHF-31041.

The calibration coefficients and their associated uncertainties (U95%) have been determined for one pyrheliometer. The unit of the calibration coefficient (S) is μV/(W/m^2). The reference standard was Eppley Laboratories Inc absolute cavity radiometer AHF31041 with its associated data acquisition system. This cavity can be traced to the World Radiation Reference determined by the World Standard Group (WSG) kept at the Physikalisch-Meteorologisches Observatorium in Davos Switzerland, It was at the 2010 International Pyrheliometer Comparison (IPC XI) The Cavity radiometer performance is verified annually at the National Pyrheliometer comparison at the National Renewable Energy Laboratory in Golden Colorado, most recently 2014. The test pyrheliometer was attached to the specified Campbell 23X data logger, shown below. These calibrations may not be valid on other loggers. The logger-pyrheliometer combination is calibrated with respect to the WSG.

The sensitivity factor and its associated uncertainty (95%) are as follows:

Manufacturer	Serial Number	logger μV/(W/m^2)	S U95	Logger
Kipp and Zonen	CH1-960133	10.68	± 0.59%	23X- 3135

Application

I = (mV output)/S ± sqrt(2)*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 of a field measurement.

Details available on request.

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 serial number AHF31041 with its associated Agilent 34970A control unit. The cavity is traceable to the World Standard Group (WSG) of pyrheliometers at the Physikalisch-Meteorologisches Observatorium in Davos, Switzerland. Calibration took place at the International Pyrheliometer Comparison (IPC) IX held in the fall of 2010. Performance has been verified at the National Pyrheliometer Comparisons in years 2011-2014.

Test Instrumentation

Possible test pyrheliometers are:
Kipp and Zonen CH1-960133 connected to Campbell data logger 23X-3135;
Kipp and Zonen CH1-010254 connected to Campbell data logger 23X-2216; and
Eppley NIP-31375E6 connected to Campbell data logger 10X-23017
. All were wired for differential measurements.

FIGURES

<u>Several figures follow read the information on each figure to see what it is.
This part of the document is for internal reference only.</u>

DATA

Data analysis was done with one second data for the two CH1s. But because only one minute data was available for the NIP, NIP data processing was done with one minute means.
CH1 data processing. Data used to determine these calibration values were collected on 2012 May 11. The data was collected at one second resolution, for the cavity and the two CH1s. The one second values were grouped by cavity run. Grouped data is combined to determine calibration values and their uncertainties, for the two CH1 pyrheliometers.
One Minute means were used for the NIP. This was because only minute means were available for the NIP.

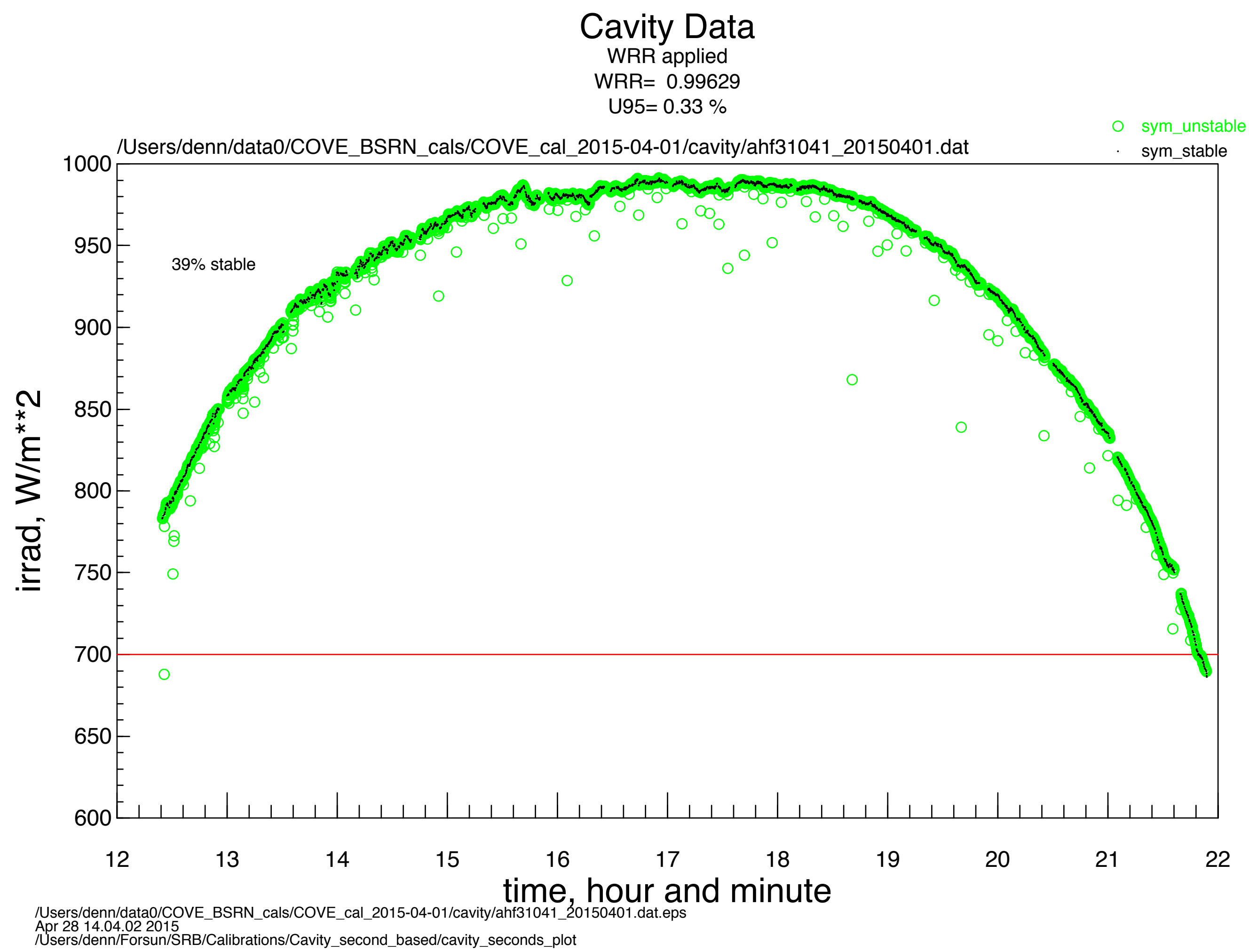


Figure 1. An Example of Irradiance measured by the reference pyrheliometer.

