An Extensive, All-Weather Comparison of Pyrheliometers

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Presenting

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David Halliwell, Meteorological Service of Canada
Eppley Laboratory
Hukseflux
Kipp and Zonen
Middleton Solar

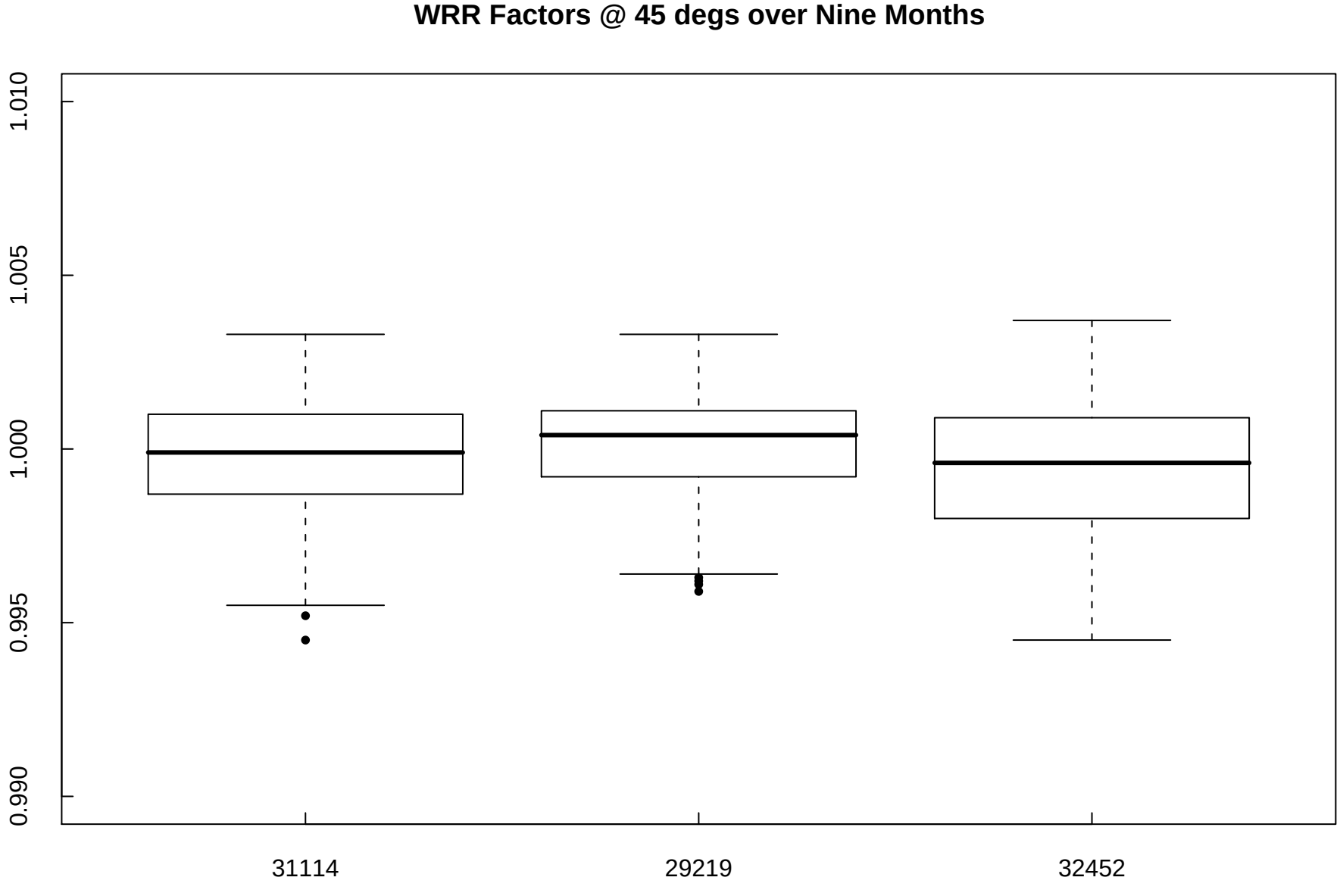
- Ideally, direct normal irradiance (DNI) should be measured by an open cavity radiometer
- Direct normal irradiance is the source of the largest uncertainty in solar measurements

Experiment (Various Conditions Pyrheliometer Comparison - VCPC)

- Ten-month comparison of 33 pyrheliometers
- Site was NREL's Solar Radiation Research Laboratory
- Cleaned on weekdays
- One-minute averages of two-second samples
- 29 pyrheliometers compared to three windowed cavities during comparison
- Approximately monthly calibrations with open cavities that are traceable to WRR
- If temperature correction provided, it was applied

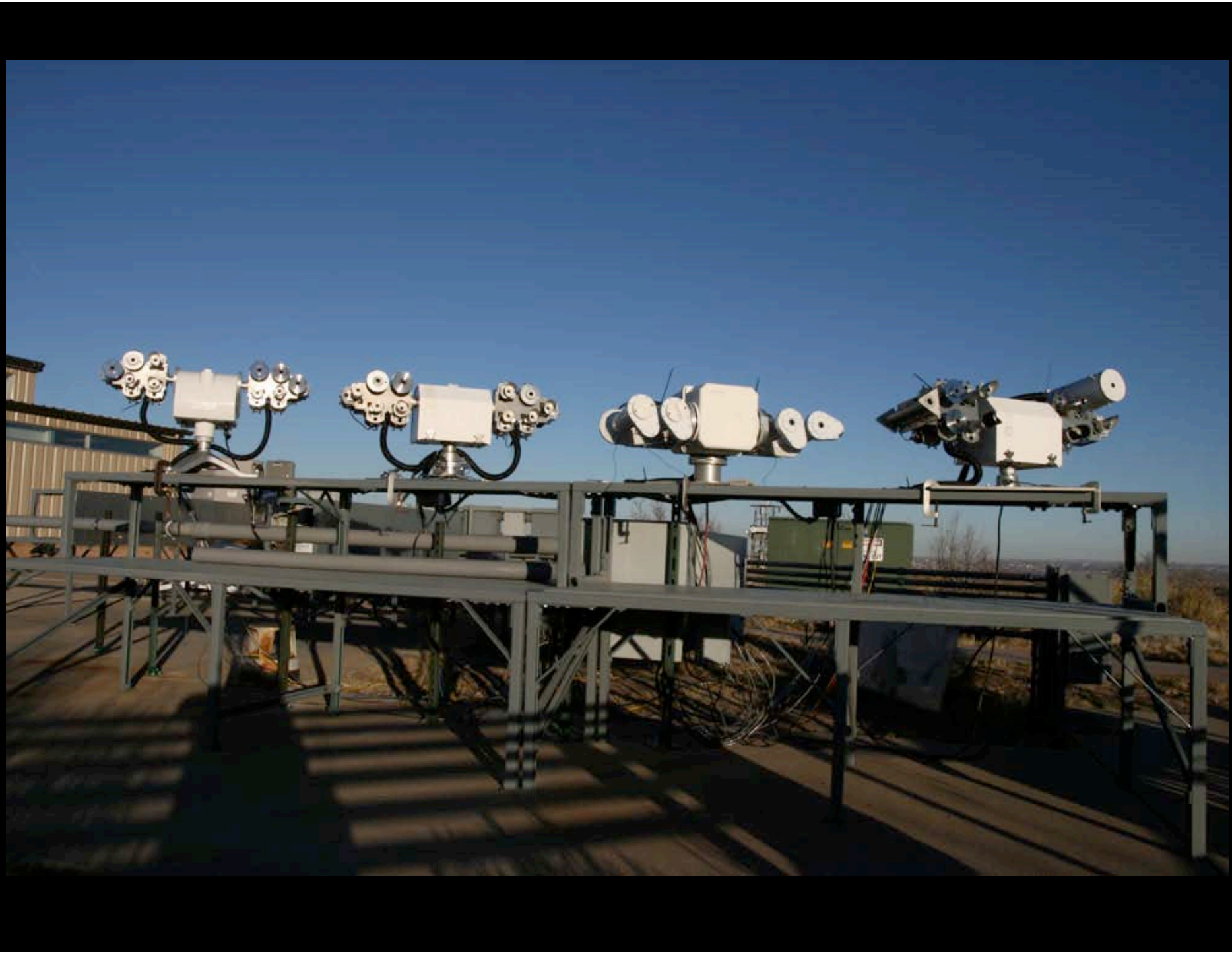
More on Calibrations

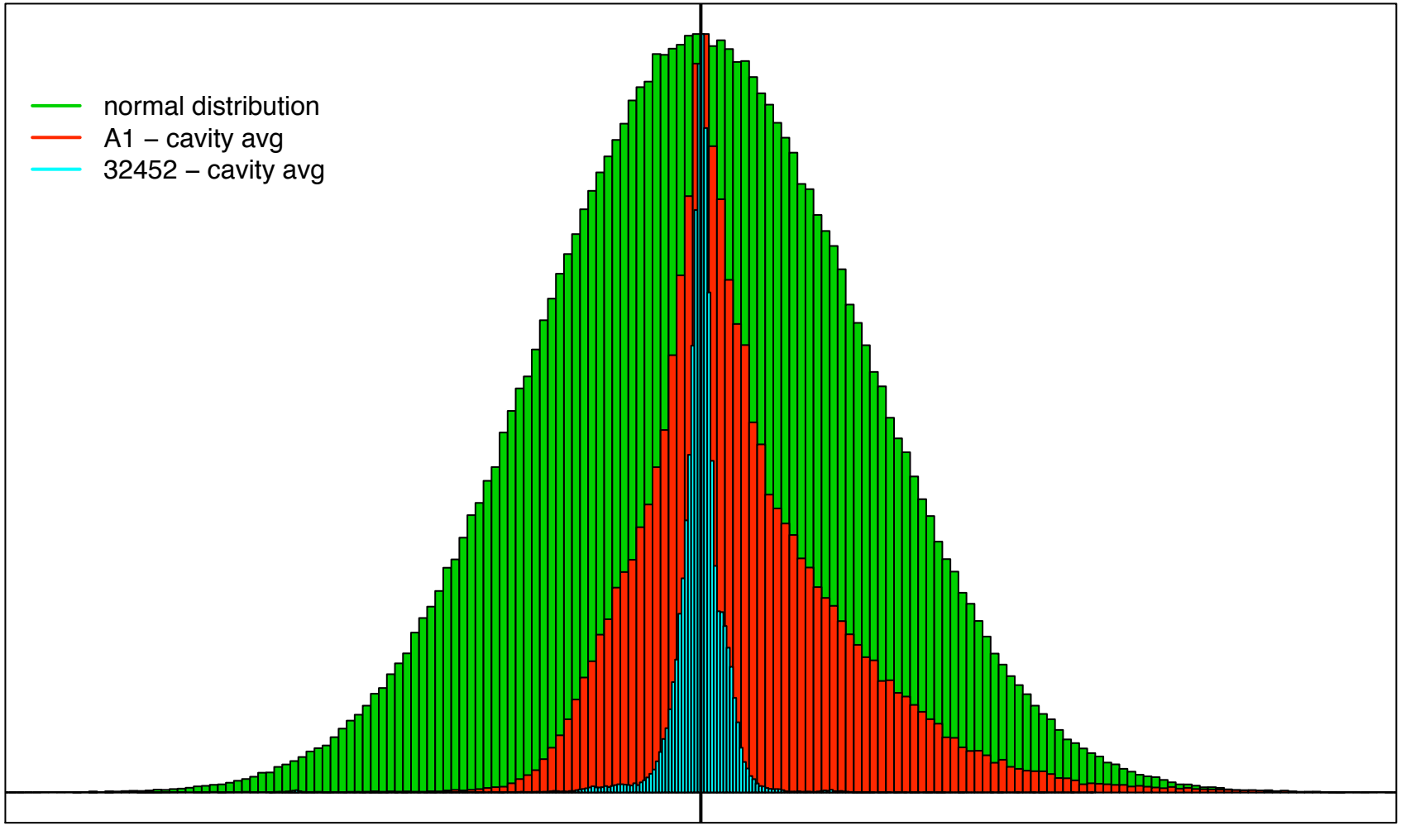
- Four open cavities
- Almost monthly open-cavity calibrations
- Electrical calibration was performed every 20 minutes
- Average calibration at 45° from the monthly calibrations used for the entire data set
- Between open-windowed calibrations the average of three windowed cavities was the standard

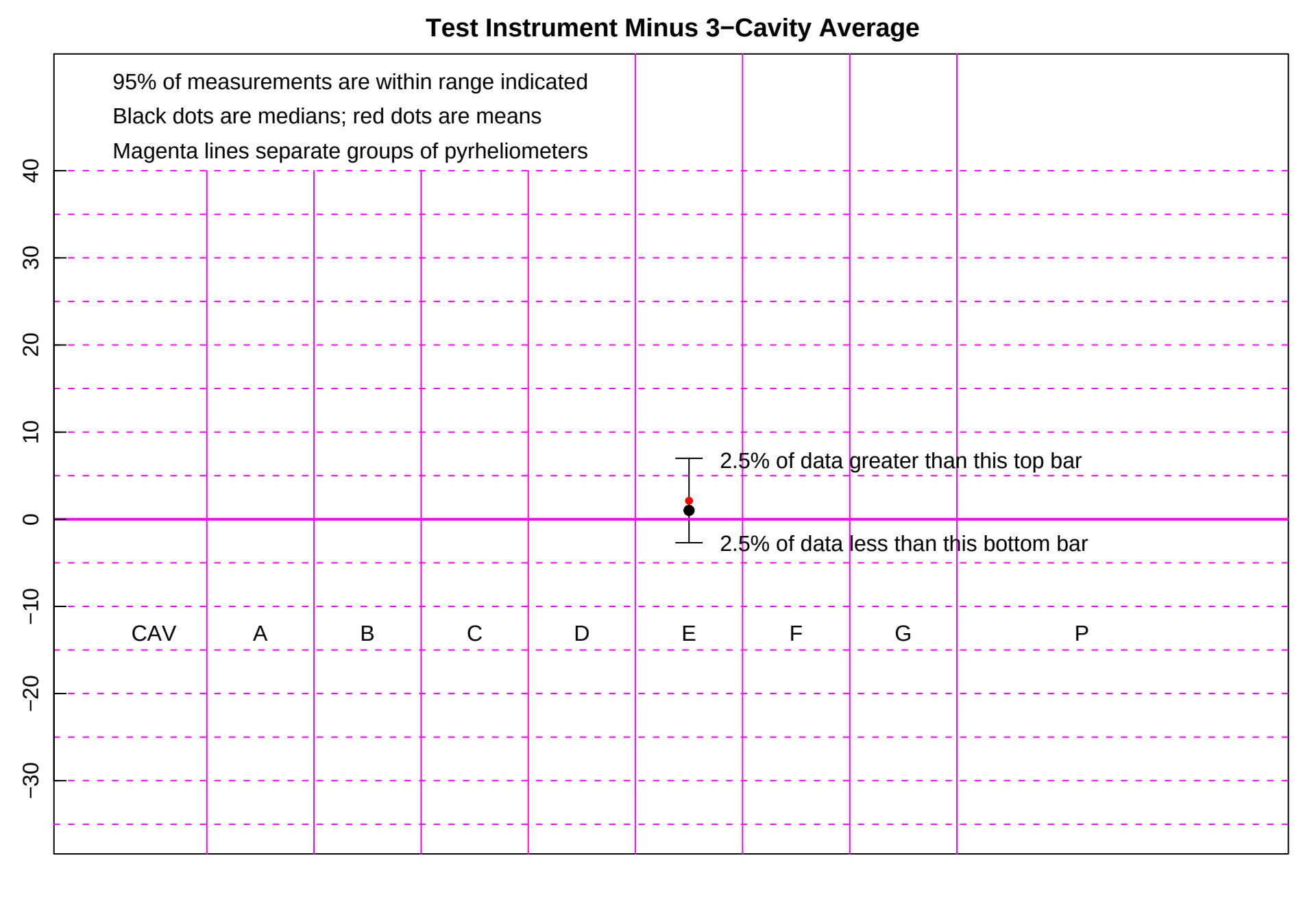

WRR Factors @ 45 degs over Nine Months
1.010
1.005
1.000
0.995
0.990
31114
29219
32452

How is this different from other comparisons (IPC's and NPC's)?

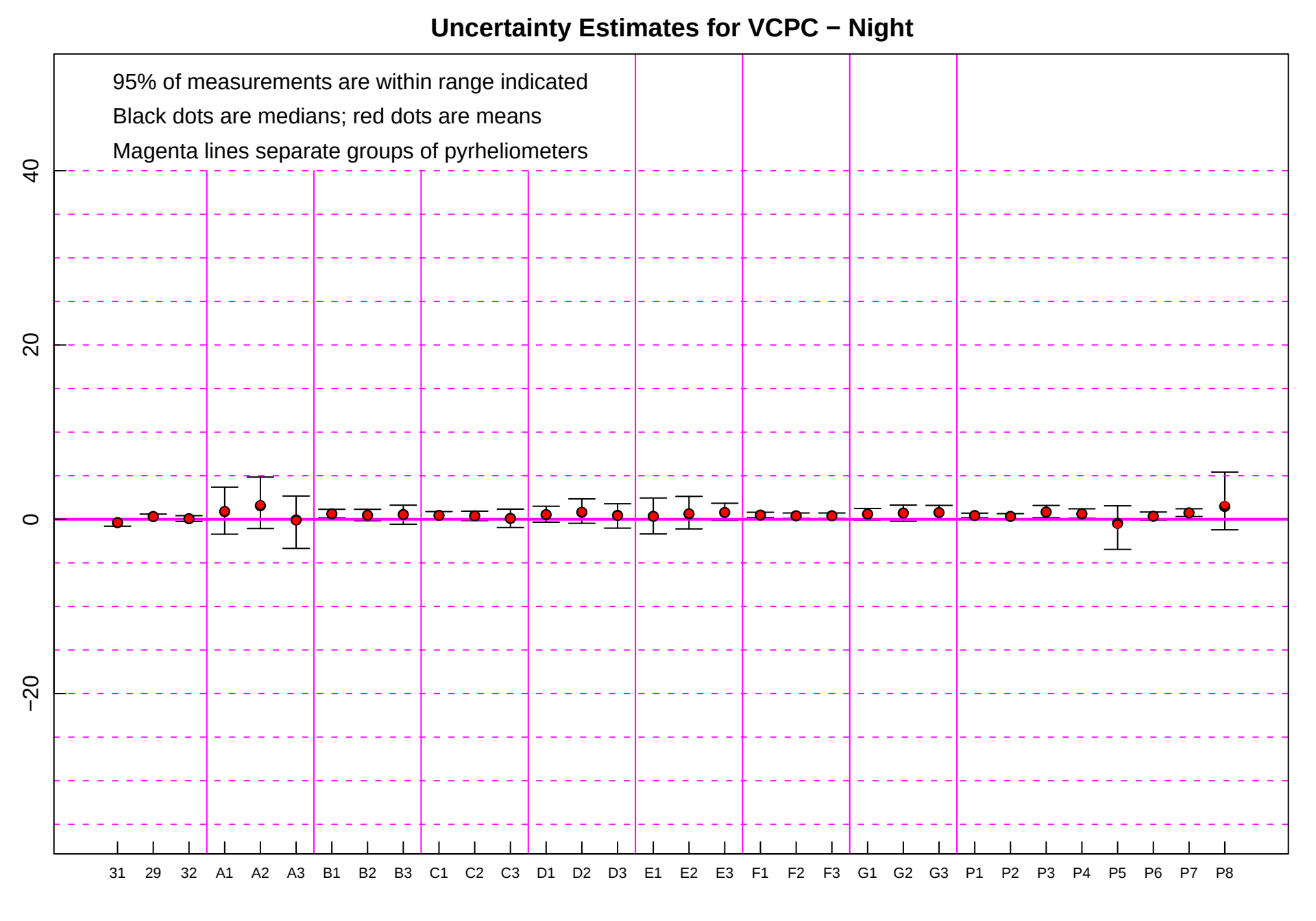
- IPCs are clear (direct > 700 W/m^2), calm, and with no hint of clouds
- VCPC was all-sky conditions (clear --> cloudy)
- Lasted 10 months, therefore, all seasons, temperatures, wind conditions, typical of mid-latitude, continental conditions
- Anonymous analysis




normal distribution
A1 – cavity avg
32452 – cavity avg


Test Instrument Minus 3−Cavity Average
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
30
20
10
0
−10
−20
−30
2.5% of data greater than this top bar
2.5% of data less than this bottom bar
CAV
A
B
C
D
E
F
G
P

