Calibration methodology of the University of Oregon Solar Radiation Monitoring Laboratory

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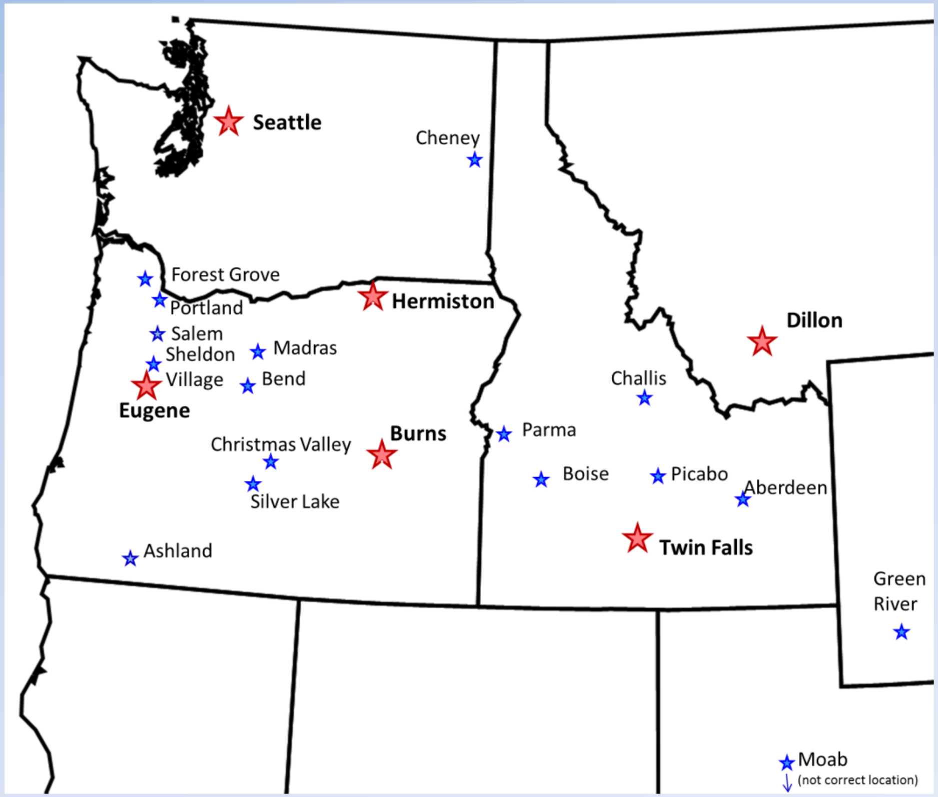
- Overview of calibration procedure
- Calibration program details
- Demonstration of calibration program
- Results and implementation

SRML Network of Monitoring Stations



1st Class Stations

Subsidiary Stations

- The SRML operates a network of around **20 solar monitoring stations**
- **50 -100 sensors** continuously deployed.

- The calibration of such a diverse network is a non-trivial task.
- To streamline and standardize the process, **a new calibration software program has been developed**.

What is a calibration

- A outdoor calibration is a comparison of two instruments that make the same type of measurement.
  - The ***reference instrument*** is considered the standard
  - The ***field instrument*** is the instrument being calibrated

- The field instrument can be recalibrated such that it's values match the reference instrument.

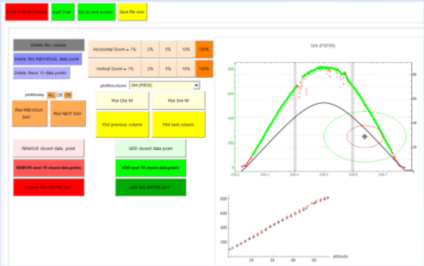
$$\mathbf{I_{RF}} = \mathbf{I_{field}} = \frac{\mathbf{V}}{\mathbf{R}_{\boldsymbol{new}}} \Rightarrow \mathbf{R_{new}} = \frac{\mathbf{V}}{\mathbf{I}_{\boldsymbol{RF}}}$$

I_{RF} = Irradiance reference instrument
I_{field} = Irradiance field instrument
V = Voltage field instrument
R_{new} = New responsivity of field instrument

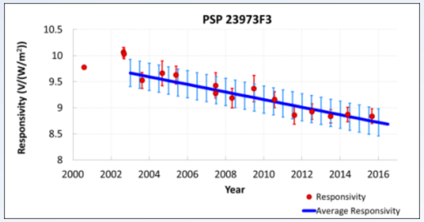
Steps involved in calibrations

1. Make measurements of the sky with various instruments

2. Analyze the data
   – Eliminate unwanted data points
   – Compute the responsivity of the instrument on that particular day
   – Compute the uncertainty of the data



3. Compute the responsivity of instrument as a function of time.



4. Apply the new responsivity to the instruments in question

$$I = \frac{V}{R}$$

Challenges in analyzing the data

Hardware/Software challenges

- Varying data structure and time formats

Data challenges

- Selecting the data points actually used in the calibration

Calculation challenges

- Varying reference instruments
- Computing GHI reference from DNI and DHI
- Computing the uncertainty of the calibration
- Selecting data points in a particular SZA range
- Applying thermal offsets adjustments

Solution to these challenges

A new calibration program

Hardware/Software challenges

Accepts multiple data and time format structures

Data challenges

Allows the user to manually identify qualifying data points using a graphical user interface.

