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Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory
Innovation for Our Energy Future

An Update on Reducing the Uncertainty in Solar Radiometric Measurements

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May 26-27, 2005
Athens, Greece

SOLARIS 2005

NREL/PR-560-38202
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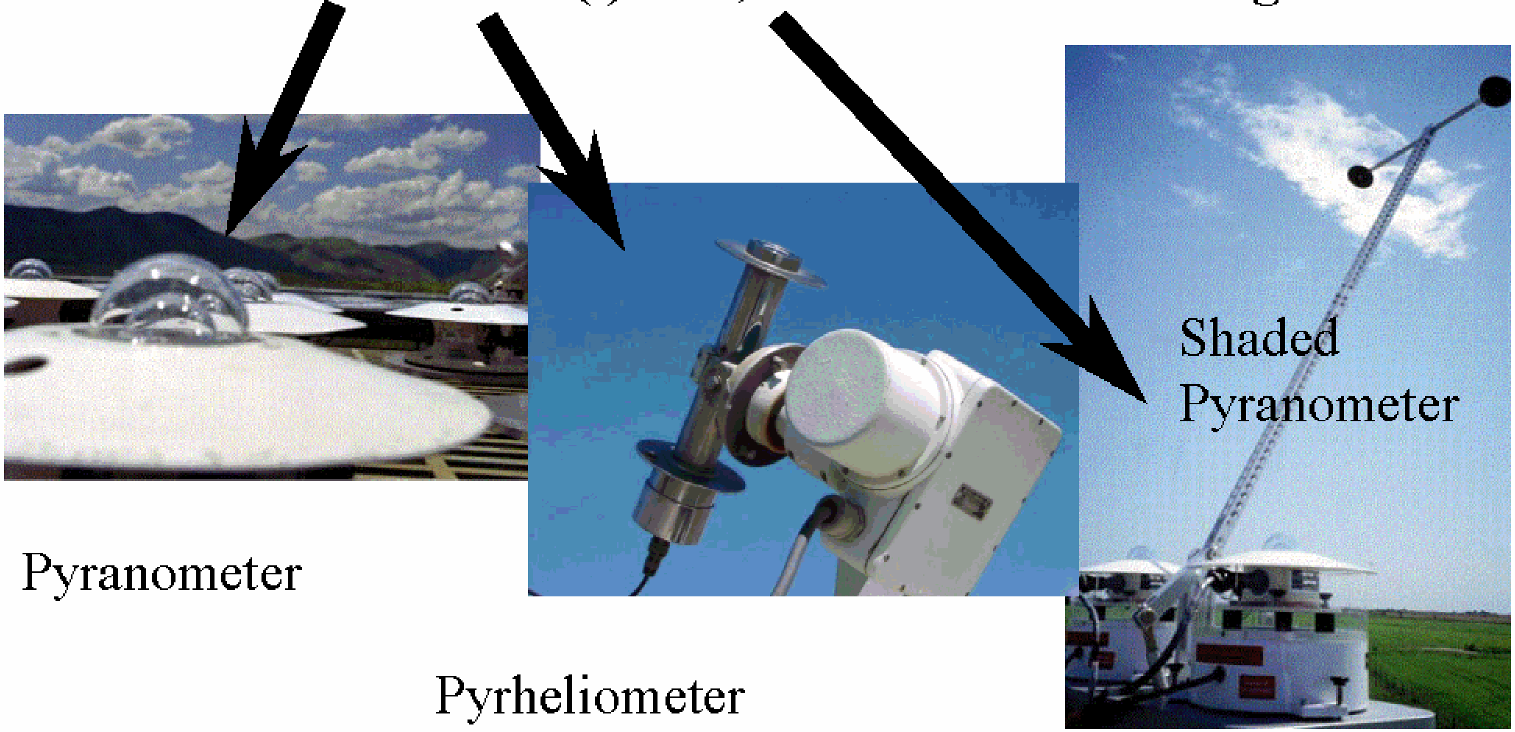
Solar Radiation Component Equation

Total (global) G, Direct beam, B, Diffuse Sky (scattered), D,

$$G = B\ \mathrm{Cos}(i) + D, \qquad i = \text{incidence angle}$$



Solar Radiometer Responsivity Issues

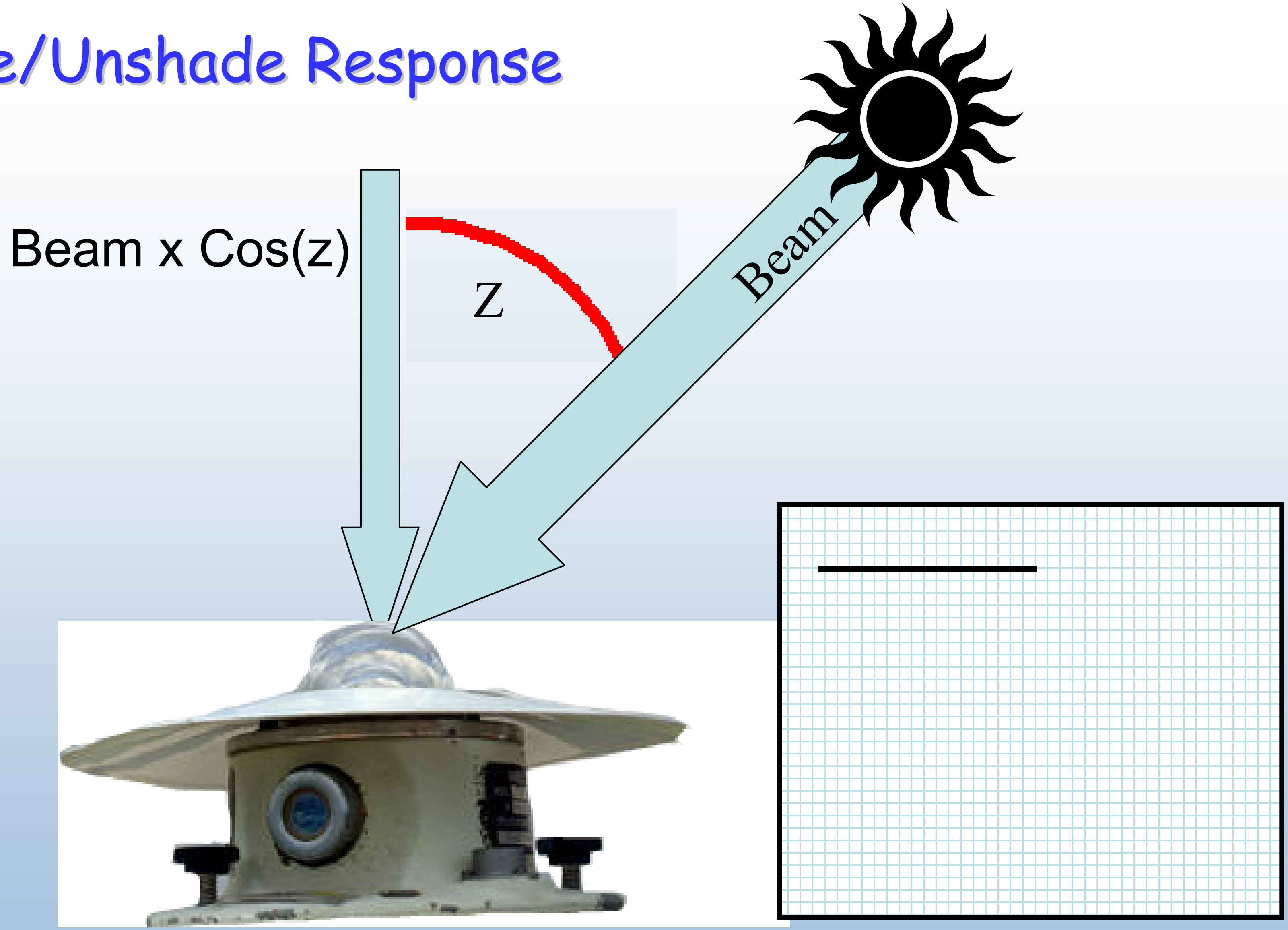
- Pyranometer Thermopile Offset IR voltage
  - Corrections at calibration time

  - Post-hoc correction schemes based on
    - "cosine response" though DAY and Year
    - IR radiation exchange error voltage

- Pyrheliometer Environmental Influences
  - Correction at calibration time α
    - Wind speed,dTemperature/dt, Irradiance

  - Post-hoc correction based on Ws,dT, I

Shade/Unshade Response



Reda, I., T. Stoffel, D. Myers, A *Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance*. Solar Energy, 2003. 74: p. p. 103-112.

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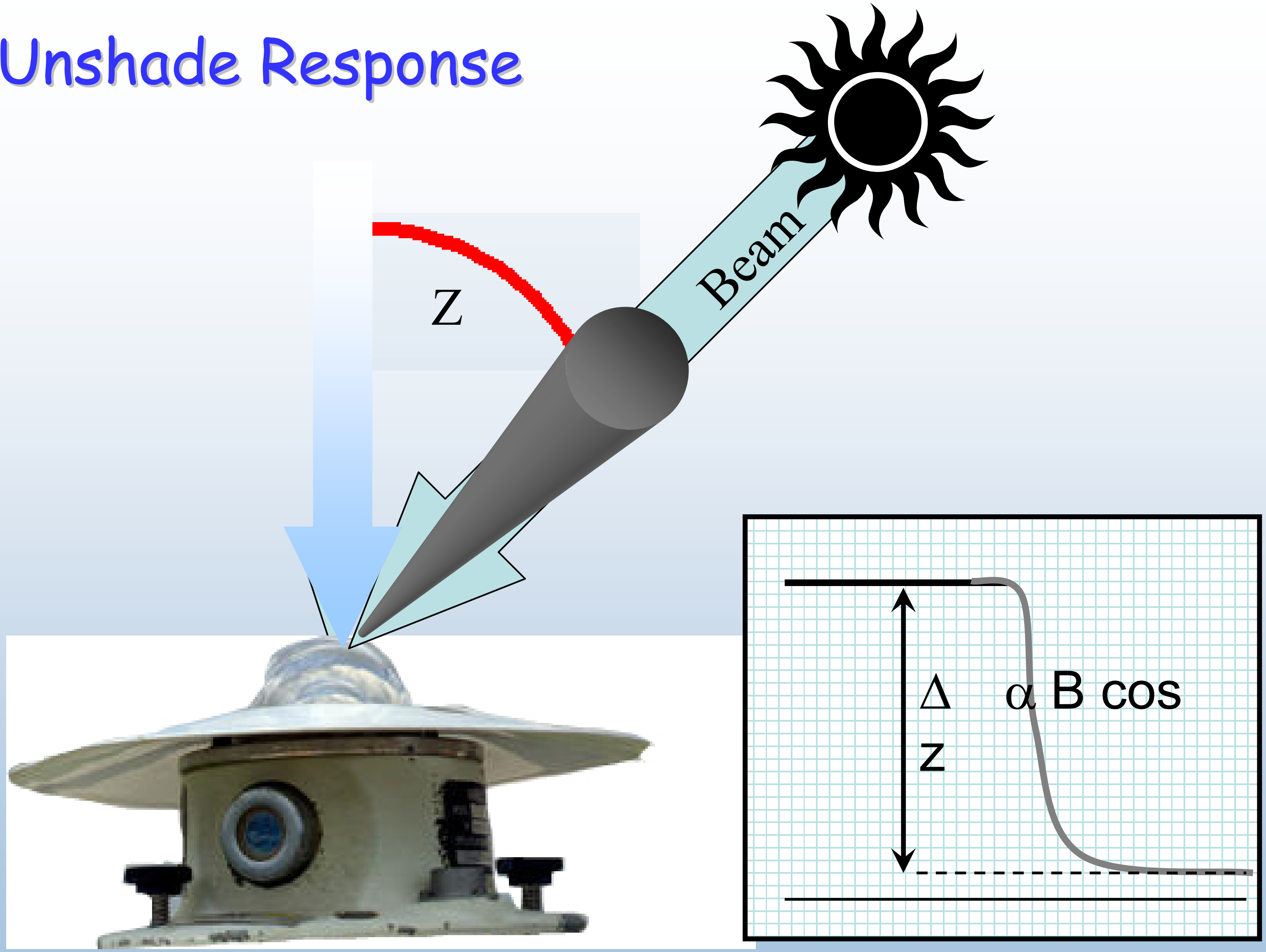

