Pyrgeometer Calibration Results

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ARM Instantaneous Radiative Flux (IRF) Working Group
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Acknowledgements

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Tom Kirk	EPLAB
Joe Michalsky	NOAA/GMD
Ibrahim Reda	NREL

Interim solution is to give credit here if you don't want to be on the title frame.

Pyrgeometer Calibration Results

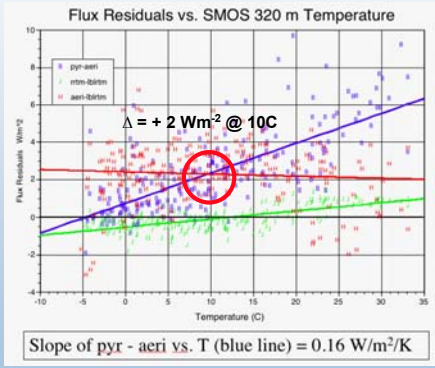
- Background
  - BBHRP & LW QME analyses
  - Calibration methods
  - BCR 01162 status
- Recent Investigations
  - World Radiation Center, Davos
  - NREL
  - EPLAB
  - NOAA
- Options
  - Recommendations

NREL National Renewable Energy Laboratory

LW QME Findings

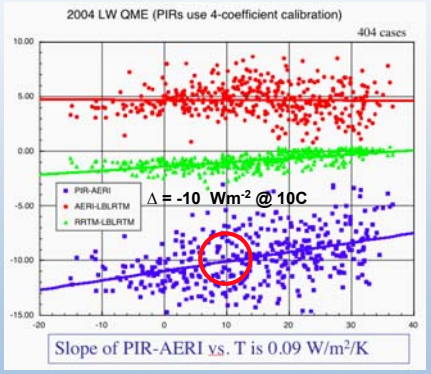
Search for temperature dependence of PIR - AERI measurements finds 12 Wm^{-2} bias between calibration methods using data from AERI, SIRS, and SMOS instruments:

AERI and SIRS Data from 1997



PIR data based on **EPLAB** blackbody calibrations and **2-coefficient** analyses of field measurements

AERI and SIRS Data from 2004



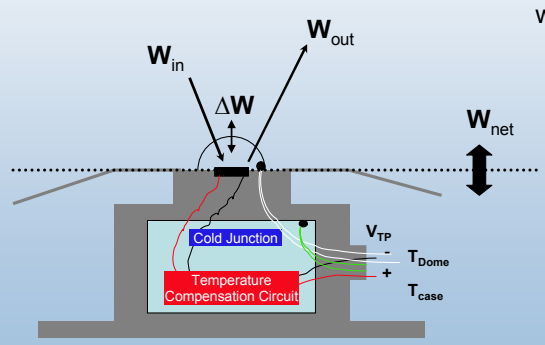
PIR data based on **NREL** blackbody calibrations and **4-coefficient** analyses of field measurements

Why we are studying pyrgeometer calibrations - the negative 12 W/sq m problem…

Calibration Basics: What's the 2- or 4-Coefficient Method?

A pyrgeometer responds to infrared flux balance at the receiver-detector:

$$W_{net} = W_{in} - W_{out} + \Delta W$$



where,

W_{in} = Incoming infrared flux, $\varepsilon_{sky}\sigma T_{sky}^4$

W_{out} = Outgoing infrared flux, $\varepsilon_{receiver}\sigma T_{reciever}^4$

ΔW = Dome-case flux interaction as "seen" by the detector, $\varepsilon_{case}\sigma T_{case}^4 - \varepsilon_{dome}\sigma T_{dome}^4$

ε = effective emissivity

σ = Stefan-Boltzmann constant

In the next two slides, QUICKLY give the audience a review of why should we care about 2- vs. 4-coefficients.