Calculation challenges

Performs all necessary calculations and outputs final responsivity and uncertainty values for each instrument.

Input calibration file (Example 1)

From the 2017 Seattle calibration file

- **Date and time**
- **Auxiliary GHI instrument**
- **DNI reference instrument**
- **GHI reference instrument**
- **Air Temperature reference instrument**
- **Row 1: Type of measurement label**
- **Row 2: Instrument serial number**
- **Row 3: Responsivity used**
- **Row 4 – End: Instrument data**

CalStw_2017_212-213_1min.dat

	A	B	C	D	E
1	Datetime	GHI	DNI_RF	GHI_RF	TEMP_RF
2	NAN	psp_13365	NIP_17668	CMP22_120363	Air_Temp
3	NAN	7.4601	8.6303	9.6916	1
4	7/31/2017 11:25	893.2654	943.4492	877.9716	25.97661
5	7/31/2017 11:26	894.5308	942.8998	879.709	25.71781
6	7/31/2017 11:27	894.6755	942.825	879.1442	25.83017
7	7/31/2017 11:28	893.7658	941.5732	878.4581	25.82322
39					
40	7/31/2017 12:00	909.0856	945.118	894.2422	25.42703
41	7/31/2017 12:01	911.2126	947.3702	895.5311	25.44949
42	7/31/2017 12:02	909.9968	945.9355	893.9208	25.75239
43	7/31/2017 12:03	910.0569	945.5291	893.3585	25.99967
44					
1357	8/1/2017 9:56	704.6758	729.9484	708.0954	26.24975
1358	8/1/2017 9:57	702.5818	726.0041	705.9547	26.19593
1359	8/1/2017 9:58	709.6901	734.0345	713.3328	26.06165
1360	8/1/2017 9:59	705.4949	729.1486	709.4767	25.9023
1361	8/1/2017 10:00	705.5419	729.6646	709.0498	25.91763
1362					

Input calibration file (Example 2)

From the Seattle station

Day of Year (DOY) | **Time (HHMM)** | **GHI station instrument** | **DNI station instrument** | **Air Temperature station instrument**

stw011707.prn

	A	B	C	D	E	F	G
1	Junk	year	doy	hhmm	GHI	DNI	TEMP_STW
2	NAN	NAN	NAN	NAN	PSP23620	NIP17009	TEMP_STW
3	NAN	NAN	NAN	NAN	8.32298	8.41333008	1
4	506	2017	212	1	-5.889	-0.116	16.05
5	506	2017	212	2	-6.019	-0.048	16.02
6	506	2017	212	3	-6.009	-0.045	16.01
723							
724	506	2017	212	1200	898	950	25.24
725	506	2017	212	1201	899	953	25.27
726	506	2017	212	1202	899	952	25.61
727	506	2017	212	1203	899	951	25.88
728							
2883	506	2017	213	2358	NA	-0.135	21.97
2884	506	2017	213	2359	NA	0.097	21.98
2885	506	2017	213	2400	NA	0.164	21.97
2886							

Row1: Type of measurement

Row 2: Instrument serial number

Row 3: Responsivity used

Row 4 – End: Instrument data

Program number (not used in analysis)

Year (not used in analysis)