Conditions	Criteria	313000	Mean Direct
Night	**sza > 91.2 degs**	**160000**	**< 1 W/m^2**
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Night
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	**sza < 91.2 degs & direct < 4 W/m^2**	**44000**	**< 1 W/m^2**
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
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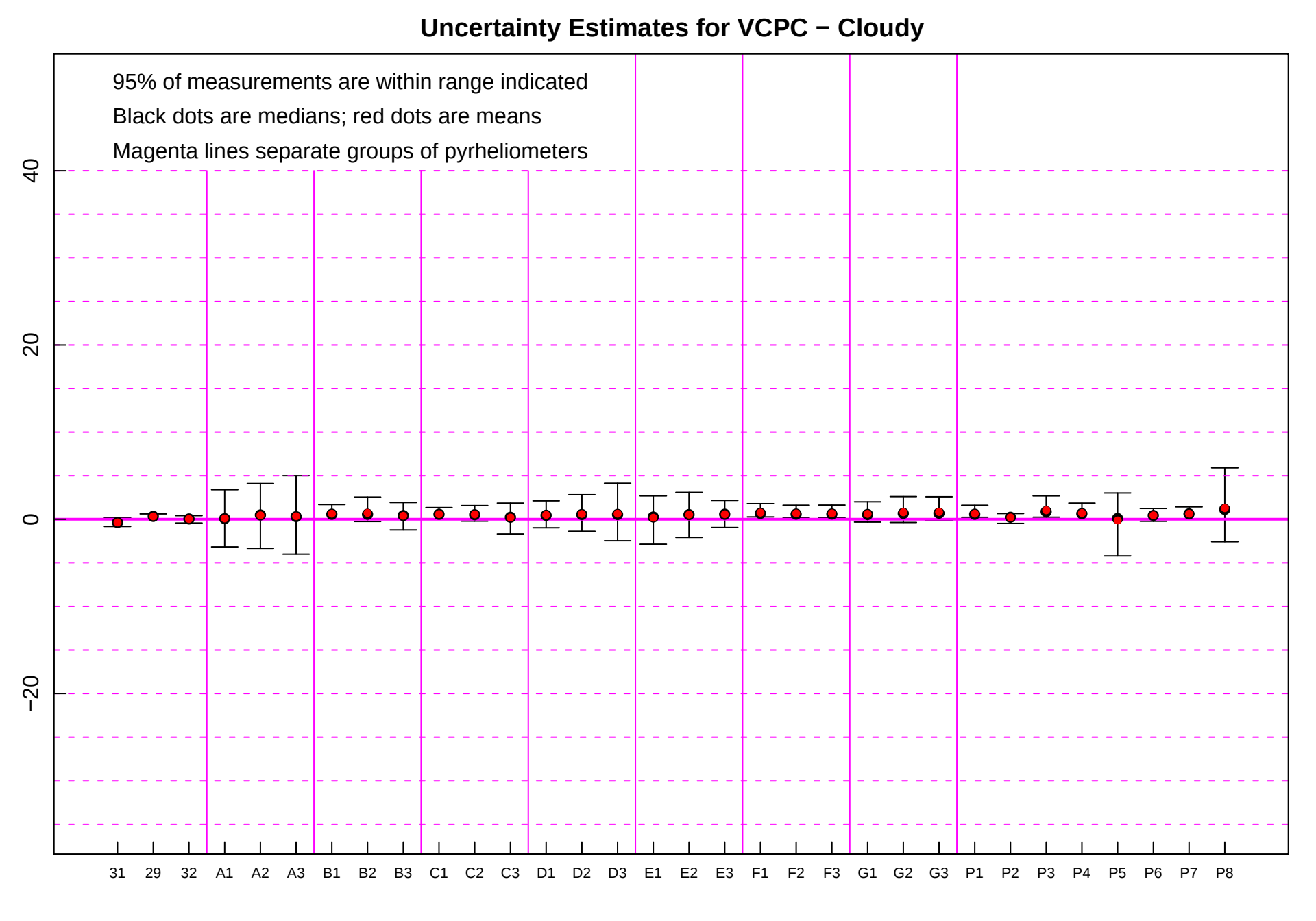
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Cloudy
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	**sza < 91.2 degs**	**154000**	**410 W/m^2**
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
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Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
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Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
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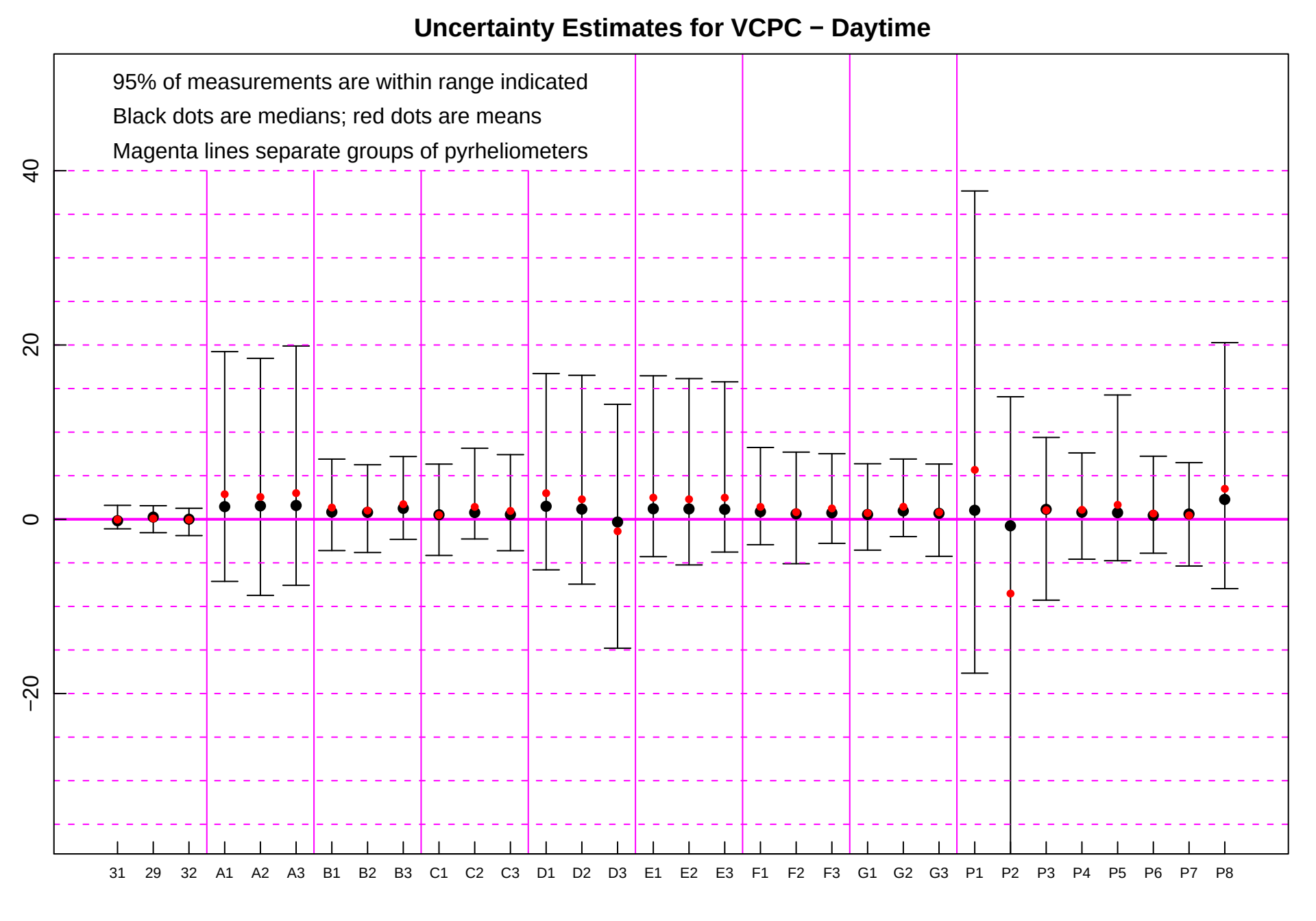
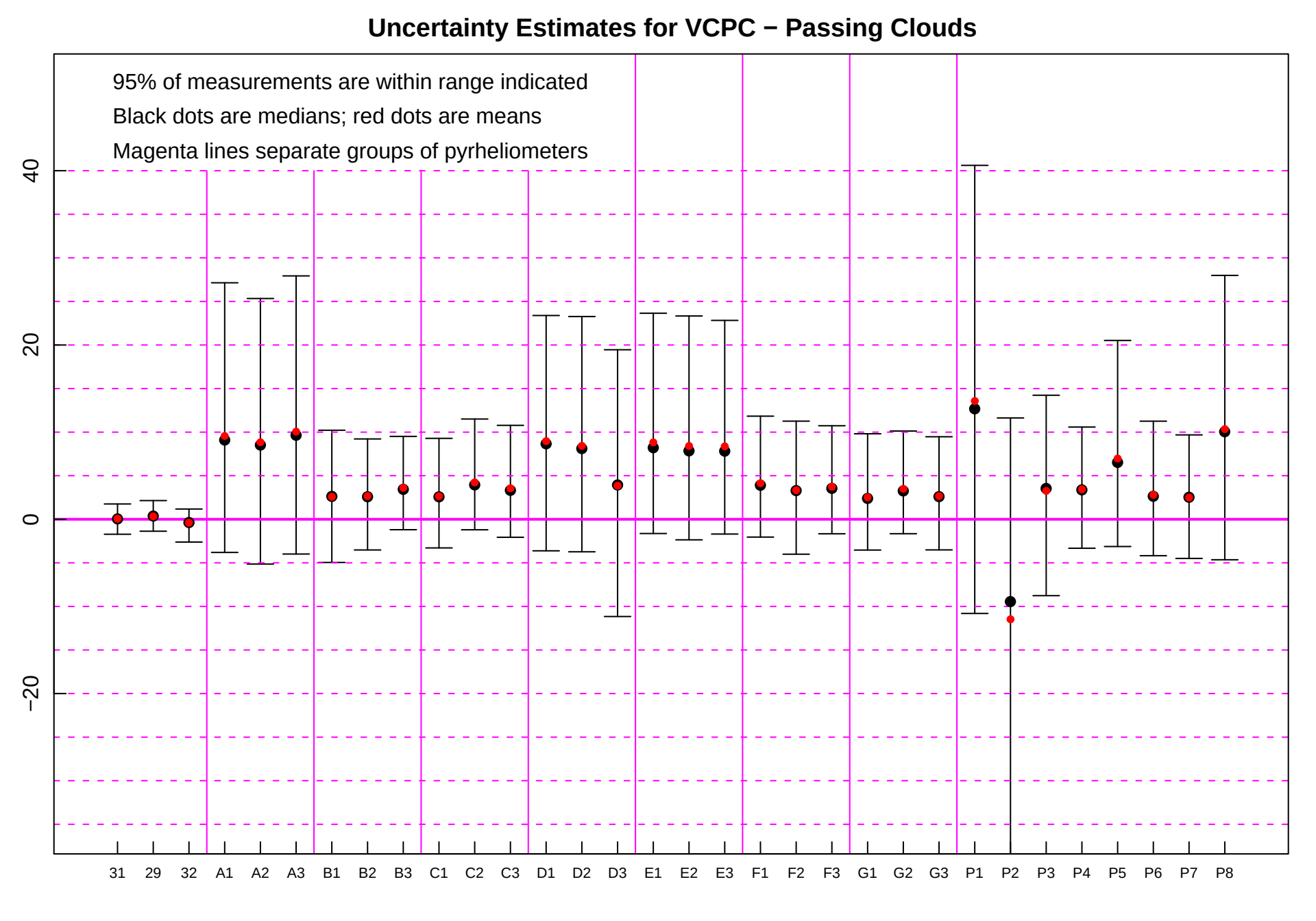
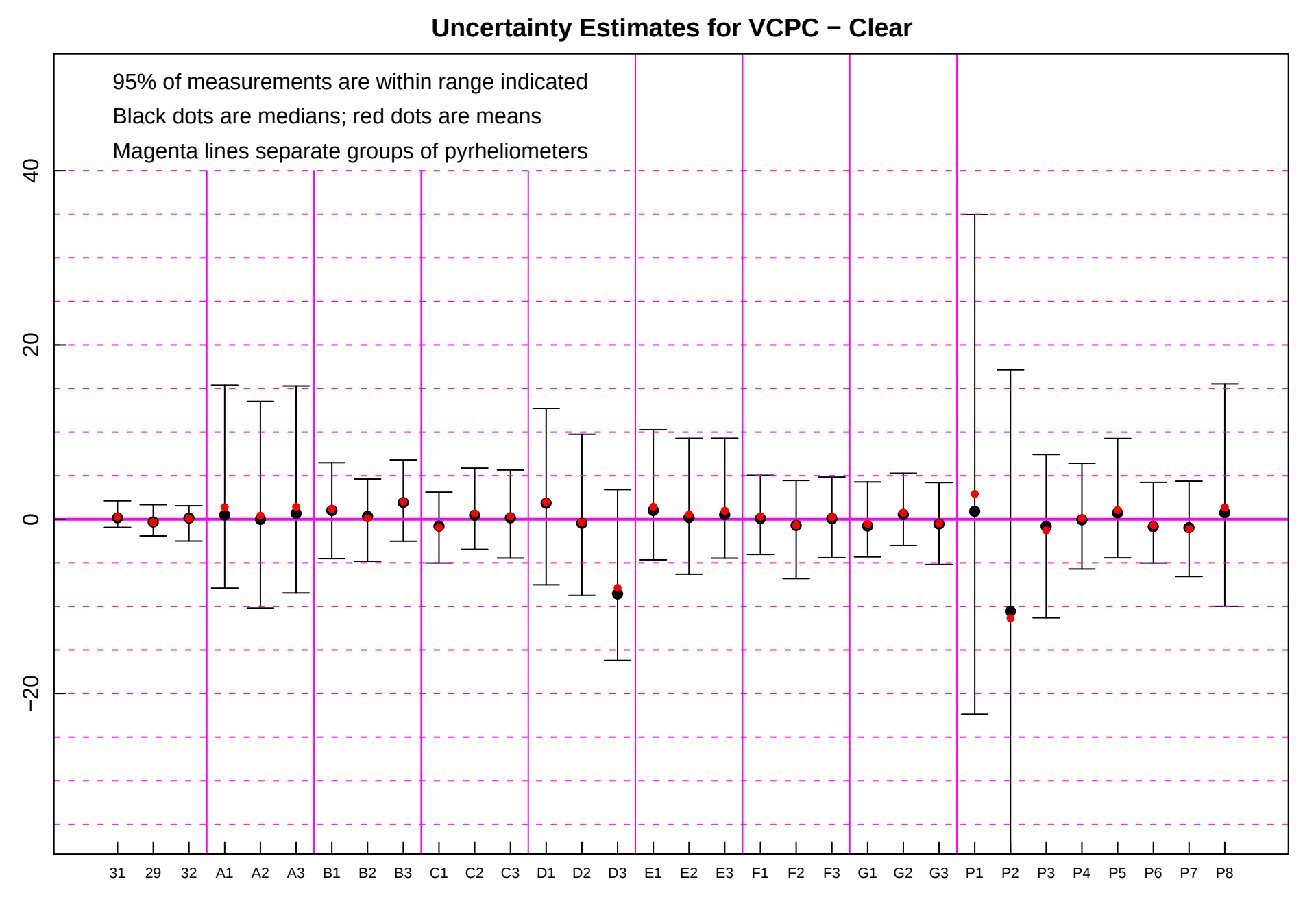

Uncertainty Estimates for VCPC − Daytime
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

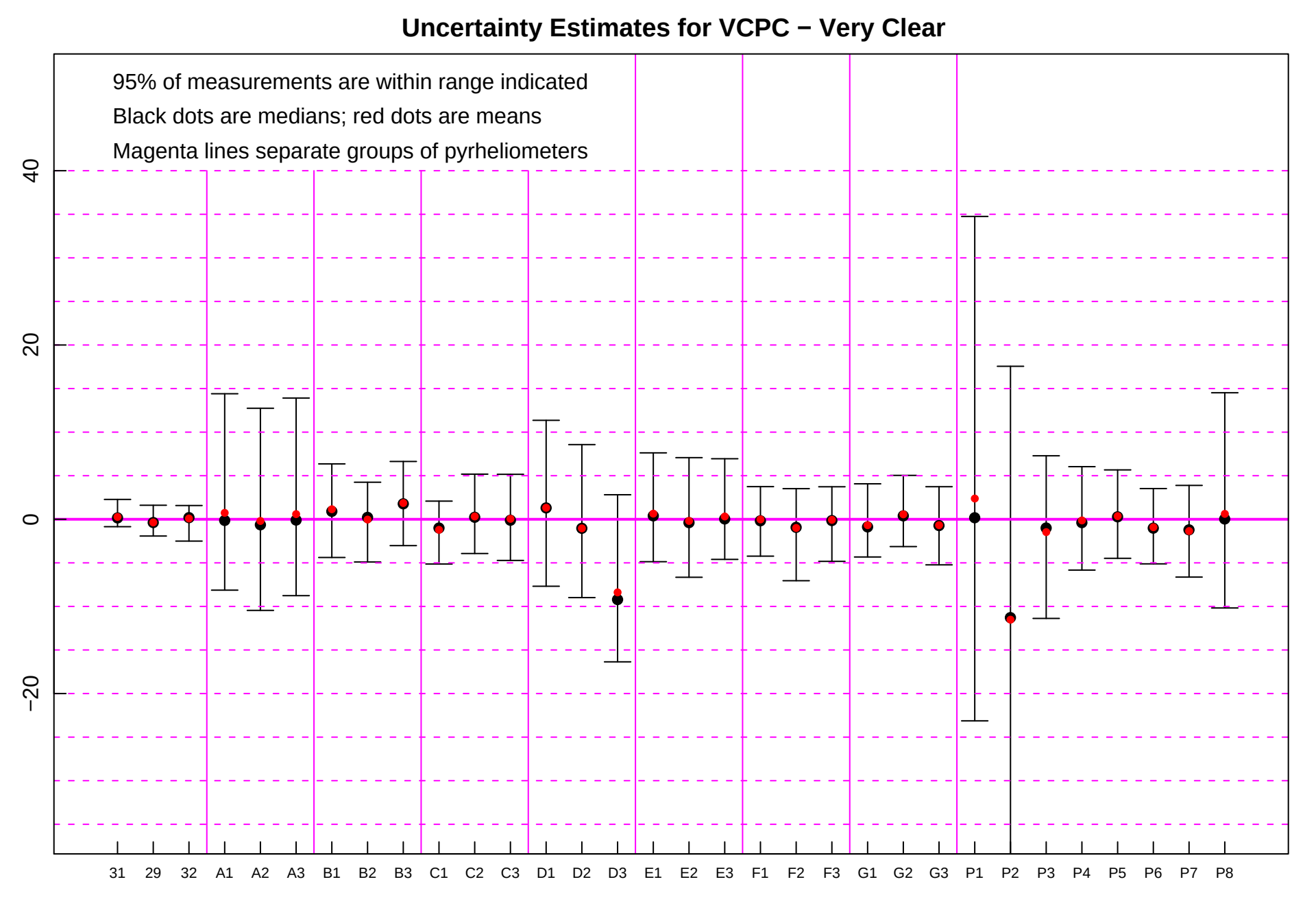
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	**sza < 91.2 & direct > 50 & stddev > 10**	**23000**	**476 W/m^2**
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Passing Clouds
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

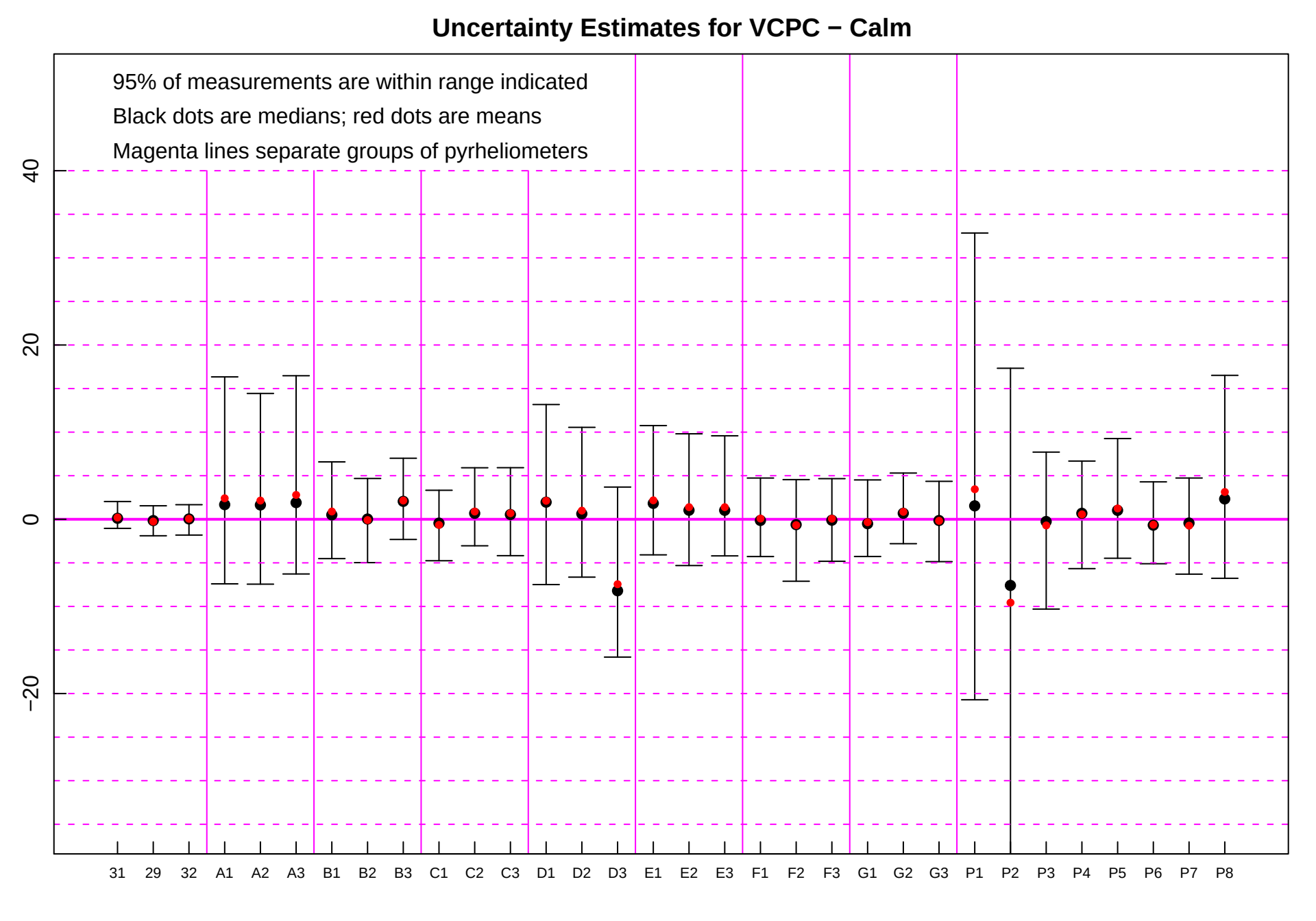
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	**sza < 91.2 & direct > 700**	**56000**	**903 W/m^2**
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Clear
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

