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Performance of Thermal Offset Corrections for Modern Pyranometers

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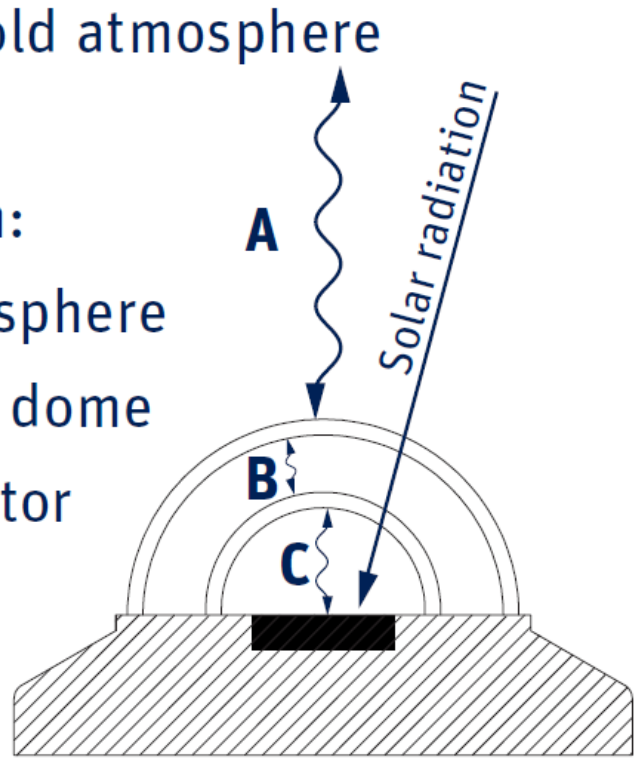
What Is Thermal Offset?

Thermal exchange between:

A Outer dome and atmosphere

B Inner dome and outer dome

C Inner dome and detector



The thermal offset is hidden within the solar radiation signal!

Inter-comparison Experiment

- We carried out an pyranometer inter-comparison experiment at NCU in cooperation with NOAA and manufactures from December 2017 to March 2018 (4 months).

Objectives:

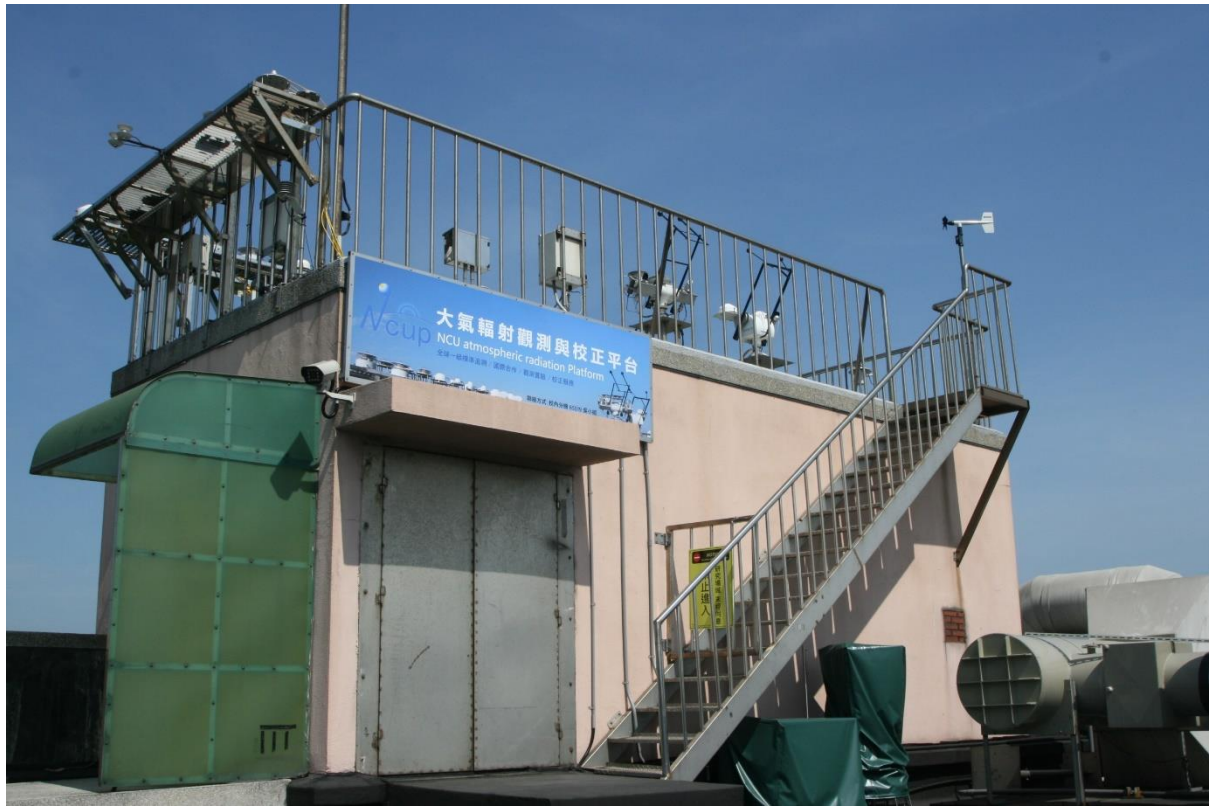
1. **To investigate the characteristics of thermal offset for modern pyranometer models**
2. **To investigate the performance of different correction methods for those pyranometers**

Site: NCU solar radiation Platform

WMO standard

NCU solar radiation Platform & Lab

Lat: 24.97 ˚N, Lon: 121.19 ˚E; Alt: 170 m



Pyranometers

6 different manufacturers
12 different models
20 pyranometers in total

Manufacturer	Pyranometer Model	Spectral Range (nm)	Inner Dome Material	Outer Dome Material
Kipp & Zonen	CMP11	285 to 2800	Glass	Glass
	CMP21	285 to 2800	Glass	Glass
	CMP22	200 to 3600	Quartz	Quartz
SpectroSun	SR-75	285 to 2800	Glass	Glass
EKO	MS-80	285 to 3000	N/A	Glass
Hukseflux	SR20-D2	285 to 3000	Glass	Glass
	SR20-T2	285 to 3000	Glass	Glass
	SR25-T2	285 to 3000	Glass	Sapphire
	SR30-D1	285 to 3000	Glass	Glass
Middleton	EQ08-S	300 to 3000	Glass	Glass
Eppley	SPP	295 to 2800	Glass	Glass
	PSP	285 to 2800	Glass	Glass

Leveling, cable outlet facing north, and daily dome cleaning

Reference units

Shaded Pyranometer

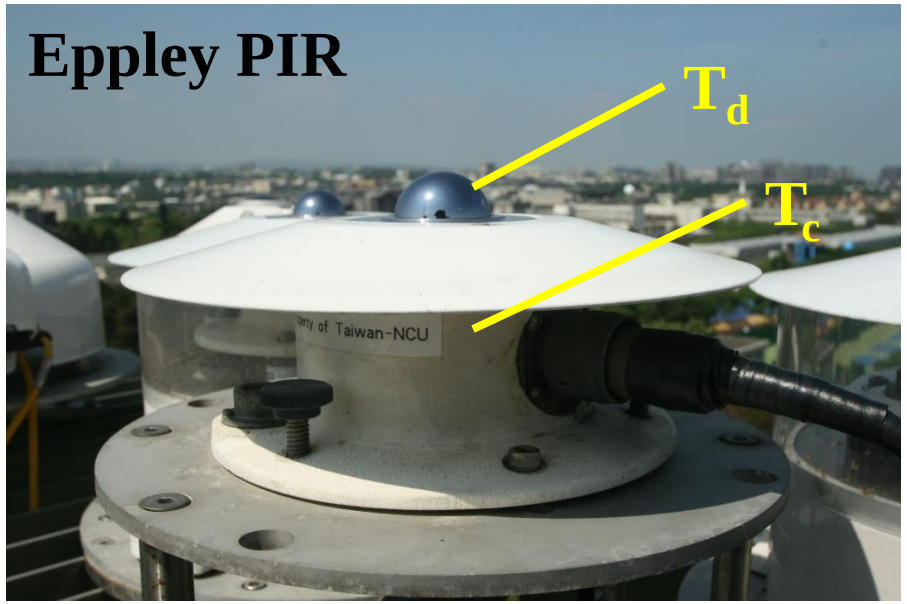
Pyrheliometer

Manufacturer	Pyrheliometer Model	Calibration
Hukseflux	DR02-T2	2015 IPC
Kipp & Zonen	CHP1	2016 NPC

Pyrgeometers (provided by NOAA)