Pyrgeometer Data Reduction Methods

Traditional - 2K's

$$W_{in} = K_1 V + W_c + K_3 (W_d - W_c)$$

Albrecht & Cox - 3K's

$$W_{in} = K_1 V + K_2 W_c + K_3 (W_d - W_c)$$

Philipona et al. - 4K's

$$W_{in} = K_1 V + K_2 W_c + K_3 (W_d - W_c) + K_4 \sigma V T_c^3$$

$$\sim (U_{emf}/C)(1 + K_1 \sigma T_c^3) + K_2 W_c + K_3 (W_d - W_c)$$

Reda et al. - 4K's

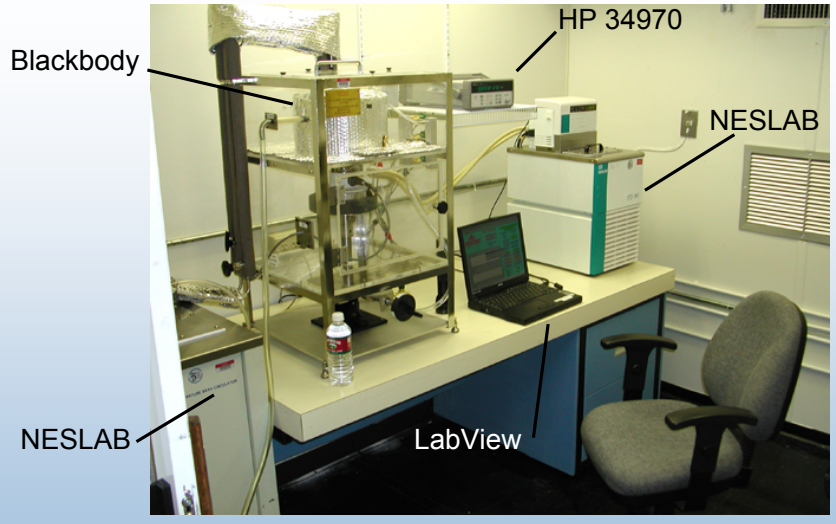
$$W_{in} = K_0 + K_1 V + K_2 W_r + K_3 (W_d - W_r)$$

where,

$$W_r = \sigma * T_r^4 = \sigma * (T c + 0.0007044 * V)^4$$

$W_x = \sigma T_x^4$
V = tp voltage
K_x = fit coefficient
d = dome
c = case
r = receiver surface

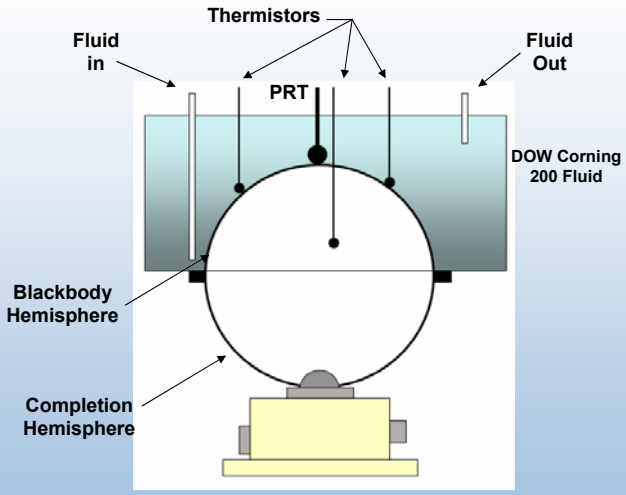
As Ells showed in Annapolis meeting, more context for the "coefficient" options. This is NOT the source of 12 W/sq m "problem," but is important for the temperature-dependence issue raised by the BBHRP/LW QME analyses.