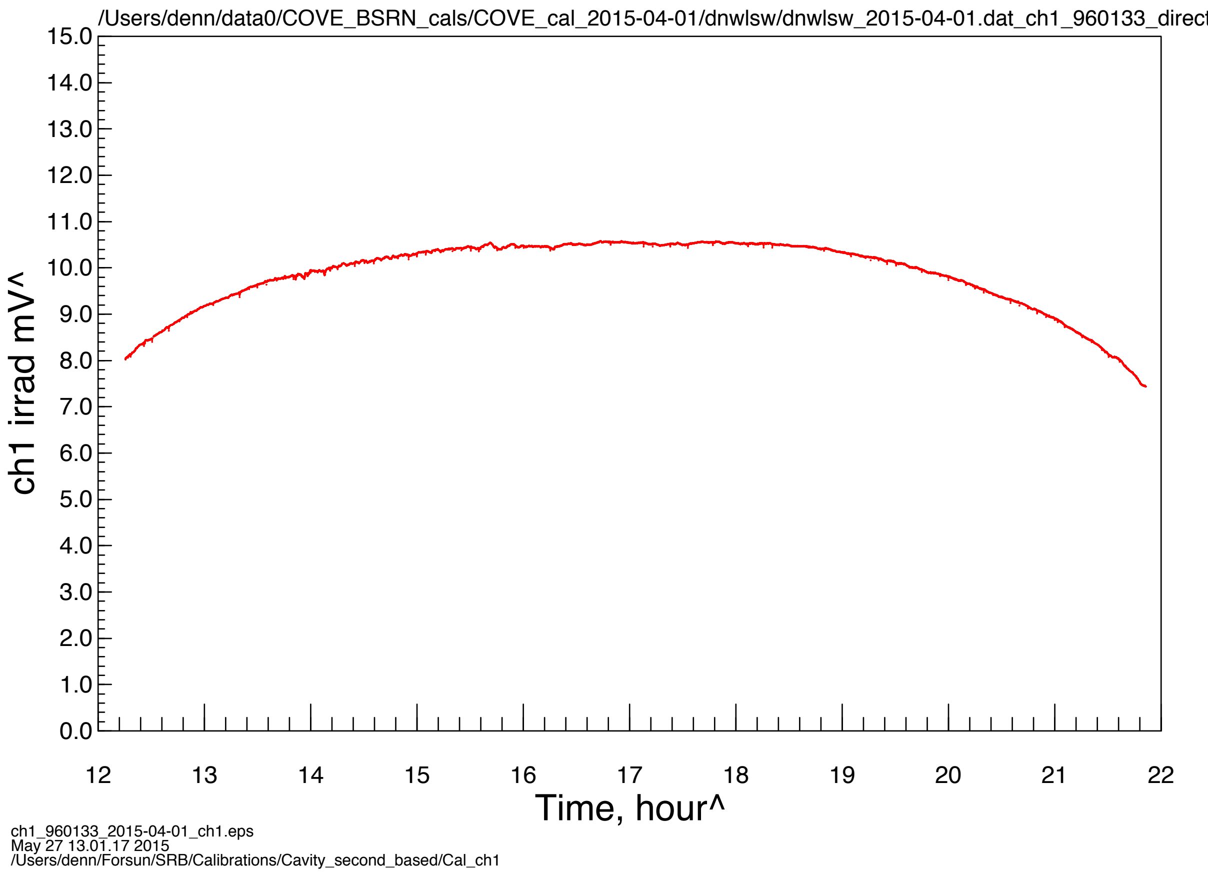


Figure 2. An example of millivolt measurements obtained by pyrheliometers CH1-010254 on 2012 May 11.