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Component Sum Method

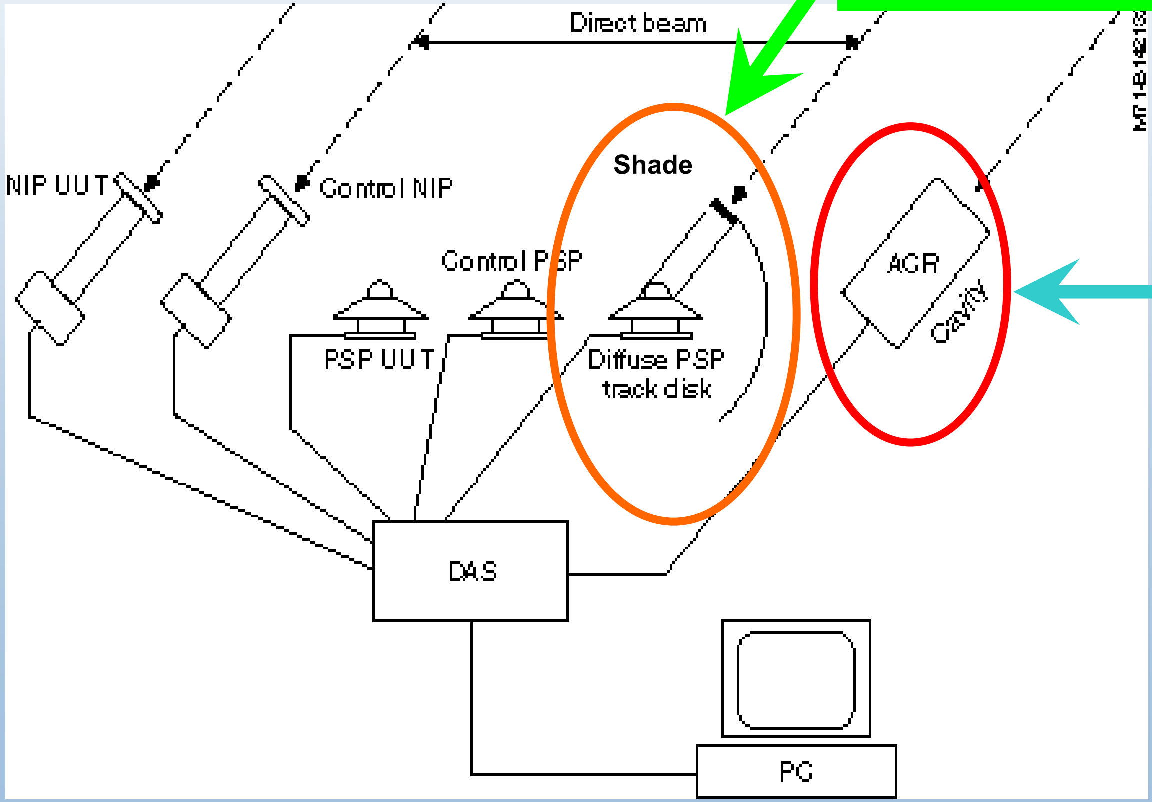
$$Rs = \frac{U}{[B \cdot Cos(z) + D]}$$

U = Test Pyranometer signal volts;

D= Diffuse

B = Beam radiation; Z = Zenith Angle

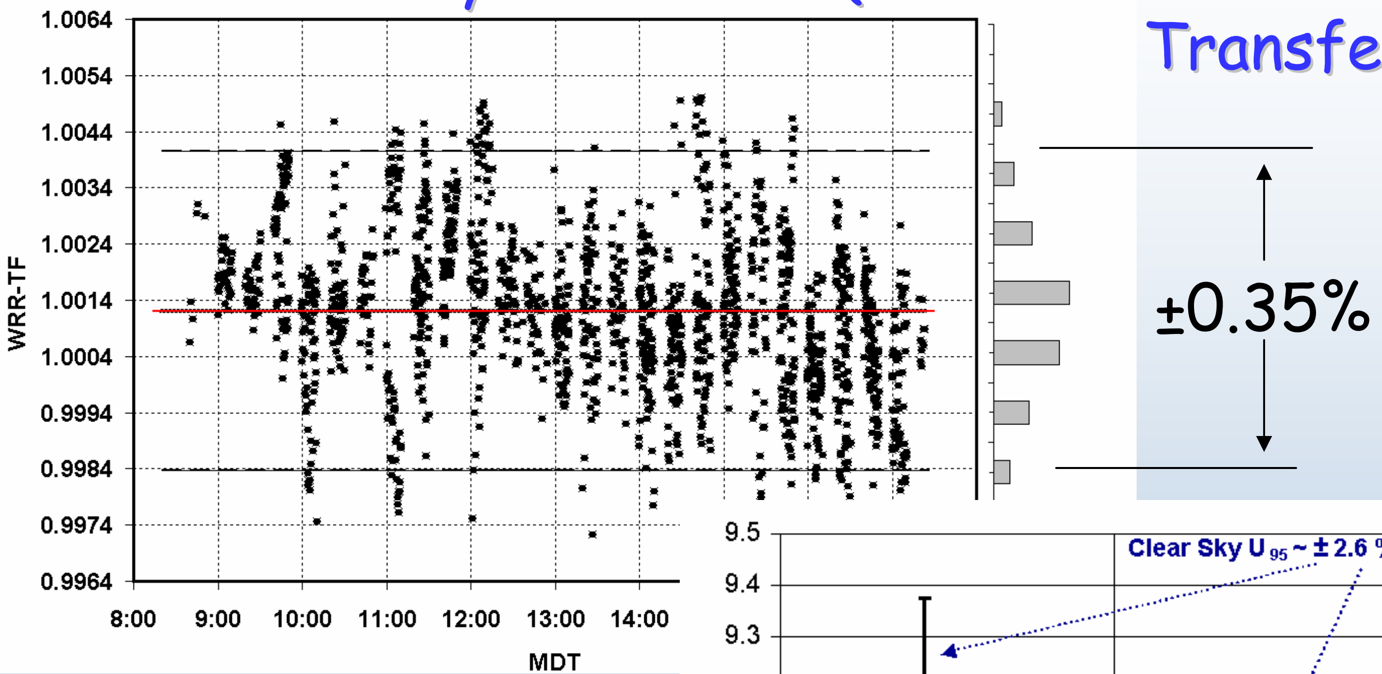
Diffuse: Shade/Unshade calibrated pyranometer (vs Beam)



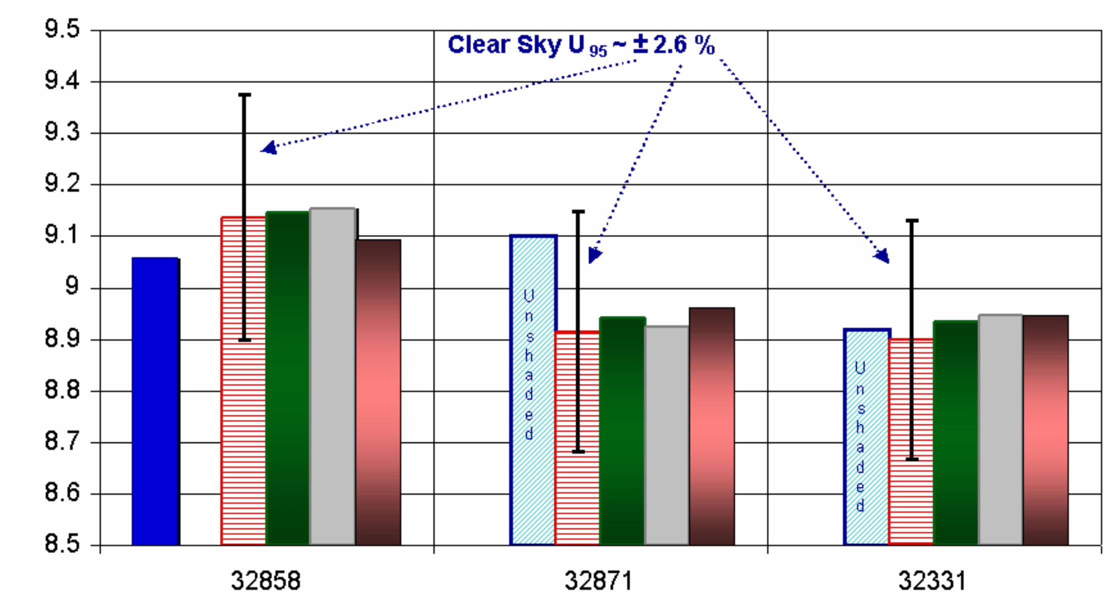
B from Working Reference Absolute Cavity Pyrheliometers

Empirical Reference Irradiance Uncertainties

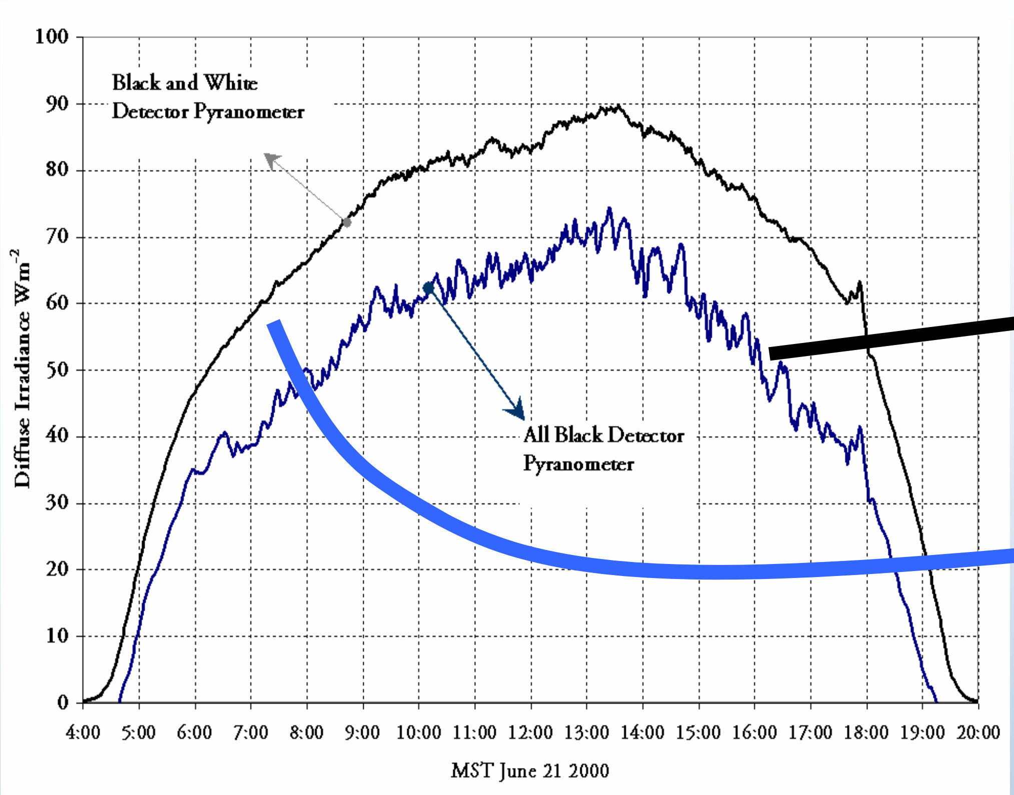
Cavity Reference (World Radiometric Reference) Transfer Uncertainty