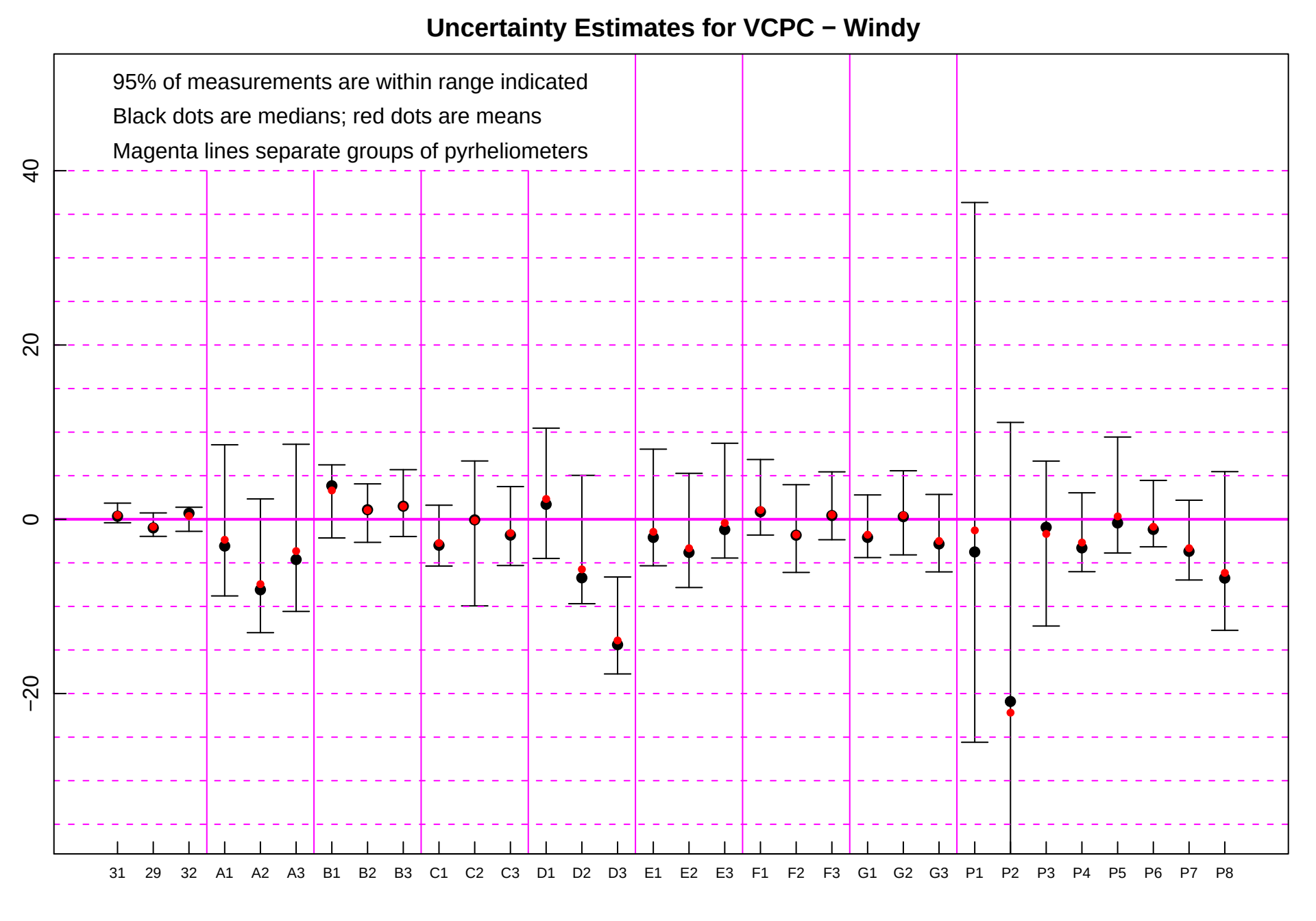
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	**sza < 91.2 & direct > 700 & stddev < 2 W/m^2**	**41000**	**918 W/m^2**
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Very Clear
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

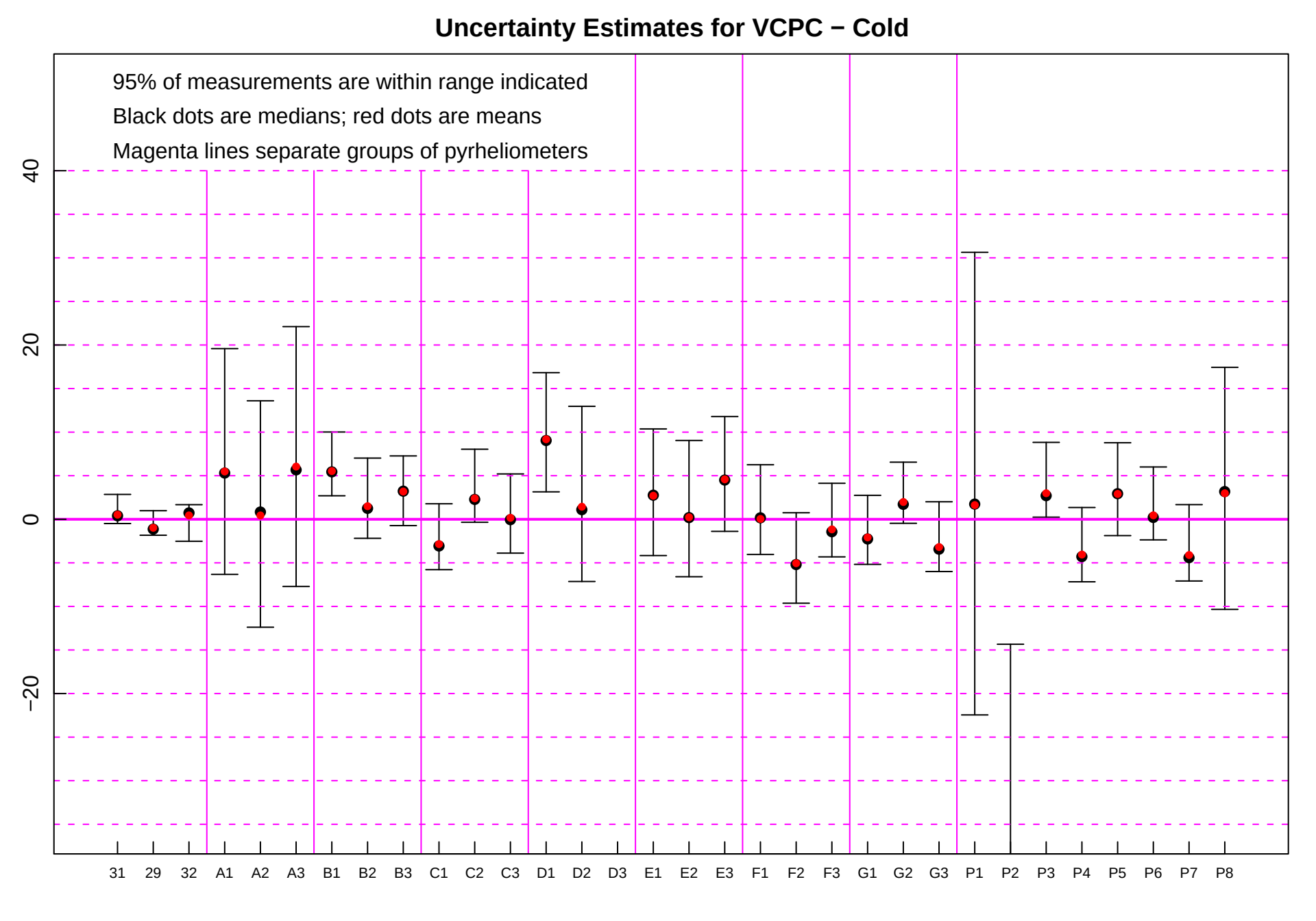
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	**sza < 91.2 & direct > 700 & ws < 2 m/s**	**39000**	**894 W/m^2**
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Calm
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

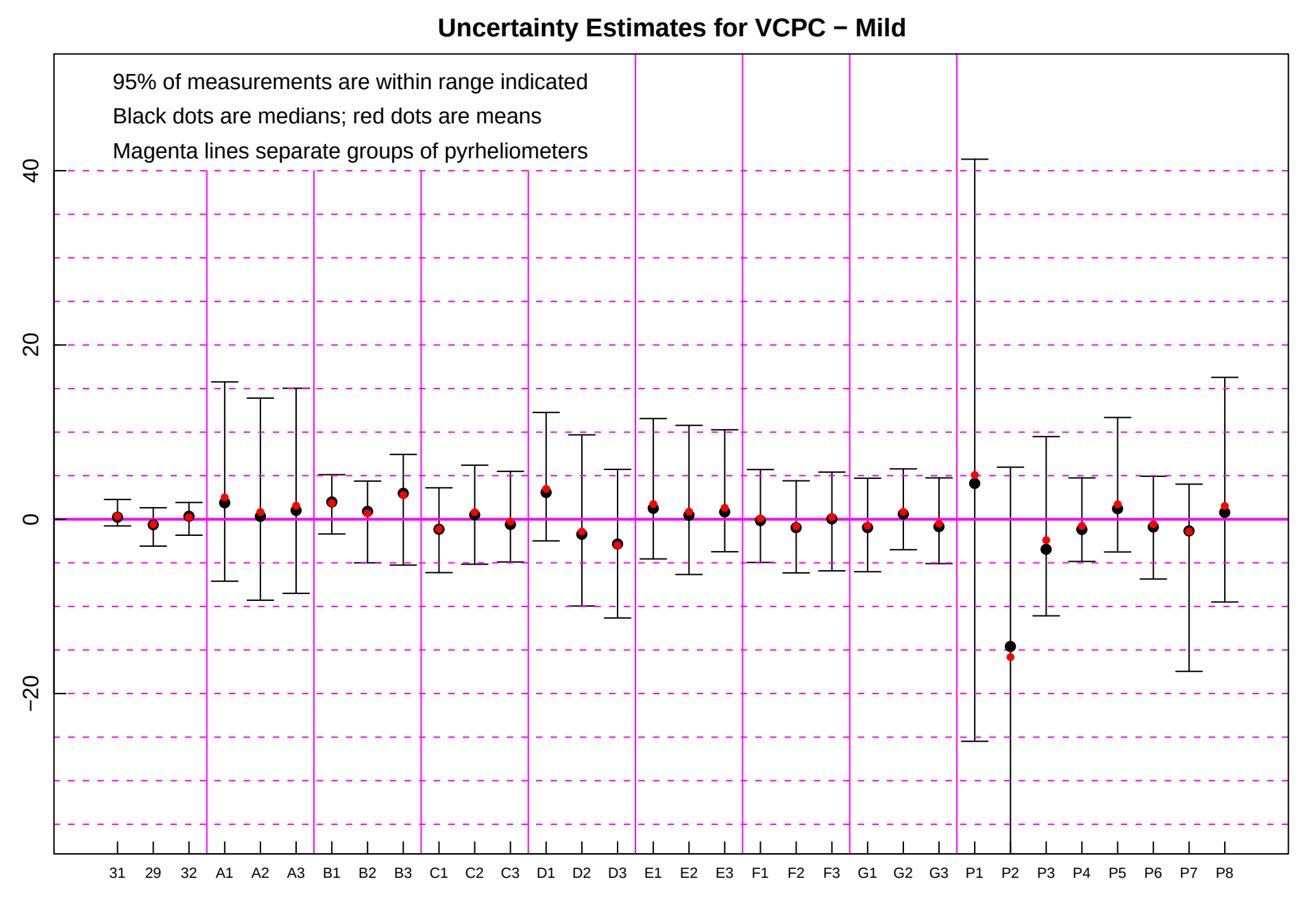
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	**sza < 91.2 & direct > 700 & ws > 5 m/s**	**3900**	**952 W/m^2**
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Windy
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

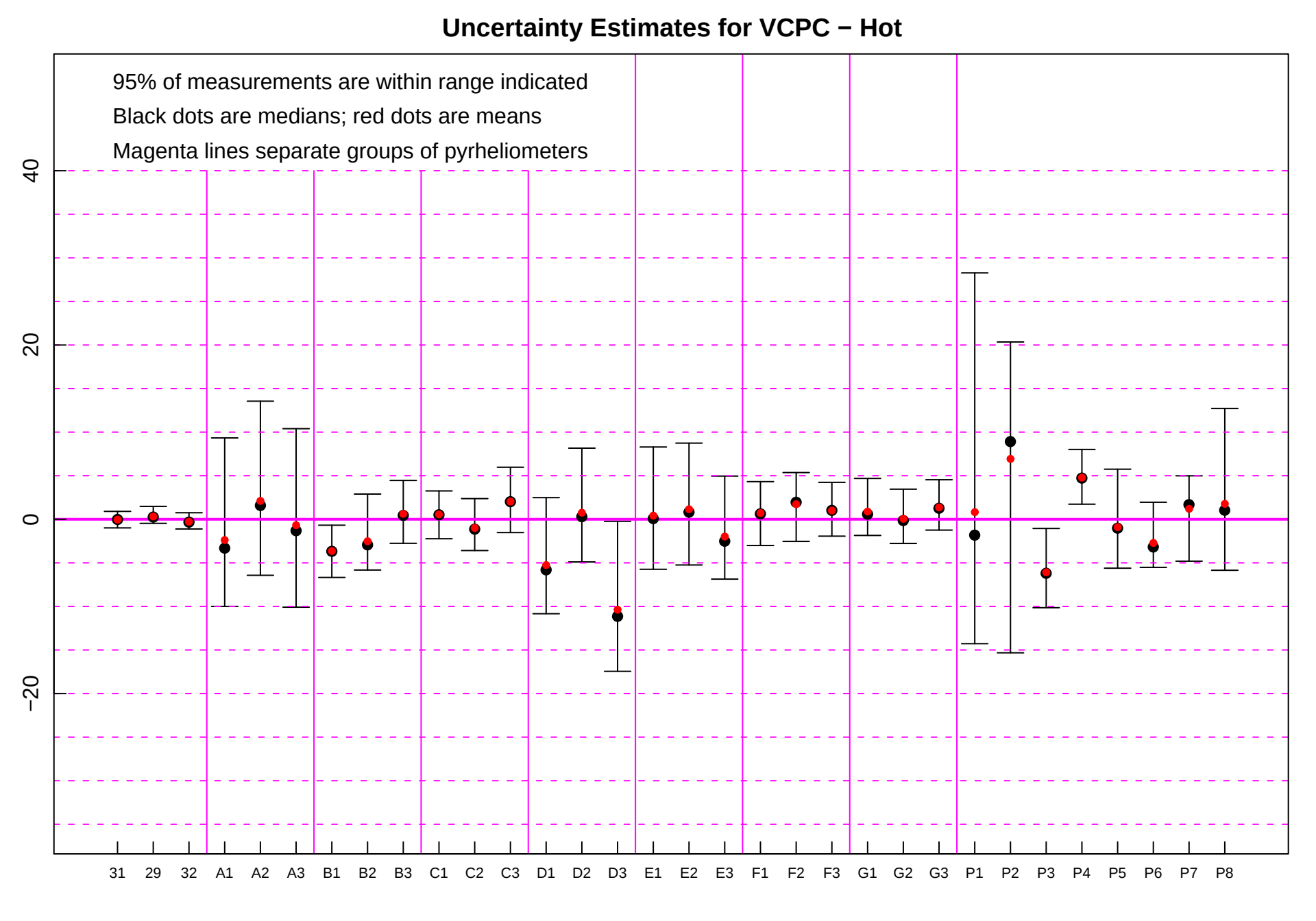
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	**sza < 91.2 & direct > 700 & temp < 0 degs**	**3300**	**896 W/m^2**
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2


Uncertainty Estimates for VCPC − Cold
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

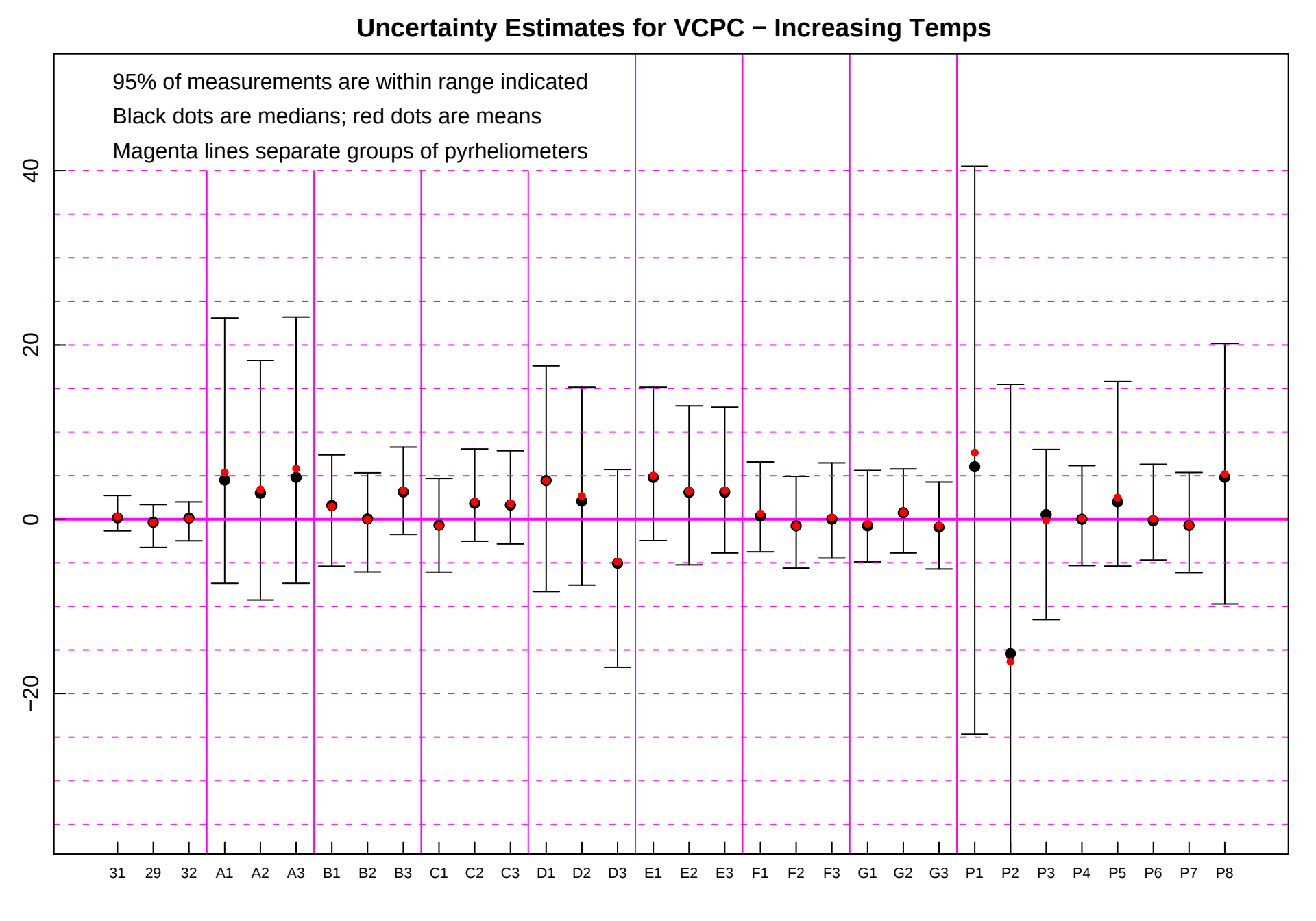
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Mild	**sza < 91.2 & direct > 700 & temp > 10 & < 20 degs**	**16500**	**905 W/m^2**
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2