Row 1 Lookup labels

GHI_RF, GHI, DHI_RF, DHI, DNI_RF, DNI, TEMP_RF, TEMP

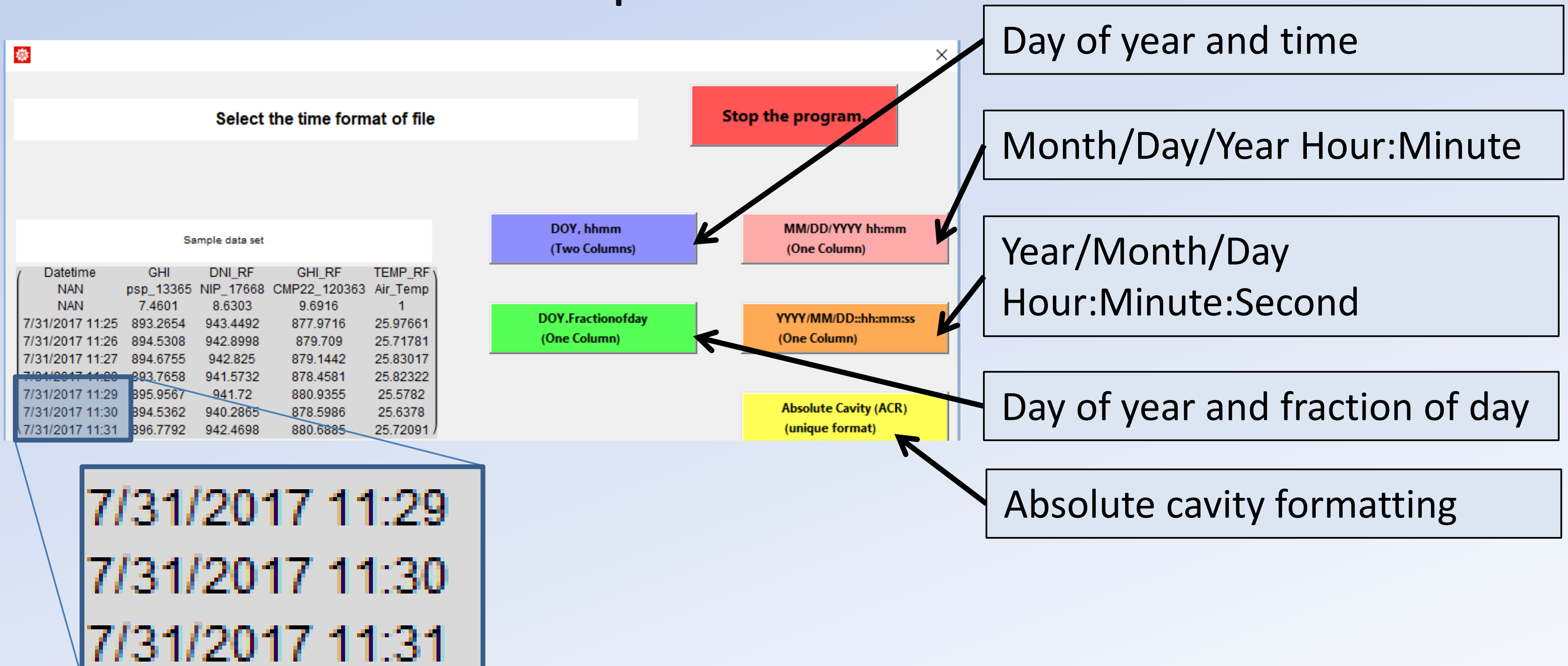
Other labels are fine, but the program will not automatically see them
Examples: GHI_TILT_RF Air_Pressure etc.

Before the data is analyzed

1. Date/time of each data point determined
2. Sun position for each point calculated (SZA, AZM)
3. Offset adjustments to data is applied
   - Nighttime value, Thermal offset
4. Reference instruments defined
   - Measured or calculated
5. Reference instrument uncertainties defined
6. Ratio of instruments computed
7. Good and Bad lists created

1. Date/time of each data point determined

- User is asked to identify the time format of the input file



- All formats are computed to standard format Day_of_Year . Fraction_of_day

2. Sun position calculated

- Translation of the SOLPOS code is implemented
  https://midcdmz.nrel.gov/solpos/
- Solar Zenith Angle (SZA) and Azimuthal Angle (AZM) are both calculated
- Effects due to refraction are included
- Plans are underway to incorporate Solar Position Algorithm (SPA)