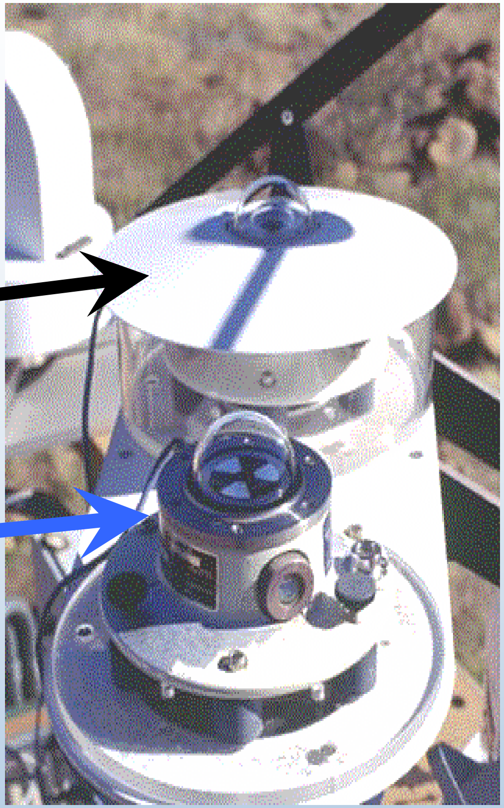


Diffuse Pyranometer Calibration Uncertainty



Pyranometer Offset Error Signal





All Black thermopile detectors with reference junctions in instrument body are never in thermal equilibrium; suffer –5 W/m² to –20 W/m² thermal offset. Offset produced by INFRARED exchange between detector & Sky/domes. Black & White reference and hot junctions in same thermal conditions, low thermal offsets. All-black unshaded units posses offset !

Dutton, E. G., J. J. Michalsky, T. Stoffel, B. W. Forgan, J. Hickey, T. L. Alberta, I. Reda, *Measurement of Broadband Diffuse Solar Irradiance Using Current Commercial Instrumentation with a Correction for Thermal Offset Errors.* Journal of Atmospheric and Oceanic Technology, 2001. 18(3): p. 297-314

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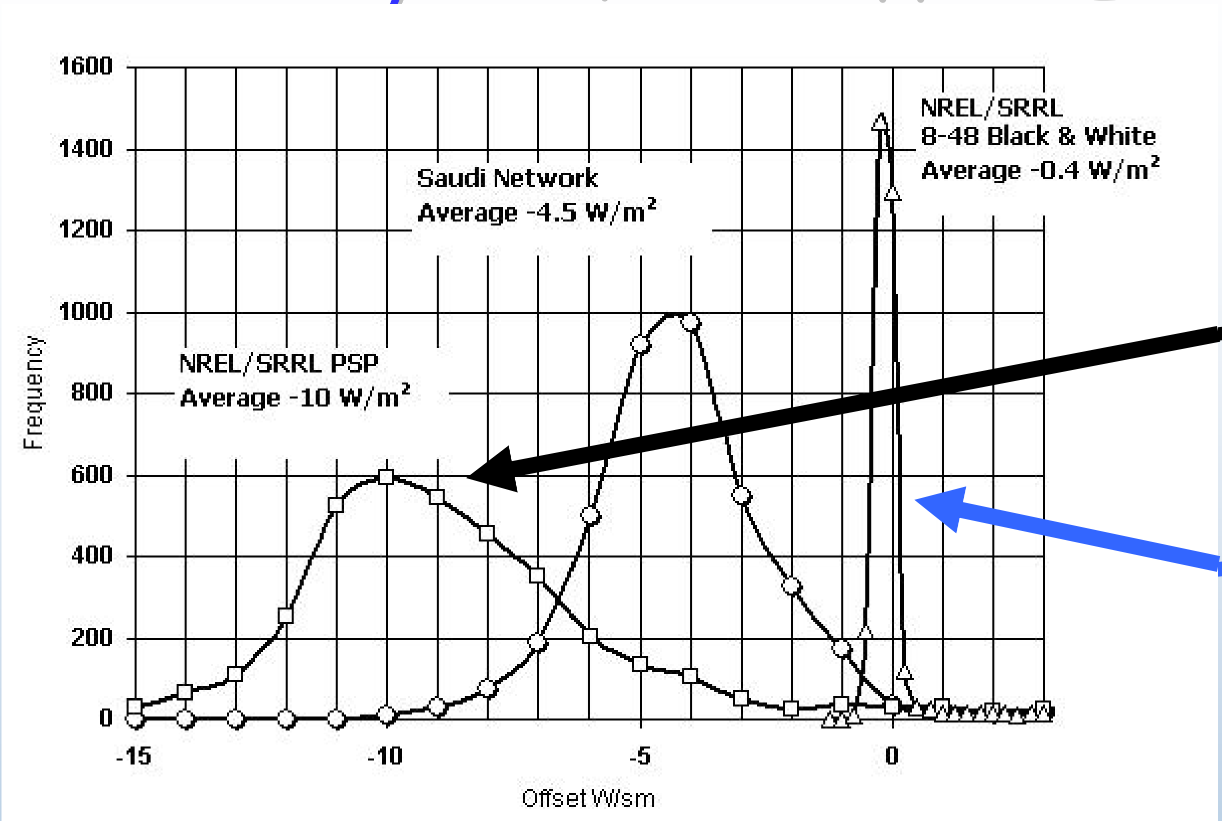

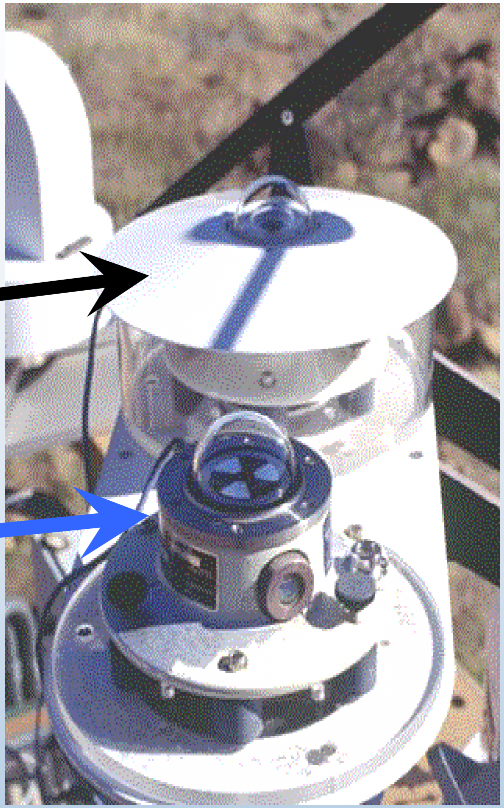

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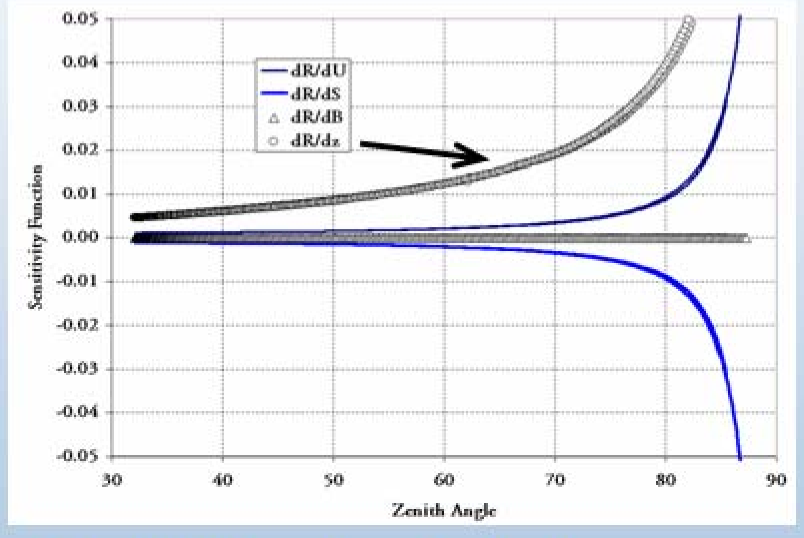
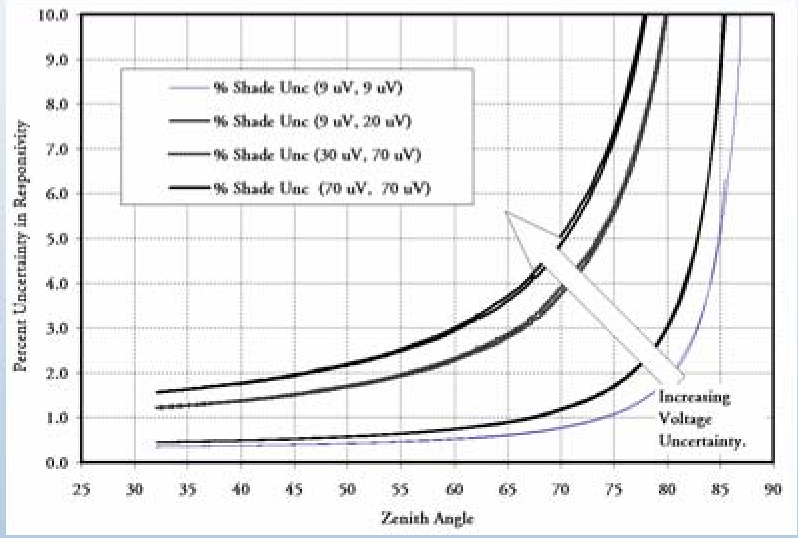
Shade-Unshade Calibration

$$Rshade = \frac{(U + e_U) - (S + e_S)}{[B \cdot Cos(z)]}$$

$$U_{shade}^2 = (\partial_U Rs * e_U)^2 + (\partial_S Rs * e_S)^2 + (\partial_B Rs * e_B)^2 + (\partial_z Rs * e_z)^2$$



Sensitivity functions for shade-unshade calibration. Sensitivity to shade (negative line) and unshade (positive line) voltages are mirror image of each other. Greatest sensitivity is to zenith angle (circles). Negligible sensitivity to beam uncertainty.