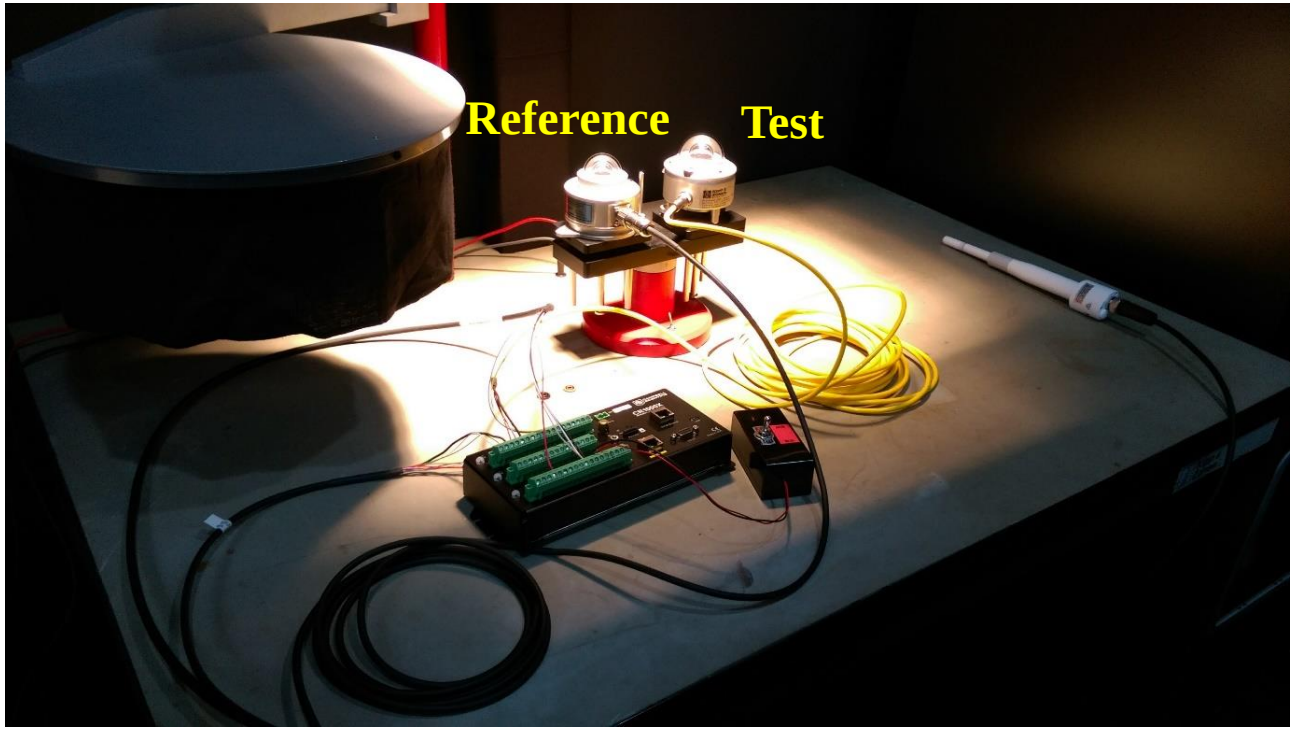
Albrecht and Cox Equation (1977):

$$LW_{down} = LW_{net} + LW_{up} = \frac{V}{S} + \sigma T_c^4 - k\sigma(T_d^4 - T_c^4)$$



Calibrations

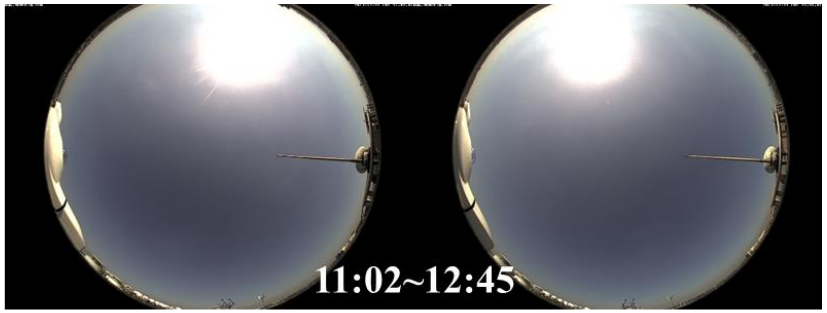
Indoor calibration (ISO 9847)



Outdoor calibration (ISO 9846)

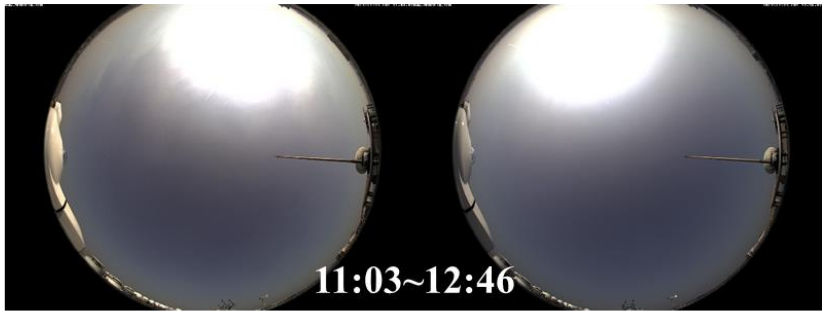
Clear sky SZA: 40~50˚

2017/12/21



2017/12/22

2017/12/23

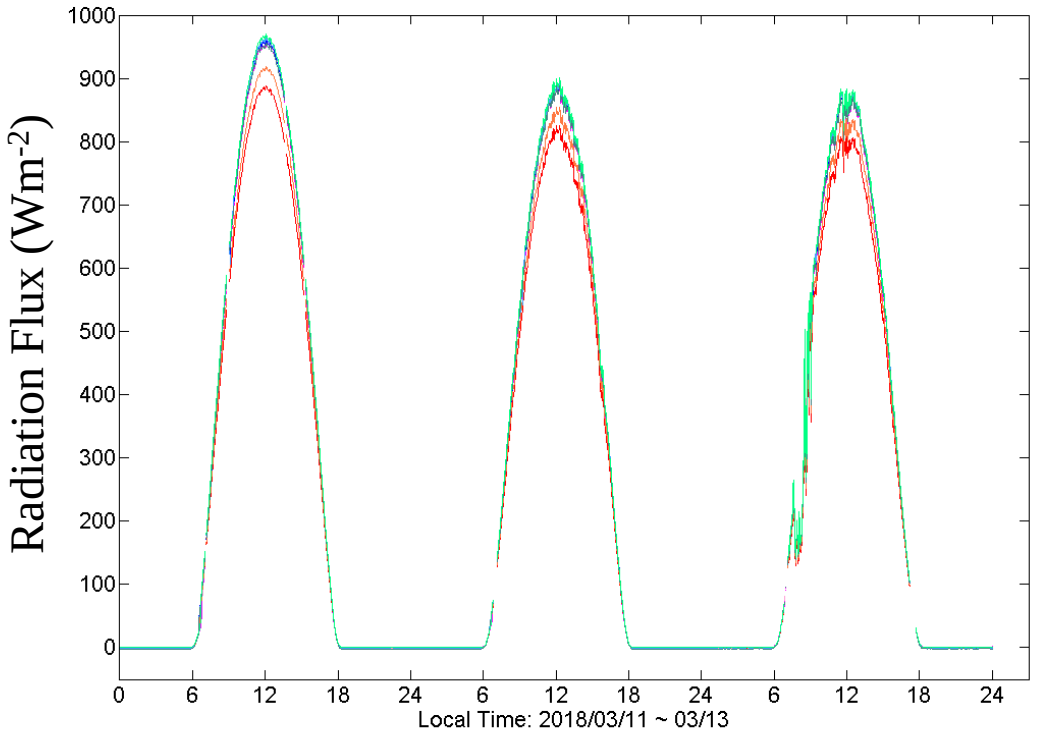


Calibration Results

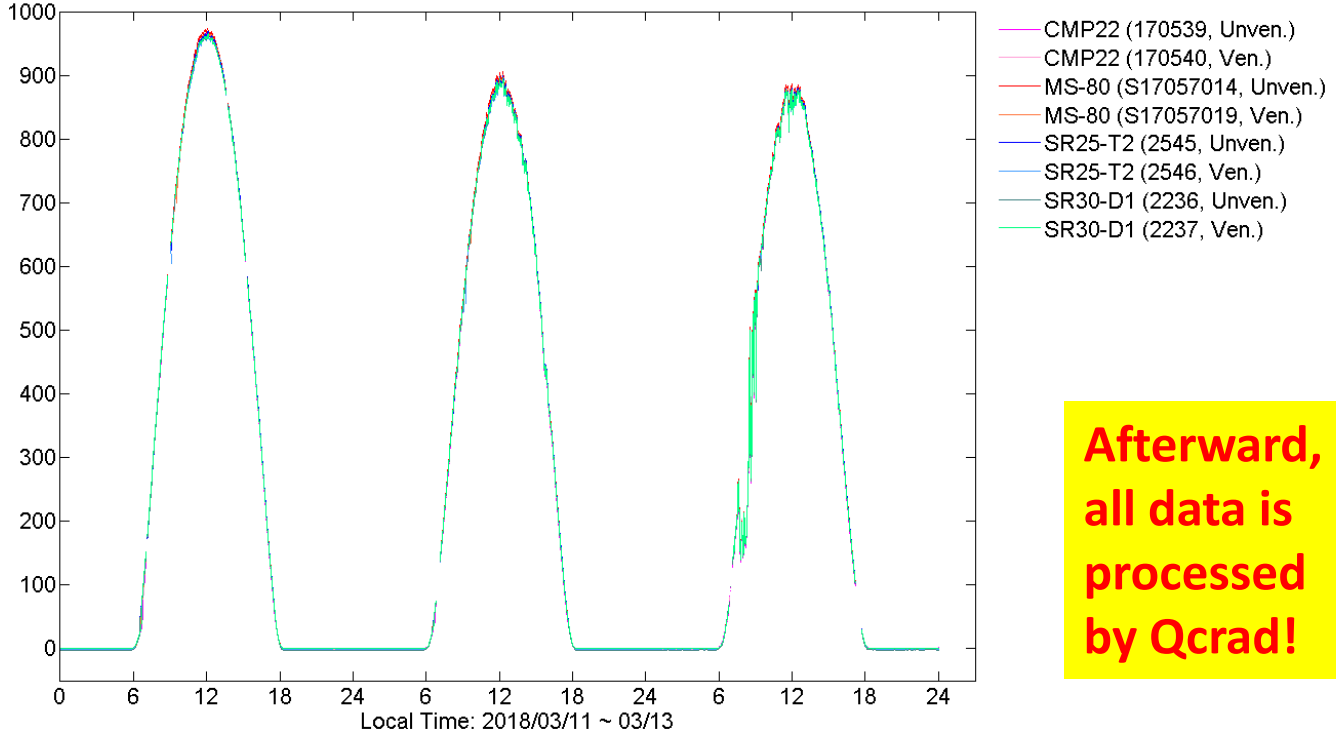
(We chose outdoor sensitivity for this study)