ARM Pyrgeometer Blackbody Calibration System

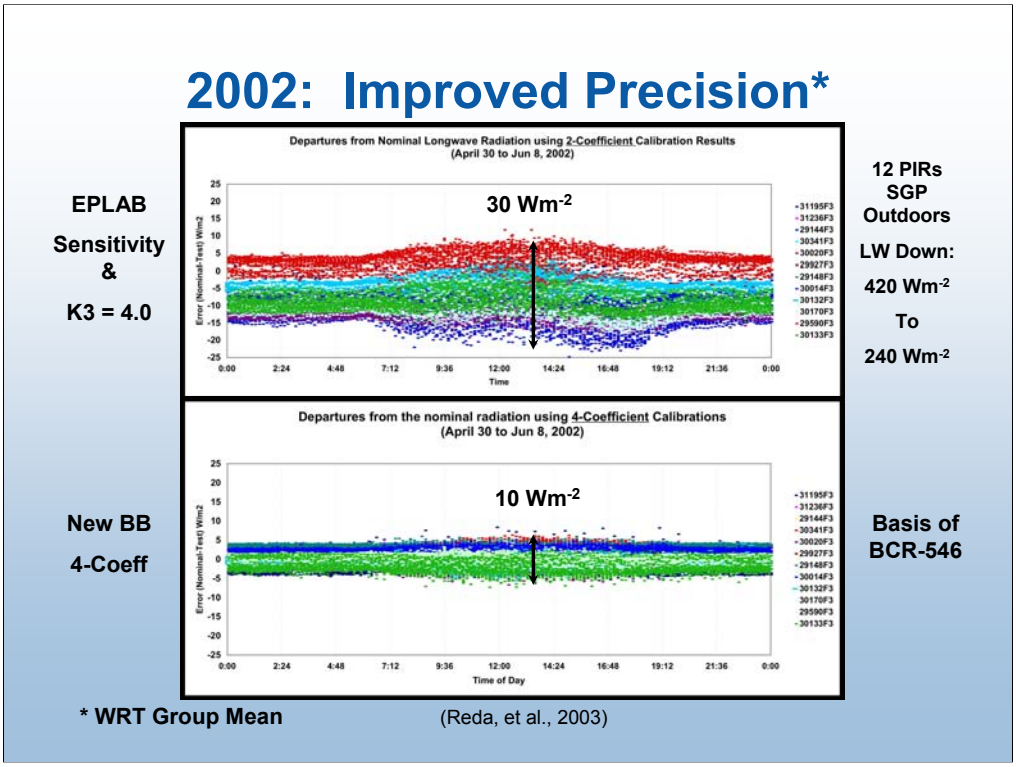
EPLAB and NREL developed a calibration system in response to the BSRN Protocol. Two temperature bath circulators hold blackbody and pyrgeometer case temperatures during calibration data acquisition.

Blackbody Calibration

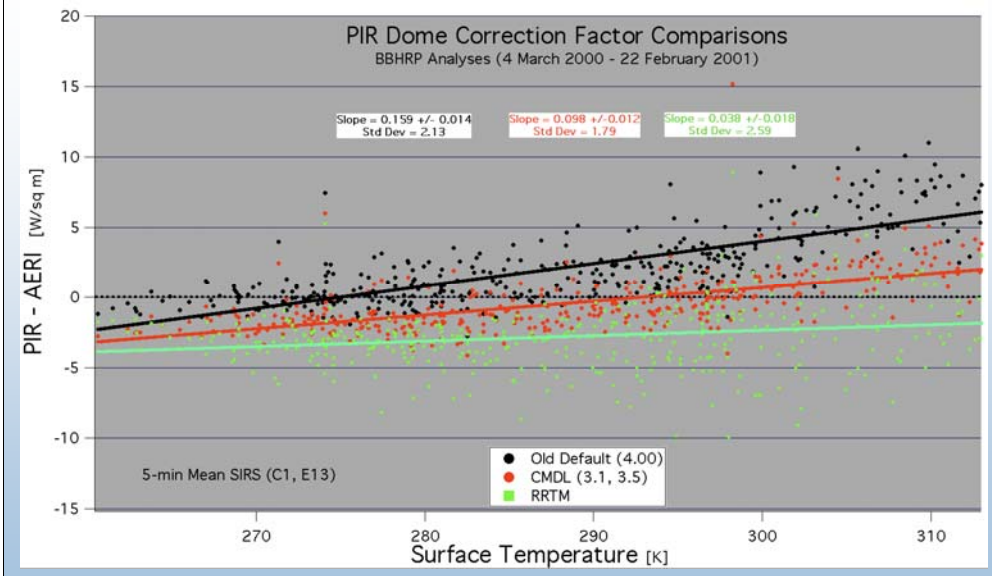


The calibration is performed at 7 *pyrgeometer case* and *blackbody* temperature combinations, then a linear regression is used to calculate the calibration coefficients.

BB temperature from 4 temperature probes calibrated to yield +/- 0.01 C precision. Thermistors (3 ea) positioned at 45 deg elevation and 120 deg azimuth.