3. Offset adjustments to data applied

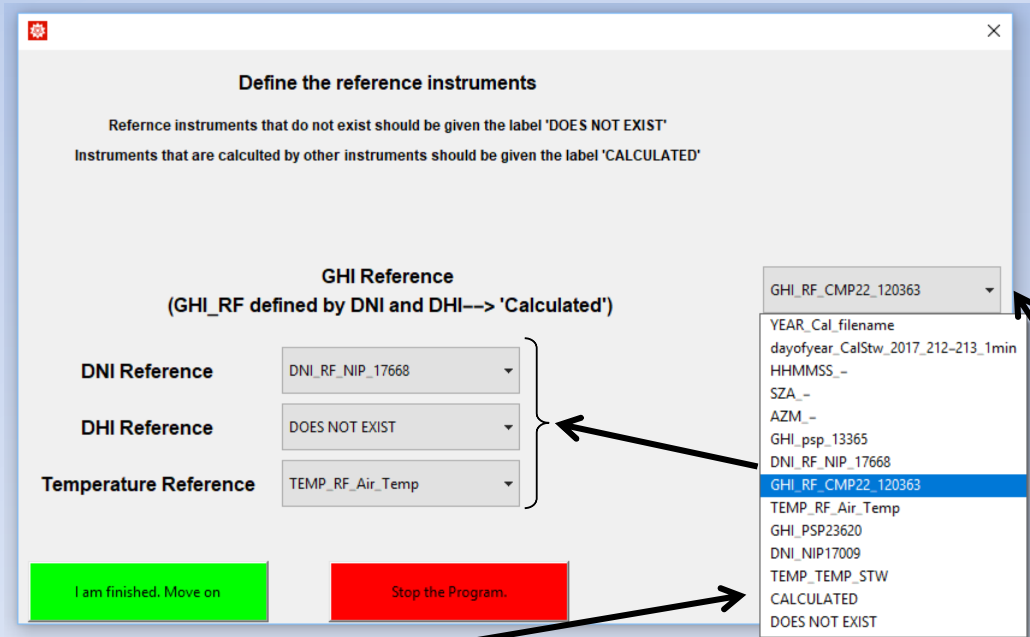
- Offset = Average instrument value at night (SZA > 108°)
- Assumption: Daytime offset = Nighttime offset
- Offset adjustment to field and reference instruments

$$I_{\text{adjusted}} = I_{\text{original}} - \text{Offset}_{\text{Nighttime value}}$$

- Uncertainties associated with the offset are included in uncertainty calculation
- Common offset values
  - PSP Pyranometer ≈ -2 – -6 W/m^2
  - LICOR Pyranometer ≈ 0 – -1 W/m^2
  - NIP Pyrheliometer ≈ 0 – -1 W/m^2

4. Reference instruments are defined

- User is asked to define the reference instruments



The reference instruments can also be defined in input file header as well

Drop down menus

GHI, DNI, DHI can be calculated from other reference instruments

$$GHI_{RF} = DNI_{RF}\ Cos[SZA] + DHI_{RF}$$

5. Reference instrument uncertainties defined

- The uncertainty of the reference instrument responsivity is given by the user
  - Given as a percentage, expanded uncertainty, at SZA = 45°
- Uncertainty in the reference irradiance is computed using sum of squares method including:
  - Uncertainties in responsivity
  - Uncertainties in nighttime offset
  - Uncertainties in the data logger
  - Uncertainties in SZA (for calculated references)
- Computed using the GUM method to calculate uncertainty
  https://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

6. Ratio of instruments computed

- The irradiance of the field instrument is compared to the irradiance of the reference instrument

$$\textbf{Ratio} = \frac{I_{field}}{I_{RF}}$$

- This is done for every data time of the calibration file
  - Not just SZA = 45°

- All irradiance values have the offset already applied

- The ratio is used in computing the new responsivity after the data is analyzed.

7. Good and Bad lists created

Each time interval (minute) is considered either “Good” or “Bad”

- If clouds were blocking the GHI sensor one minute, they were also blocking the DNI sensor that same minute.
- All instruments of this time interval are labeled as such.