	Indoor Calibration	Outdoor Calibration
Mean percentage change in sensitivity (%)	1.76	**-0.42**
Mean expanded uncertainty (%)	2.33	**1.28**

Apply **Indoor Sensitivity**



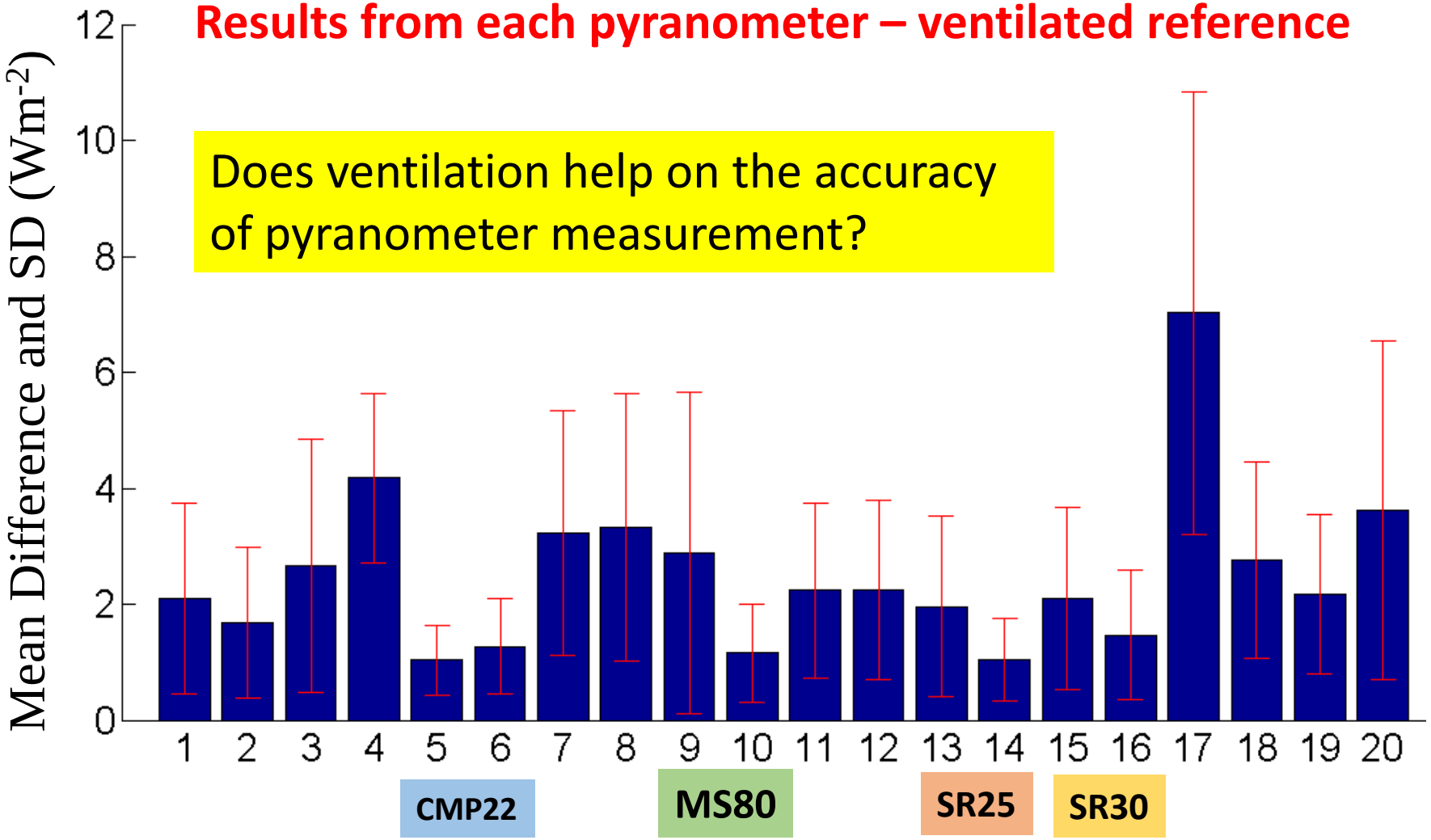
Apply **Outdoor Sensitivity**



Afterward, all data is processed by Qcrad!

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mean Difference (Wm^{-2})	**2.10**	**1.68**	**2.67**	**4.17**	**1.04**	**1.27**	**3.22**	**3.32**	**2.89**	**1.16**	**2.24**	**2.24**	**1.96**	**1.04**	**2.10**	**1.47**	**7.02**	**2.76**	**2.18**	**3.62**
SD (Wm^{-2})	**1.63**	**1.30**	**2.18**	**1.45**	**0.61**	**0.82**	**2.12**	**2.31**	**2.77**	**0.85**	**1.52**	**1.55**	**1.56**	**0.71**	**1.58**	**1.12**	**3.82**	**1.69**	**1.38**	**2.91**

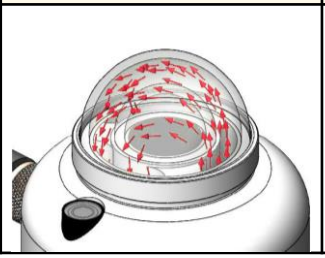
Results from each pyranometer – ventilated reference



Does ventilation help on the accuracy of pyranometer measurement?

1: CMP11 (Unven.)
2: CMP11 (Ven.)
3: CMP21 (Unven.)
4: CMP21 (Ven.)
5: CMP22 (Unven.)
6: CMP22 (Ven.)
7: SR-75 (Unven.)
8: SR-75 (Ven.)
9: MS-80 (Unven.)
10: MS-80 (Ven.)
11: SR20-D2 (Unven.)
12: SR20-T2 (Ven.)
13: SR25-T2 (Unven.)
14: SR25-T2 (Ven.)
15: SR30-D1 (Unven.)
16: SR30-D1 (Ven.)
17: EQ08-S (Unven.)
18: SPP (Ven.)
19: PSP (Unven.)
20: PSP (Ven.)

Pyranometer

Pyranometer	CMP22	SR30-D1	SR25-T2	MS-80
Spectral range (nm)	200 to 3600	285 to 3000	285 to 3000	285 to 3000
Inner dome material	Quartz	Glass	Glass	N/A
Outer dome meterial	Quartz	Glass	Sapphire	Glass
Ventilation unit (DC) 				

Thermal Offset Corrections (Younkin and Long, 2003)

Offset: Pyranometer nighttime offset (Wm^{-2})
Net IR: Pyrgeometer (PIR) nighttime net IR (Wm^{-2})

Detector only correction

At nighttime (cosSZA < -0.2), calculate **detector only correction coefficients** for each pyranometer:

$$\text{Offset} = b_1 \cdot \text{Net IR} + b_0$$

Full correction

At nighttime (cosSZA < -0.2), calculate **full correction coefficients** for each pyranometer:

$$\text{Offset} = b_2 \cdot \sigma(T_d^4 - T_c^4) + b_1 \cdot \text{Net IR} + b_0$$