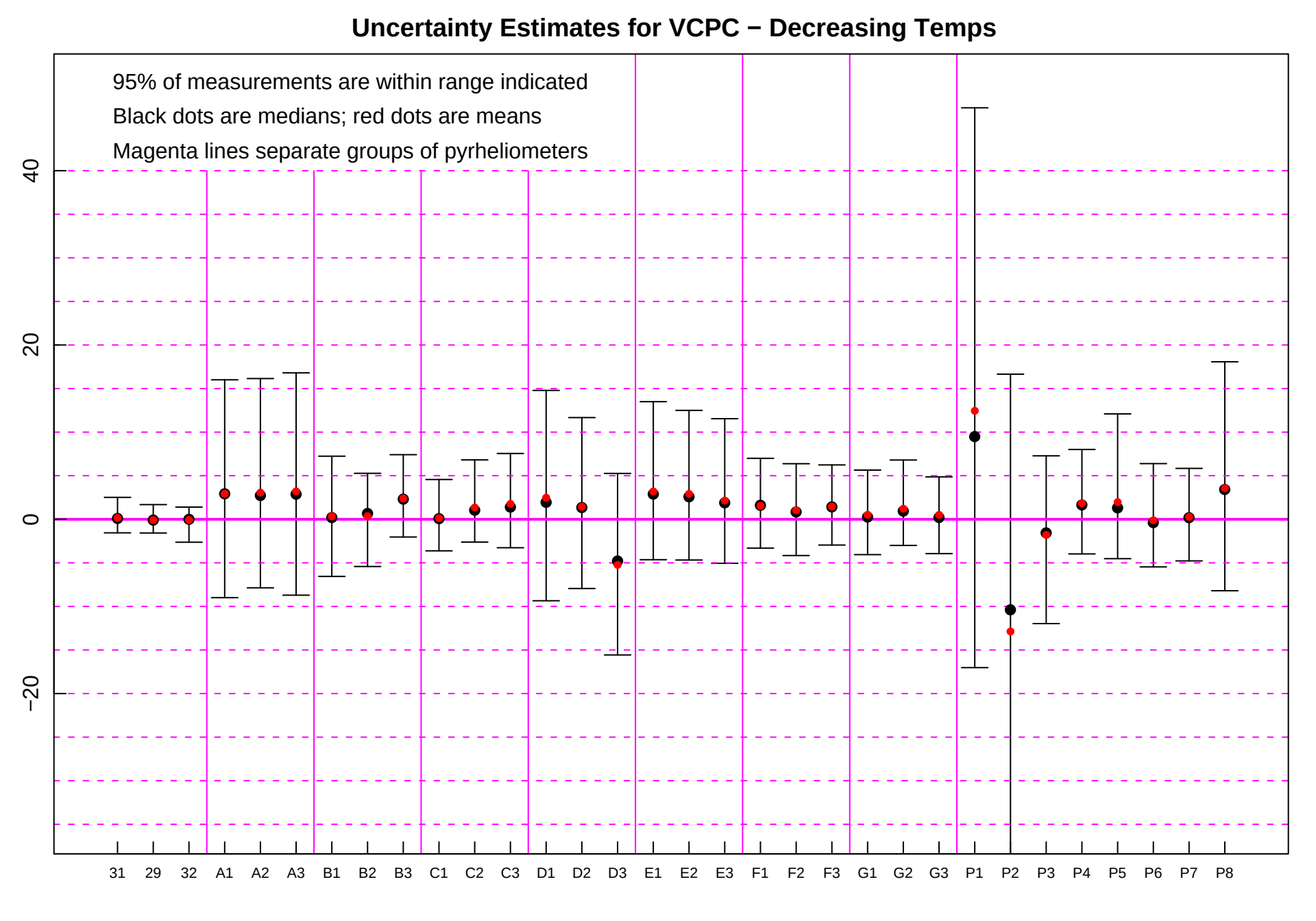

Uncertainty Estimates for VCPC − Mild
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	**sza < 91.2 & direct > 700 & temp > 30 degs**	**3300**	**899 W/m^2**


Uncertainty Estimates for VCPC − Hot
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

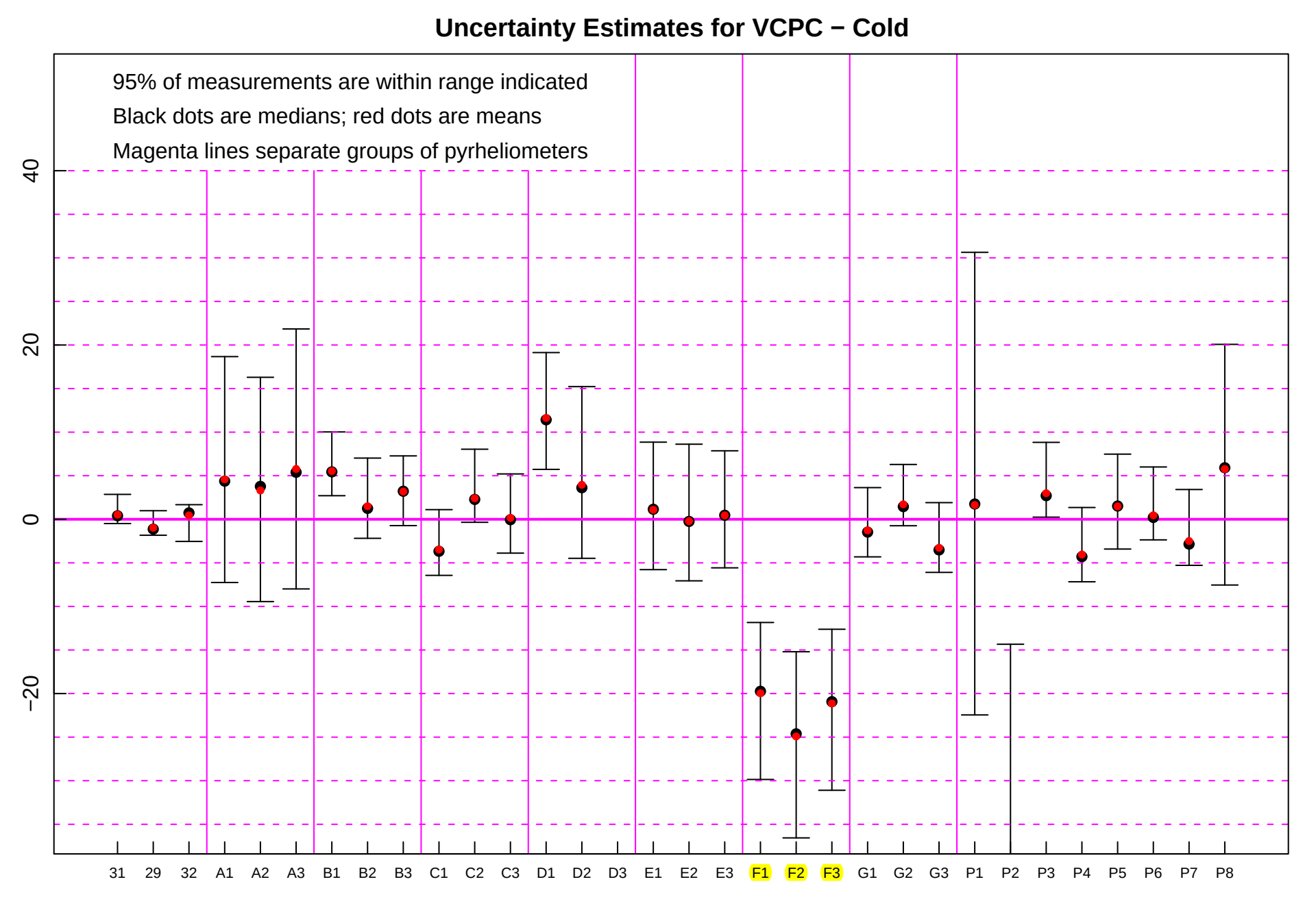
Conditions	Criteria	313000	Mean Direct
Night	sza > 91.2 degs	160000	< 1 W/m^2
Cloudy	sza < 91.2 degs & direct < 4 W/m^2	44000	< 1 W/m^2
Daytime	sza < 91.2 degs	154000	410 W/m^2
Passing clouds	sza < 91.2 & direct > 50 & stddev > 10	23000	476 W/m^2
Clear	sza < 91.2 & direct > 700	56000	903 W/m^2
Very Clear	sza < 91.2 & direct > 700 & stddev < 2 W/m^2	41000	918 W/m^2
Clear/Calm	sza < 91.2 & direct > 700 & ws < 2 m/s	39000	894 W/m^2
Clear/Windy	sza < 91.2 & direct > 700 & ws > 5 m/s	3900	952 W/m^2
Clear/Cold	sza < 91.2 & direct > 700 & temp < 0 degs	3300	896 W/m^2
Clear/Moderate	sza < 91.2 & direct > 700 & temp > 10 & < 20 degs	16500	905 W/m^2
Clear/Hot	sza < 91.2 & direct > 700 & temp > 30 degs	3300	899 W/m^2
Temperature change	**Increase of more than 1 C in 5 mins & > 700**	**280**	**848 W/m^2**
	Decrease of more than -1 C in 5 mins & > 700	**330**	**811 W/m^2**

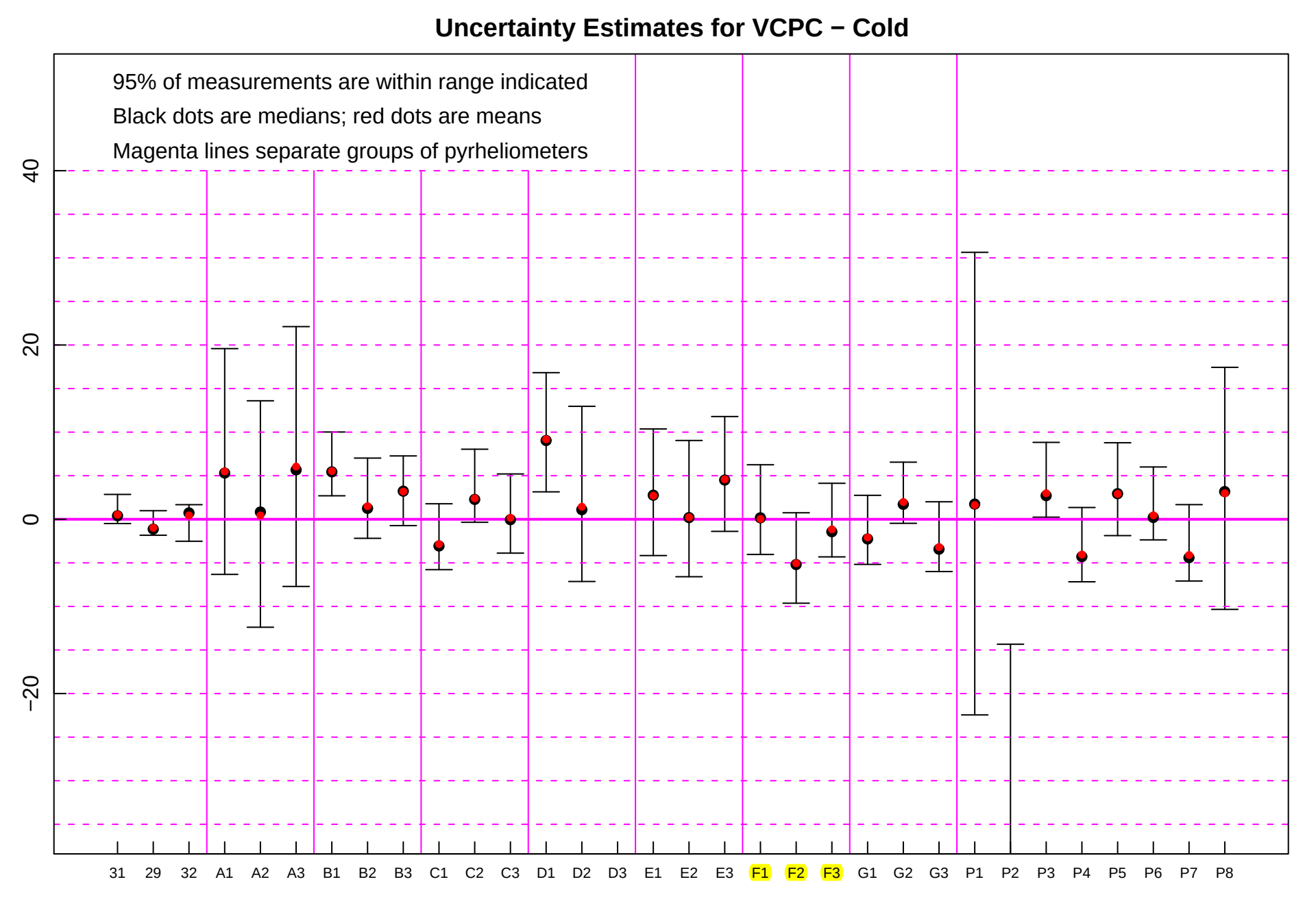

Uncertainty Estimates for VCPC − Increasing Temps
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8


Uncertainty Estimates for VCPC − Decreasing Temps
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

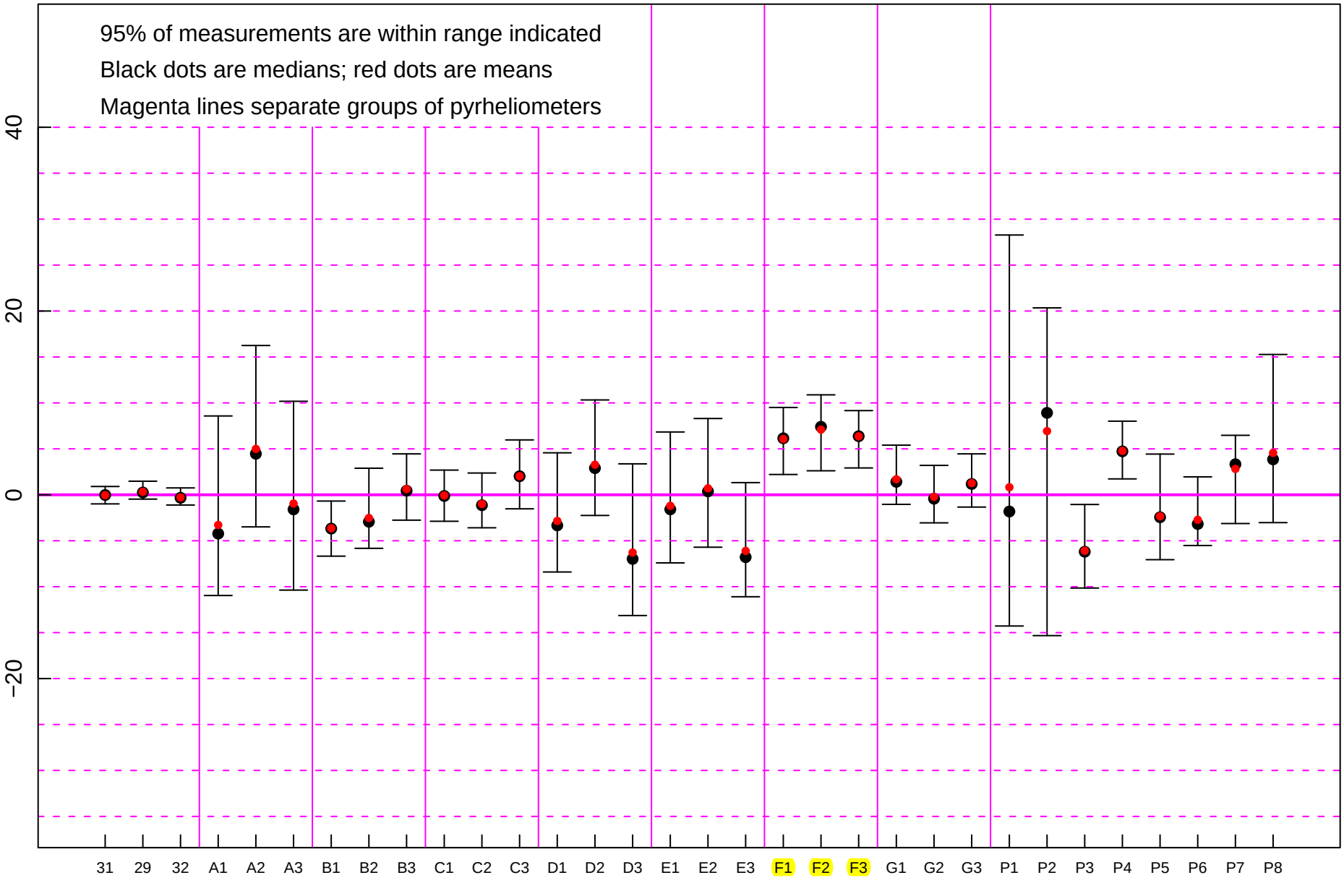
Importance of Temperature Correction or Compensation

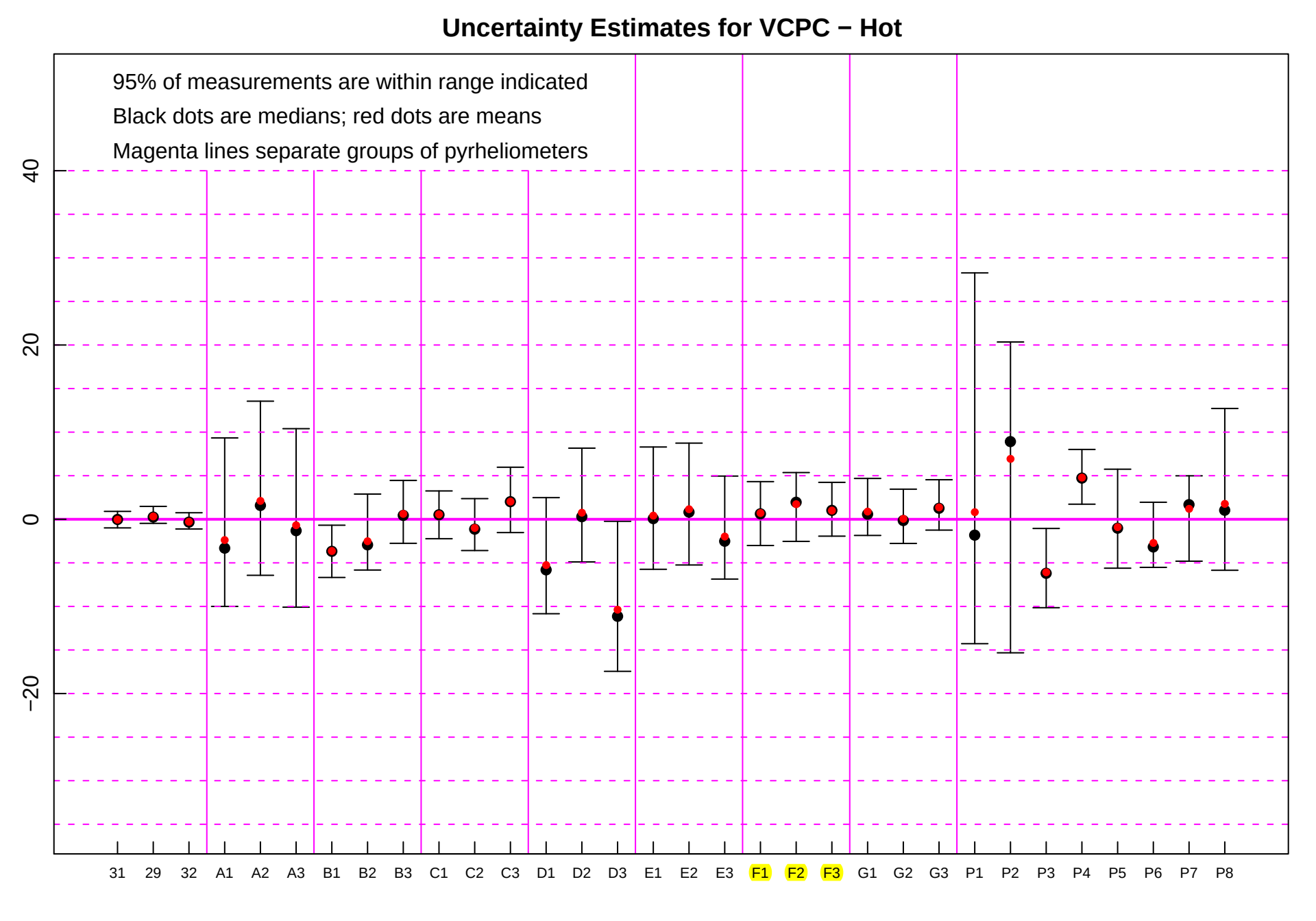
- Focus only on **F1, F2, F3**
- Cold (< 0 C) uncorrected; then corrected
- Hot (> 30 C) uncorrected; then corrected

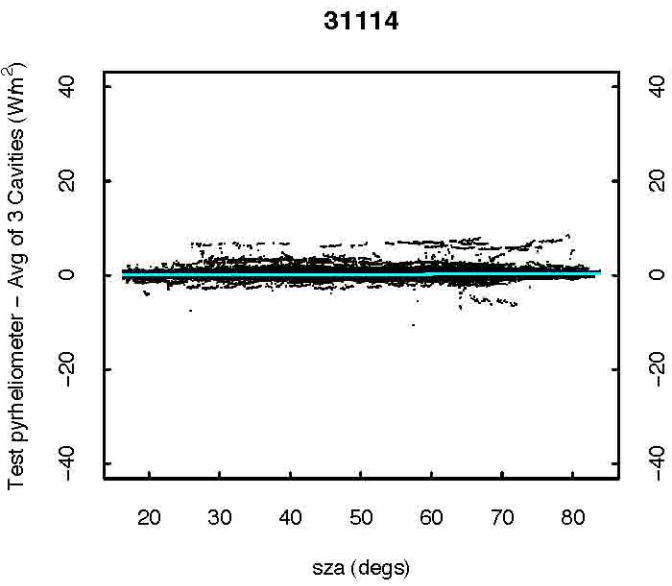

Uncertainty Estimates for VCPC − Cold
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

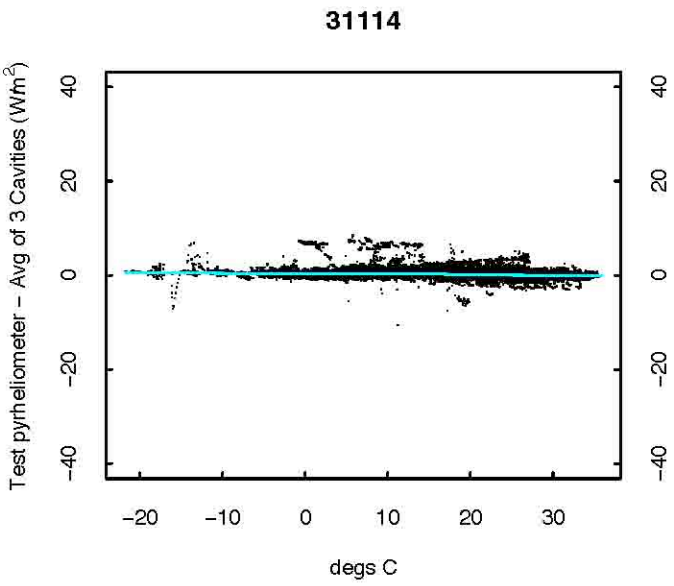

Uncertainty Estimates for VCPC − Cold
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