Good list

- No obvious problems in this time interval
- Clear sky, no problems

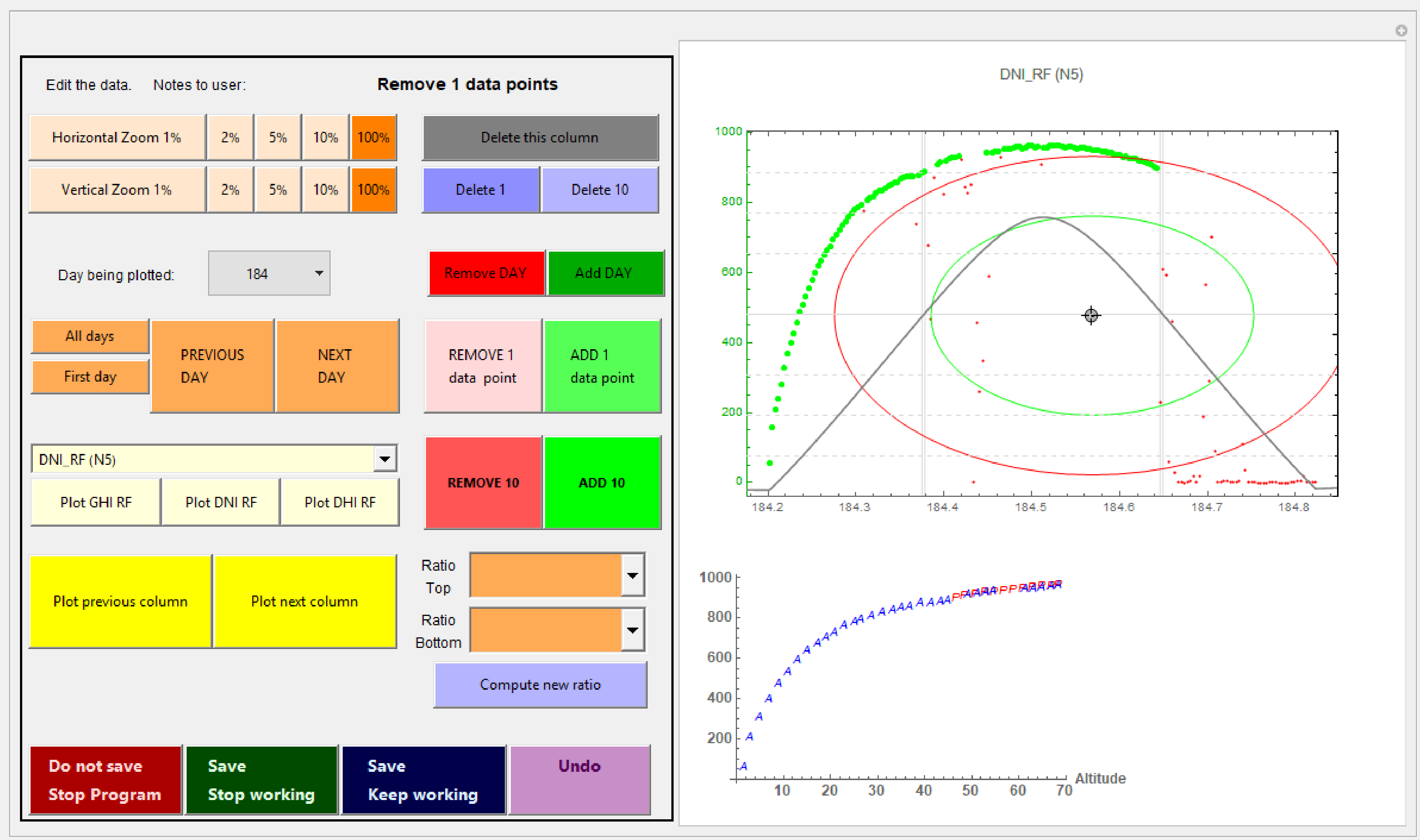
Bad list

- Obvious problems disqualify this time interval
- Clouds, user adjustments, tracker alignment, etc.

“NA” data points

- If one sensor is behaving strange but the other instruments are good.
- Within each list, it is possible to set individual instruments and data points to “NA”.
- This instrument (at this time) is no longer a valid data point.

Demonstration of program



Various Buttons

Zoom
Vertical or horizontal
Mouse clicks move the graph

Day being plotted
One day or All days
Forward or Backward

Instrument being plotted
List of all columns
Common reference instruments
The next instrument in the list

Delete Buttons
Make the closest value “NA”
Only applies to this one instrument
All other instruments left unchanged

Add Adds closest data points to good list. All data points in this time interval are made to “good” data points (Green).

Remove: Removes closest data points from good list. All data points in this time interval are made to “Bad” data points (Red).

Compute new ratio
Ratio = top/bottom
Computes ratio of two columns defined by user.

Plot: Instrument value vs time

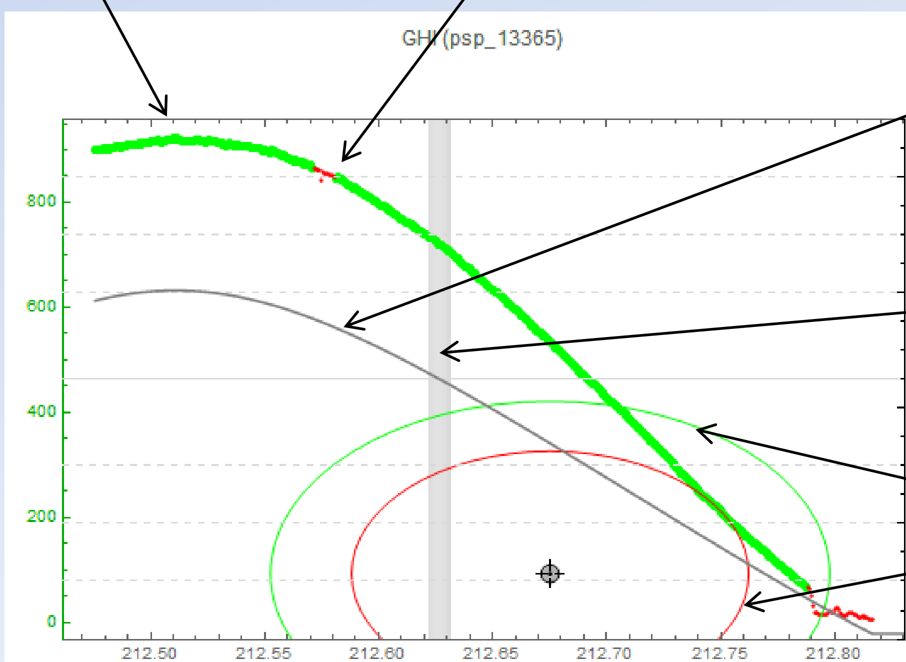
Green = Good data points

These points are considered in the calibration.