Applying the new BB calibration results to 12 PIRs deployed outdoors at SGP/Radiometer Calibration Facility (shaded and ventilated) for ~40 days showed increased precision with respect to the group mean. Based on these results, I submitted BCR - 546 to change PIR calibrations from the original EPLAB sensitivities and Dome Correction Factor = 4.0 to the 4-Coefficient results.



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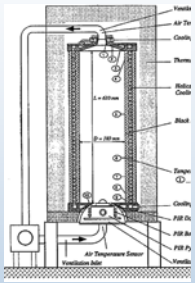
Remove Pyrgeometer Calibration Bias: BCR-01162 Status

- All NSA & TWP SKYRAD and GNDRAD platforms re-programmed and data verified on 12/30/05
- All SGP BRS, SIRS, & 25 m tower platforms re-programmed
- AMF installation Niger using EPLAB + K_3=4.0
- 6 PIRs recalibrated by EPLAB at no cost
  - ✓ Sensitivities stable 1993/96 to 2006
- Reprocessing of SGP/SIRS in progress
  - ✓ Thanks to Robin Perez & Bill Jackson!

My notes indicate 5 of the 6 PIR calibration results (sensitivities) agreed to better than 1% of the original 1993-96 values.

Infrared Radiation Calibration Center of the
World Radiation Center - Davos, Switzerland (1/1/04)

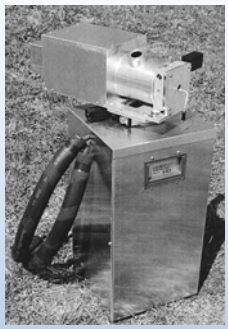


Blackbody

World IR Standard Group WISG

Modified EPLAB PIR's 31463F3 & 31464F3

Kipp & Zonen CG4's FT004 & 010535



Absolute Sky-scanning Radiometer ASR

Calibration = BB (K_2, K_3, K_4) + ASR-adjusted Outdoor (K_1)

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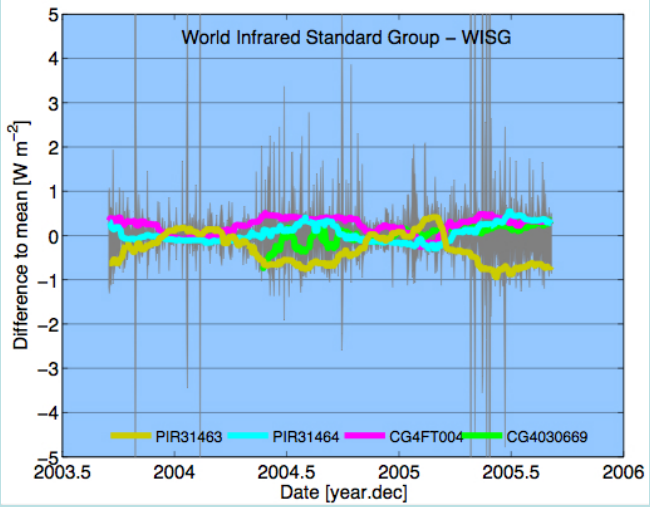
World Infrared Standard Group



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Calibration uncertainty
-work in progress-

- Uncertainty contributions from:
- ASR ±2 W (Philipona, App. Optics, 2001)
- WISG ±1 W (variability)
- Uncertainty of IRC ±2.3 W (1σ)

- Typical uncertainty for test pyrgeometer ±2.4 W with a variability during calibration of ±0.5 W

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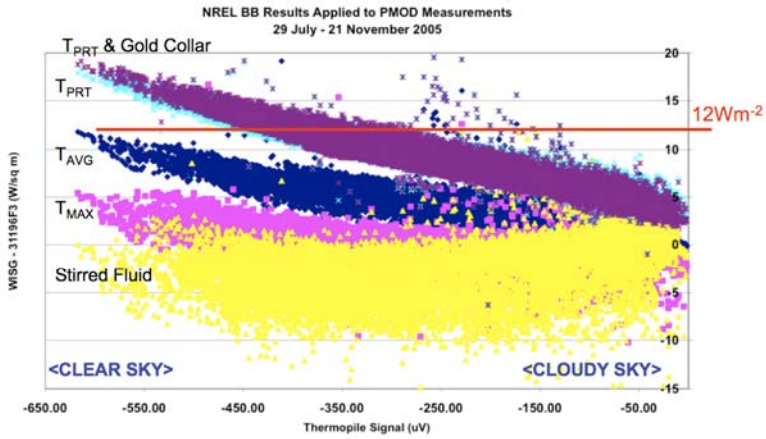
PIR 31195F3 at PMOD/WRC