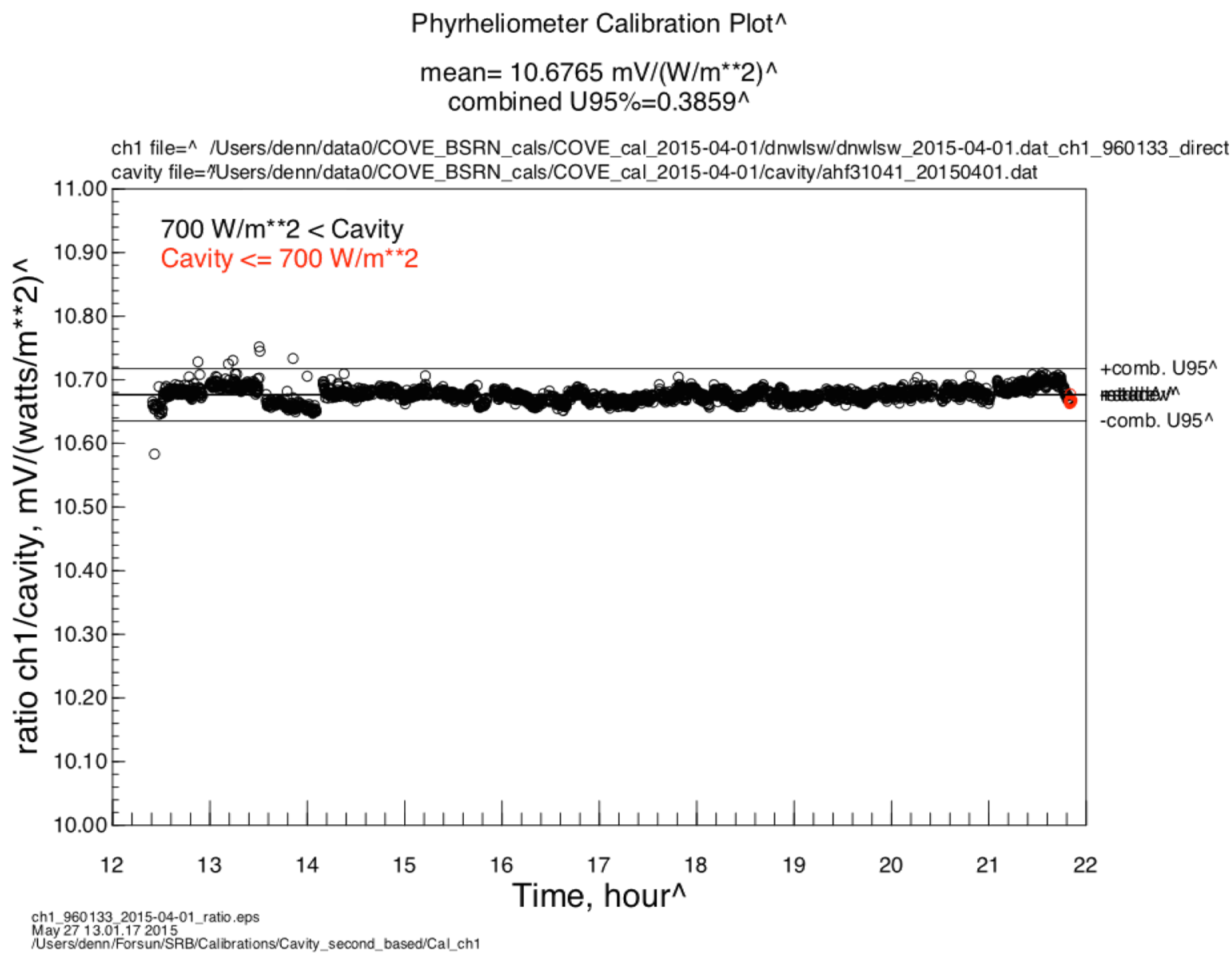
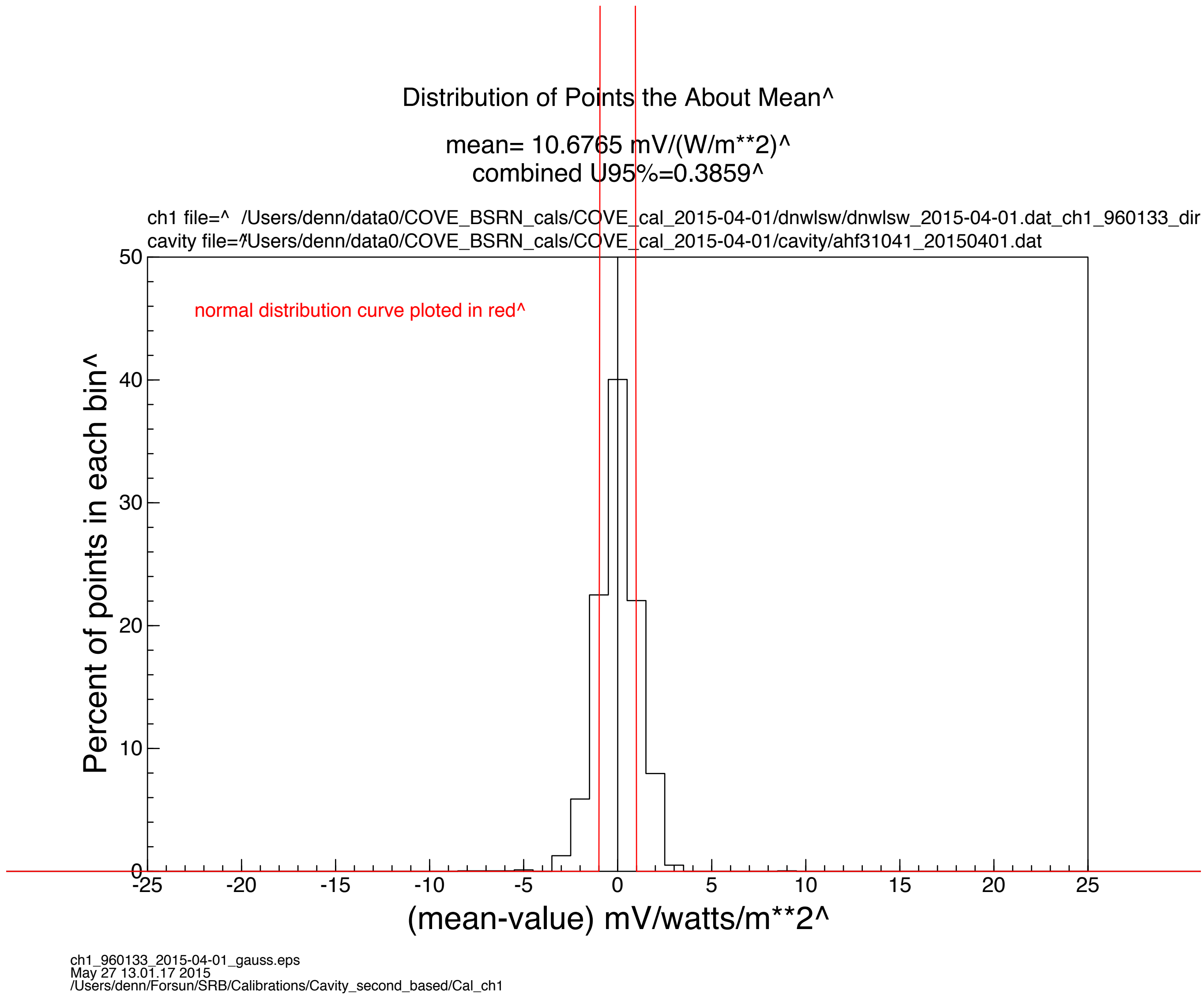


Figure 3. The selected calibration coefficients for a field pyrheliometer.



Distribution of individual calibration values about the mean with the U95 uncertainties included.