Red = Bad data points.

These points are not considered in the calibration.

Value of instrument (units vary)



Time (day of year. Fraction of day

Solar zenith angle vs time

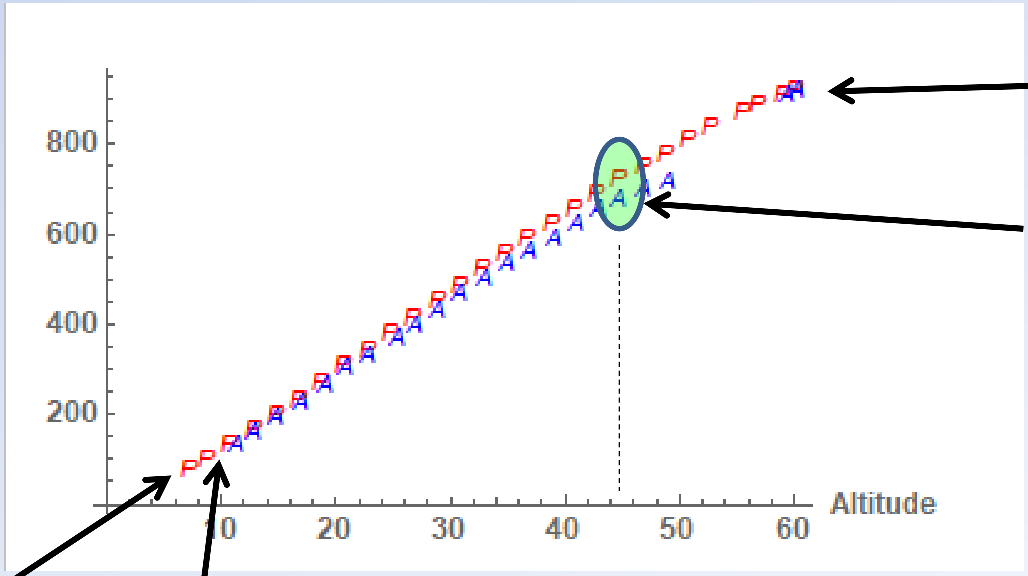
Solar zenith angle =45°

Area to Add/Remove 10 data points

Plot: Instrument value vs altitude

- Data is averaged into two degree SZA bins.
- Only good data is considered.
- Morning and afternoon data are considered separately
  - A = Morning (AM) P = Afternoon (PM)
  - Discrepancies between morning and afternoon can be seen

Value of instrument (units vary)



Altitude (degrees)

A, P = Midday

SZA = 45°
These data points will be used to calculate the new responsivity

P = Dusk **A** = Dawn

Note: Altitude = 90 – SZA
Altitude (Dawn/Dusk) = 0°
Altitude (Noon, summer, Eugene) ≈ 70°