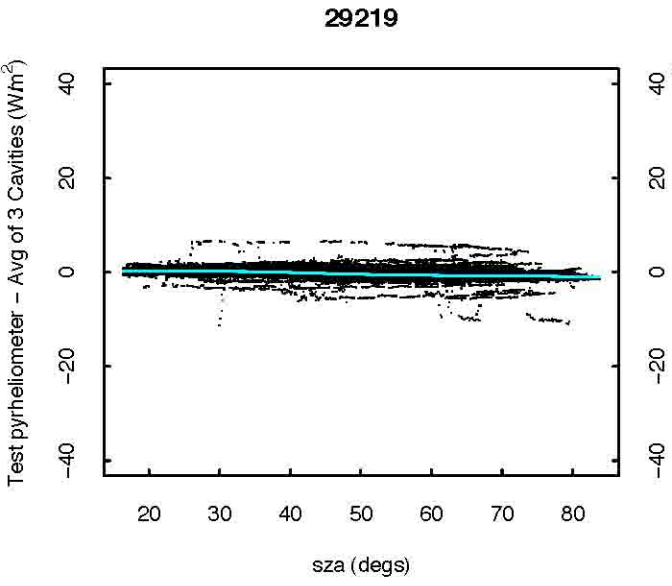
Uncertainty Estimates for VCPC − Hot

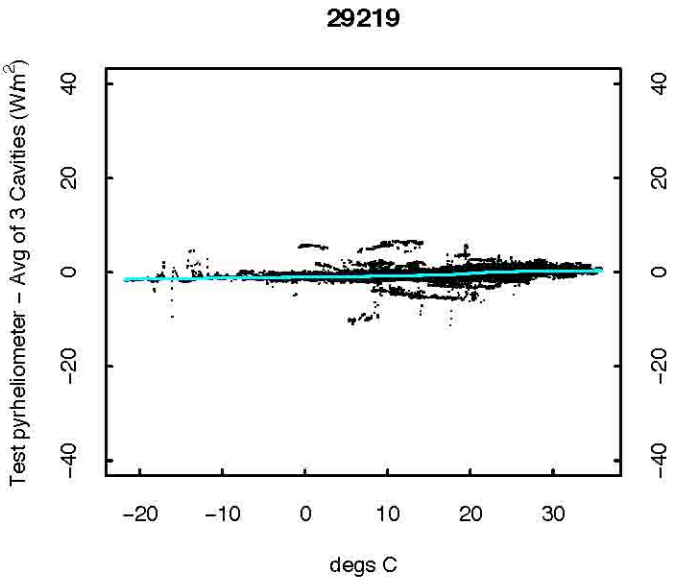


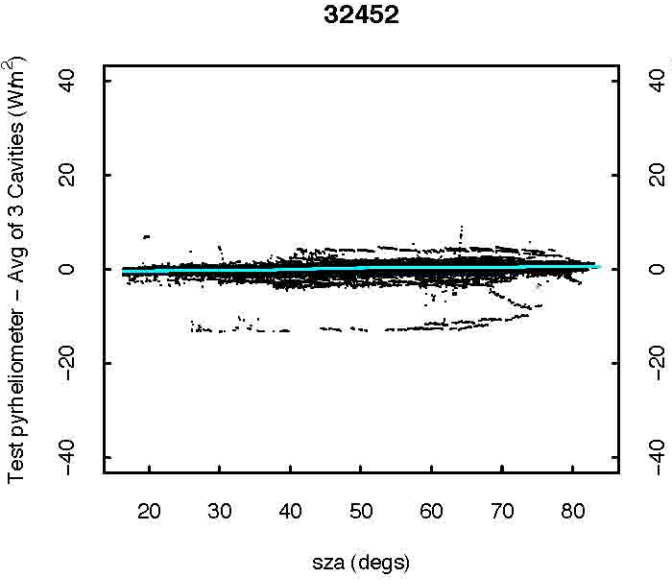

Uncertainty Estimates for VCPC − Hot
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
−20
31
29
32
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
E1
E2
E3
F1
F2
F3
G1
G2
G3
P1
P2
P3
P4
P5
P6
P7
P8

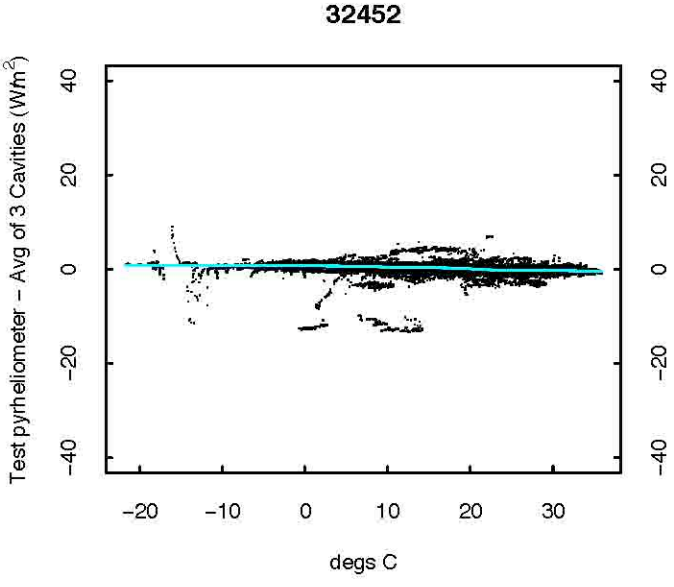

31114
Test pyrheliometer – Avg of 3 Cavities (W/m2)
sza (degs)

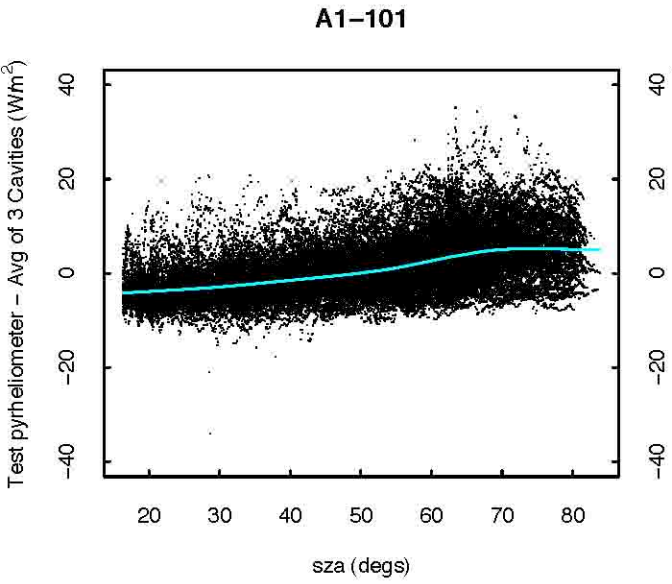

31114
Test pyrheliometer – Avg of 3 Cavities (W/m2)
degs C

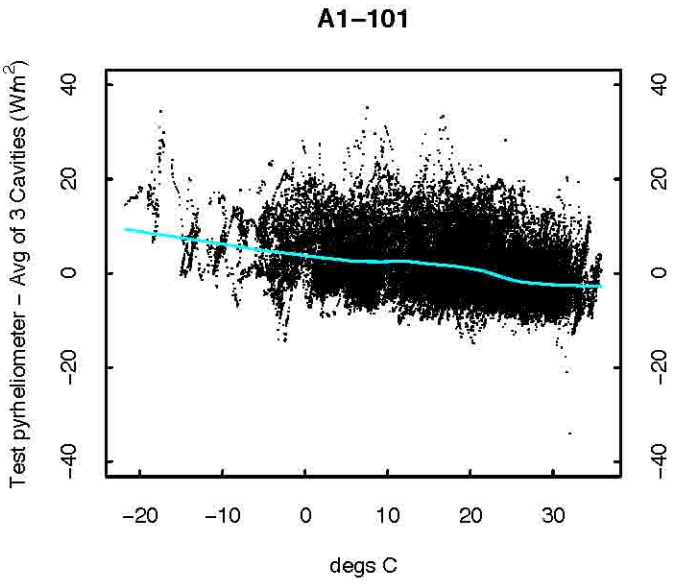

29219
Test pyrheliometer – Avg of 3 Cavities (W/m2)
sza (degs)

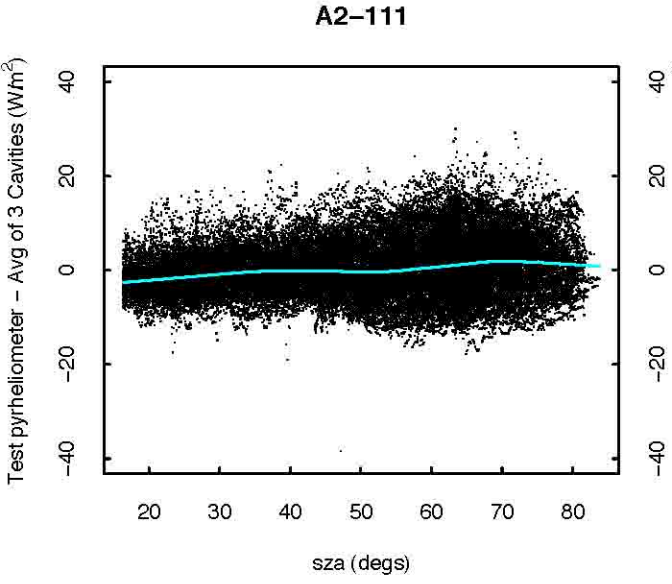

29219
Test pyrheliometer – Avg of 3 Cavities (W/m2)
degs C

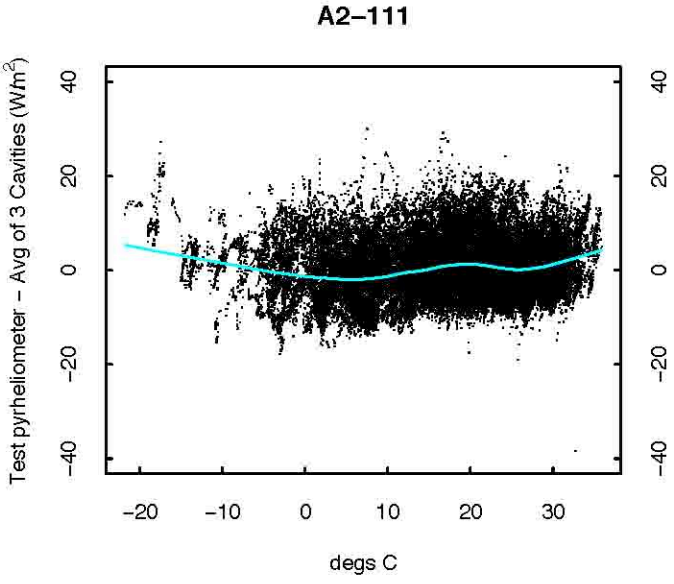

32452
Test pyrheliometer – Avg of 3 Cavities (W/m2)
sza (degs)

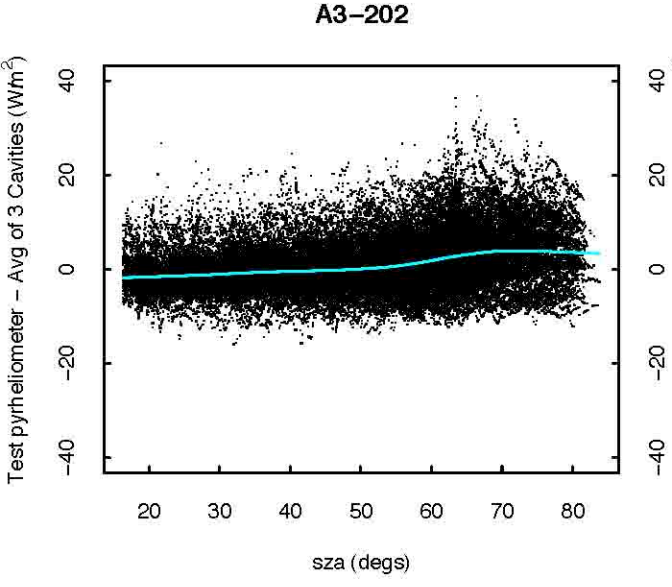

32452
Test pyrheliometer – Avg of 3 Cavities (W/m2)
degs C

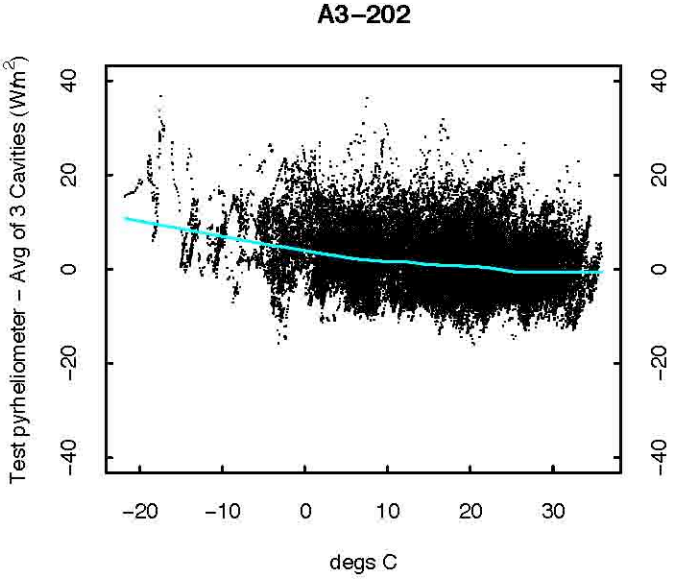

A1–101
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
sza (degs)

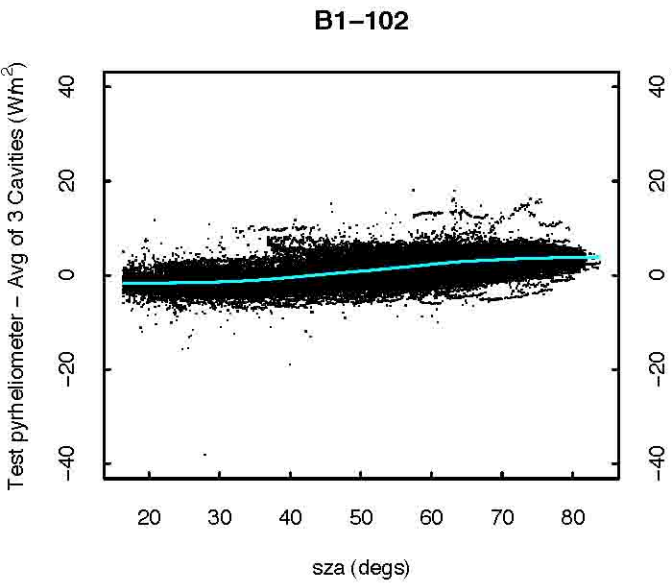

A1–101
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
degs C

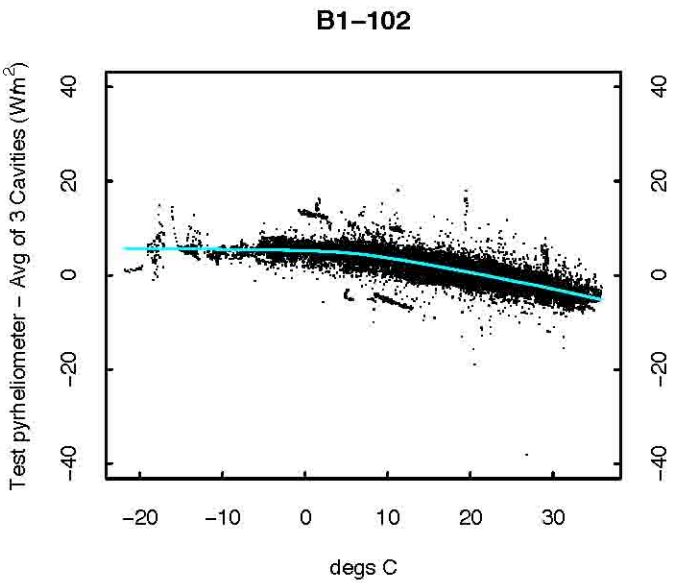

A2–111
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
sza (degs)

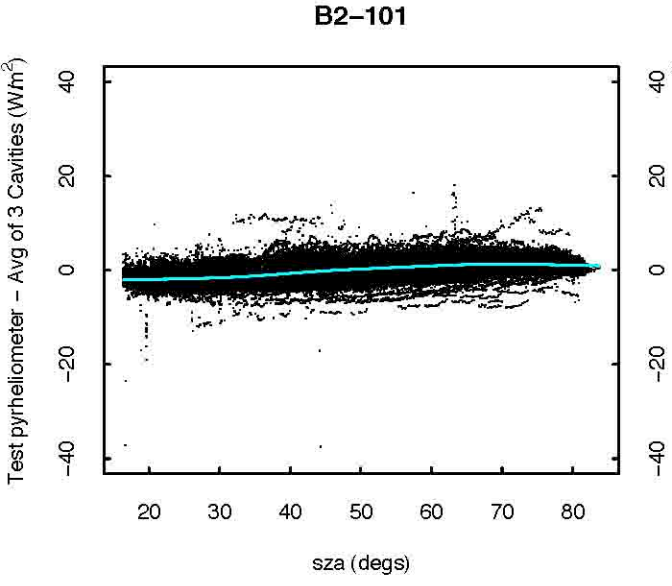

A2–111
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
degs C

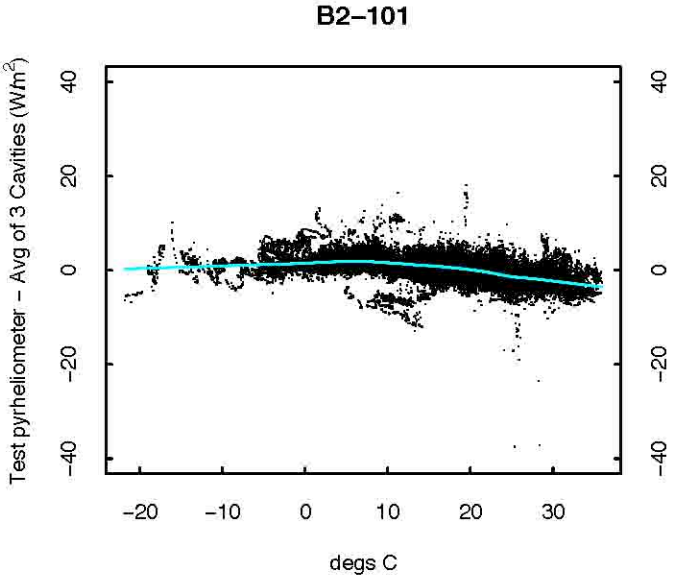

A3–202
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
sza (degs)

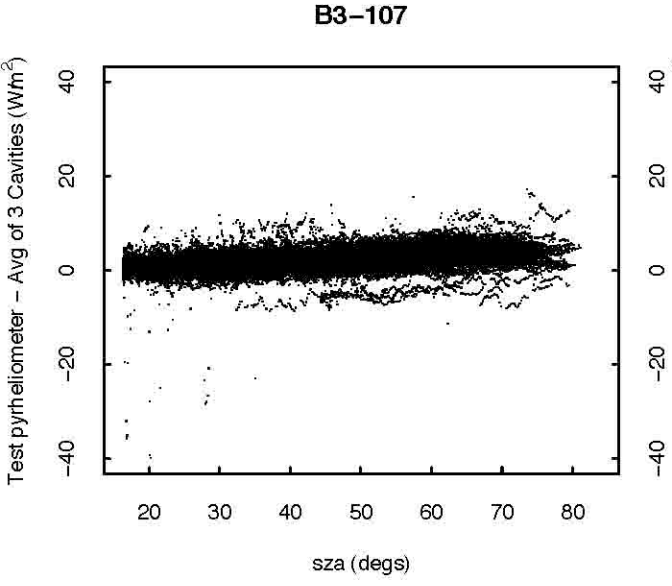

A3–202
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
degs C

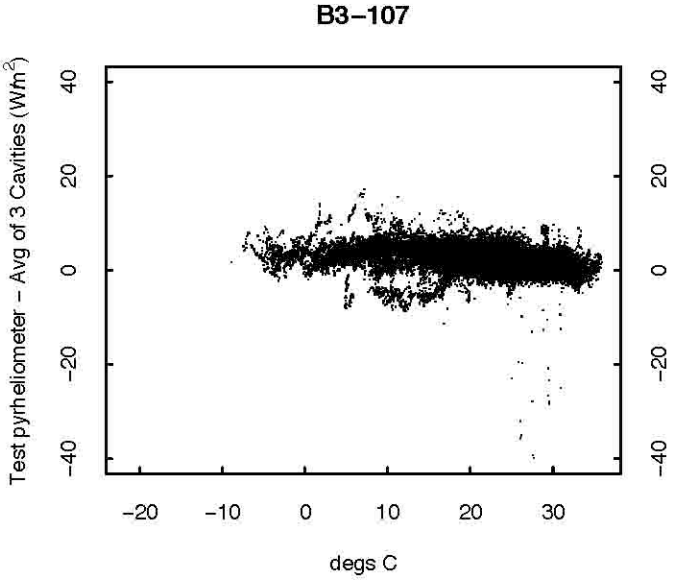

B1–102
Test pyrheliometer – Avg of 3 Cavities (W/m2)
sza (degs)