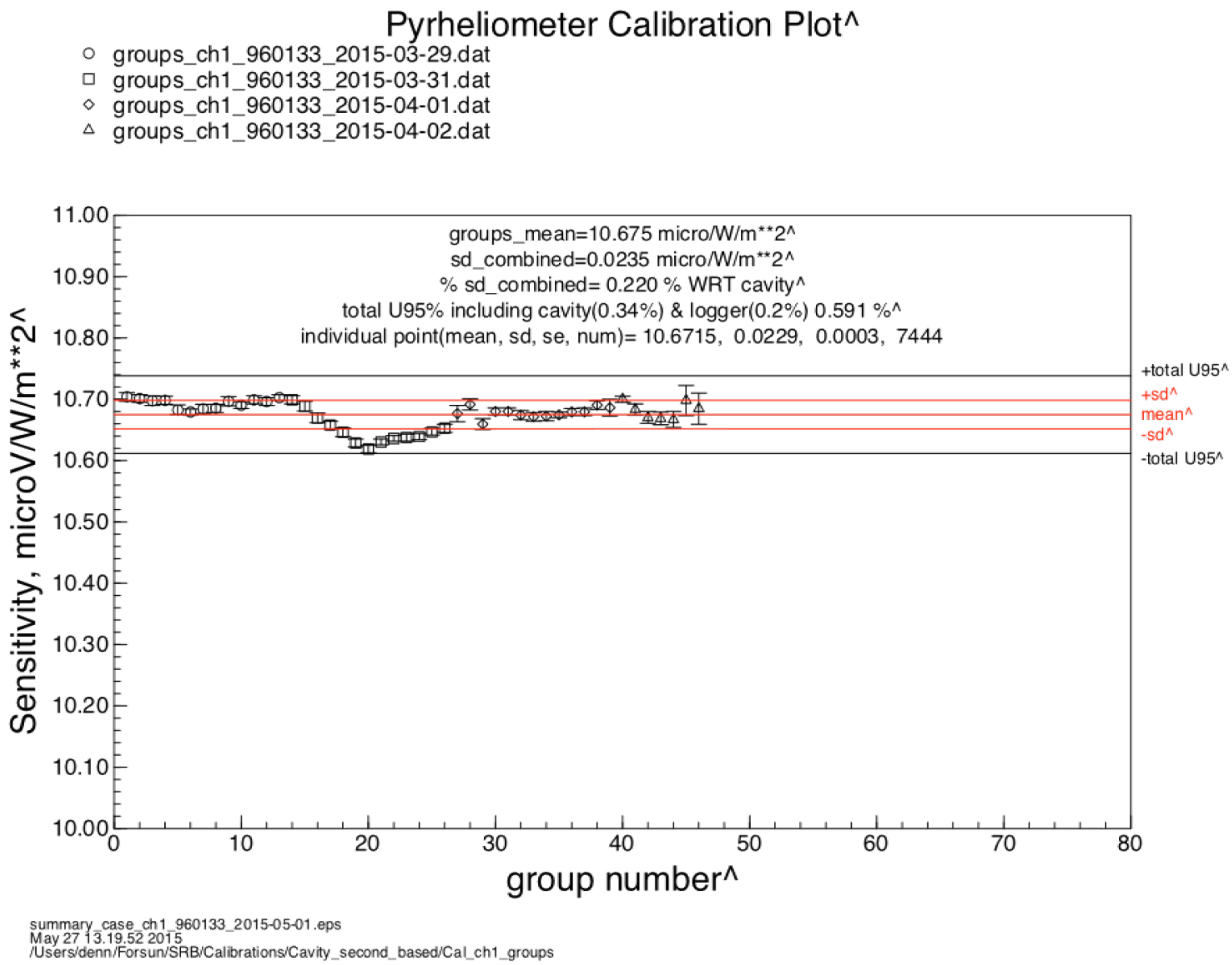


Figure 4a. several calibration runs, just to see if the calibration coefficients are changing.

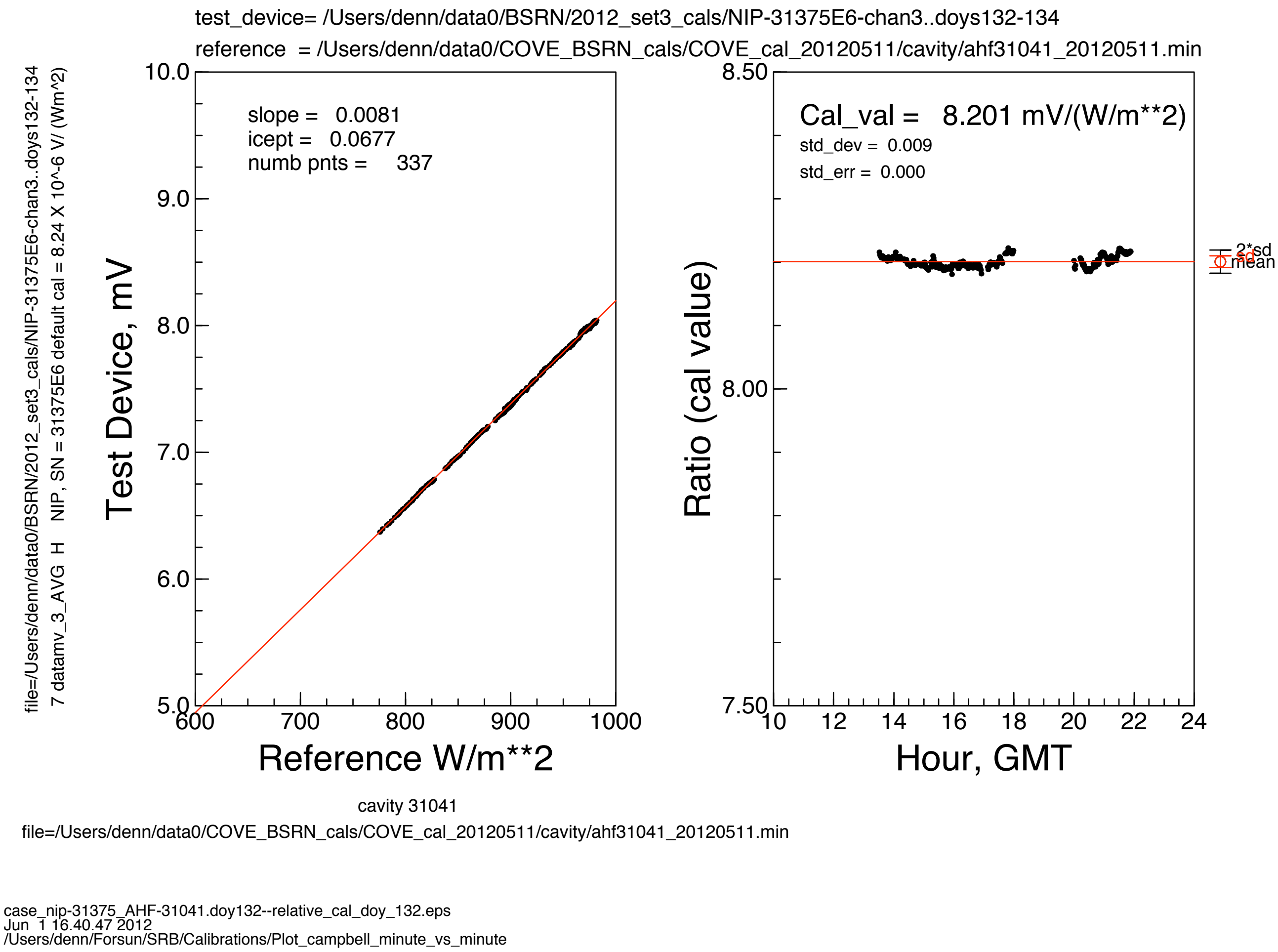


Figure 5. The plot on the right shows the calibration values for NIP-31375E6. These are based on one minute means for the NIP and for the Cavity. Only one minute mean values were available for the NIP.