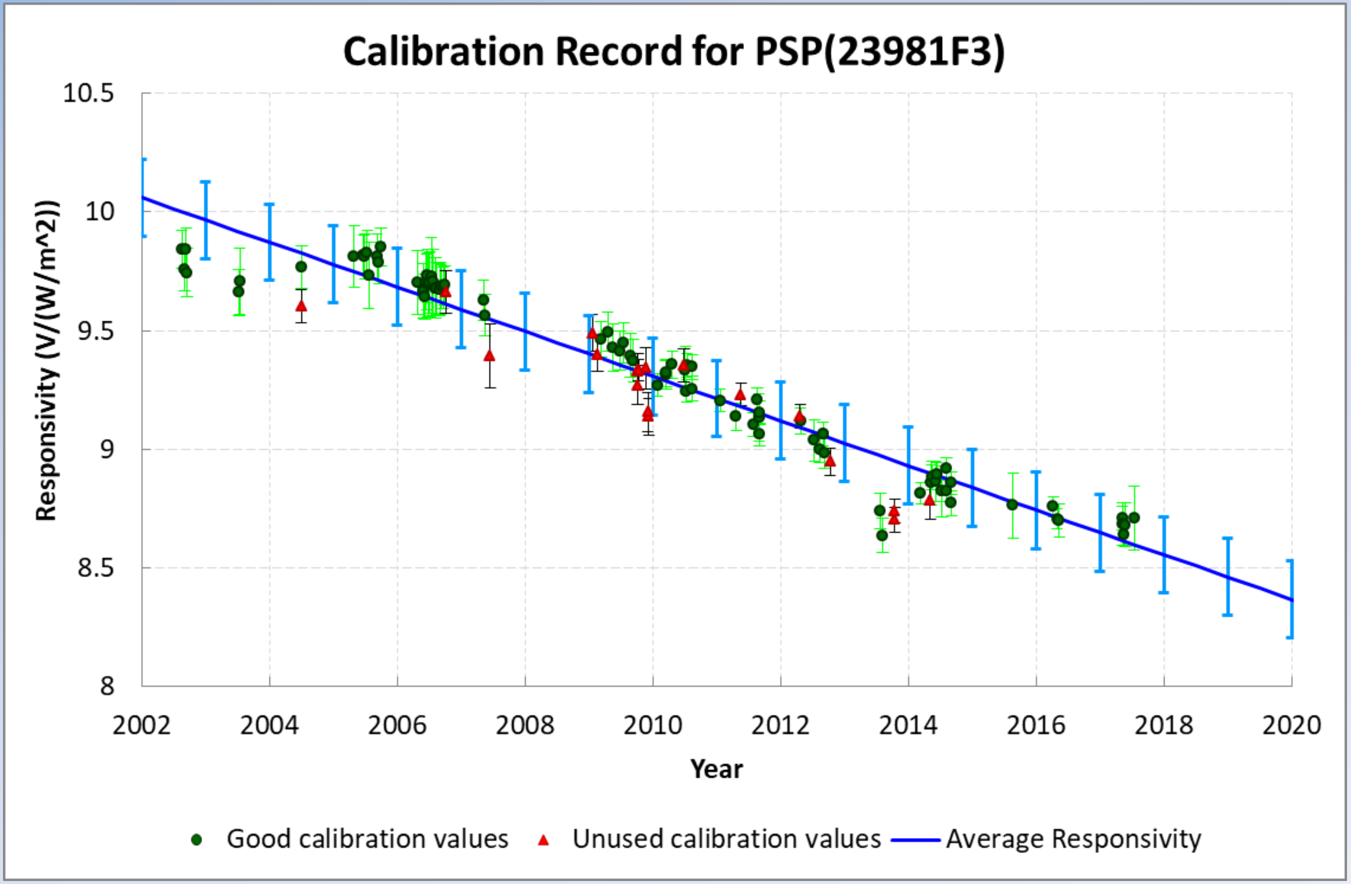
Calibration output values

- After the data has been analyzed the following quantities are written to an output file:
- The new responsivity at SZA = 45°

$$R_{new} = Ratio(45) * R_{old}$$

- Expanded uncertainty in responsivity at SZA = 45° and 30 ° < SZA < 60 °
  - Uncertainty calculations follow the rules of the GUM model.
- General information about the conditions during the calibration.