PIR 31196F3 compared with PMOD Reference Group (WISG)

T_{PRT} = Top of Dome T_{AVG}= Mean of 4 probes T_{MAX}= Hottest Value of 4
Stirred = Mechanical Mixing of Fluid Gold Collar = Covers PIR Collar

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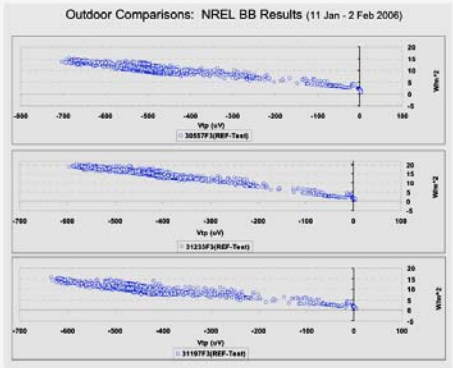
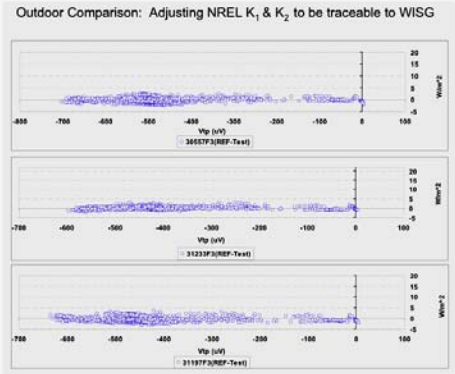
NREL Calibration Transfer to WISG





Outdoor comparisons of three PIRs at NREL Jan-Feb 2006

Left: NREL Blackbody K's **Right:** K1 and K2 adjusted to WISG reference

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The Sky as Calibration Source

IR Flux at Pyrgeometer Receiver

$$W_{net} = W_{in} - W_{out}$$

Time Rate of Change

$$K_1 \frac{dV}{dt} = \frac{dW_{in}}{dt} - \frac{dW_{out}}{dt}$$

For Stable Conditions

$$K_1 = -\frac{dW_{out}}{dt}$$

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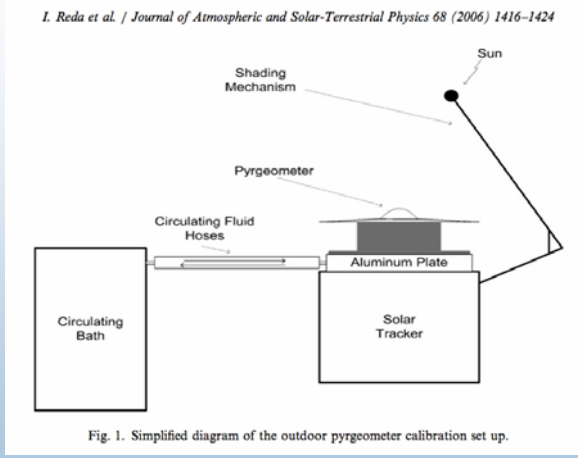
The Sky as Calibration Source



Reda, I., J. Hickey, J. Grobner, A. Andreas, T. Stoffel, 2006: Calibrating pyrgeometers outdoors independent from the reference value of the atmospheric longwave irradiance.