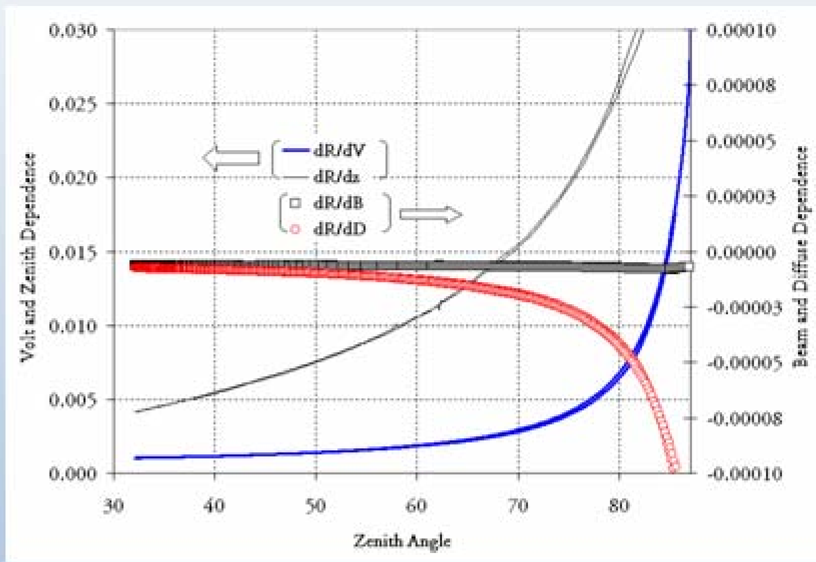


Total Uncertainty in shade-unshade calibrations versus zenith angle for various uncertainties in *voltage measurement* with fixed beam (4 Wm^{-2}) and z angle (0.06°) uncertainty. Arguments in parenthesis are uncertainty in shade unshade voltages, respectively

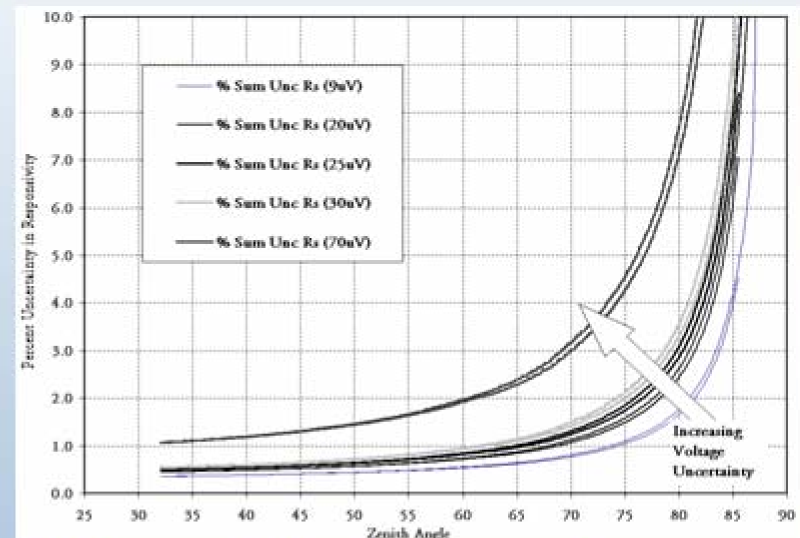
Component Sum Calibration

$$Rsum = \frac{U}{[B \cdot Cos(z) + D]}$$

$$U_{sum}^2 = (\partial_U Rs * e_U)^2 + (\partial_D Rs * e_D)^2 + (\partial_B Rs * e_B)^2 + (\partial_z Rs * e_z)^2$$

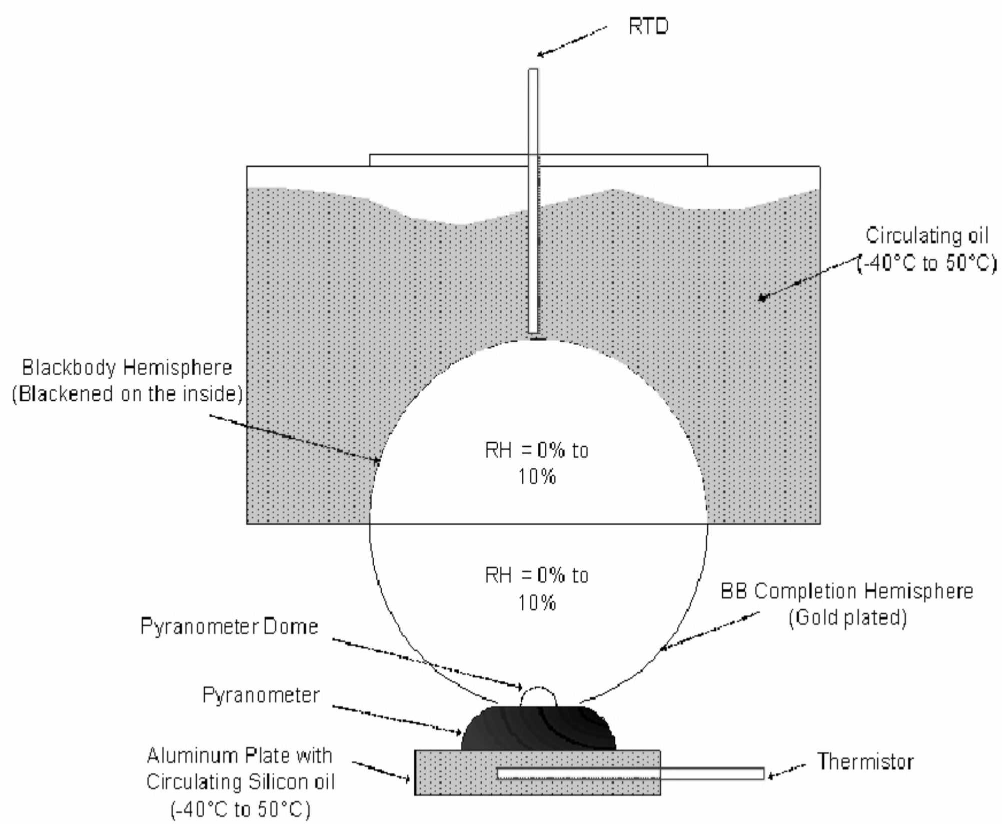


Sensitivity functions for component summation calibration. Sensitivity to beam (square) and diffuse (circle) irradiances are much less (right scale) than to *voltage* (heavy line) and zenith angle (light line) (left scale).



Total uncertainty in component sum calibrations as a function of zenith angle for various uncertainties in *voltage measurement* (in parenthesis), and fixed beam (4 Wm^{-2}), zenith angle (0.06°), and diffuse (2 Wm^{-2}) uncertainty.

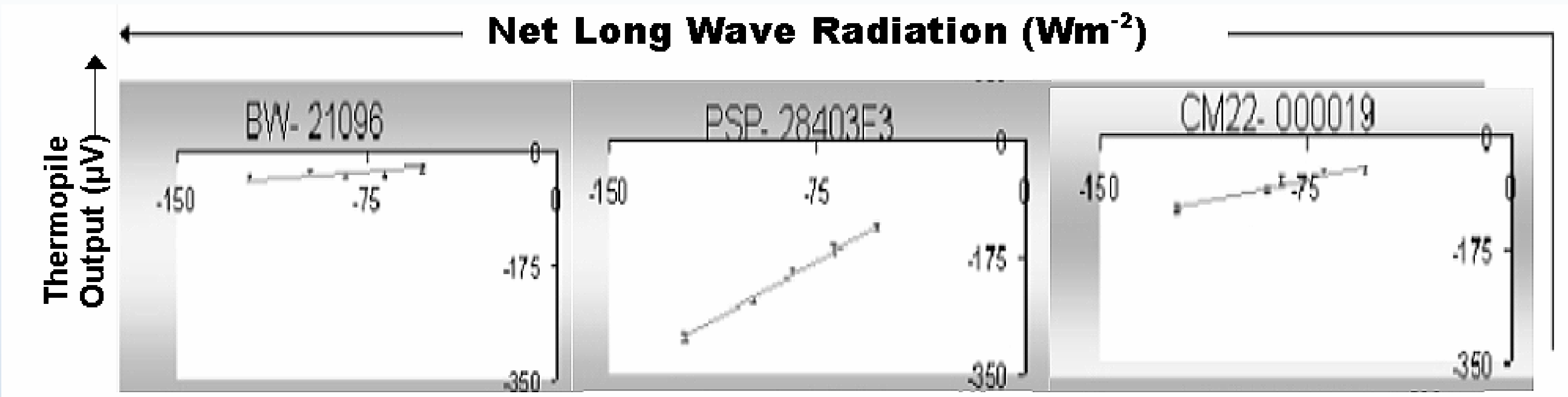
Characterize shortwave pyranometer net-IR response using Blackbody IR system



W_{NET} W_{bb} - W_c (Wm^{-2})	Pyran Signal (uV)	NET IR Rs(bb) uV W^{-1} m^{-2}
-110.8	-243.7	**2.20**
-60.3	-130.8	**2.17**
-131.6	-289.5	**2.20**
-71.3	-154.7	**2.17**
-83.6	-183.9	**2.20**

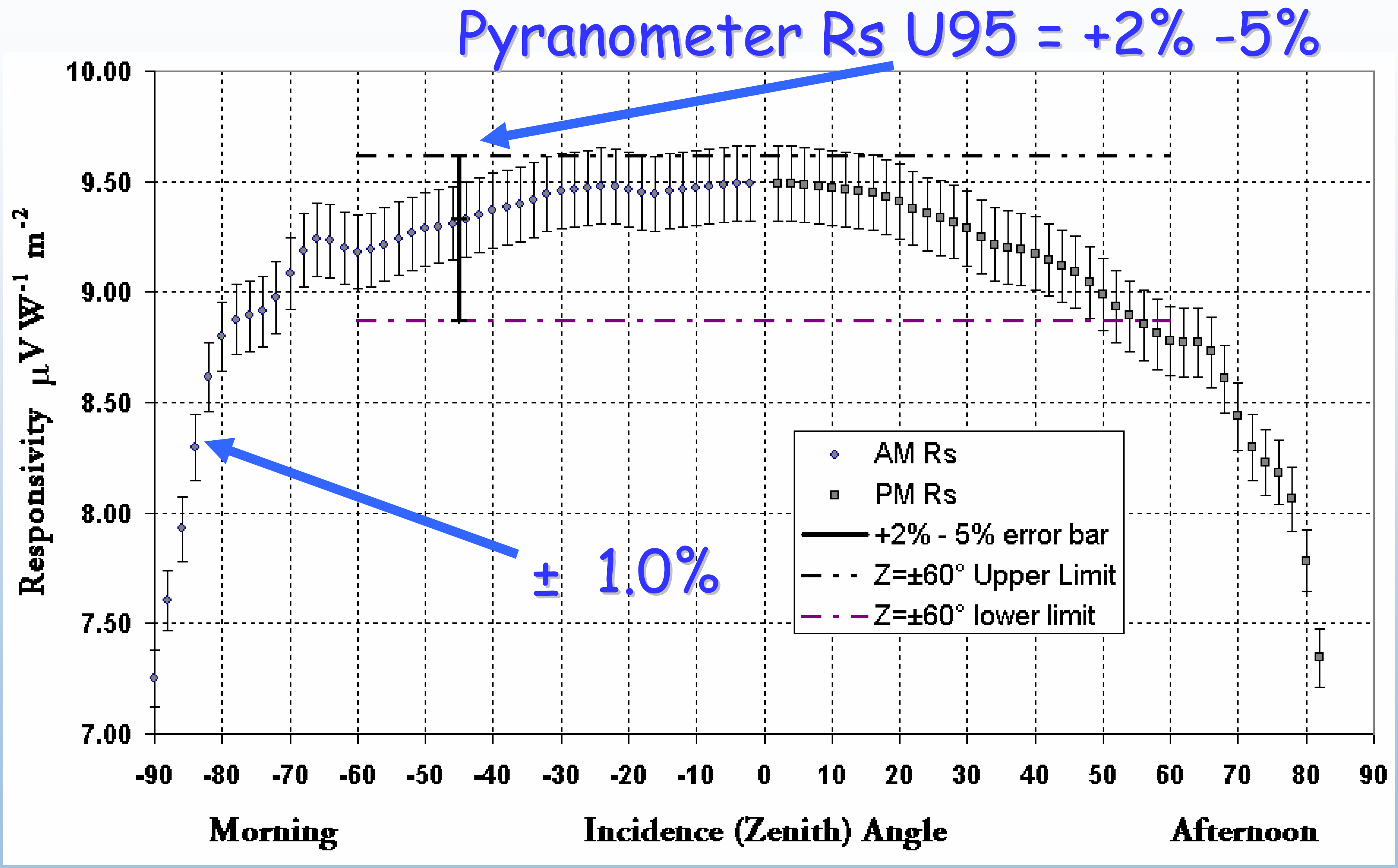
Reda, I., J. Hickey, C. Long, D. Myers, T. Stoffel, S. Wilcox, J.J. Michalsky, E.G. Dutton, D. Nelson, ***Using a Blackbody to Calculate Net-Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method*****. Journal of Atmospheric and Oceanic Technology, 2005. In Press.**