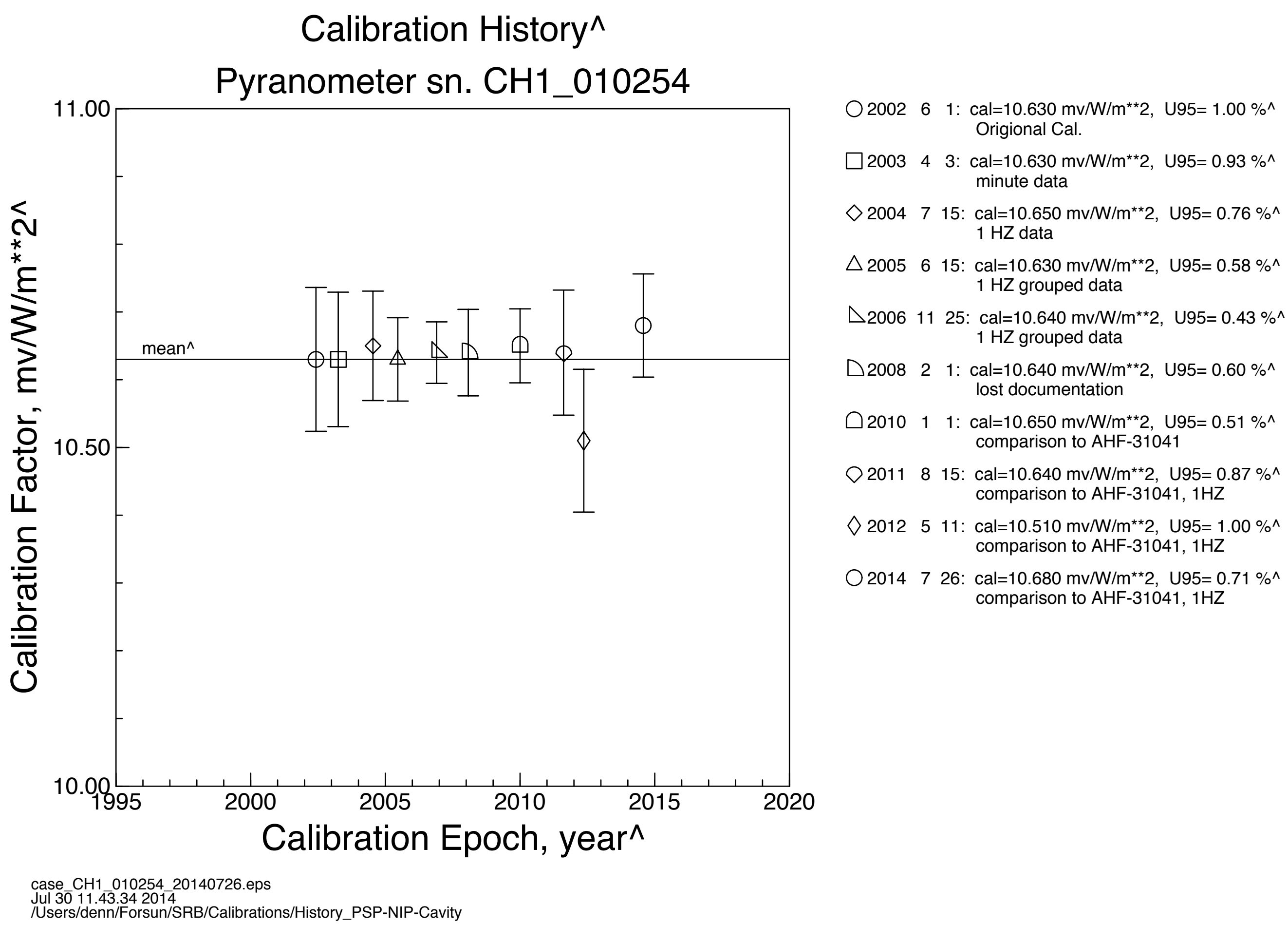


Figure 6a. Calibration history for pyrheliometer CH1-010254 is presented. The solid horizontal line represents the mean value. The symbols and their error bars represent the mean and U95 of each calibration event. The column on the right presents numerical values for each calibration event and a brief description of the calibration method used.

NOTE: The unit on the axis should be micro-volts.