Calibration results Example 1

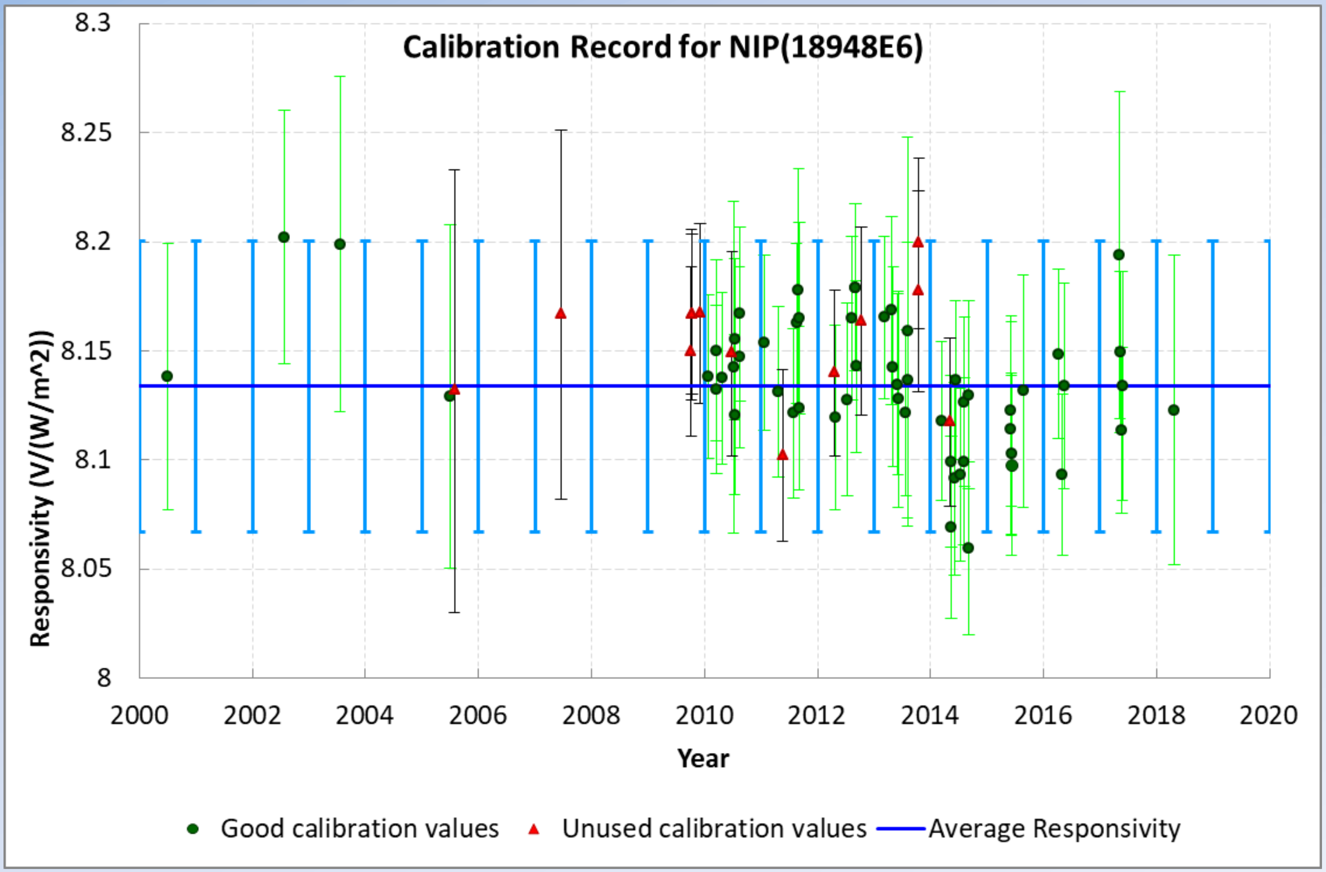


This instrument is currently in Eugene Oregon making GHI measurements

$$\mathbf{I} = \frac{\mathbf{V}}{\mathbf{R}}$$

- Responsivity (2018) **R = 8.5008 (±.162) V/(W/m²)**
- Calibrations will be performed this summer
- These values will be added to this list
- Tentative Responsivity for 2019 is R = 8.4148

Calibration results Example 2



This instrument is currently in Eugene making DNI measurements

$$I = \frac{V}{R}$$

- Responsivity (2018) **R = 8.1338 (±.06675) V/(W/m^2)**
- Calibrations will be performed this summer
- These values will be added to this list
- Tentative Responsivity for 2019 is R = 8.1338 W/m^2

Are there any questions

- ***Website:*** *http://solardat.uoregon.edu/index.html*
- ***Phone:*** *(541) 346-4745*
- ***Email:*** *jpeters4@uoregon.edu*

- I would like to thank the following people for their contribution to this work
  - **Frank Vignola** (for offering guidance and support)
  - **Rich Kessler** (for sitting in the sun many days and answering all my questions)

<u>The SRML would like to thank the following sponsors</u>:

- The Bonneville Power Administration
- The Energy Trust of Oregon
- The Oregon Department of Energy
- The National Renewable Energy Laboratory
- Portland General Electric

Calculating the new responsivity

a bit of math

- Define the irradiance of the field instrument
  - Note the Voltage (V) listed has already had the thermal offset adjustment subtracted.

$$I_{field\ old} = \frac{V}{R_{field\ old}} \qquad \mathrm{I_{RF}} = \mathrm{I_{field\ new}} = \frac{\mathrm{V}}{\mathrm{R}_{field\ new}}$$

- Define the a ratio of irradiance values

$$\mathbf{Ratio} = \frac{\mathrm{I_{field\ old}}}{\mathrm{I_{RF}}} = \frac{I_{field\ old}}{I_{\mathrm{field\ new}}} = \frac{V/Rold}{V/R_{\mathrm{new}}} = \frac{R_{new}}{R_{old}}$$

- Solve for the new responsivity $\mathrm{R_{new}}$

$$\boxed{\mathrm{R_{new}} = \mathbf{Ratio} * \mathbf{Rold}} = \frac{I_{field\ old}}{I_{RF}} * \mathbf{Rold} = \frac{V/Rold}{I_{RF}} * R_{old} = \frac{\mathrm{V}}{\mathrm{I_{RF}}}$$

- Which confirms our original statement