Shortwave pyranometer signals in response to net infrared (longwave) radiation

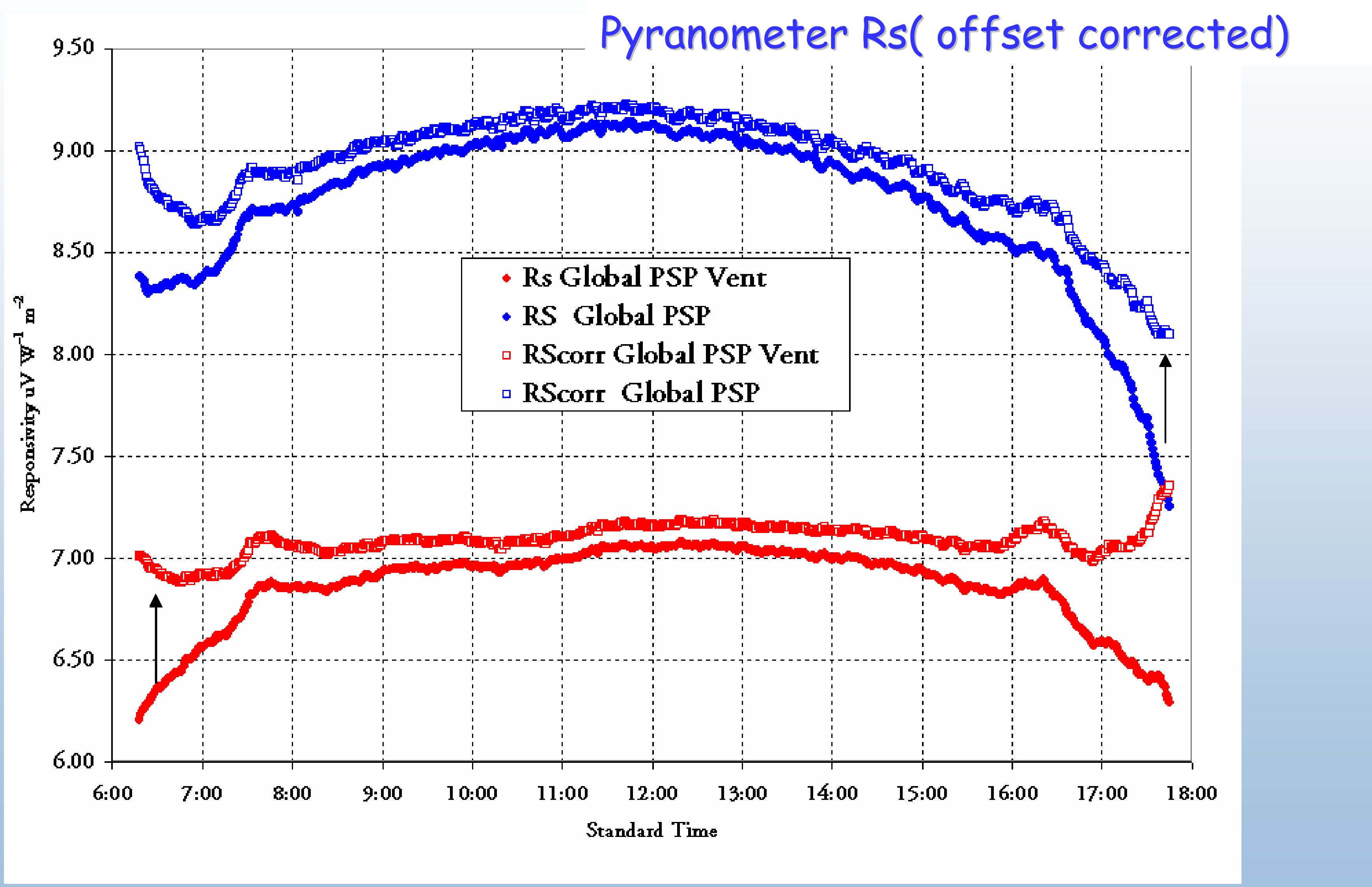


Pyranometer Model	# Tested	RS_{bb} (µV/Wm^{-2})	**RS_{MFR} (µV/Wm^{-2})**
EPLAB 8-48	2	0.8314	9.465
K&Z CM-22	1	0.8872	9.300
EPLAB PSP	**12**	**2.1757**	**8.46**
Spectrosun SR-75	1	1.1851	8.69

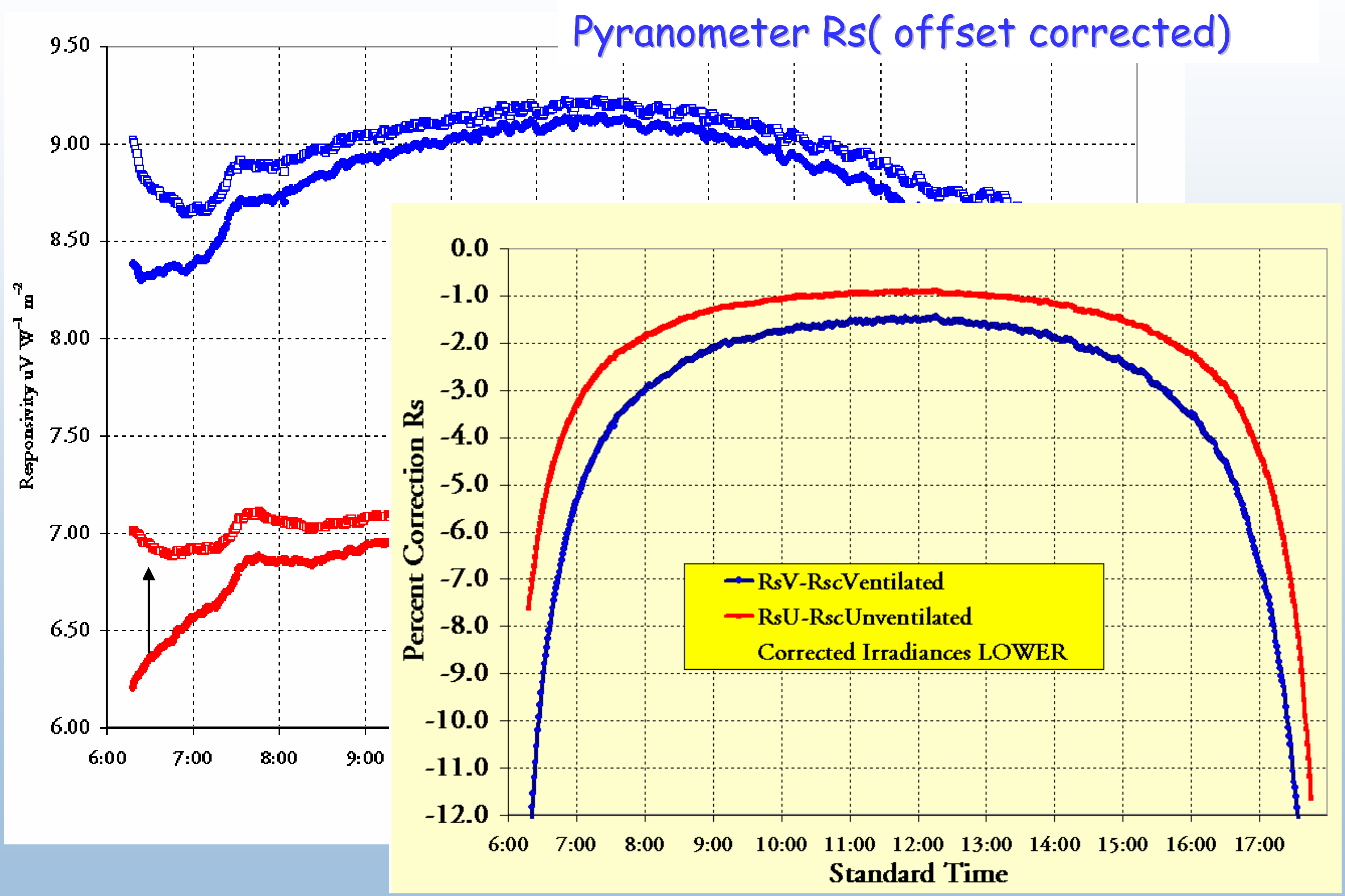
Pyranometer Responsivity Calibration Results