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The Sky as Calibration Source

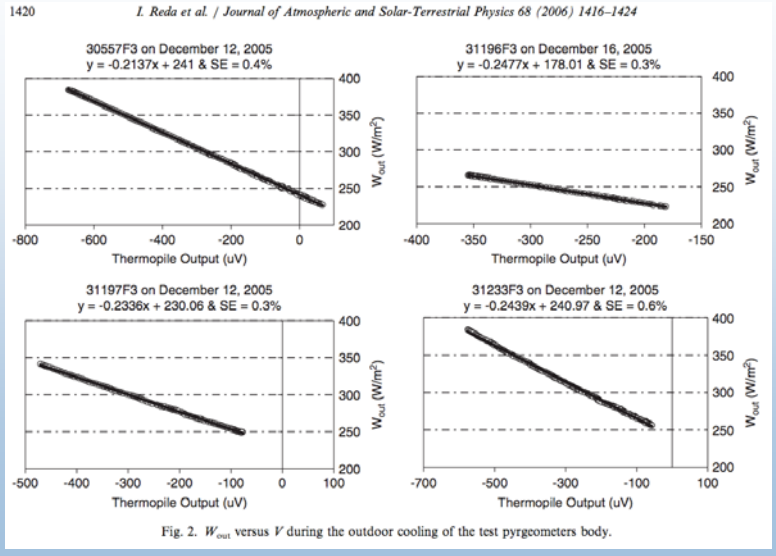
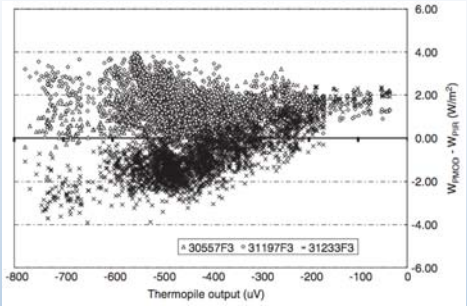
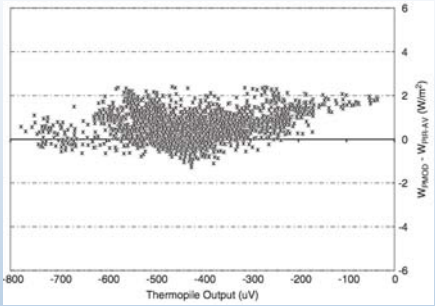


Fig. 2. W_{out} versus V during the outdoor cooling of the test pyrgeometers body.

The Sky as Calibration Source

Outdoor Evaluation of 3 PIRs wrt CG4 (WISG)





Range of Differences: +/- 4 Wm^{-2}

Average Difference: +/- 2 Wm^{-2}

Timing is Everything…

- Insertion Method (EPLAB)
- Steady-State Method (NREL/BSRN)

Blackbody Temperature

Thermal interactions?

PIR Case Temperature

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The Eppley Laboratory : Insertion Data 1

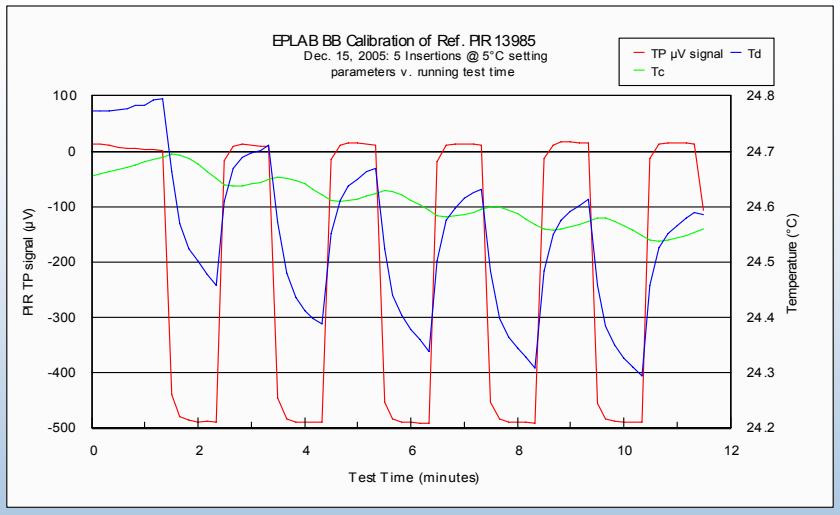
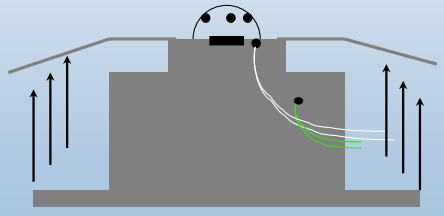


Chart 1EP: Sample run data for PIR measured parameters for 5 degree C set Blackbody Temperature. Automated version of normal EPLAB calibration. The case & dome temperatures are given on the right scale. These results for no completion hemisphere on BB.