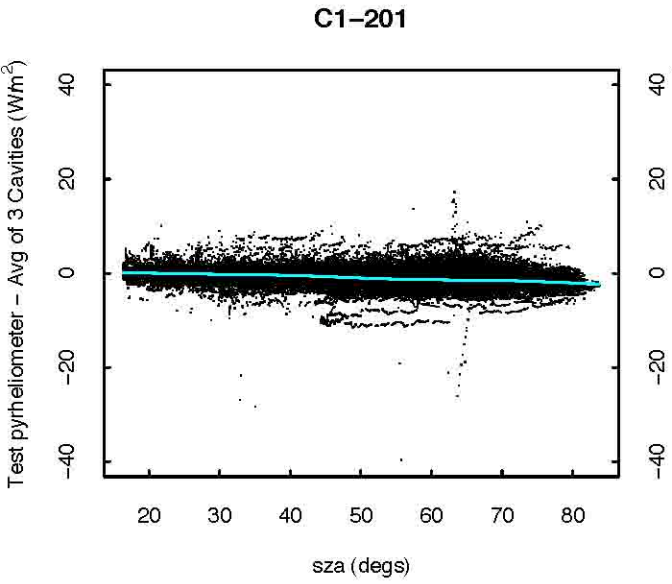

B1–102
Test pyrheliometer – Avg of 3 Cavities (W/m2)
degs C

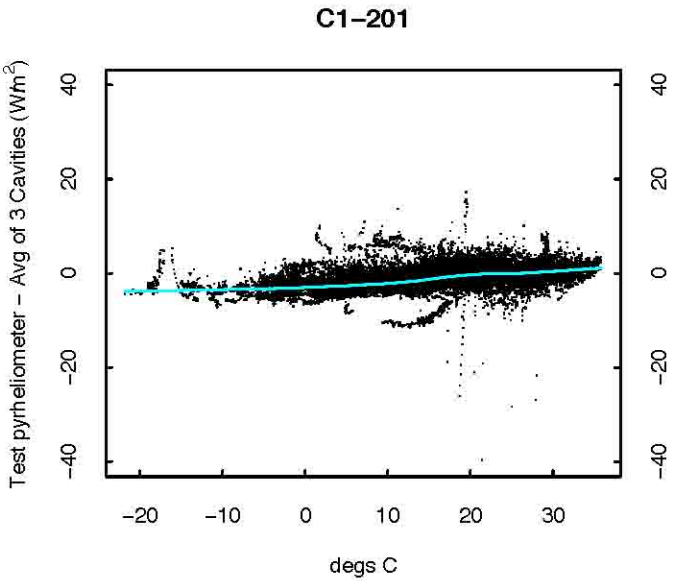

B2–101
Test pyrheliometer – Avg of 3 Cavities (W/m2)
sza (degs)

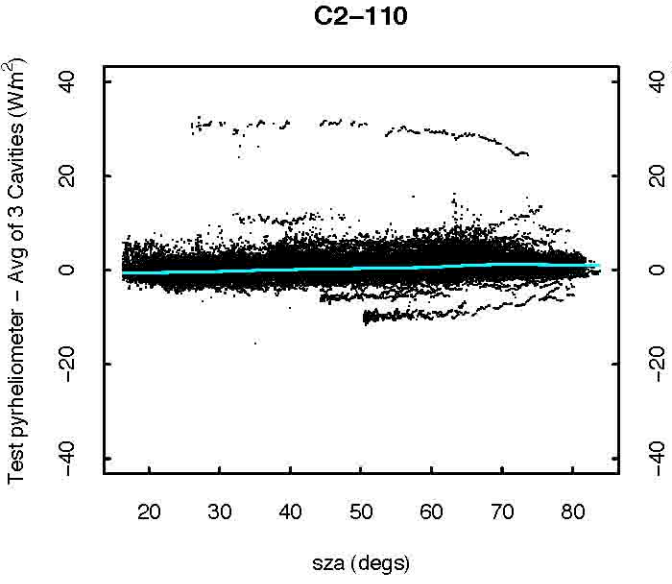

B2–101
Test pyrheliometer – Avg of 3 Cavities (W/m2)
degs C

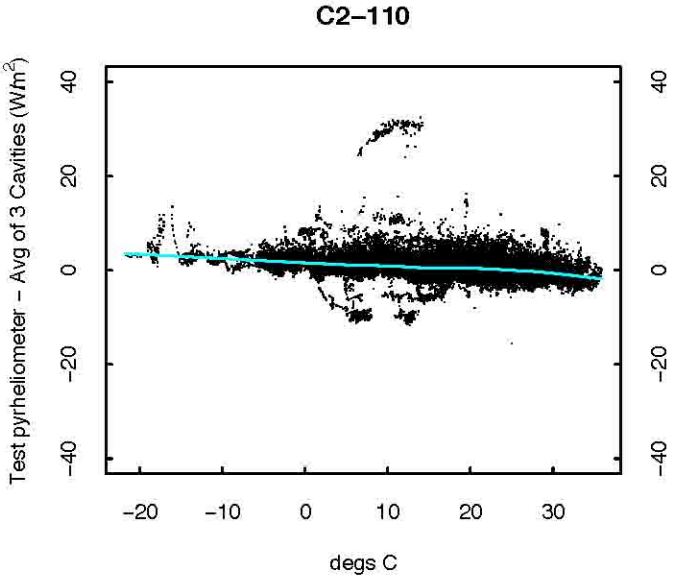

B3–107
Test pyrheliometer – Avg of 3 Cavities (W/m2)
sza (degs)