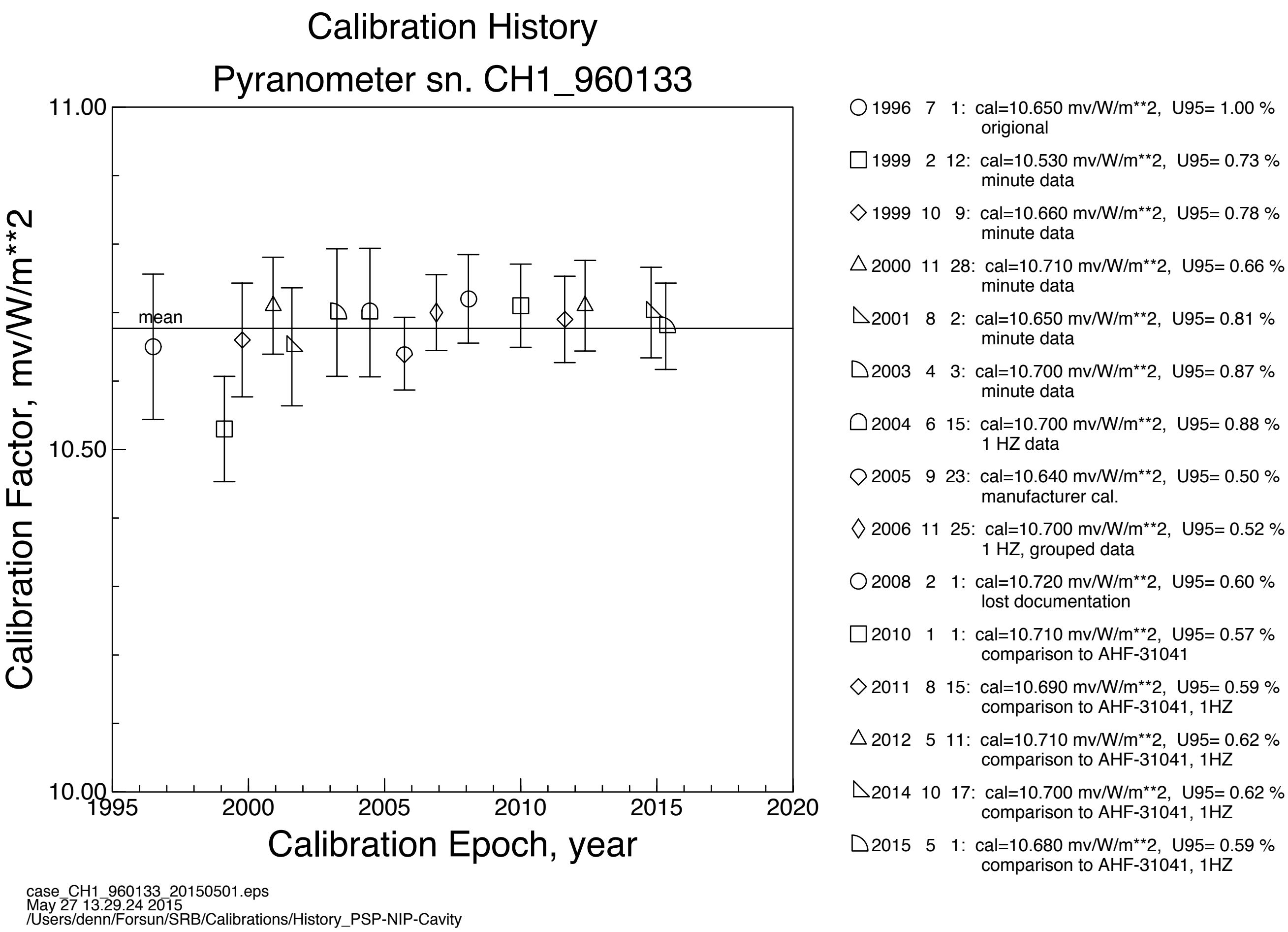


Figure 6b. Calibration history for pyranometer CH1-960133 is presented. The solid horizontal line represents the mean value. The symbols and their error bars represent the mean and U95 of each calibration event. The column on the right presents numerical values for each calibration event and a brief description of the calibration method used.

NOTE: The unit on the axis should be micro-volts.

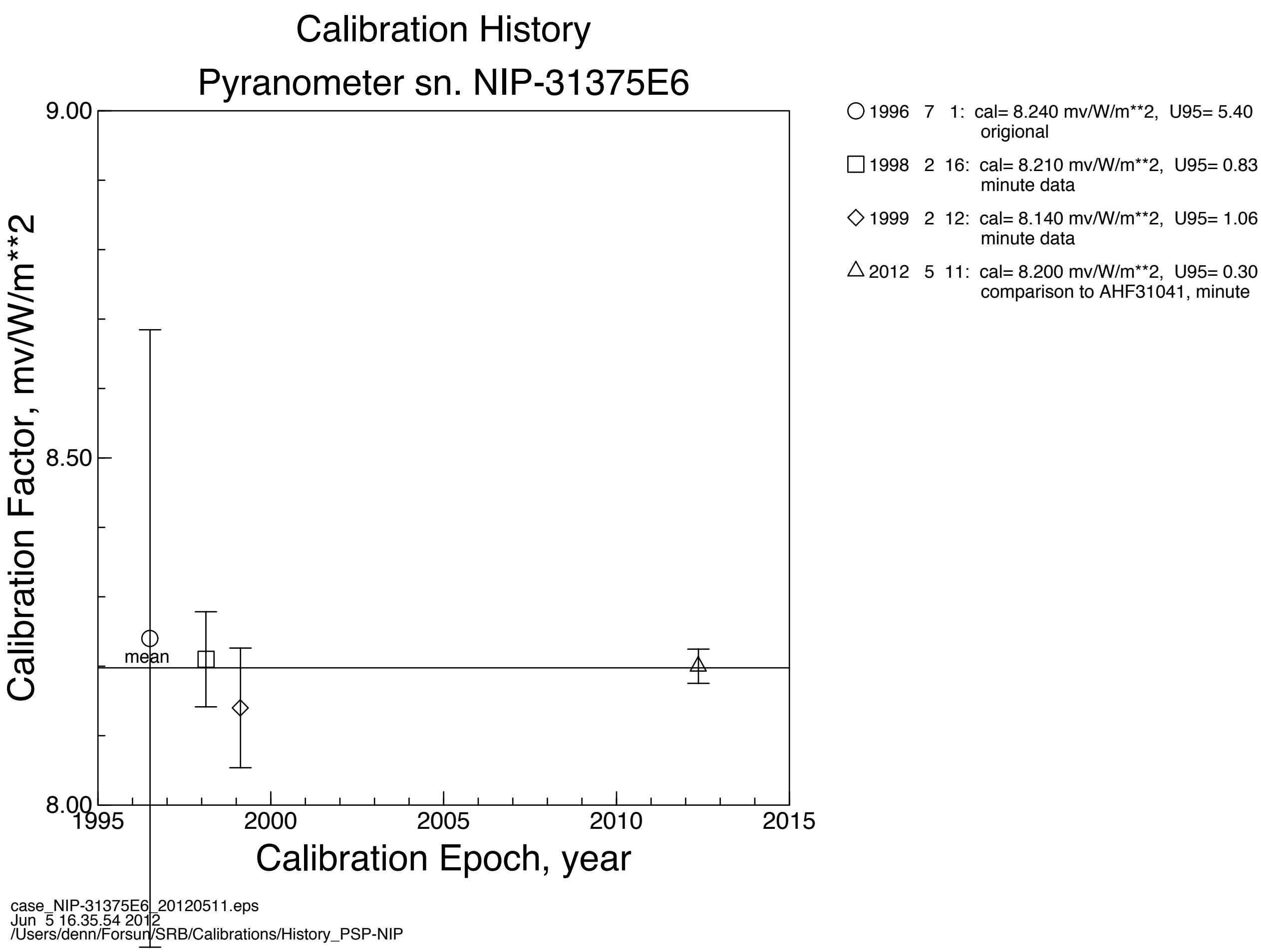


Figure 6c. Calibration history for pyranometer NIP-31375E6 is presented. The solid horizontal line represents the mean value. The symbols and their error bars represent the mean and U95 of each calibration event. The column on the right presents numerical values for each calibration event and a brief description of the calibration method used.