Pyranometer Calibration IR Corrections

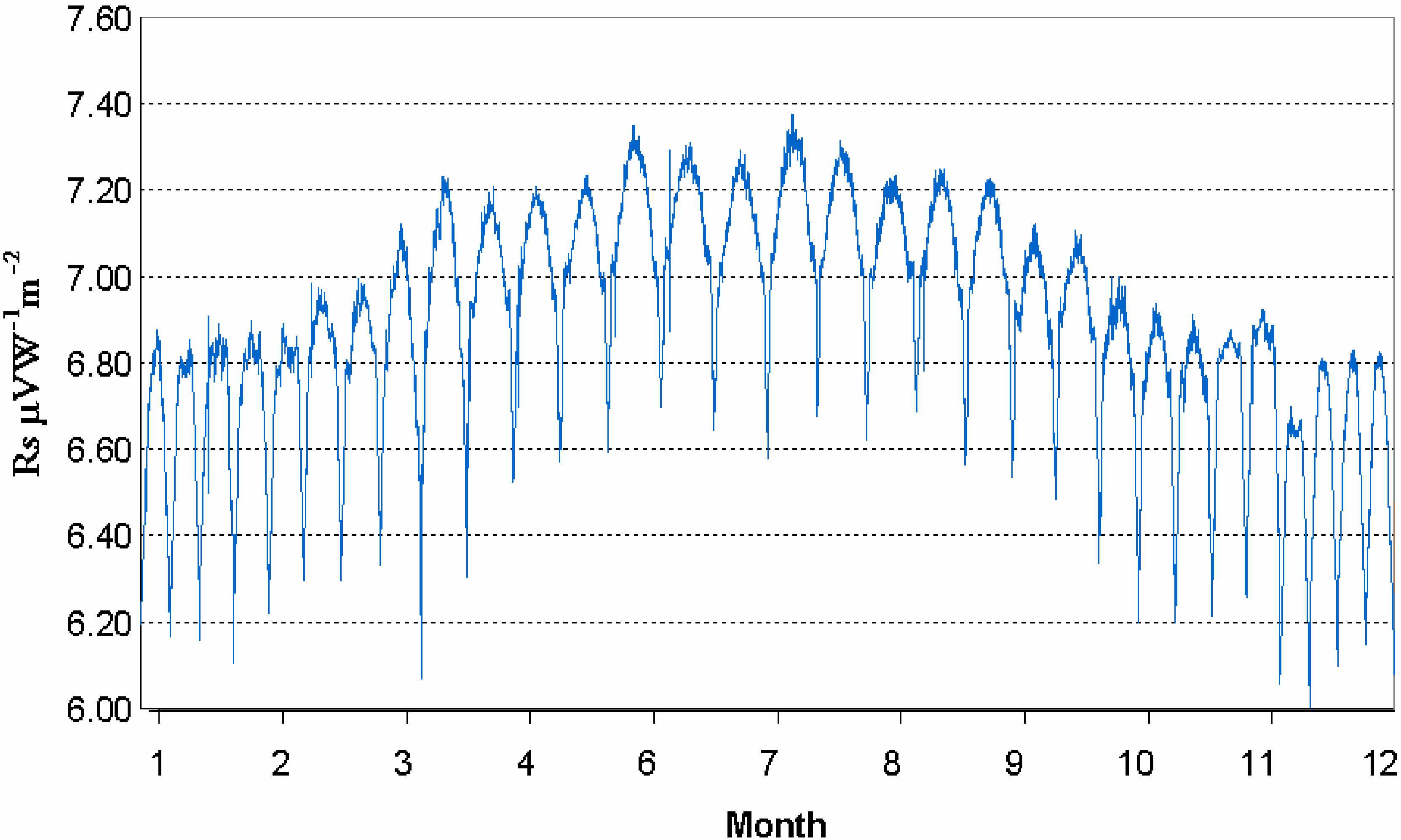


Pyranometer Calibration IR Corrections



"Daily" Calibration & Characterization

Pyranometer Rs through the Year

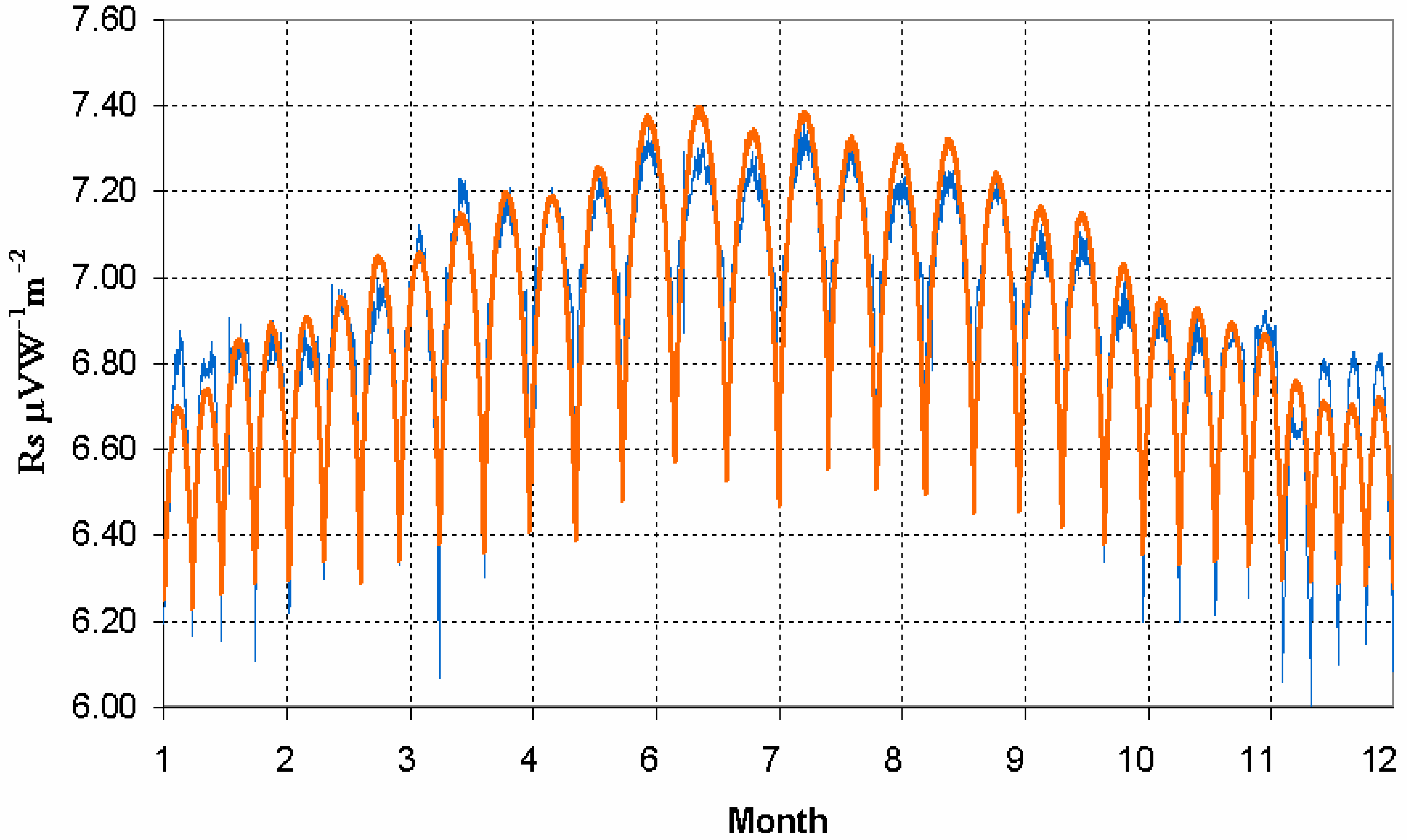


Lester, A., D. Myers, *A Method for Improving Global Pyranometer Measurements by Modeling Responsivity Functions.* Solar Energy, 2005. In Press.

"Daily" Calibration & Characterization

Pyranometer Rs through the Year

$$RS_{u8\text{-}48}(Z,D,I) = 0.6392 \ln[\cos(Z)] - 0.0936 \cos[(D\ 2\pi\ 360)/365] + 0.0008\ I + 7.545$$