Nighttime-fitted Models

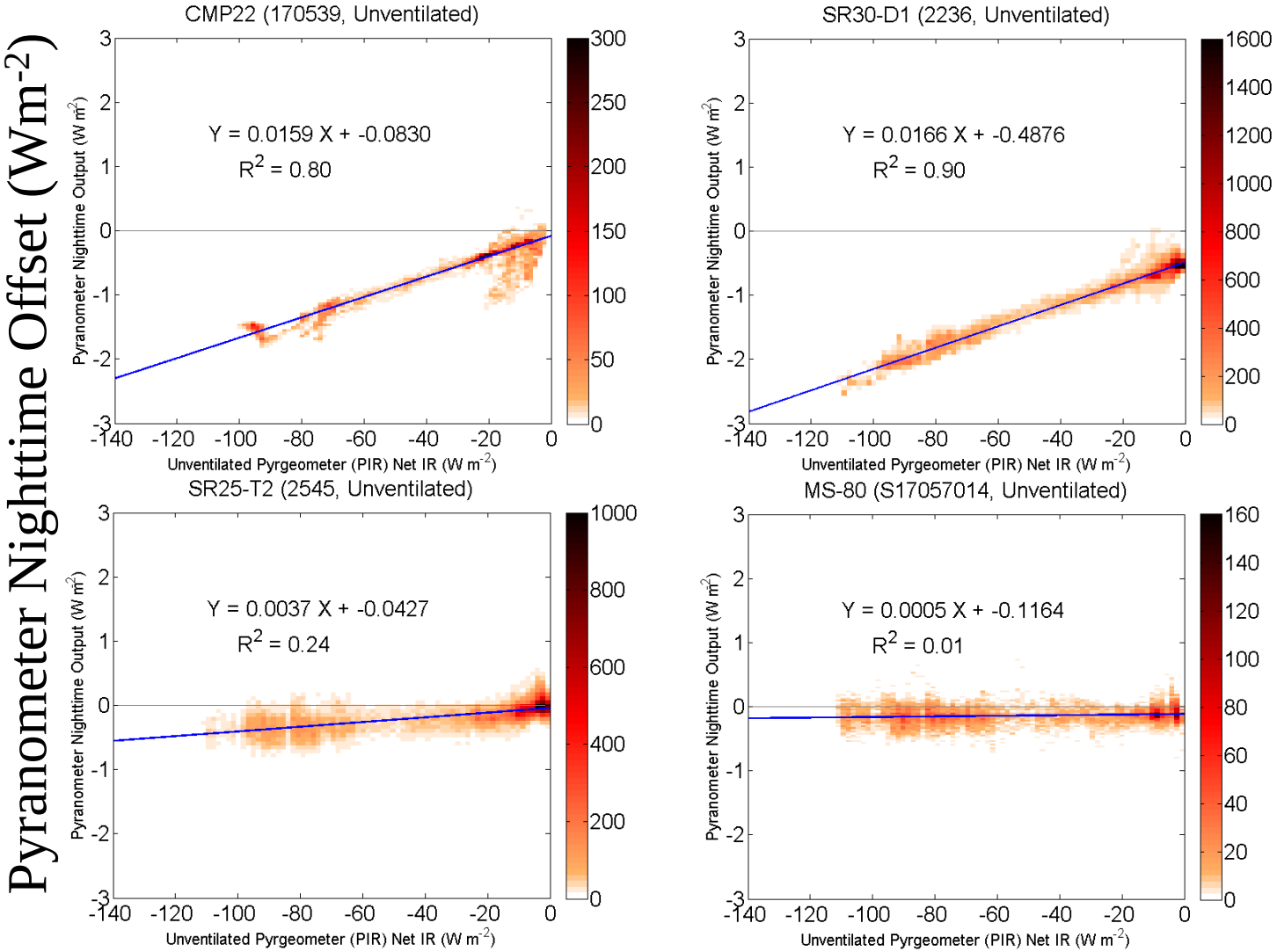
Detector only correction

CMP22

SR30

SR25

MS80



Nighttime-fitted Models

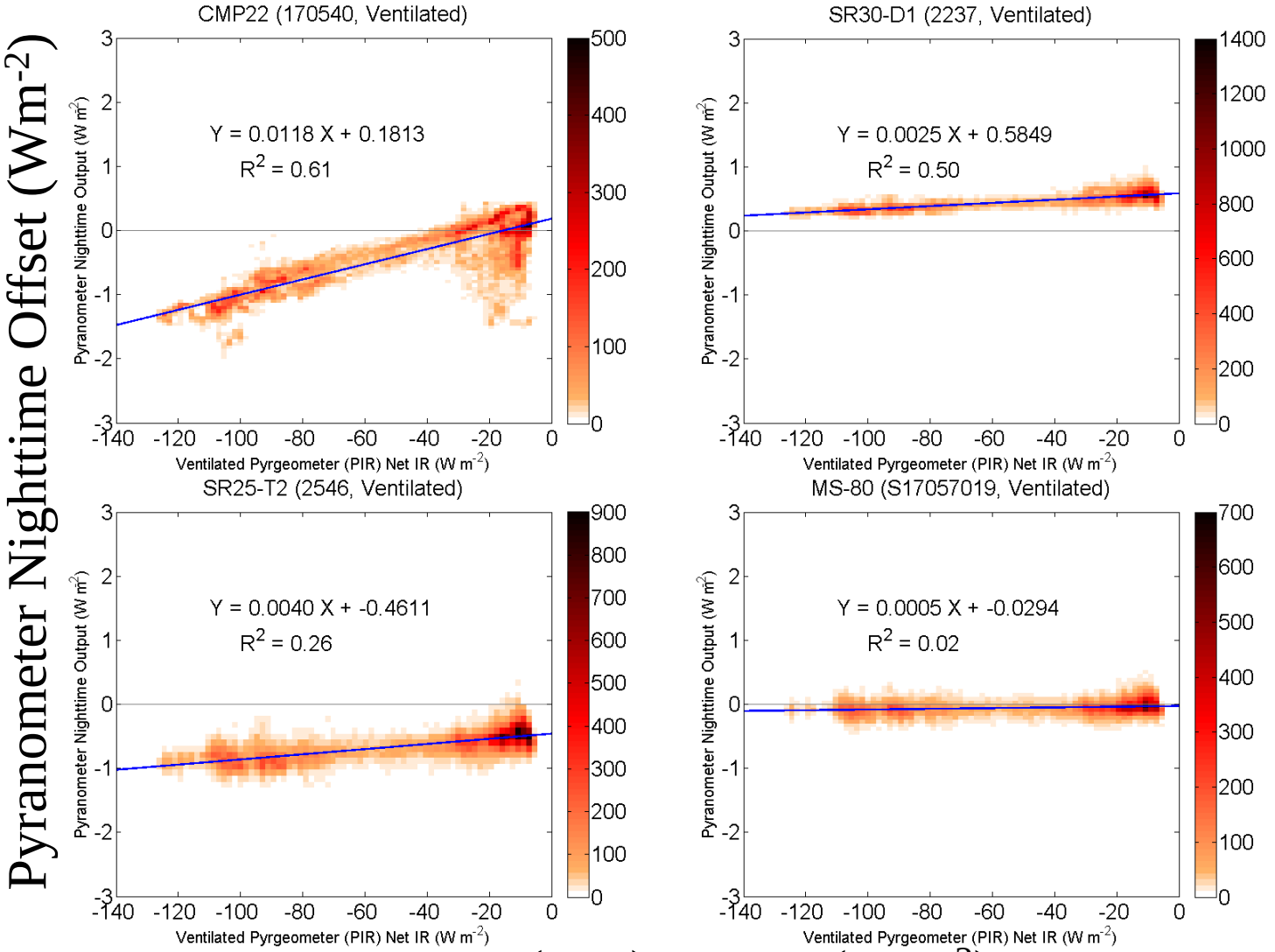
Detector only correction

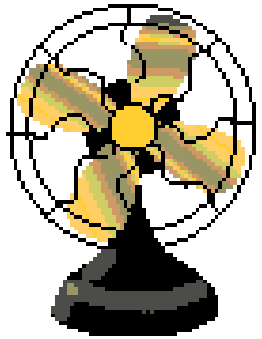
CMP22

SR25

SR30

MS80

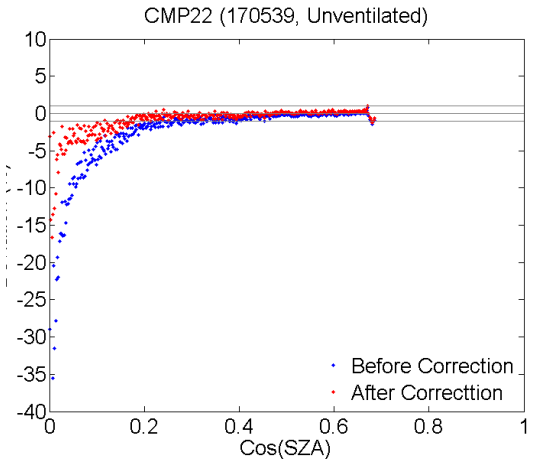


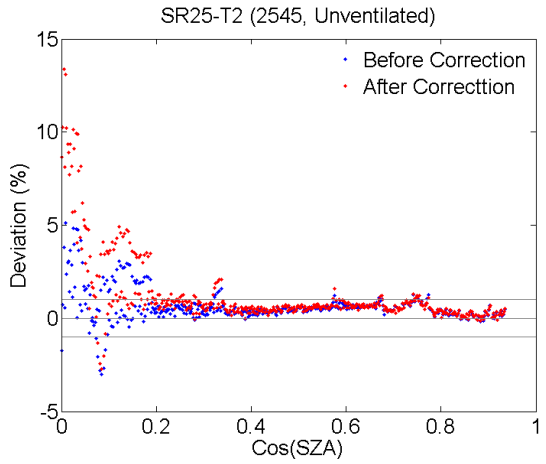


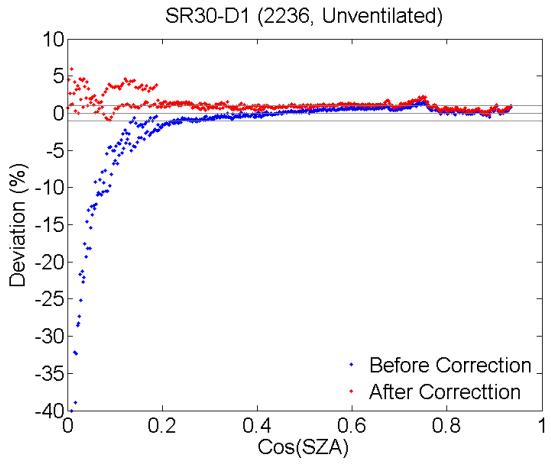
Detector Only Correction Results

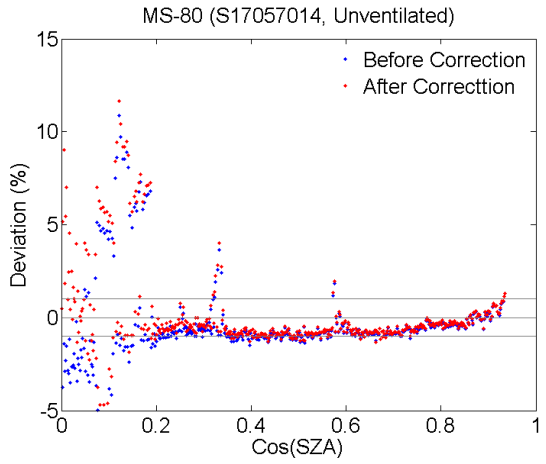
CMP22 | **SR25** | **SR30** | **MS80**

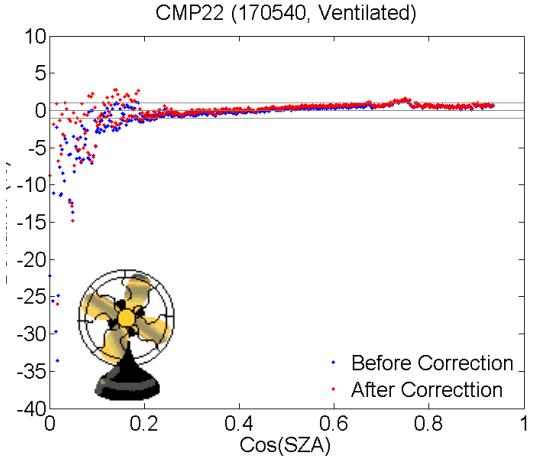
Percentage of deviation from ref. (%)