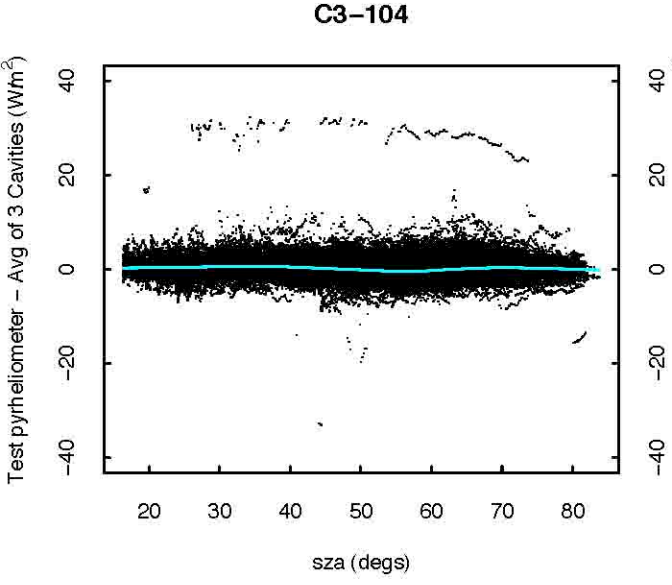

B3–107
Test pyrheliometer – Avg of 3 Cavities (W/m2)
degs C

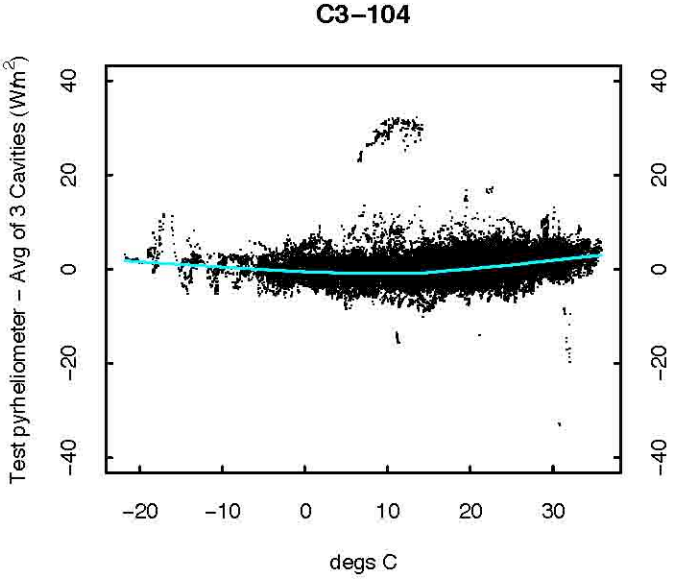

C1–201
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

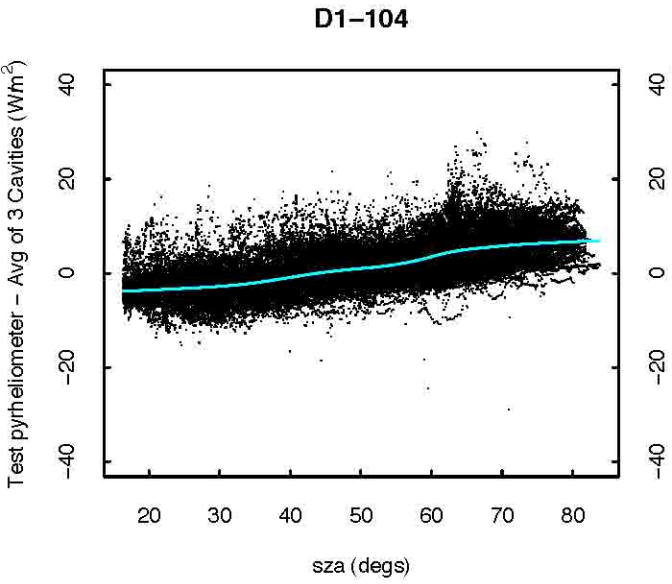

C1–201
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

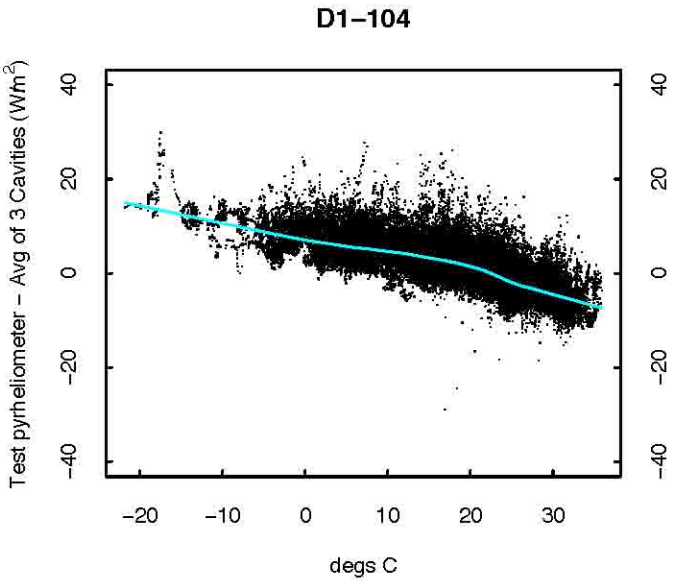

C2–110
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

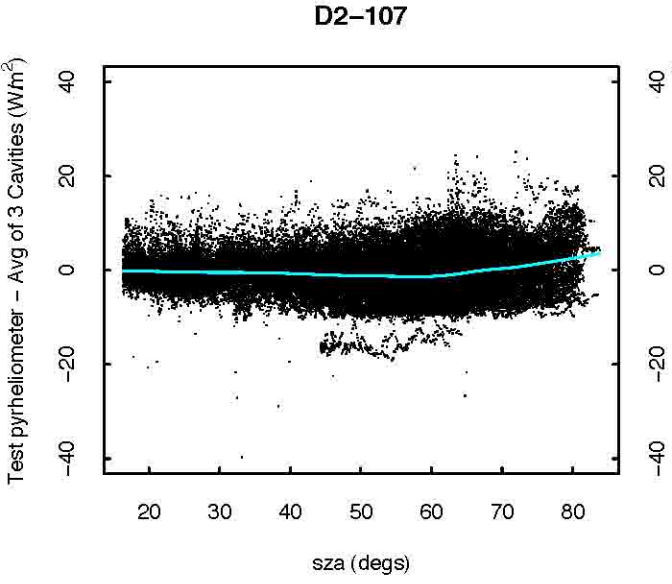

C2–110
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

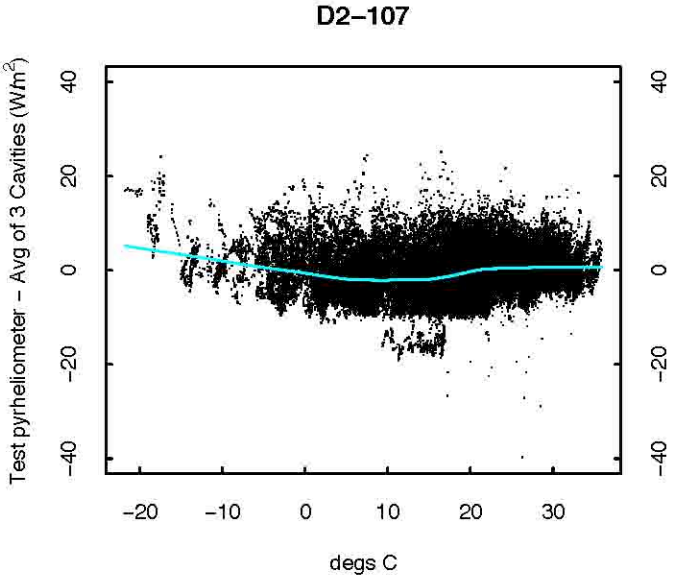

C3–104
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

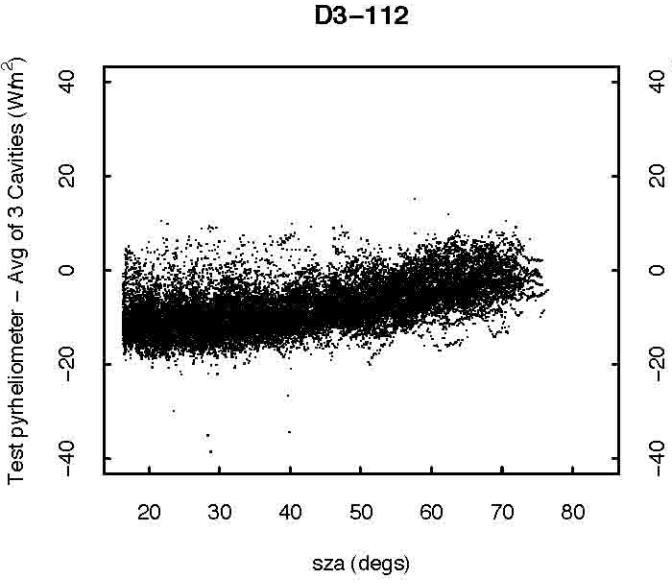

C3–104
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

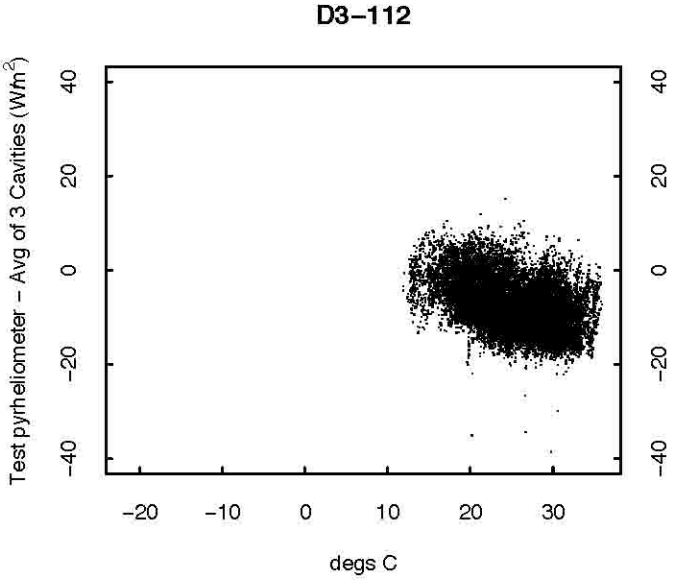

D1–104
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

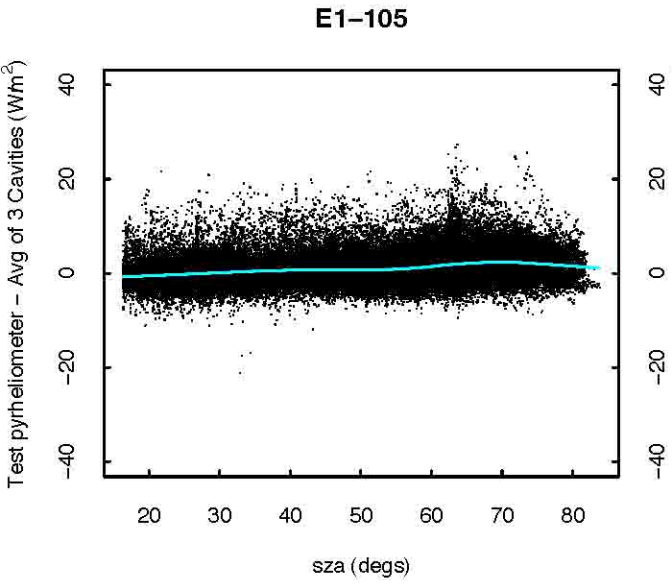

D1–104
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

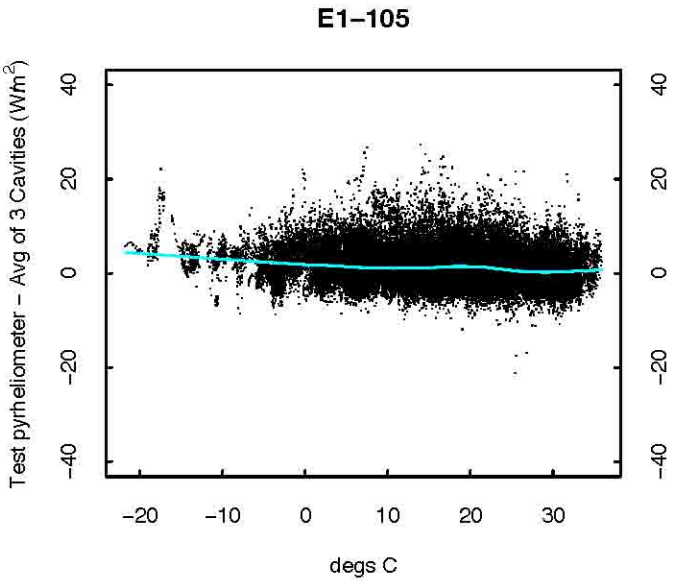

D2–107
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

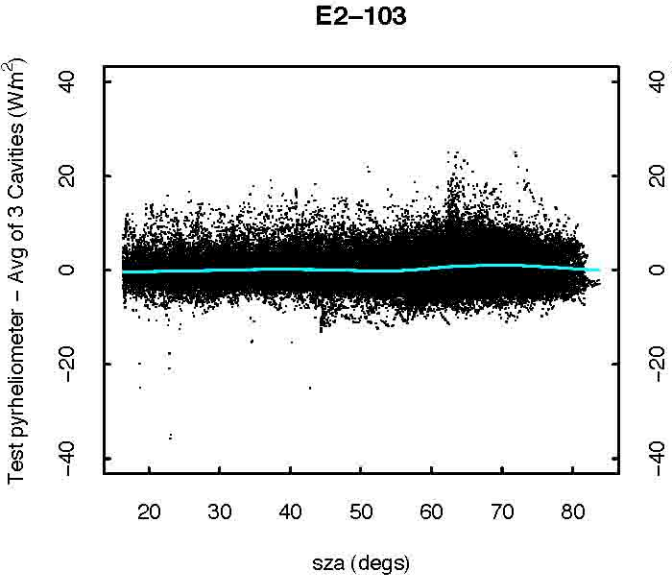

D2–107
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

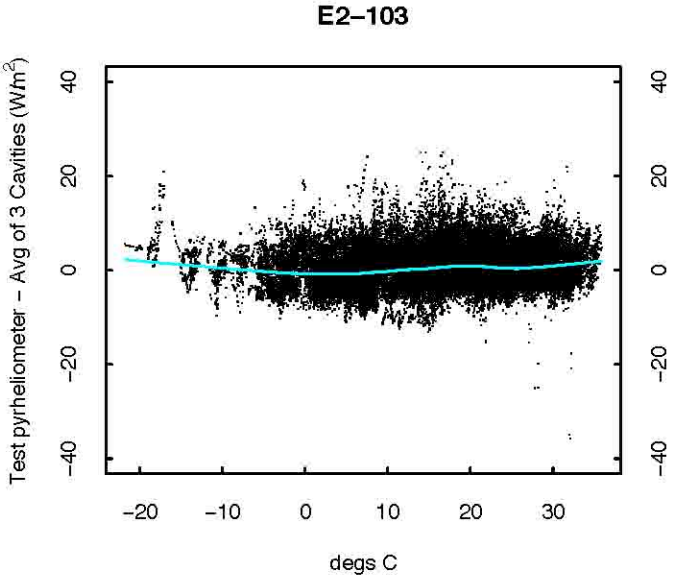

D3–112
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

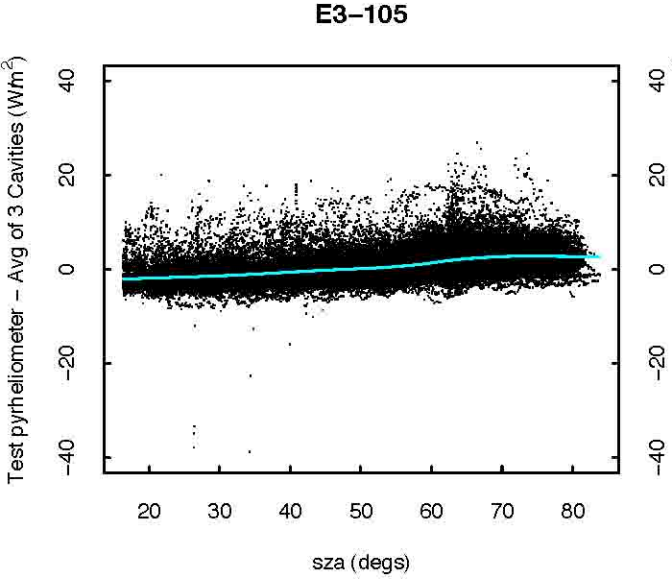

D3–112
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

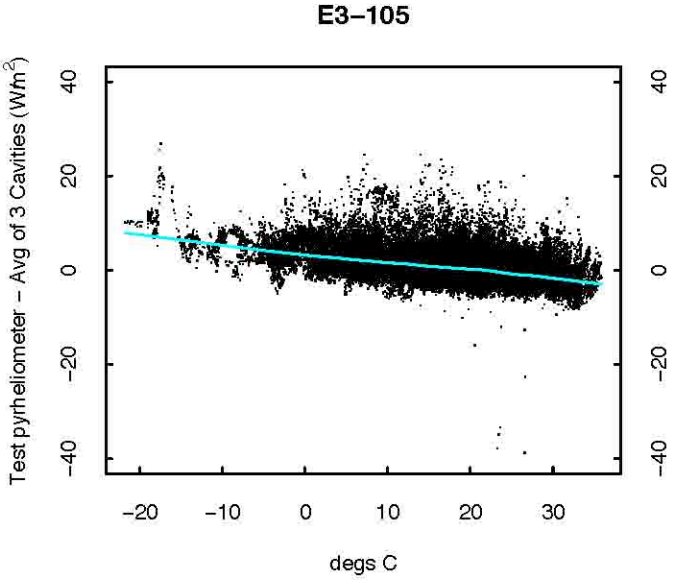

E1–105
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

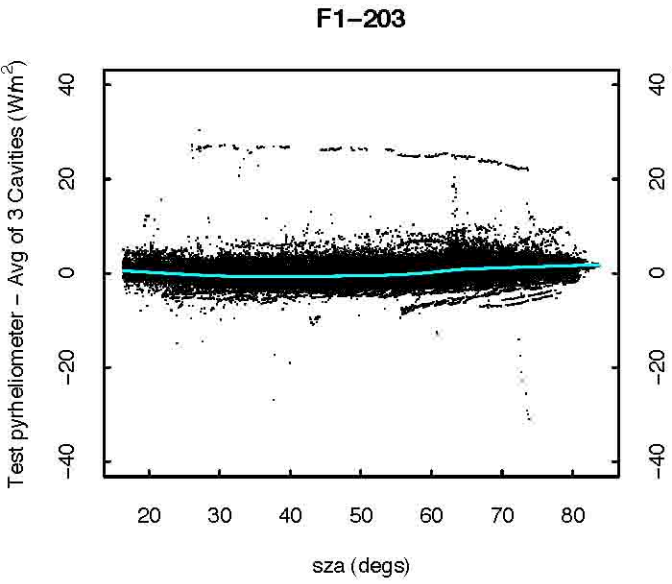

E1–105
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

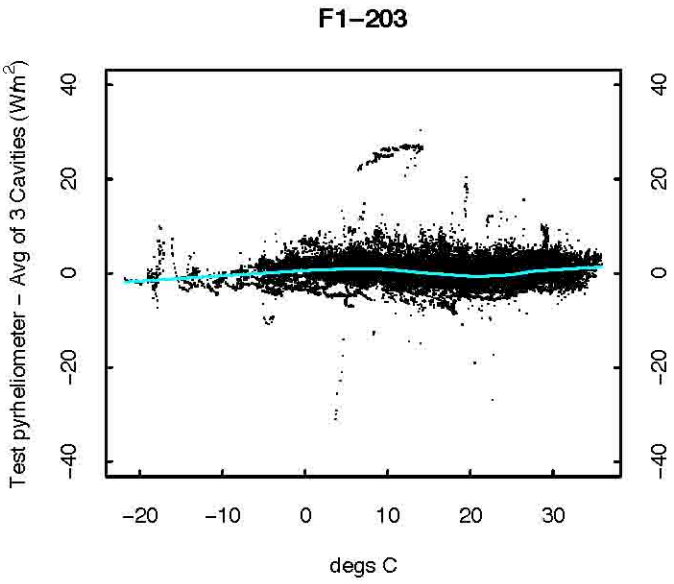

E2–103
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

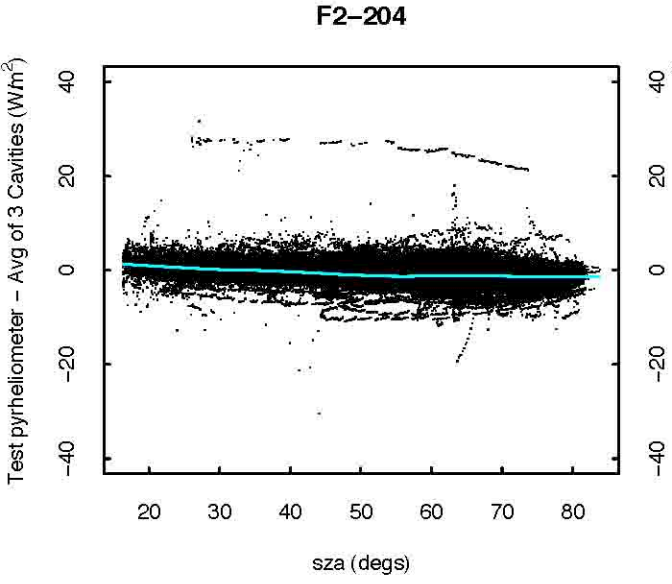

E2–103
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

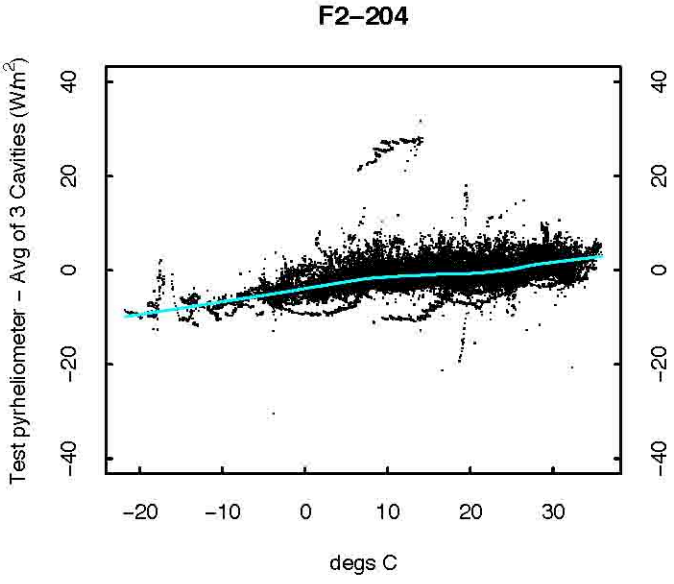

E3–105
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

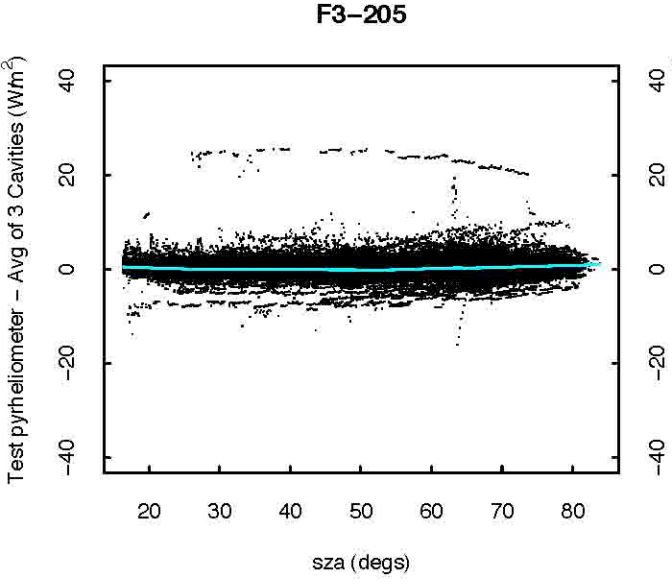

E3–105
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

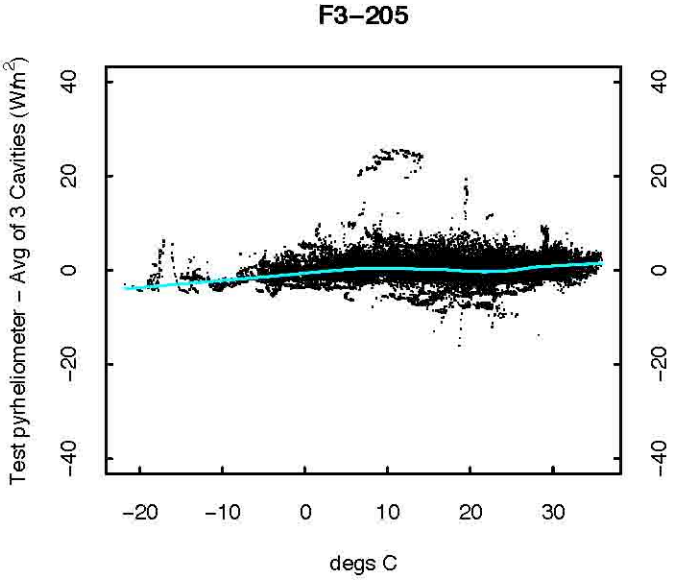

F1–203
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

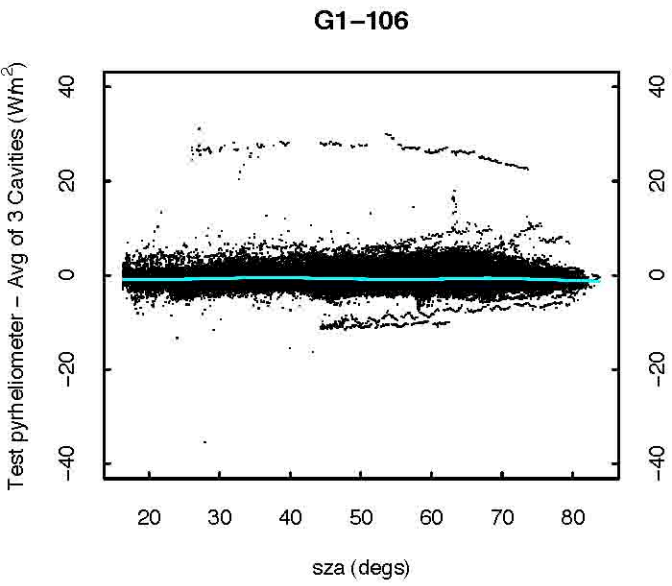

F1–203
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

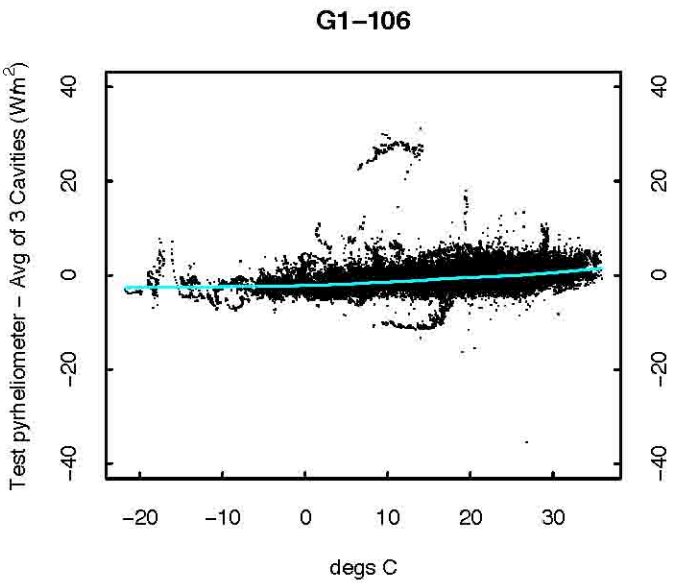

F2–204
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

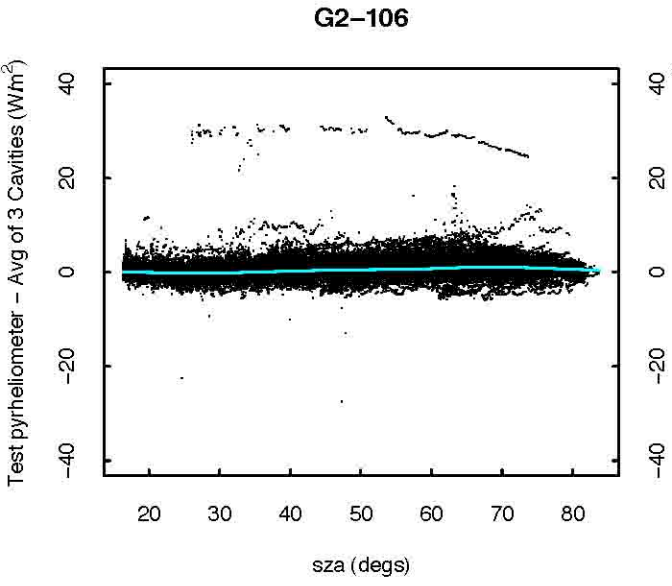

F2–204
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

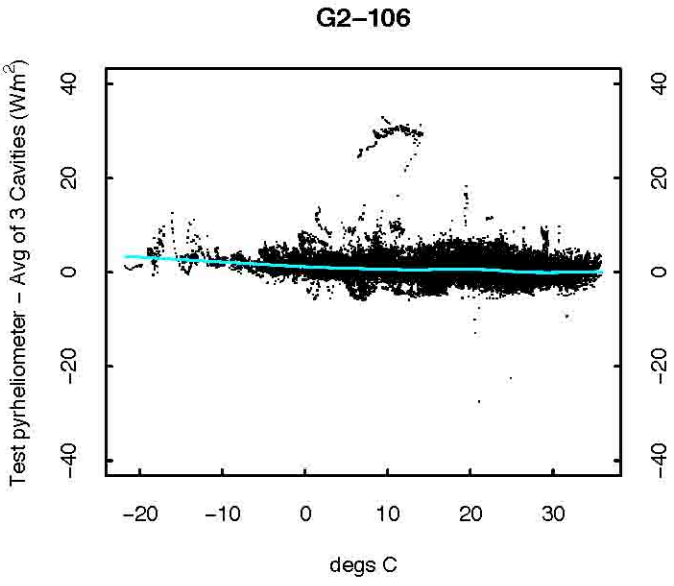

F3–205
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

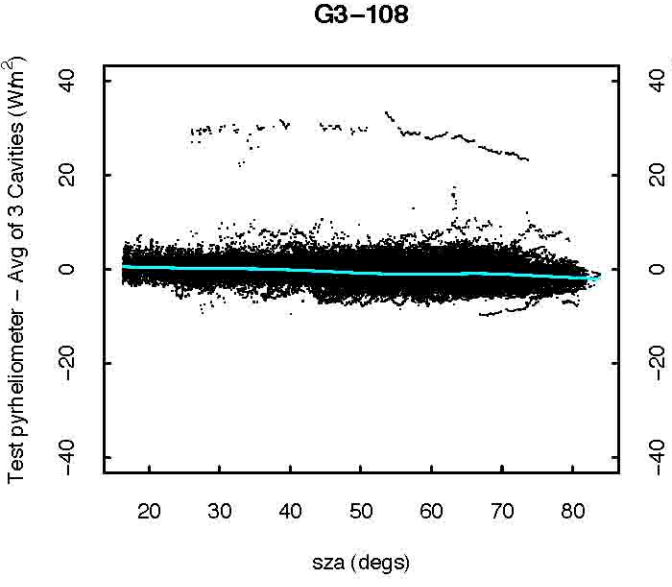

F3–205
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

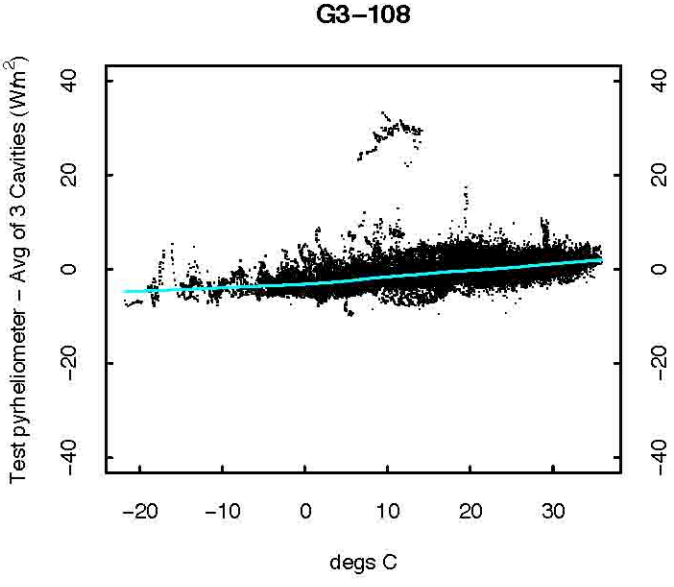

G1–106
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
sza (degs)

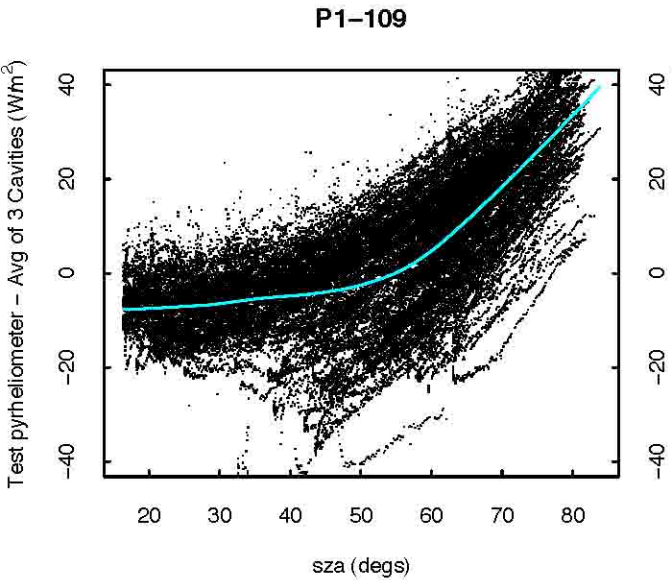

G1–106
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
degs C

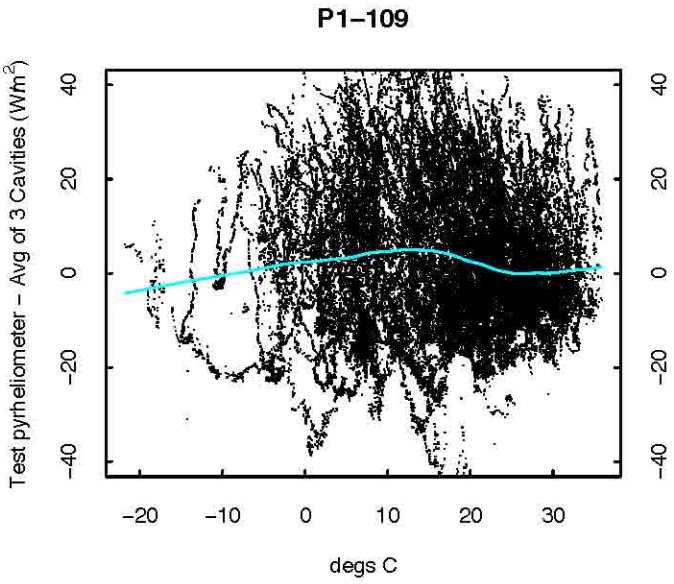

G2–106
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
sza (degs)

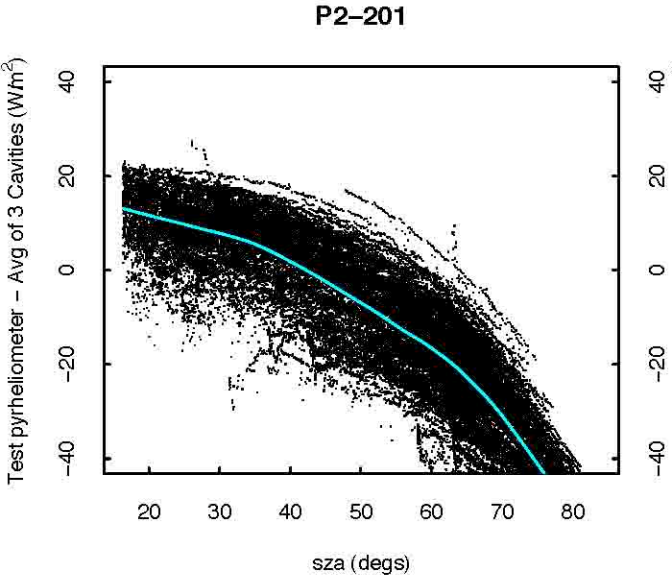

G2–106
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
degs C

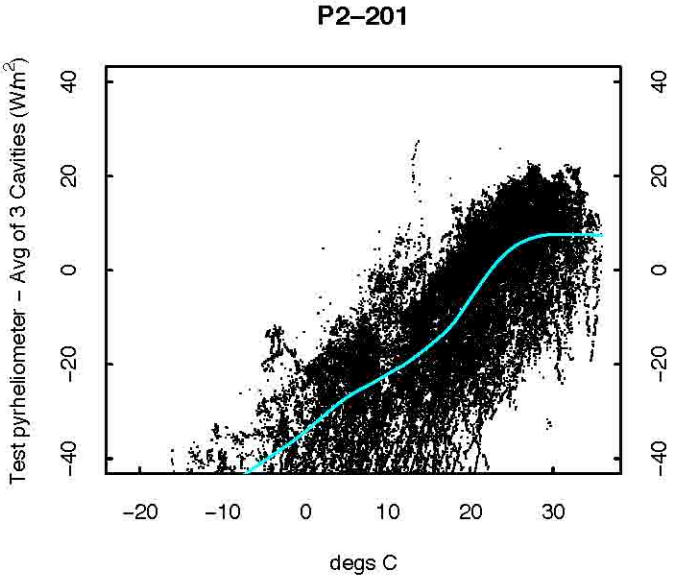

G3–108
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
sza (degs)