CALIBRATION HISTORIES

Pyrheliometer: Kipp and Zonen CH1-010254.

date	day of year	S (μV/(W/m^2))	U95 (%)	
2014 July 26	207	10.68	0.714	1Hz, ref. AHF-31041
2012 May 11	118	10.51	1.43	1HZ, ref. AHF-31041
2011 Sep 01	244	10.64	0.87	1HZ, ref. AHF-31041
2010 Jan 01	001	10.65	0.51	comparison to AHF-31041
2008 Feb 01	032	10.64	0.60	lost document
2006 Nov 25	329	10.64	0.58	(1 HZ grouped data)
2006 May 10	130			Setup error, no useable data.
2006 Jan 27	357			Setup error, no useable data.
2005 Jun 15	166	10.63	0.58	(1 HZ grouped data)
2004 Jul 15	197	10.65	0.76	(1 HZ data)
2003 Apr 03	093	10.63	0.93	(minute data)
2002 Jun 01	182	10.63	0.50	(manufacturer calibration)

Pyrheliometer: Kipp an Zonen CH1-960132.

date	day of year	S (μV/(W/m^2))	U95 (%)	
2001 Jun 01	152	damaged and removed from service		
2000 Nov 28	333	11.18	0.67	(minute data)
1999 Nov 19	323	11.19	0.71	(minute data)
1999 Feb 12	043	11.06	0.73	(minute data)
1996 Jun 30	182	11.06	0.50	(manufacturer calibration)

Pyrheliometer: Kipp and Zonen CH1-960133.

date	day of year	S (μV/(W/m^2))	U95 (%)	
2015 May 15	135	10.68	0.59	1HZ, ref. AHF-31041
2014 Oct 17	290	10.71	0.55	1HZ, ref. AHF-31041
2012 May 11	118	10.71	0.62	1HZ, ref. AHF-31041
2011 Sep 01	244	10.69	0.59	1HZ, ref. AHF-31041
2010 Jan 01	001	10.71	0.57	comparison to AHF-31041
2008 Feb 01	032	10.72	0.60	lost document
2006 Nov 25	329	10.70	0.58	(1 HZ grouped data)
2006 May 10	130			Setup error, no useable data.
2005 Sep 23	266	10.64	0.50	(manufacturer calibration)
2005 Jun 15	166	Failed, sent in for repairs.		
2004 Jul 15	197	10.70	0.88	(1 HZ data)
2003 Apr 02	093	10.70	0.87	(minute data)
2001 Aug 02	214	10.65	0.81	(minute data)
2000 Nov 28	333	10.71	0.66	(minute data)
1999 Oct 09	282	10.66	0.78	(minute data)
1999 Feb 12	043	10.53	0.73	(minute data)
1996 Jun 30	182	10.65	0.50	(manufacturer calibration)

Pyrheliometer: Eppley NIP-31375E6.

date	day of year	S (μV/(W/m^2))	U95 (%)	
1012 May 11	043	8.20	0.24	(minute data)
1999 Feb 12	043	8.14	1.06	(minute data)

1998 Feb 16	047	8.21	0.83	(minute data)
unknown		8.24	5.00	(manufacturer calibration)

Pyrheliometer: Eppley NIP-31376E6.

date	day of year	S ($\mu V/(W/m^2)$)	U95 (%)	
1999 Feb 12	043	7.88	1.00	(minute data)
1998 Feb 16	047	7.92	1.24	(minute data)
unknown		8.00	5.00	(manufacturer calibration)

ABSTRACT

Calibrations of pyrheliometers are made periodically to maintain data quality and traceability to the World Radiometric Reference (WRR). The radiometric reference used is an Eppley Laboratory, Inc. Absolute Cavity Radiometer (ACR). Calibration data from pyrheliometers have been collected periodically for the past several years. The data is typically collected at the Clouds and the Earth's Radiant Energy System (CERES) Ocean Validation Experiment (COVE) site located at the Chesapeake light station, in the Atlantic Ocean approximately 25 km east of Virginia Beach, Virginia. Calibrated devices have included Eppley Laboratory, Inc. Normal Incident Pyrheliometers (NIPs) and Kipp & Zonen, Inc. CH1 pyrheliometers. These calibration data are analyzed to produce calibration coefficients with 95% uncertainty bounds (U95). Current and historical calibration coefficients are presented here.

REFERENCE STANDARDS

The reference pyrheliometers are the Eppley Laboratories Inc. Absolute Cavity Radiometer (ACR) serial number AHF-31105 and AHF-31041 each with its associated Agilent 34970A control unit. These NASA Langley owned absolute cavity radiometers can be traced to the World Radiation Reference (WRR). Direct linkage was obtained at the International Pyrheliometer Comparisons (IPC-IX, IPC-X, and IPC-XI) in October of 2000, 2005, and 2010. Other years starting in 1997 they were linked to the WRR through the National Standard Group (NSG) at the National Renewable Energy Laboratories (NREL) in Golden, Colorado. The NSG is also linked to the WRR at the IPCs. The WRR is an average of the World Standard Group (WSG) of pyrheliometers which is kept at the Physikalisch-Meteorologisches Observatorium in Davos, Switzerland. The uncertainty of the WSG is 0.3% (U95% with respect to SI units). Unless a major difference is found, indicating a physical change has taken palce to the cavity, the WRR values obtained at the IPCs are used not the ones from NREL, as the IPC values are a step closer to the WSG. After each cavity intercomparison is completed, new WRR correction values and their U95 uncertainties, with respect to SI, are determined for each participant cavity. The raw irradiances as measured by a given ACR are multiplied by its WRR correction value to get the final ACR determined direct beam irradiance values. See the cavity calibration documents for greater detail.

The Agilent 34970As, used as cavity controllers, contain 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.

METHODOLOGY

Attach the ACR, and test pyrheliometers as necessary, to the solar tracker. Verify the instruments are aligned with the sun. Connect the ACR to the ACR controller and the controller to the PC. Verify that the ACR window and the ACR cover are off. Check the desiccant in each instrument and replaced as necessary. Clean the pyrheliometer windows. Verify the pyrheliometers are attached to the Campbell Scientific Inc. data logger system. Modify the data logger programs to store millivolt pyrheliometer 1 HZ data.

During a calibration session the following process is repeated as long as sky conditions permit. The ACR self calibration process is performed, this takes about 3 minutes. The program is then instructed to take 400 measurements, one every 4 seconds, this is considered to be a run. (Before January 2006, a run consisted of 300 measurements taken at intervals of 3-4 seconds). If pyranometers are being calibrated at the same time operate them in the shade/unshade mode. A run is about 30 minutes.

DATA ANALYSIS

The WRR factor is applied to the ACR measurements. The ACR and test pyrheliometer are matched to the nearest second. A calibration value is calculated for each ACR value. The data is edited to remove periods with unstable sky conditions. For a run to be considered valid 66% of the points must remain after removing bad data. For each run a run-mean and run-standard-deviation are determined. All of the runs for a calibration session are combined. The mean of the calibration values and the mean of the standard deviations of the run-means is then determined. These two standard deviations are used in the uncertainty analysis below. Ideally a calibration event would consist of data gathered on several days with varying sky but this is seldom possible because of poor site access.