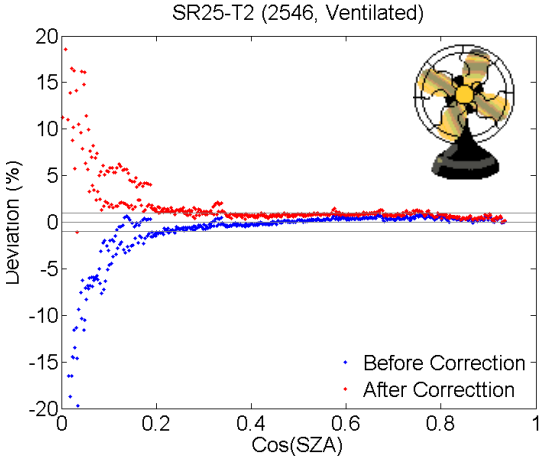


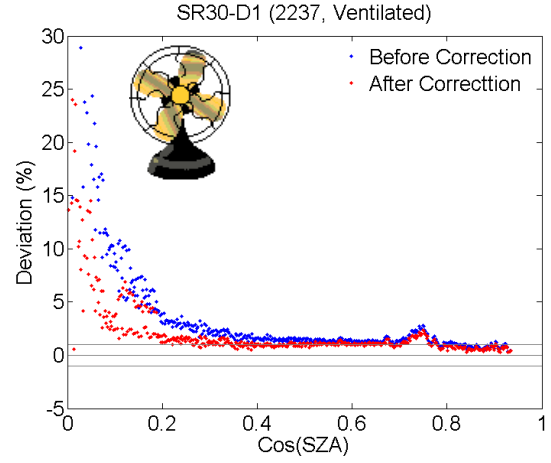


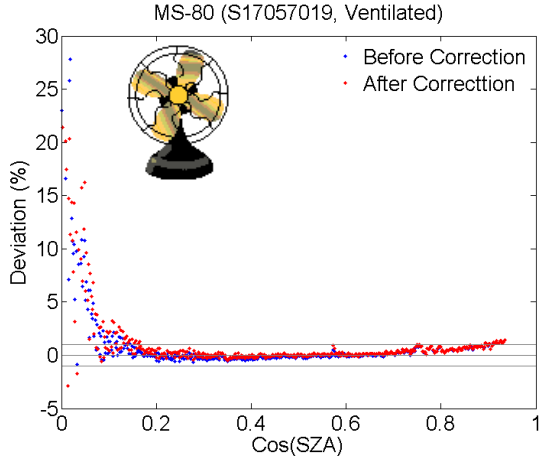










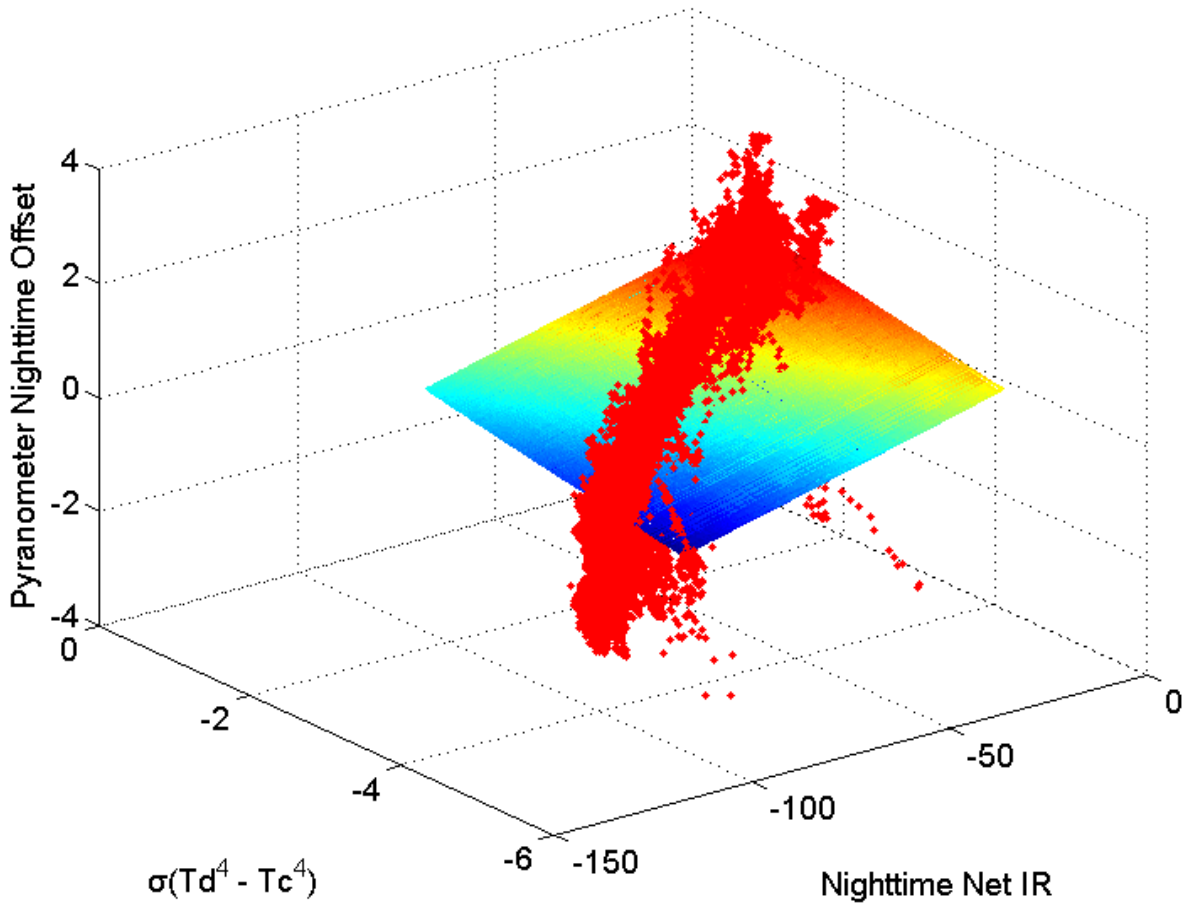


Detector Only Correction Results

Pyranometer Model	Serial Number	Ventilation (Y/N)	Mean Difference before Correction (Wm^{-2})	Mean Difference after Correction (Wm^{-2})
CMP22	170539	N	1.50	0.83
CMP22	170540	Y	1.54	1.59
MS-80	S17057014	N	1.57	1.55
MS-80	S17057019	Y	2.07	2.04
SR25-T2	2545	N	0.57	0.66
SR25-T2	2546	Y	0.91	1.14
SR30-D1	2236	N	1.01	1.25
SR30-D1	2237	Y	1.63	1.30

The values in red are the smaller mean difference from the reference for the pyranometer.

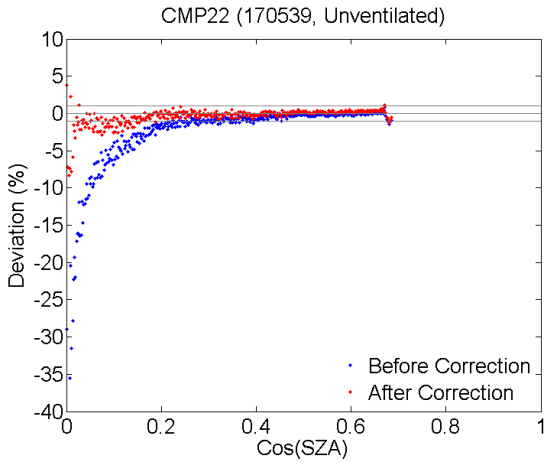
Full correction: Nighttime-fitted Model
CMP21 as example