Tom and John: This begins the series of slides for your work investigating the differences between a "transcient first-order" calibration vs. the present implementation of the BSRN protocol by PMOD and NREL blackbody systems using extended exposures under "stable temperature" conditions.

NOAA Global Monitoring Division

(Joe speaks next about his WISG transfer)



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Current and future work at IRC

- **Maintain** the WISG
- Characterise the **absolute sky-scanning radiometer** and make routine comparisons with the WISG
- **Build a second ASR** - same principle, different design
- Construct a **second Black Body**
- Characterise pyrgeometers in the laboratory and try to understand **systematic differences** between black-body and ASR based calibrations.
- **Work jointly** with the IR-Community.

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Key Concepts & Options

- ARM needs ***accurate*** pyrgeometer calibration method ***traceable*** to the *Interim* World Infrared Standard Group (WISG)
- The ***WISG*** was established by PMOD/WRC in 2004 based on ***IPASRC I & II*** (Low-temperature blackbody sources + Absolute Sky-scanning Radiometer) + Outdoor pyrgeometer comparisons
- ***Characterizations*** of pyrgeometer calibration methods and equipment ***continue*** at EPLAB, NOAA, NREL, and PMOD
- ***Outdoor characterization*** of pyrgeometers with respect to a recognized reference is ***essential*** for determining the best calibration method

Put the important stuff first! These are the key points I hope we can agree upon and communicate to the audience.

Key Concepts & Options

- ***WISG*** must be based on a ***variety*** of measurement (ASR) & blackbody calibration ***designs*** (as done for the shortwave WRR)
  - SBIR for ARM Absolute Sky-scanning Radiometer ($250K)
  - SBIR for ARM 4th generation blackbody ($200K)
  - NREL/ARM Blackbody needs better working fluid ($9K)

- **Calibrate** the pyrgeometer in a manner **consistent** with its **use**:
  - Atmospheric LW spectral distributions vs Blackbody?
  - Range of environmental conditions?
  - Ventilated?
  - Heated?

- ARM must have a **pyrgeometer calibration reference**:
  - Blackbody?
  - ✓ Blackbody + Outdoor Comparisons with WISG Reference?
  - Outdoor Comparisons with WISG Reference?

Put the important stuff first! These are the key points I hope we can agree upon and communicate to the audience.

How should we calibrate ARM pyrgeometers?

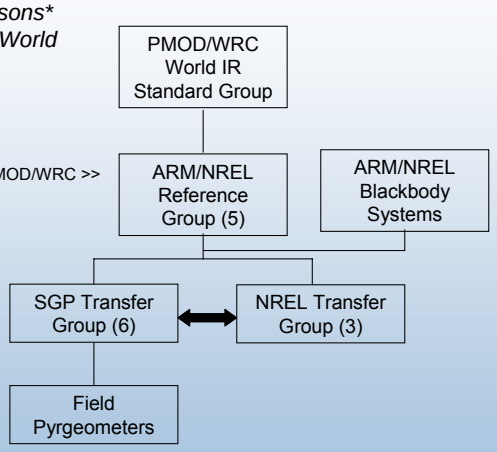
New Traceable Method: Outdoor comparisons with reference standards traceable to new World Infrared Standard Group*

5 pyrgeometers calibrated at PMOD/WRC >>

9 pyrgeometers calibrated* at NREL & SGP/RCF >>

6 serve as Measurement Assurance Standards, rotating sets of 3 each annually between SGP & NREL.

3 serve as Transfer Standards to calibrate field pyrgeometers.



* Note: All pyrgeometers require blackbody characterization to determine thermal offset and dome correction factor. Case emissivity and thermopile sensitivity adjusted as needed by outdoor comparisons with Transfer Group under cloudy and clear-sky conditions respectively.