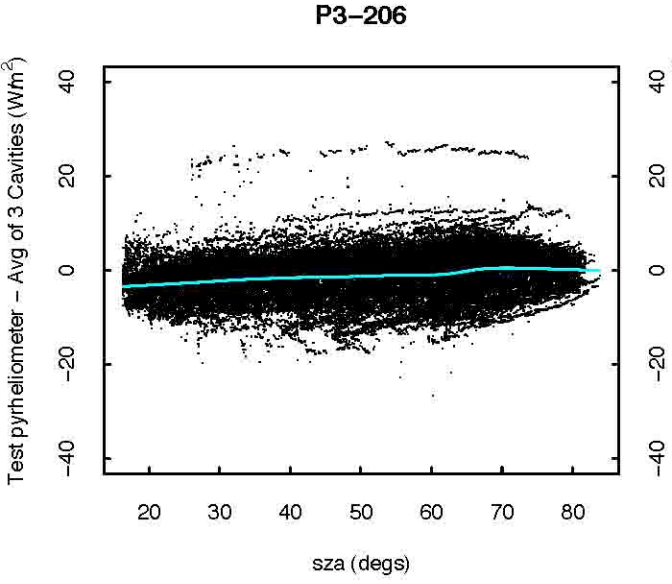

G3–108
Test pyrheliometer – Avg of 3 Cavities (Wm^2)
degs C

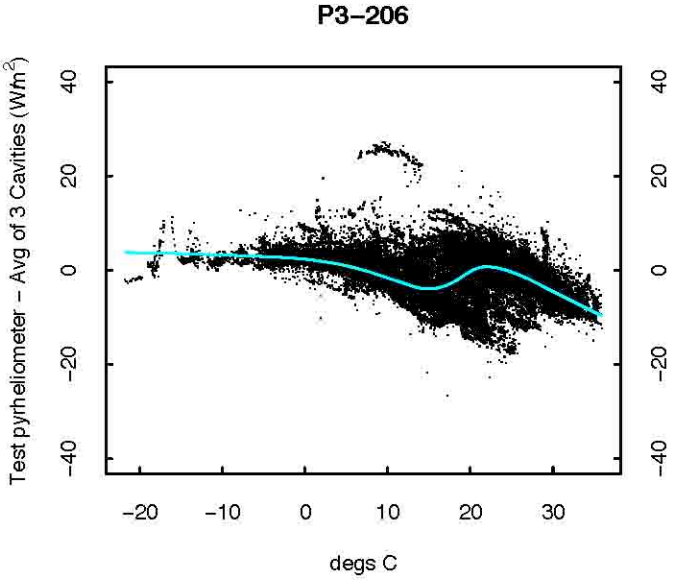

P1–109
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

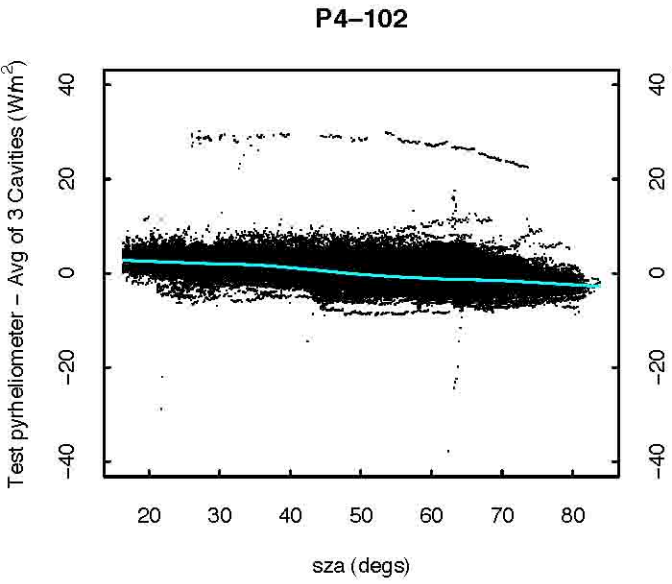

P1–109
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

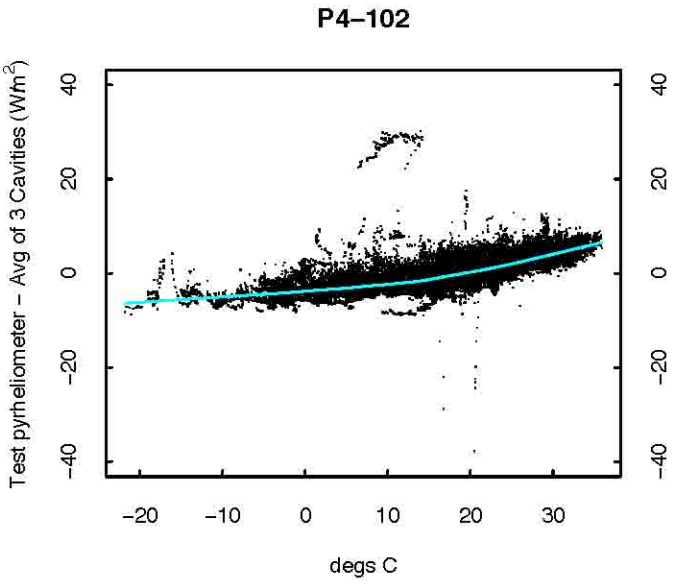

P2–201
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

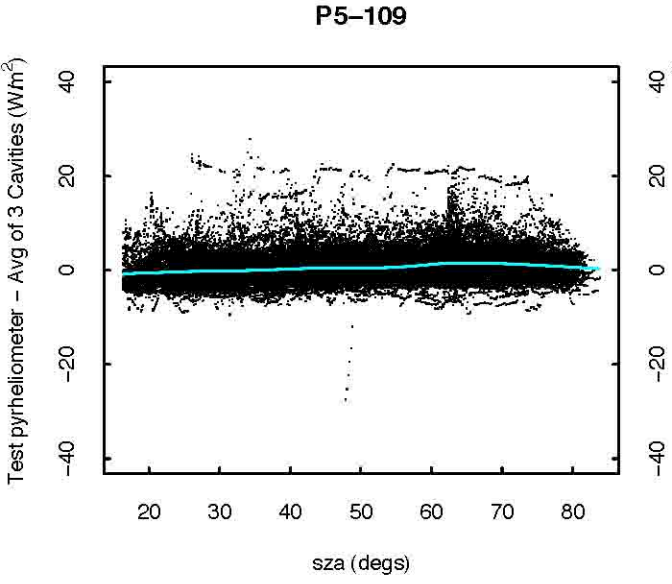

P2–201
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

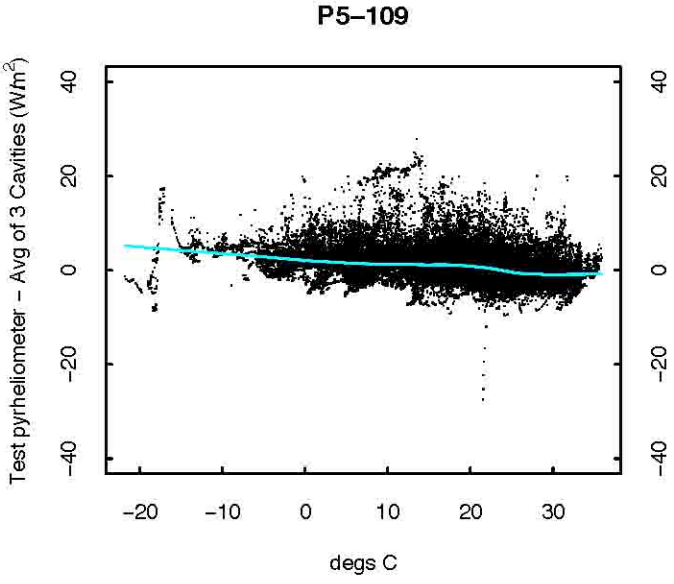

P3–206
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

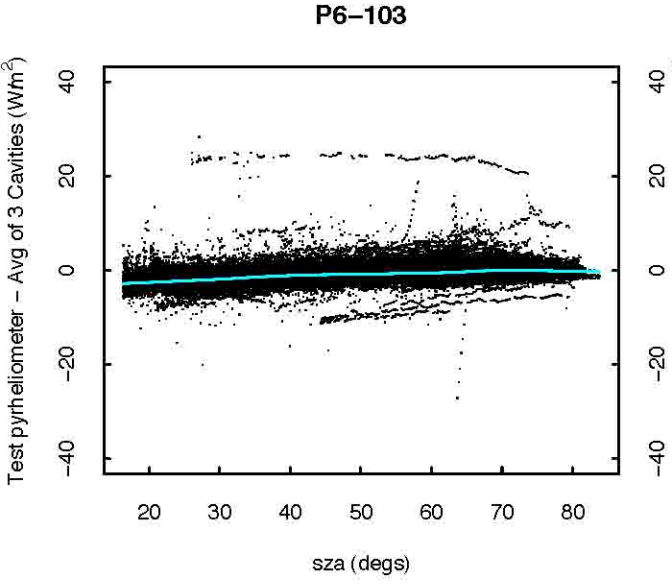

P3–206
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

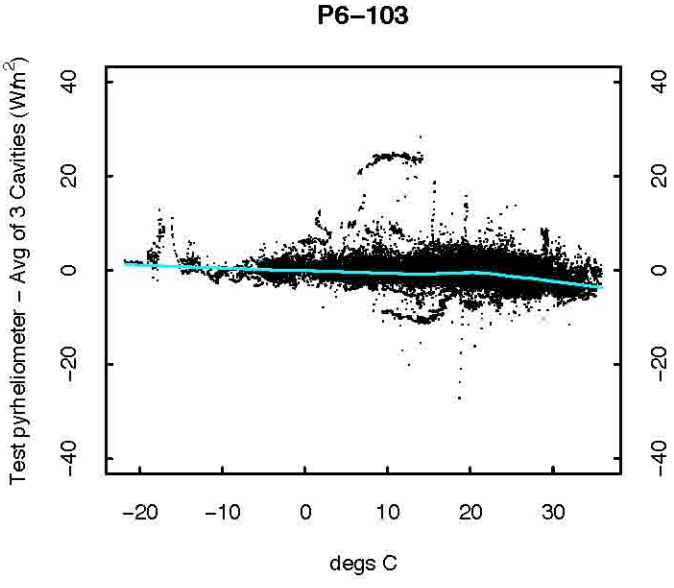

P4–102
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

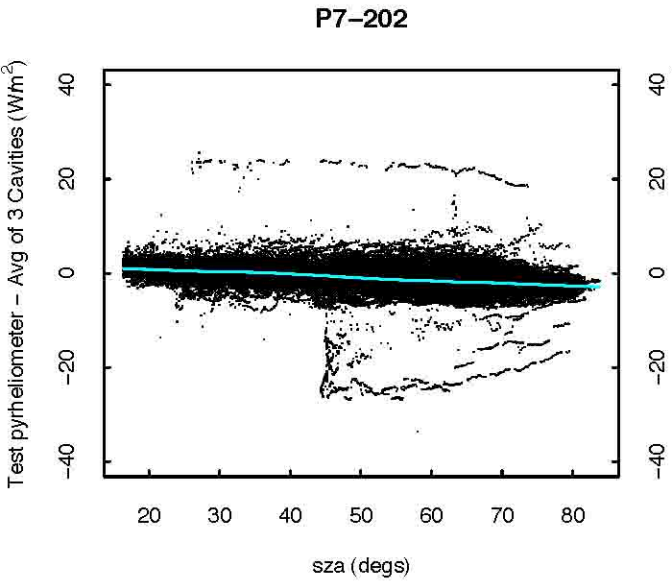

P4–102
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

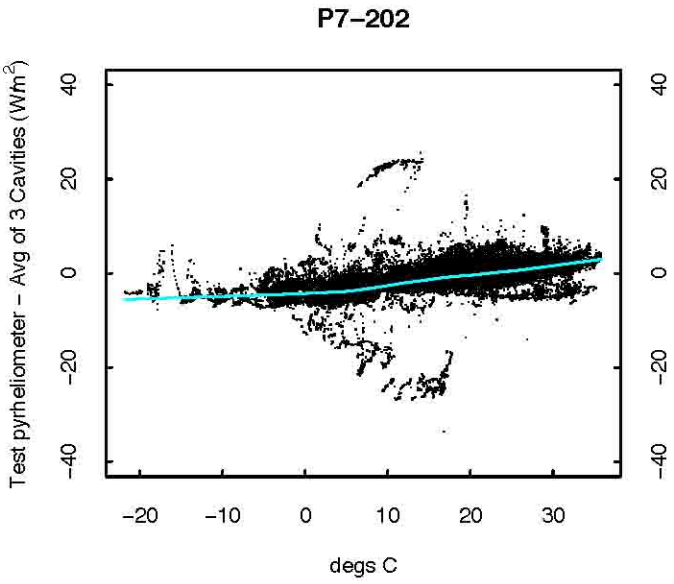

P5–109
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

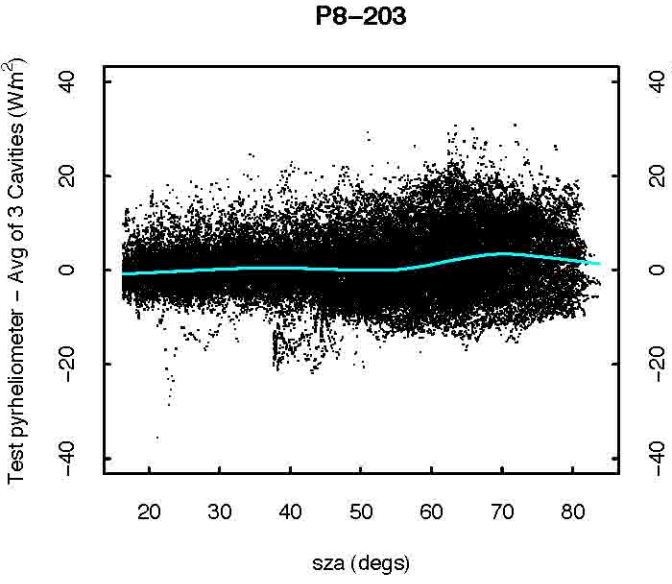

P5–109
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C

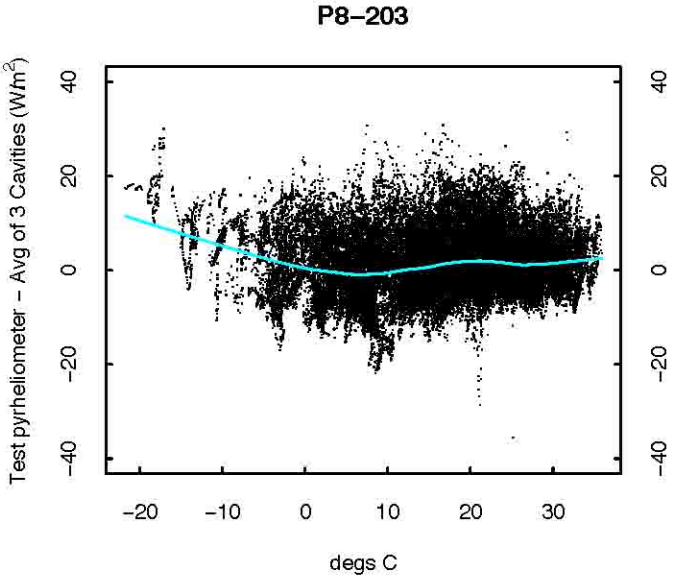

P6–103
Test pyrheliometer – Avg of 3 Cavities (W/m²)
sza (degs)

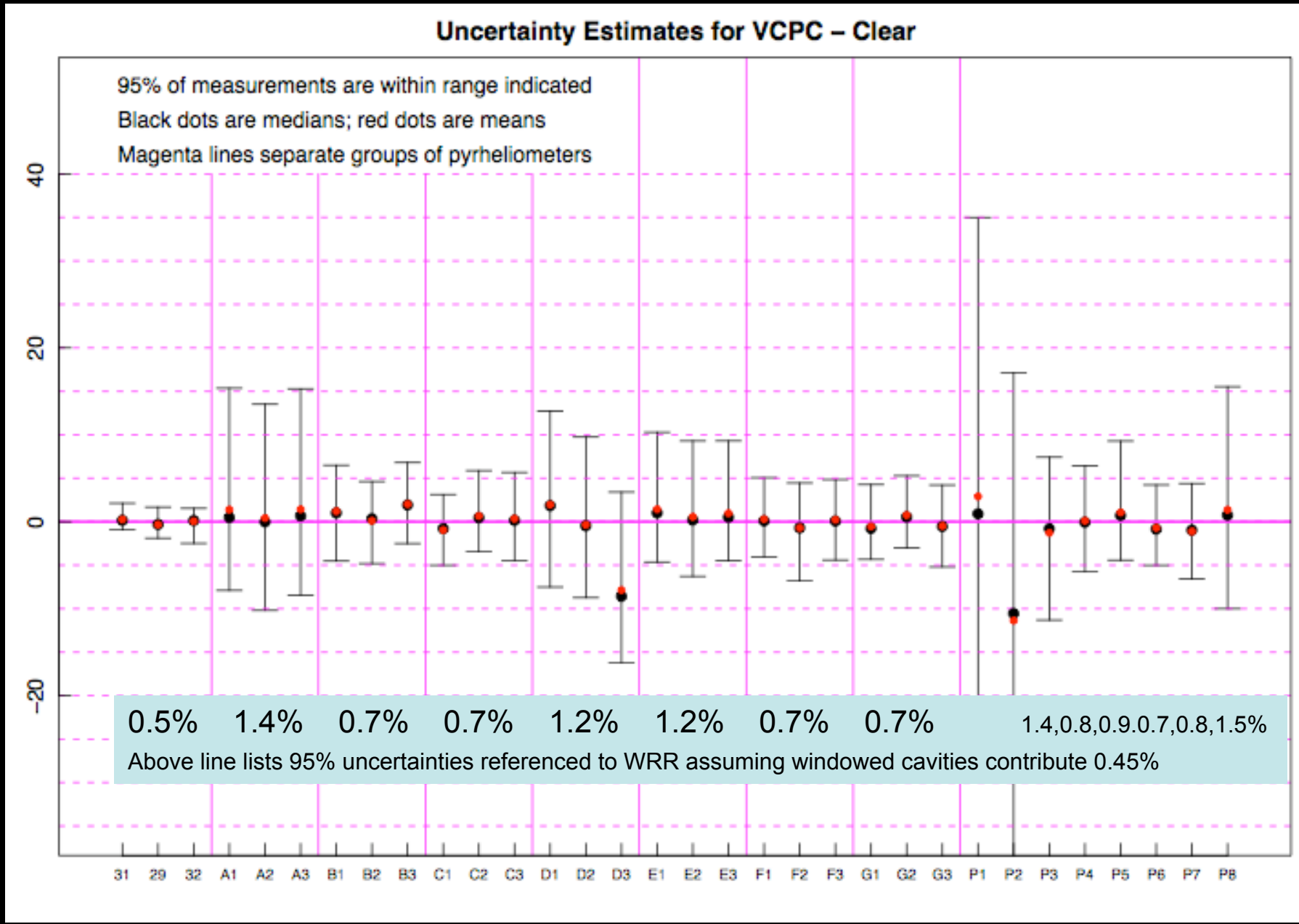

P6–103
Test pyrheliometer – Avg of 3 Cavities (W/m²)
degs C


P7–202
Test pyrheliometer – Avg of 3 Cavities (W/m2)
40
20
0
−20
−40
20
30
40
50
60
70
80
sza (degs)


P7–202
Test pyrheliometer – Avg of 3 Cavities (W/m2)
40
20
0
−20
−40
−20
−10
0
10
20
30
degs C


P8–203
Test pyrheliometer – Avg of 3 Cavities (W/m2)
40
20
0
−20
−40
20
30
40
50
60
70
80
sza (degs)


P8–203
Test pyrheliometer – Avg of 3 Cavities (W/m2)
40
20
0
−20
−40
−20
−10
0
10
20
30
degs C


Uncertainty Estimates for VCPC – Clear
95% of measurements are within range indicated
Black dots are medians; red dots are means
Magenta lines separate groups of pyrheliometers
40
20
0
-20
0.5% 1.4% 0.7% 0.7% 1.2% 1.2% 0.7% 0.7% 1.4,0.8,0.9.0.7,0.8,1.5%
Above line lists 95% uncertainties referenced to WRR assuming windowed cavities contribute 0.45%
31 29 32 A1 A2 A3 B1 B2 B3 C1 C2 C3 D1 D2 D3 E1 E2 E3 F1 F2 F3 G1 G2 G3 P1 P2 P3 P4 P5 P6 P7 P8