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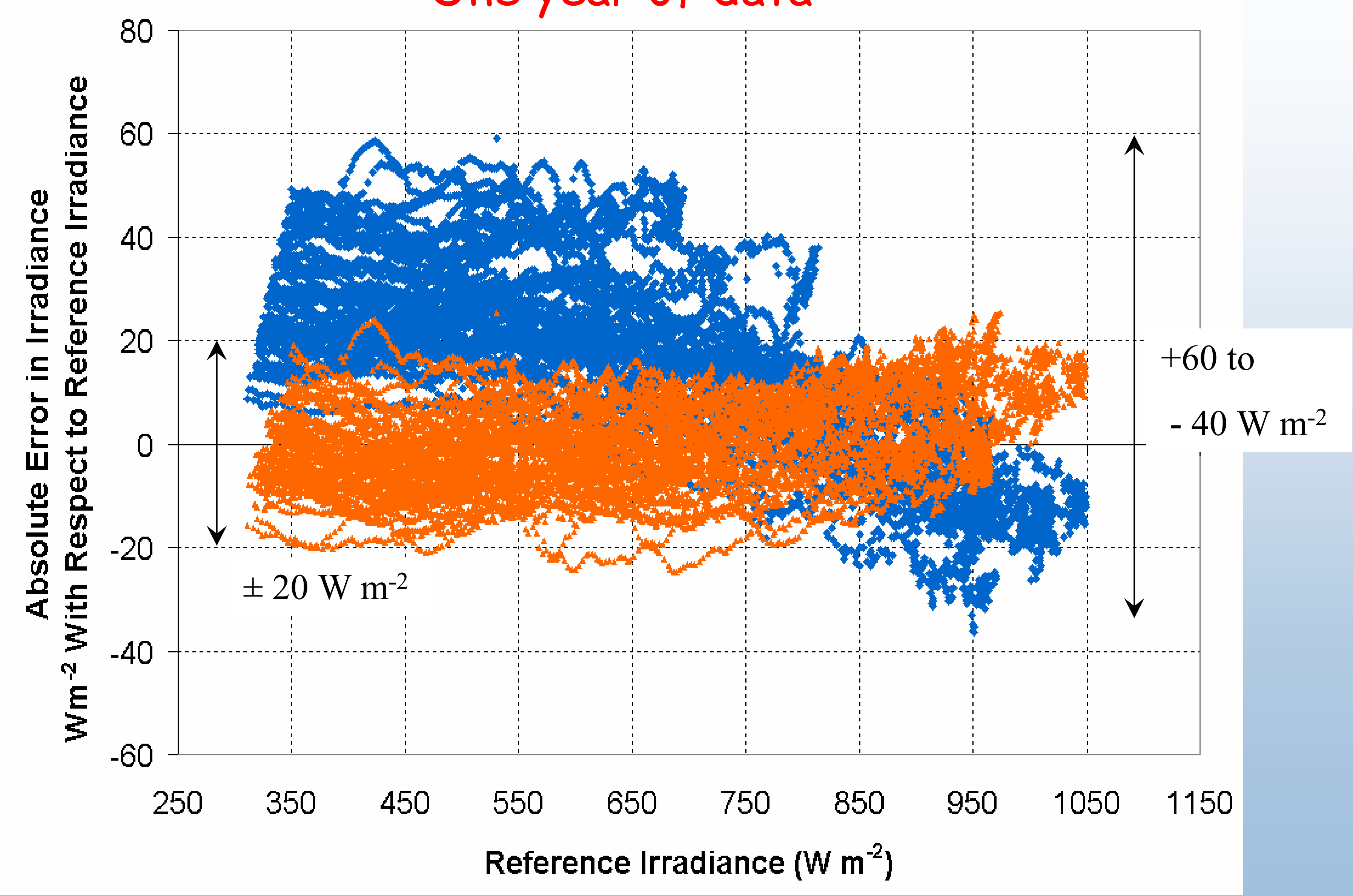
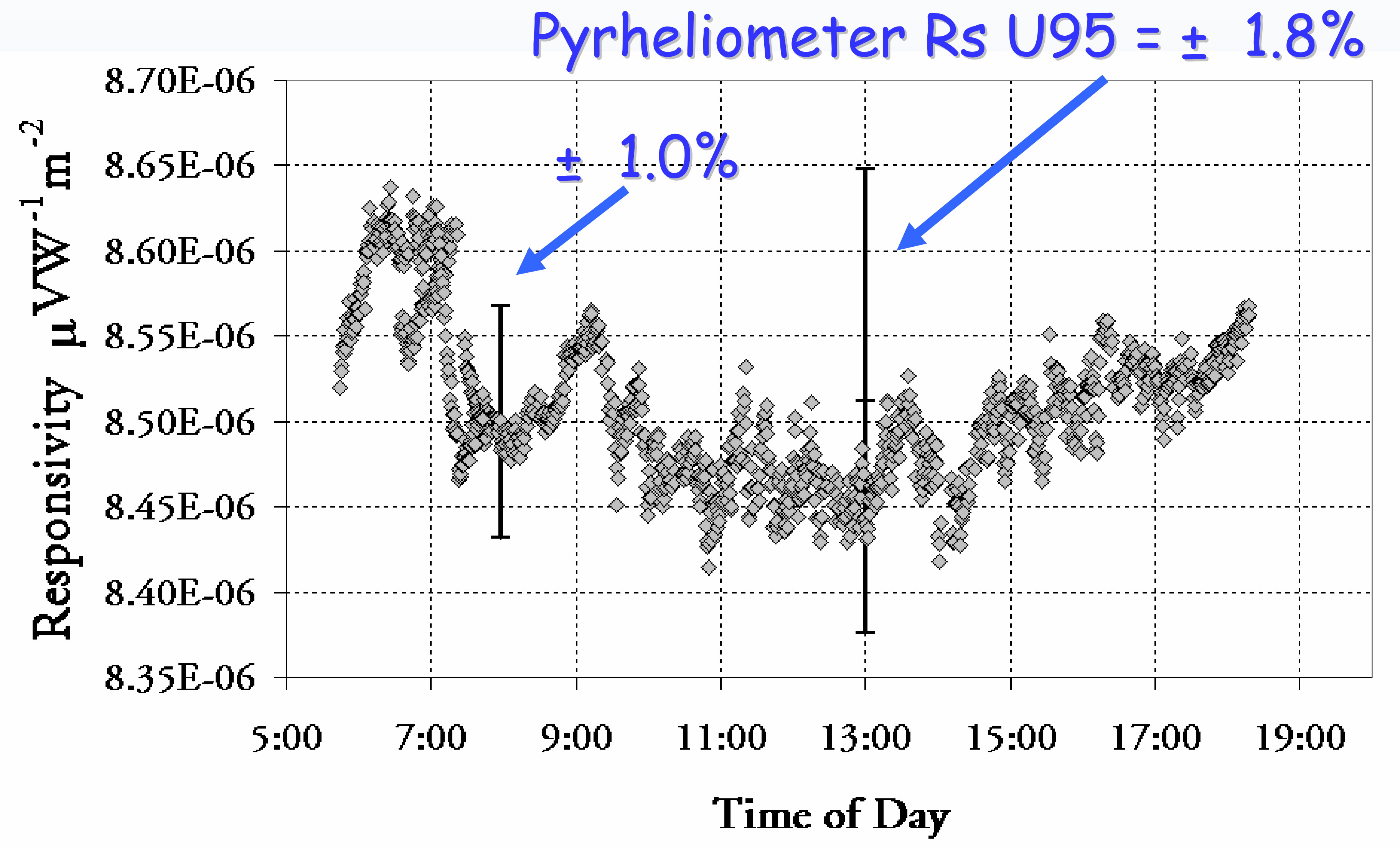
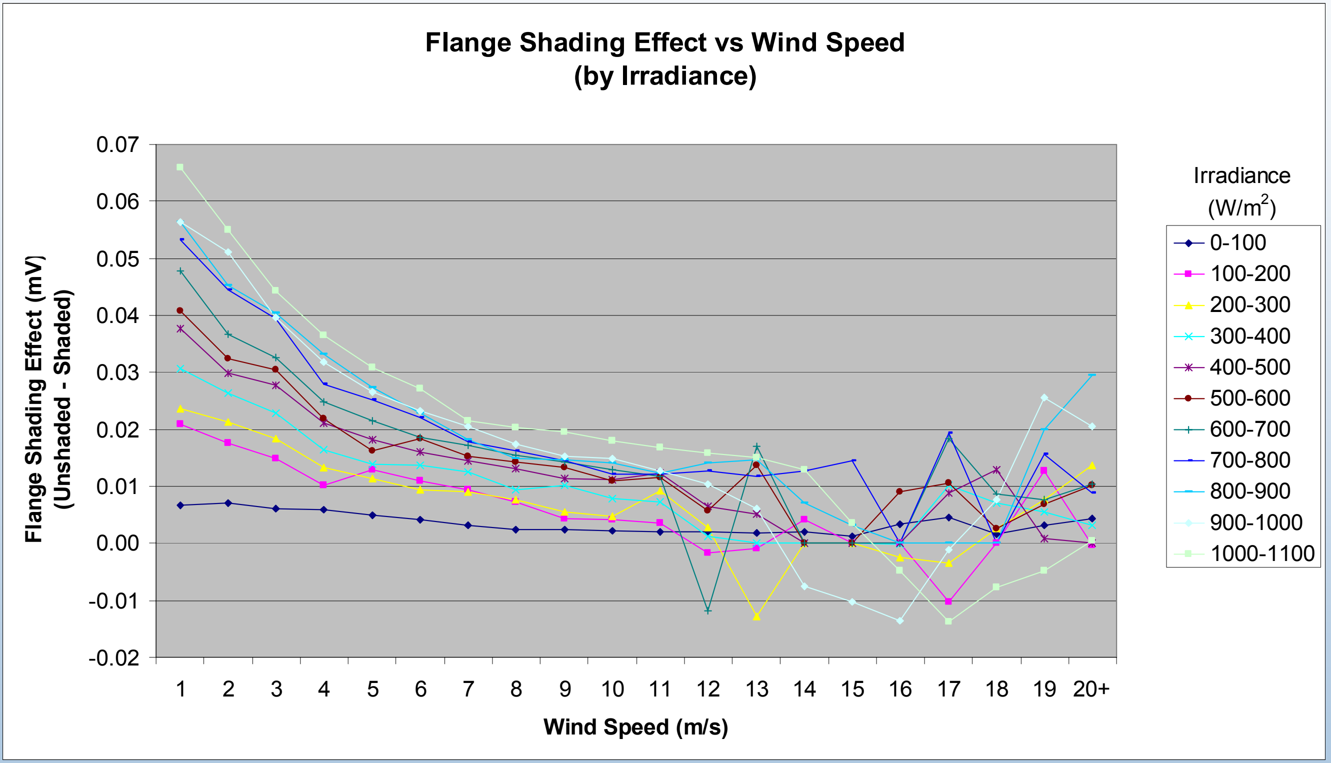
$RS_{8\text{-}48U}$ (Z, DA, IR) Applied to Pyranometer mV
One year of data



Pyrheliometer Rs Calibration Results



Pyrheliometer Rs environmental influences (flange, window, instrument)



Environmental Thermal Effects on the Eppley Normal Incidence Pyrheliometer

Stephen Wilcox, John Hickey,Daryl Myers Draft research summary; – April 5, 2005

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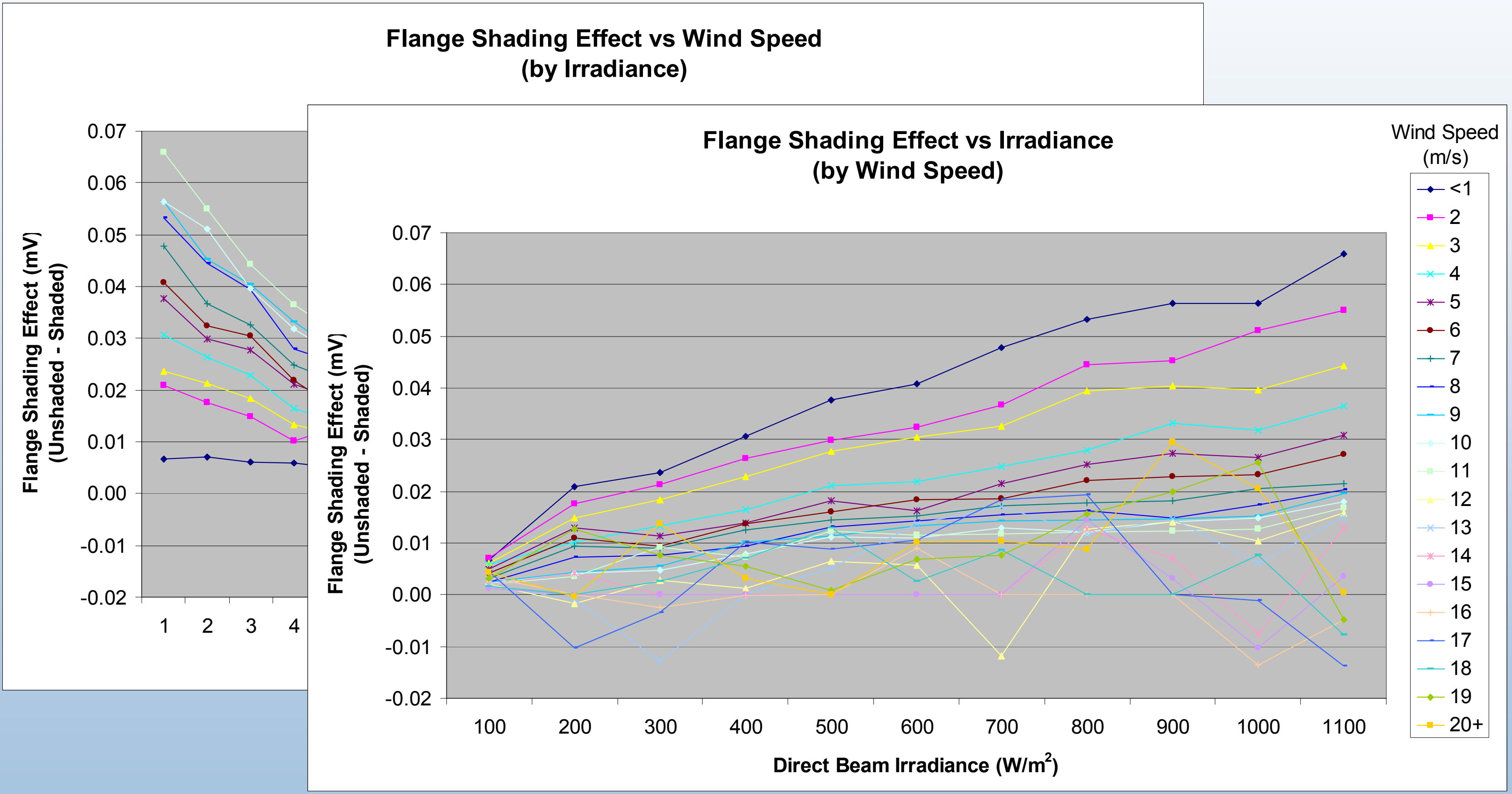