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Pyrgeometer Calibration procedure

- Based on Philipona et al. formula:

$$E = \frac{U_{emf}}{C}(1 + k_1 \sigma T_b^3) + k_2 \sigma T_b^4 + k_3 (T_d^4 - T_b^4)$$

- C, k_1, k_2,k_3 are unknown coefficients and are retrieved from the calibration.

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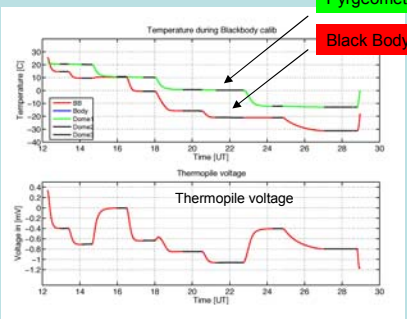
Calibration procedure
First Step

- Characterisation in the black body to retrieve k_1, k_2,k_3. C is retrieved but not used as calibration constant.

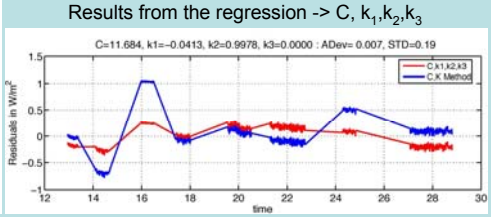
Pyrgeometer temperature range: +20ºC to -10ºC

Black Body temperature range:+15ºC to -30ºC



Thermopile voltage

Results from the regression -> C, k_1,k_2,k_3



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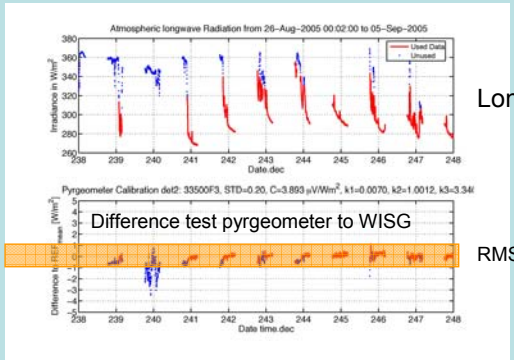
Calibration procedure
Second Step

- Comparison to the WISG on the measurement platform to determine the pyrgeometer sensitivity C.



Longwave radiation

±1 W

RMS 0.2 W/m²

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Calibration procedure
Conclusion

- k_1,k_2,k_3 are retrieved from the black body characterisation
- Sensitivity C is obtained from comparison to the WISG, and indirectly relative to the ASR.

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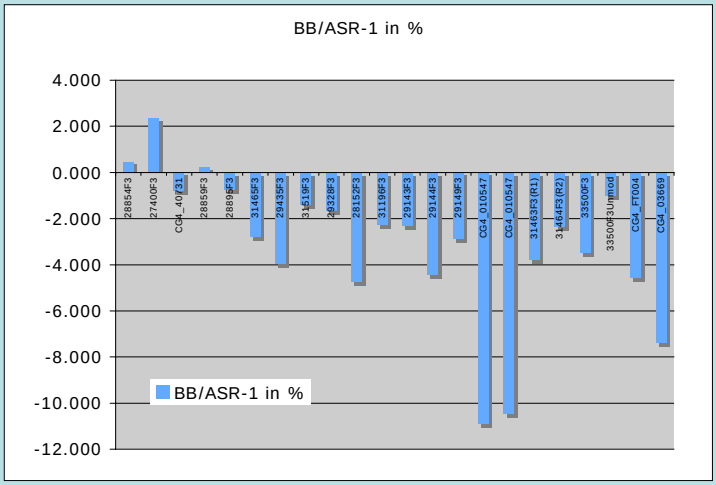
Ratio between ASR-based and Black-Body based Sensitivity C



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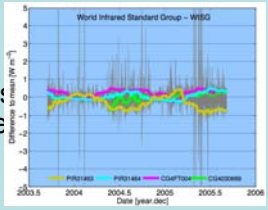
Absolute uncertainty versus stability

- For detecting long-term trends, a stable reference over long time periods is fundamental.
- Absolute levels can be adjusted, if measurements are traceable (for example to the IRC). The quoted uncertainties of the reference should be larger than the potential future level changes.



First important role of the IRC