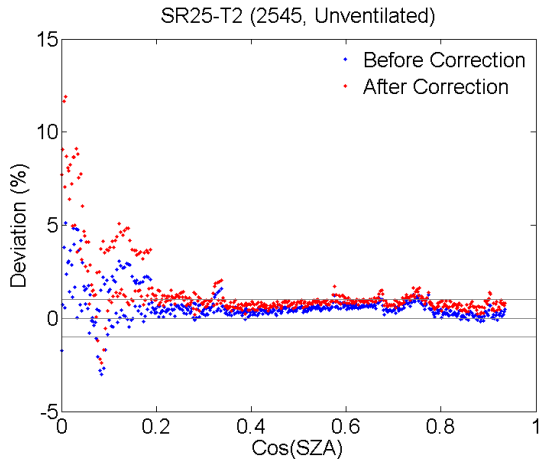


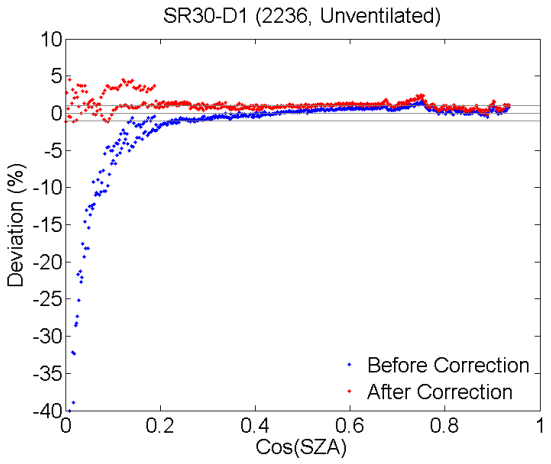
Full Correction Results

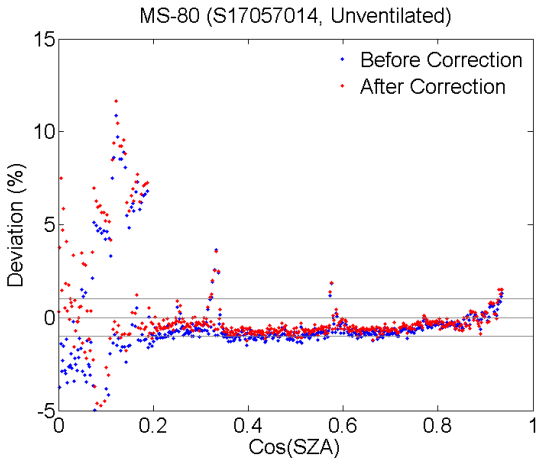
CMP22 | **SR25** | **SR30** | **MS80**

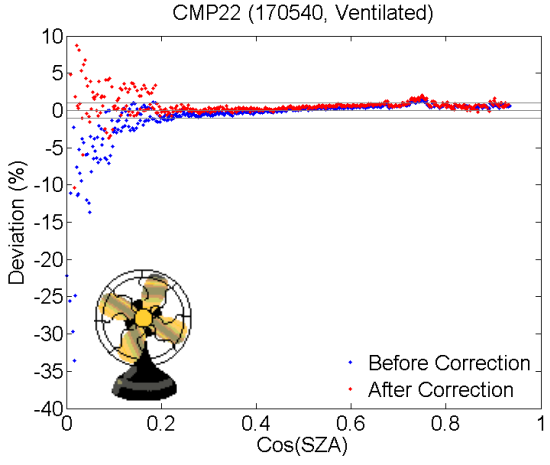
Percentage of deviation from ref. (%)

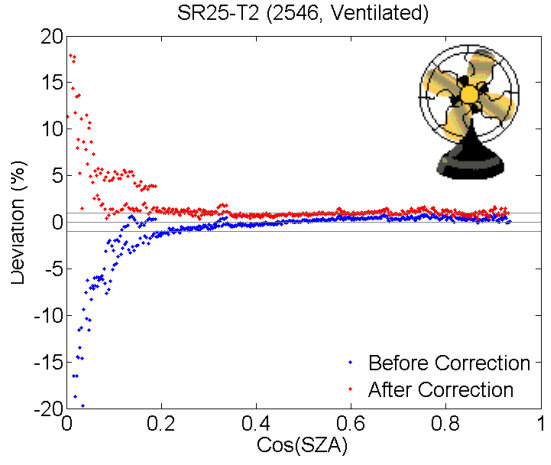


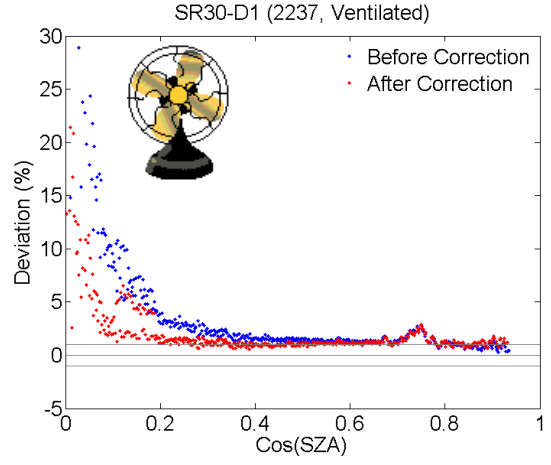


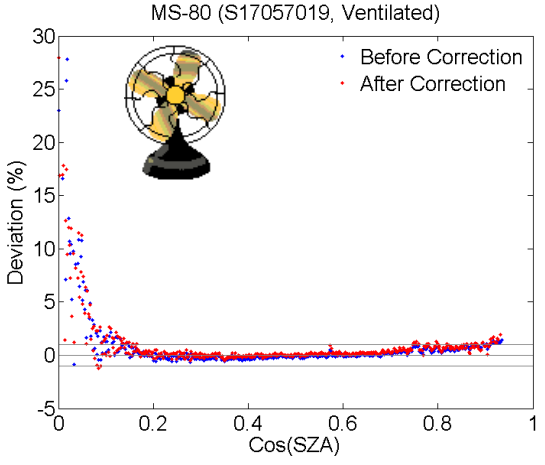












Full Correction Results

Pyranometer Model	Serial Number	Ventilation (Y/N)	Mean Difference before Correction (Wm^{-2})	Mean Difference after Correction (Wm^{-2})
CMP22	170539	N	1.50	0.77
CMP22	170540	Y	1.54	1.28
MS-80	S17057014	N	1.57	1.40
MS-80	S17057019	Y	2.07	1.81
SR25-T2	2545	N	0.57	1.43
SR25-T2	2546	Y	0.91	1.73
SR30-D1	2236	N	1.01	1.51
SR30-D1	2237	Y	1.63	1.68

The values in red are the smaller mean difference from the reference for the pyranometer.

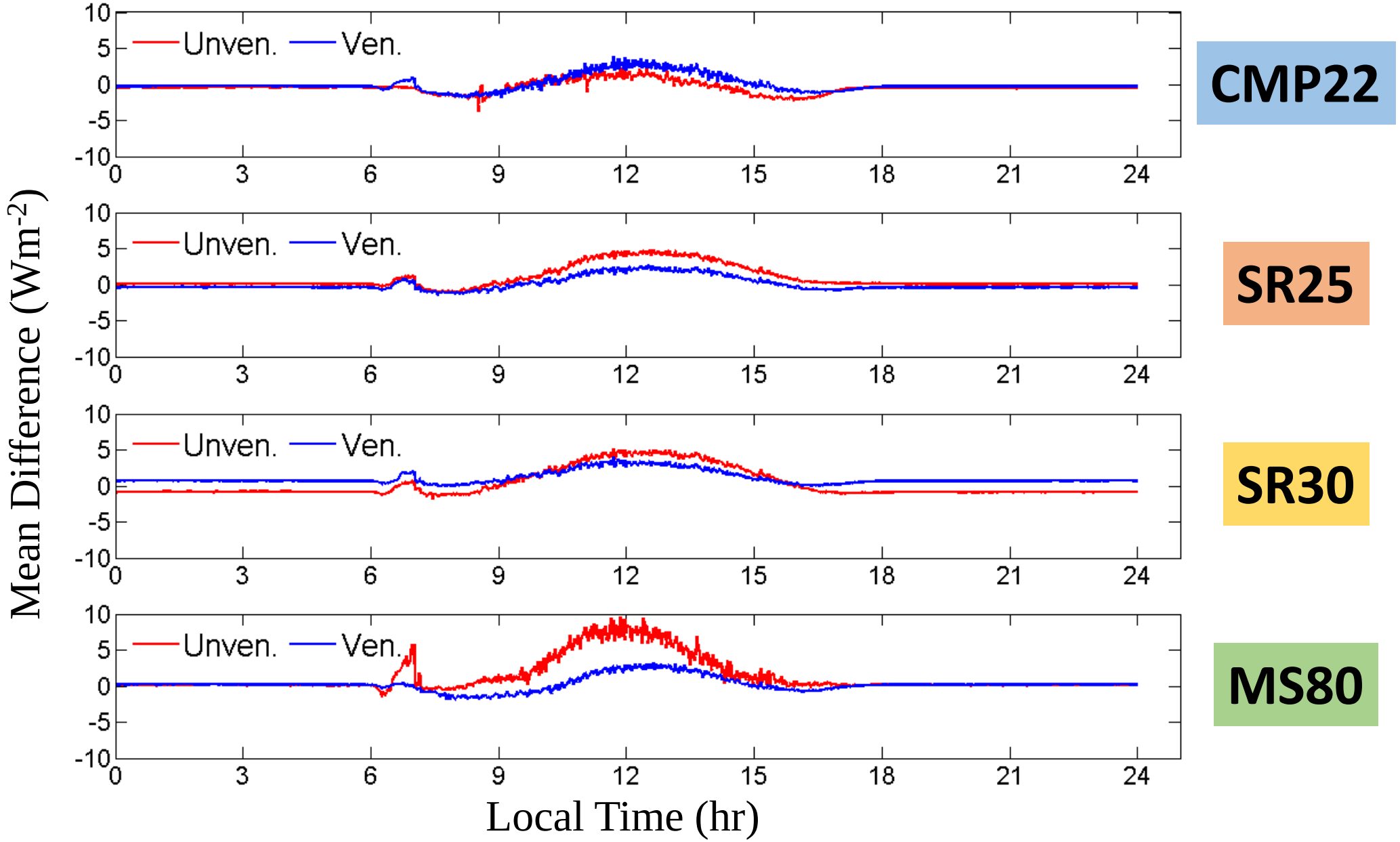
Results and Discussion

Pyranometer Model	Serial Number	Ventilation (Y/N)	Suitable Correction Method
CMP11	130616	N	Full correction
CMP11	130785	Y	Full correction
CMP21	080107	N	Full correction
CMP21	080108	Y	Full correction
CMP22	170539	N	Full correction
CMP22	170540	Y	Full correction
SR-75	73-66	N	None of the above
SR-75	73-68	Y	Full correction
MS-80	S17057014	N	Full correction
MS-80	S17057019	Y	Full correction
SR20-D2	4604	N	Detector only correction
SR20-T2	3810	Y	None of the above
SR25-T2	2545	N	None of the above
SR25-T2	2546	Y	None of the above
SR30-D1	2236	N	None of the above
SR30-D1	2237	Y	Detector only correction
EQ08-S	5069	N	None of the above
SPP	38569F3	Y	Full correction
PSP	29468F3	N	Detector only correction
PSP	34153F3	Y	Full correction