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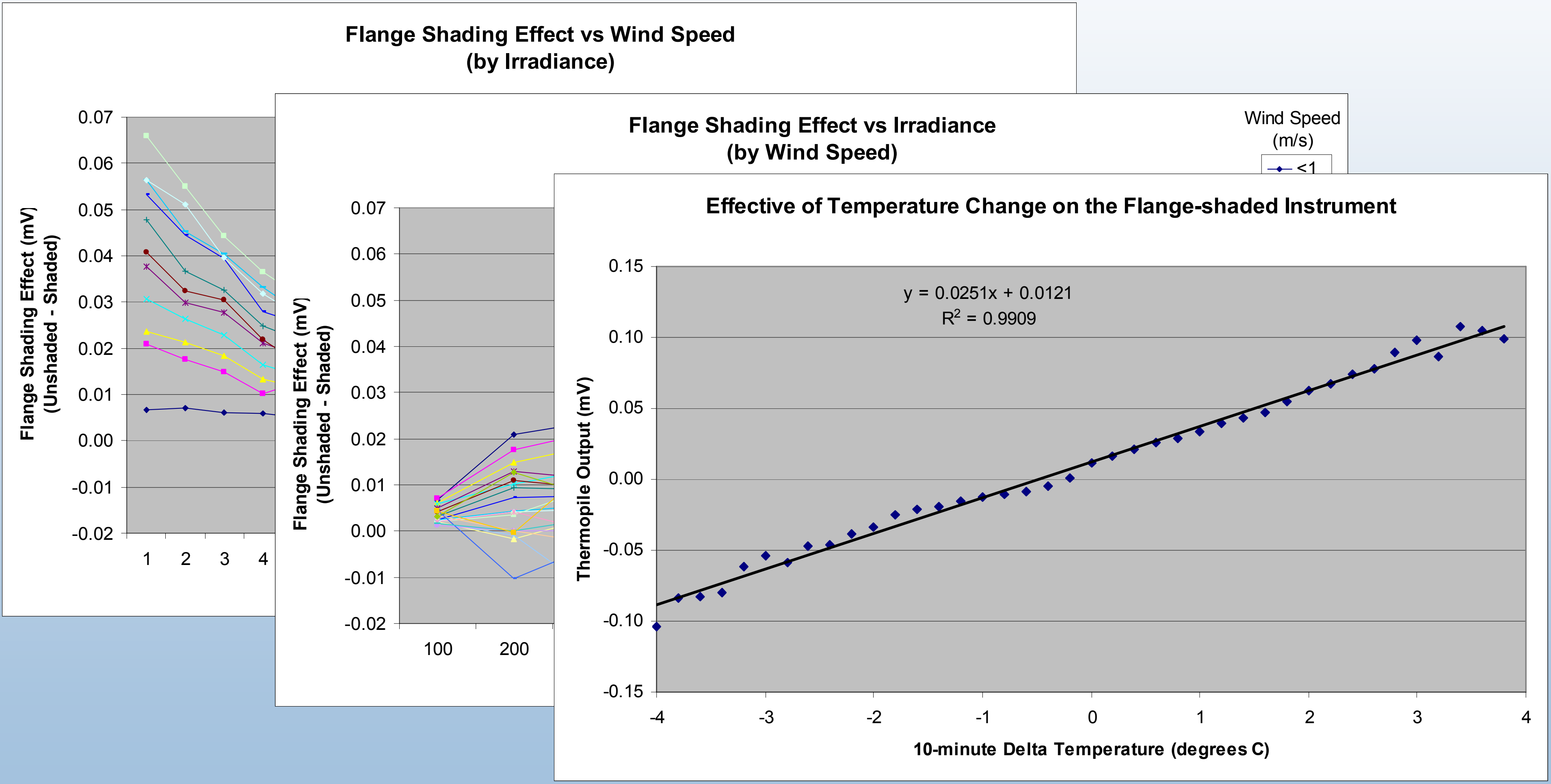

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Instrument Calibration & Characterizaton

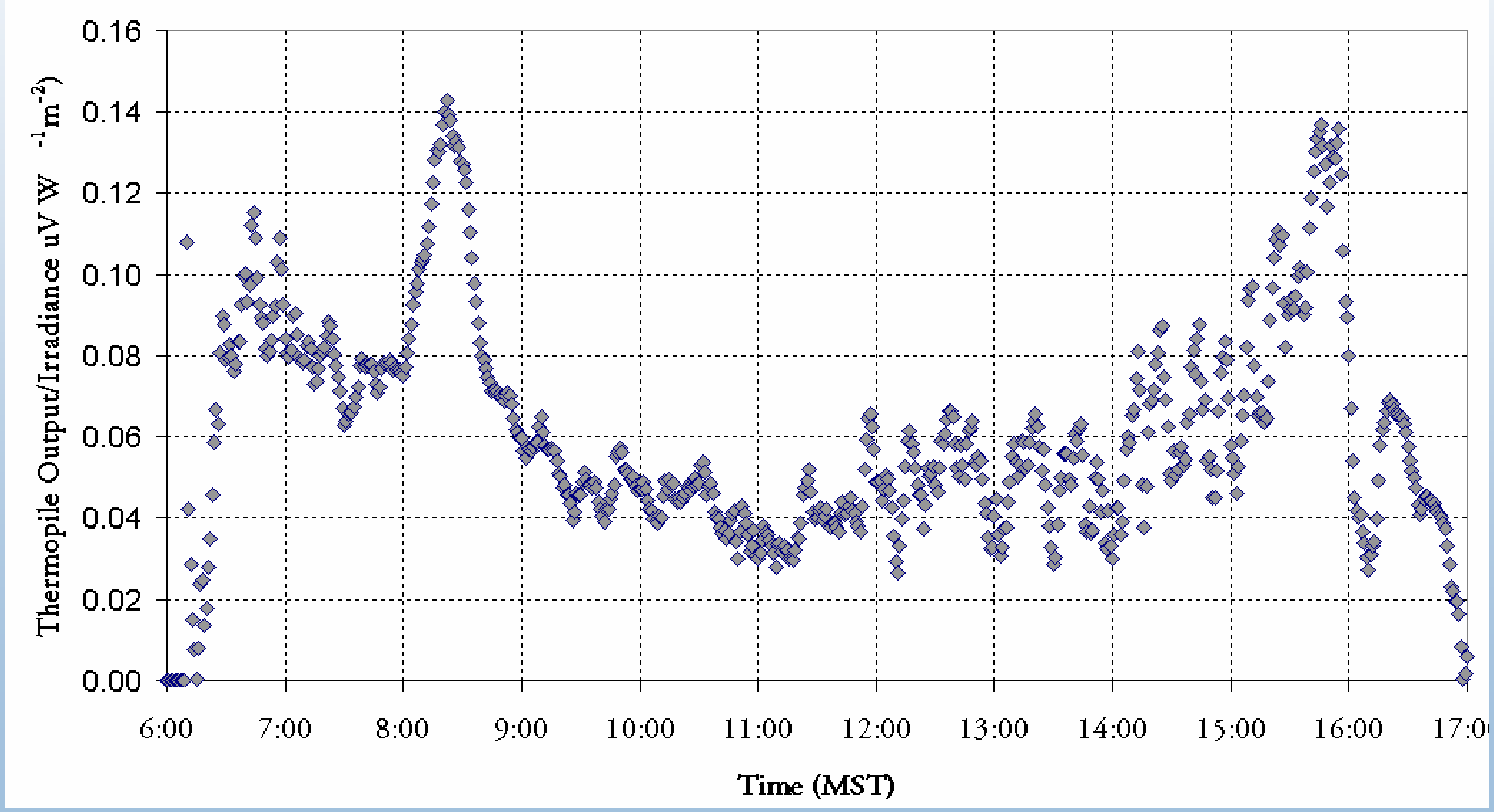
Shade window

Minus

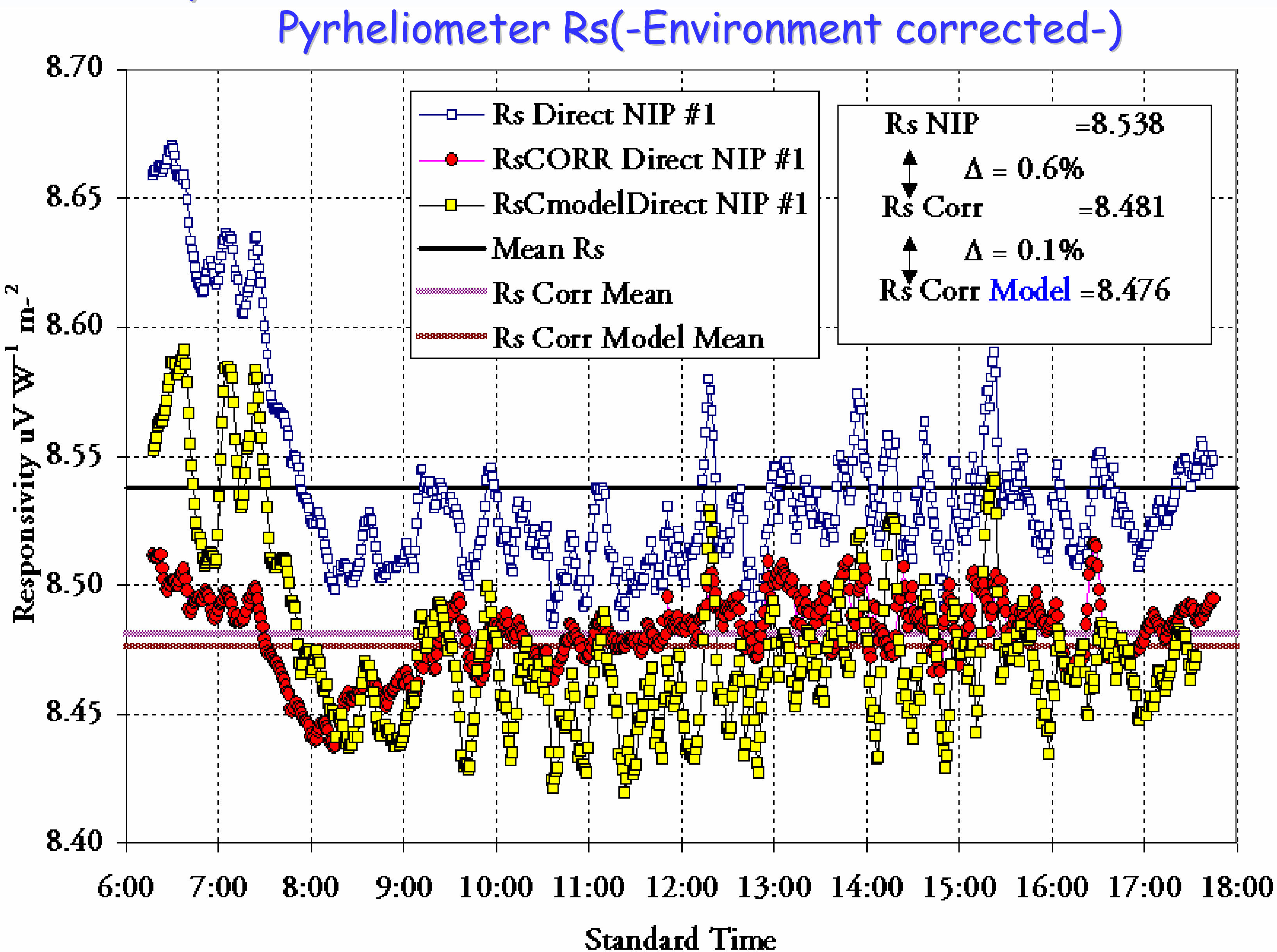
Shade Flange

/ DNI

Pyrheliometer Responsivity variations from environmental influences (on flange, instrument)



Pyrheliometer Calibration Corrections



Solar Radiometer Responsivity Issues

- Pyranometer Thermopile Offset IR voltage
  - Corrections at calibration time –
    - Monitor IR; reduce U95 by ½ to 1% ∀ Z
  - Post-hoc correction schemes based on
    - "cosine response" though DAY and Year
      - Global data uncertainty 60 Wm^{-2}-> 20 Wm^{-2}
- Pyrheliometer Environmental Influences
  - Correction at calibration time α Ws,dT/dt, DNI
    - Reduce U95 offset in Rs ~ 1/3; 0.6% to 0.2%
  - Post-hoc correction based on Ws,dT/dt, I

    Research continues!