MINUTE DATA ANALYAIS
AT times second resolution data may not be available for the test pyrheliometers. In these cases it is necessary to determine minute means of the ACR data. The following can be used to get minute means form the second resolution cavity data.
/Users/denn/Forsun/SRB/Calibrations/Cavity_31041_to_minutes
And then compare these values to the minute values from the test pyrheliometers. A useful program can be found in directory.
/Users/denn/Forsun/SRB/Calibrations/Plot_campbell_minute_vs_minute

UNCERTAINTY ANALYSIS

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

The final uncertainty of the test pyrheliometer calibration factor is the root sum square of the component U95 uncertainties listed below.

$$U95_{total} = \mathrm{sqrt}\left((U95_{cavity})^2 + (U95_{mean})^2 + (U95_{sd})^2 + (U95_{logger})^2 \right)$$

Where:
$U95_{total}$ = U95 for the test pyrheliometers.
$U95_{cavity}$ = U95 of the cavity with respect to the WRR.
$U95_{mean}$ = U95 of the calibration event mean.
$U95_{sd}$ = U95 of the calibration event standard deviation.
$U95_{logger}$ = U95 of the of the data logger (0.2%)

SUMMARY

Calibration of pyrheliometers 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.

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.

International Pyrheliometer Comparison – 10 (IPC-X). IOM report No. 91. WMO/TD No. 1320. (Contact PMOD WRC for more information)

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===================== Calibration instructions as of 2012-06-06 =====================

see
/Users/denn/data0/COVE_BSRN_cals/___________instructions_____________

for the most current version. (small changes take place from time to time.)

1) collect calibration data at the site.
put the loggers (dnwl & proj) into second mode by changing
the flag near the top of the logger programs to second mode.

2) go to /Users/denn/data0/COVE_BSRN_cals
make a directory with a name of the form
COVE_cal_yyyymmdd

3) make the following 3 sub directories
cavity dnwlsw proj
put the data files in the appropiate sub directories

4) rename the data files
the cavity file should have a name like ahfnnnnn_yyyymmdd.dat
where nnnnn is the cavity serial number (31041 or 31105)
the project file name should be proj_yyyymmdd
the dnwlsw should be dnwl_yyyymmdd

5) remove data from outside the calibration data period.
remove all minute data from dnwl and proj files.

6) add some lines at the begining of each the dnwl and the proj file to
define the file and the columns. see examples from previous months.

6) SPLIT
cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Split_COVE_logger_files
modify the program so in_file = 'the desired file name'
maybe the next two lines also.
make a 'runs' file of the form 'runs_yyyymmdd' see an example.
this file should have a line for each, the proj file and, the dwnl file.

7) compile and execute the program (comp & runs)

8) cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Plot_split_file
create a runs_yyyymmdd file, see examples, put the shade/unshade or all files in it.
leave one of them uncommented (no #) and run program.
the program puts the *.eps files in the same place as it gets the data.
look at the plot file and edit out points which should not have been
incleded, e.g. global points in the diffuse file.
Data start time can be included in the execution line. some files may have
data with the wrong sign i.e. negative.
the starting time can be a parameter in the execution line.
adjust the scales as need be.
edit the data file if necessary.
repeat some of this until satisified with the result.
the time range (6 digits) can be selected with a value at the end of the file name

9) do each file, one for each sensor.

--CAVITY
10) check cavity data.
go to /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/cavity_seconds_plot
look in the program for sample file names. look as a previously plotted file

to see what form the file should have. add the WRR and uncertainty lines to
each file to be plotted. the data file will require some editing: to remove
colons ":" and to remove a string to big to read.

cav-2 edit out cloud periods.

FILL DIFFUSE
F1) go to the filler program
cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Diffuse_fill
see the "runs" script.
define new cases using the program as an example.
add a line for each of the new cases.
run each new case
END FILL DIFFUSE

----
may need to fill global from project logger
is is every other second.
cd to
cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Fill_one_sec_gaps
make new runs_yyynmndd scripts for the new dates and run them.

10-P) PYRHELIOMETER
cd /Users/denn/Forsun/SRB/Calibrations/cavity_second_based/Cal_ch1
look at input data files for an example e.g. case_ch1_960133_20080430
This program combines cavity data and pyrheliometer (NIP or CH1) data

11-P) Copy the output files to
/Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_ch1_groups
and go to
/Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_ch1_groups
look at the runs file.
pick one of the cases in it. i.e. case_ch1_960133 modify this file
to include new cases for the same sensor.

12-P) run the 'runs' file. look at the result. it may be necessary to remove
some more data here.

13-P) cd to /Users/denn/Forsun/SRB/Calibrations/PSP/History_PSP
modify the appropiate case file (e.g. case_CH1_010254)
modify the 'runs' file for the case.
run the program get a plot of calibration history.
-
---- end Pyrheliometer ---------
****

----
may need to fill global from project logger
is is every other second.
cd to
cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Fill_one_sec_gaps
make new runs_yyynmndd scripts for the new dates and run them.
GLOBAL FILLING DID NOT SEEM TO MAKE A DIFFERENCE FOR THE PYRANOMETER CASE
filling is most usefull for the relative calibration case.

---- do pyranometer shade/unshade -----------

14) execute the following line to get to the first pyranometer program
cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_pyr
look at the "runs" script for an example
add new cases.

15) plot multipal data groups
cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_pyr_groups
****

****
****
After doing the shade/ start relative calibration for globals *******************
be calibrated using a direct compairson the the ones done using
shade/unshade.

rel-1) go to the relative calibration program
cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_relative_cav_groups
- setup new case files
- run the program
- run the program
copy new group files to
/Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_pyr_groups
- cd /Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_pyr_groups
- set up new case files
- run the cases

*********************** end relative calibration for globals ********************
****

****
Histories
make new calibration history plots.
cd /Users/denn/Forsun/SRB/Calibrations/PSP/History_PSP
modify the cases to include new data
make plots
****
rel-2) relative cal, by cavity groups, ISO like.
cd /Users/denn/Forsun/SRB/Calibrations/cavity_second_based/Cal_relative_cav_groups

copy the "group" output files to
/Users/denn/Forsun/SRB/Calibrations/Cavity_second_based/Cal_relative_cav_groups
the files will need to edited to get the group boundires right.

set up a case and run
plot the results.
put the result in the cal doucumet.

assemble all this in a new document make sure it gets in the data base.

HIST-1
make history plots for each pyranometer and each pyrheliometer
cd /Users/denn/Forsun/SRB/Calibrations/History_PSP-NIP
modify the case files to incluce the latest data.
modify and execute the 'runs' script

****
find the old calibration document and update it, making a new calibration document.
for example cd to
/Users/denn/Documents

and open the following documents
Pyrheliometers_cals_2006_nov.docx
Calibration_pyranometer_2010-03.docx