Conclusions

- **Ventilation may not guarantee to reduce the measurement mean bias.**
- **All modern pyranometers (i.e. CMP22, SR25, SR30, MS80) have significant improvement on thermal offset issue.**
- **The thermal offset play differently between pyranometer models, therefore we identify a suitable correction method for each pyranometer.**
- **The full correction method is suitable for more than half the pyranometers in the experiment because the method can obtain more information about the thermal exchange in a pyranometer.**

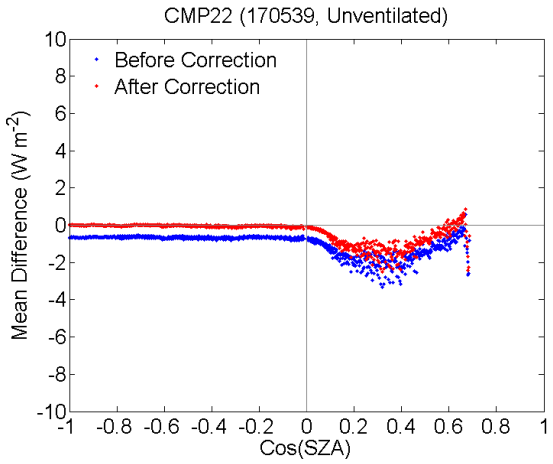
Thank you for your attention!

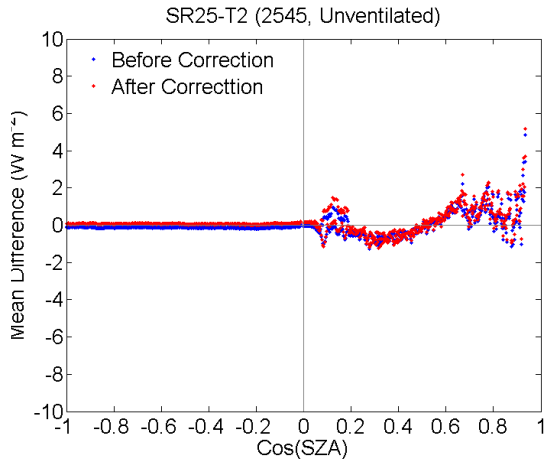

Mean Difference (Wm-2)
Unven.
Ven.
10
5
0
-5
-10
0
3
6
9
12
15
18
21
24
Local Time (hr)
CMP22
SR25
SR30
MS80

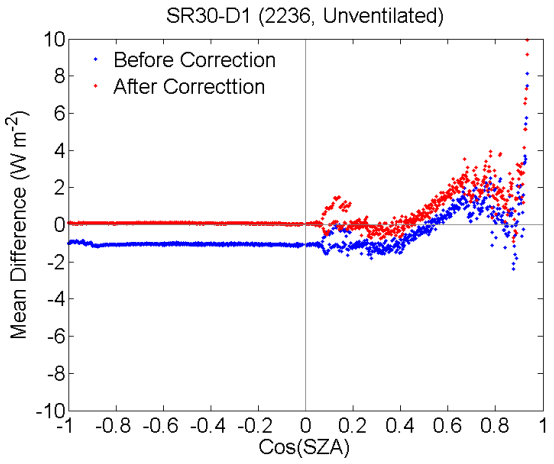
Detector Only Correction Results

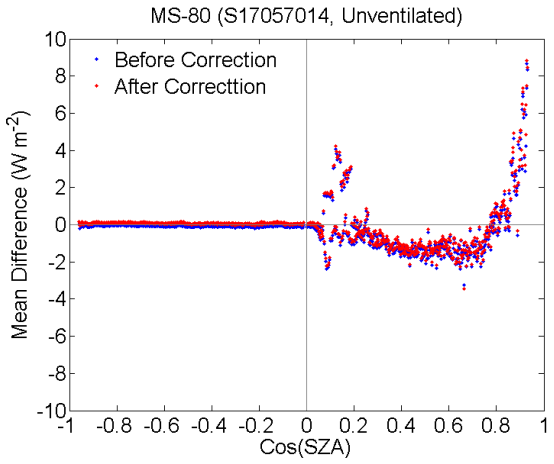
CMP22 | **SR25** | **SR30** | **MS80**

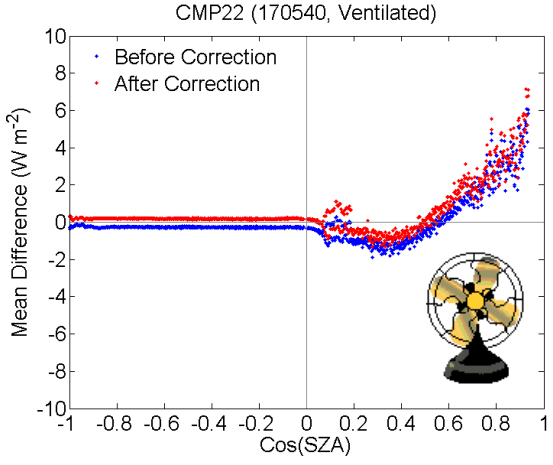
Mean Difference (Wm^{-2})

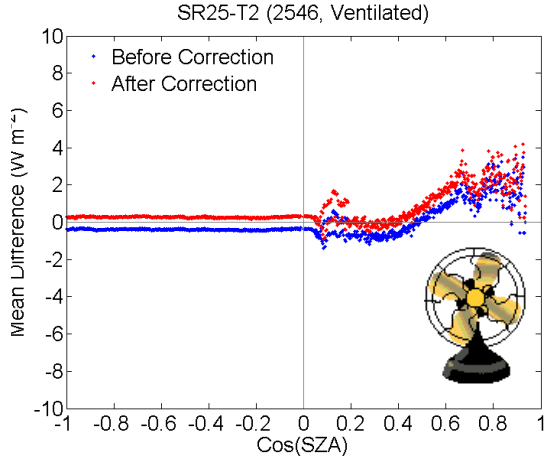


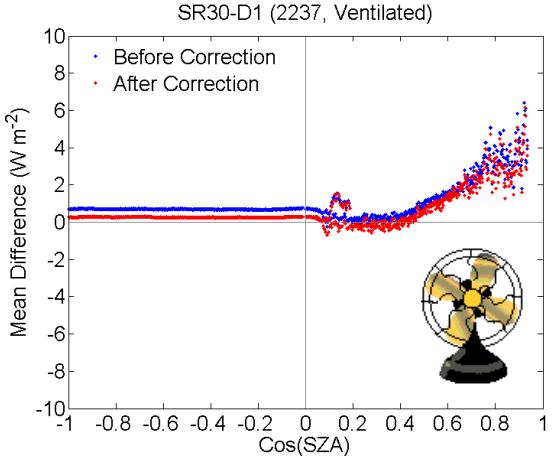


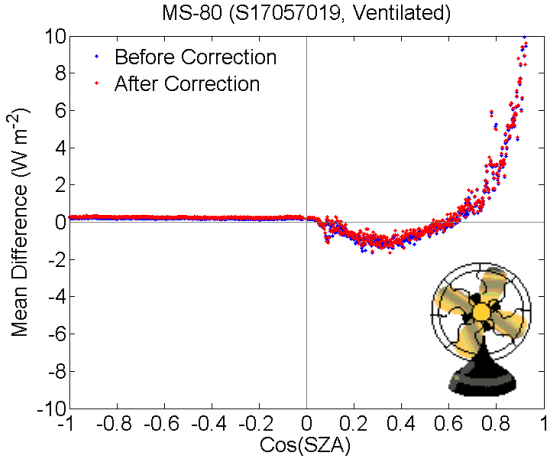








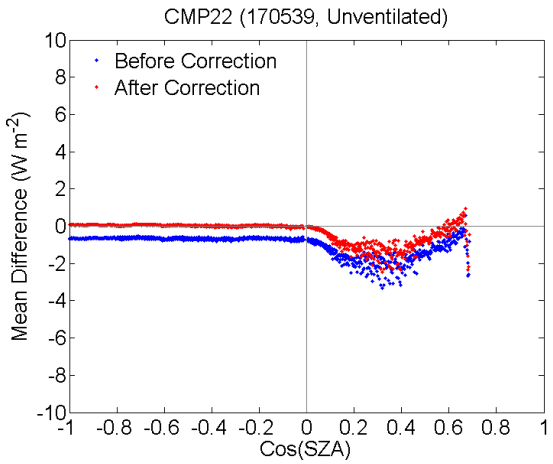


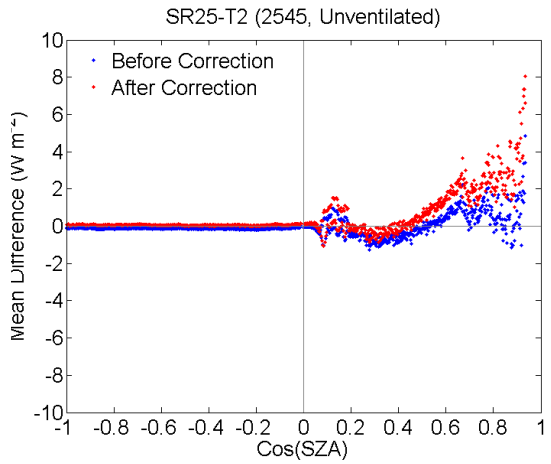


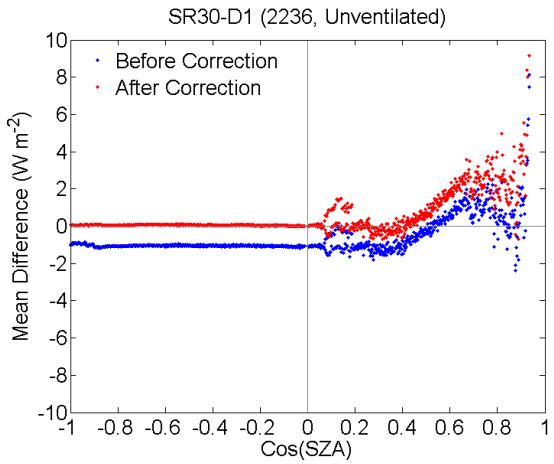
Full Correction Results

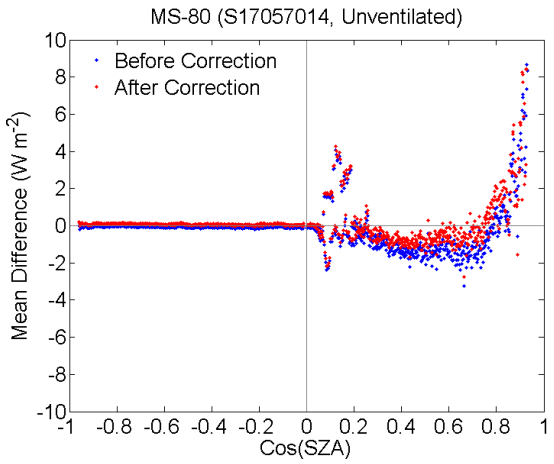
CMP22 | **SR25** | **SR30** | **MS80**

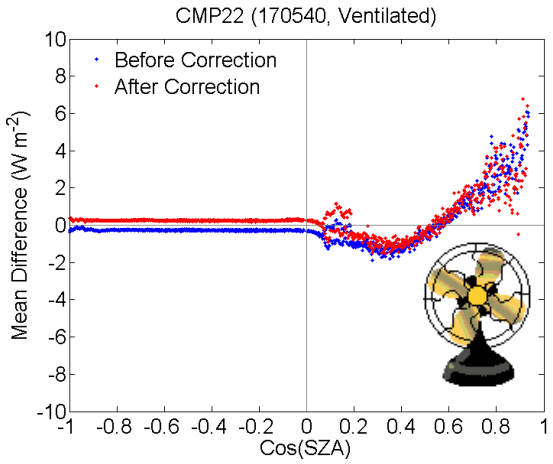
Mean Difference (Wm^{-2})

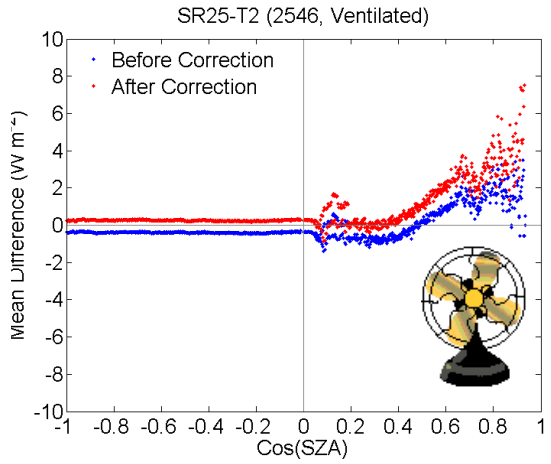


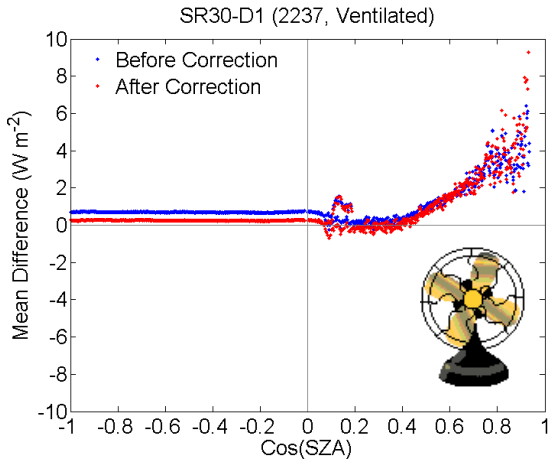


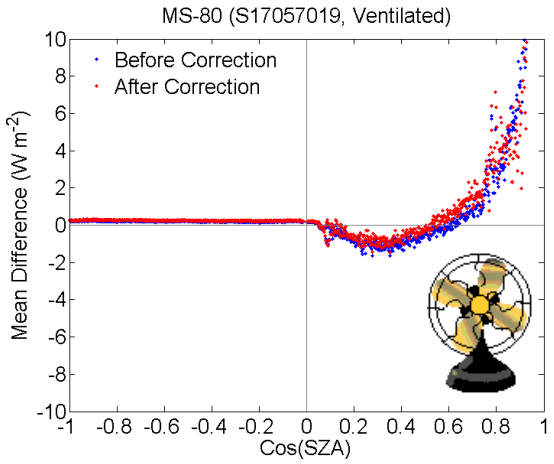












下表為: Mean values and standard deviation (SD) of the magnitudes of daytime (cos(SZA) > 0) thermal offset for each pyranometers.

除了SR-75與SR20(紅字)兩種型號，其他型號在通風時的thermal offset都是比無通風時小的。其中通風的SR25-T2, MS-80, CMP22之thermal offset最小(綠字)。

Pyranometer Model	Serial Number	Ventilation (Y/N)	Mean (Wm^{-2})	SD (Wm^{-2})
CMP11	130616	N	0.61	0.66
CMP11	130785	Y	0.50	0.41
CMP21	080107	N	0.76	0.41
CMP21	080108	Y	0.64	0.37
CMP22	170539	N	0.84	0.53
CMP22	170540	Y	**0.35**	0.31
SR-75	73-66	N	0.81	0.70
SR-75	73-68	Y	1.91	0.36
MS-80	S17057014	N	0.56	0.45
MS-80	S17057019	Y	**0.30**	0.26
SR20-D2	4604	N	1.08	0.48
SR20-T2	3810	Y	1.91	0.49
SR25-T2	2545	N	0.68	0.16
SR25-T2	2546	Y	**0.20**	0.13
SR30-D1	2236	N	1.22	0.60
SR30-D1	2237	Y	0.45	0.10
EQ08-S	5069	N	0.69	0.71
SPP	38569F3	Y	0.96	0.69
PSP	29468F3	N	1.45	1.17
PSP	34153F3	Y	1.03	0.72

Detector Only Correction Results

The values in red are the smaller mean difference from the reference for the pyranometer.

Pyranometer Model	Serial Number	Ventilation (Y/N)	Mean Difference before Correction (Wm^{-2})	Mean Difference after Correction (Wm^{-2})
CMP11	130616	N	1.50	1.59
CMP11	130785	Y	2.25	2.48
CMP21	080107	N	1.85	1.92
CMP21	080108	Y	4.80	3.64
CMP22	170539	N	1.50	0.83
CMP22	170540	Y	1.54	1.59
SR-75	73-66	N	3.62	3.69
SR-75	73-68	Y	3.59	2.80
MS-80	S17057014	N	1.57	1.55
MS-80	S17057019	Y	2.07	2.04
SR20-D2	4604	N	1.89	1.79
SR20-T2	3810	Y	1.88	3.28
SR25-T2	2545	N	0.57	0.66
SR25-T2	2546	Y	0.91	1.14
SR30-D1	2236	N	1.01	1.25
SR30-D1	2237	Y	1.63	1.30
EQ08-S	5069	N	5.74	6.79
SPP	38569F3	Y	3.61	3.78
PSP	29468F3	N	2.97	1.93
PSP	34153F3	Y	6.05	6.35

Full Correction Results

The values in red are the smaller mean difference from the reference for the pyranometer.

Pyranometer Model	Serial Number	Ventilation (Y/N)	Mean Difference before Correction (Wm^{-2})	Mean Difference after Correction (Wm^{-2})
CMP11	130616	N	1.50	1.06
CMP11	130785	Y	2.25	1.85
CMP21	080107	N	1.85	1.57
CMP21	080108	Y	4.80	3.14
CMP22	170539	N	1.50	0.77
CMP22	170540	Y	1.54	1.28
SR-75	73-66	N	3.62	4.31
SR-75	73-68	Y	3.59	2.24
MS-80	S17057014	N	1.57	1.40
MS-80	S17057019	Y	2.07	1.81
SR20-D2	4604	N	1.89	2.15
SR20-T2	3810	Y	1.88	3.91
SR25-T2	2545	N	0.57	1.43
SR25-T2	2546	Y	0.91	1.73
SR30-D1	2236	N	1.01	1.51
SR30-D1	2237	Y	1.63	1.68
EQ08-S	5069	N	5.74	6.24
SPP	38569F3	Y	3.61	2.10
PSP	29468F3	N	2.97	2.75
PSP	34153F3	Y	6.05	3.54