

Instrumentation: *Broadband Radiometry*

Radiative Processes Working Group

Princeton, New Jersey

November 18, 2008

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Topics

- Radiometer Calibration Facility Upgrades
- NREL Pyrheliometer Comparisons 2008
- Improvements to Pyrgometer Blackbody Calibration System
- Pyrgometer Calibrations Traceability
- Shortwave Radiometer Uncertainties

Radiometer Calibration Facility



Broadband Outdoor Radiometer CALibrations - BORCAL

Annual Calibrations of ~200 Pyrheliometers and Pyranometers
Traceable to the **World Radiometric Reference** using
Radiometer Calibration and Characterization (RCC) Software



RCF DAS Upgrades

Fluke Helios



← Obsolete
~ 9 μ Vdc thermal EMF
(1 W/sq m)
Scan Groups

NIST-consulted
DataProof →
<1 μ Vdc thermal EMF
+
Agilent 34420 meters
(Faster Scanning)
+
New RCC code

RAPDAQ*

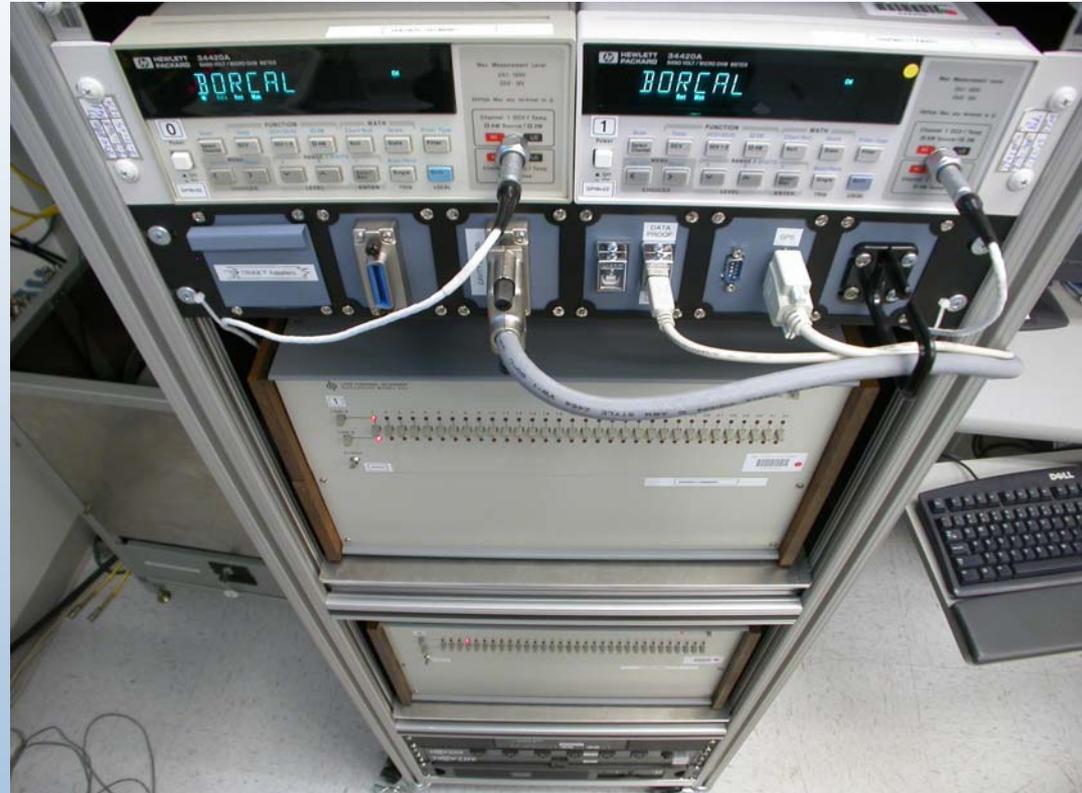


*Reda/Afshin/Pete Data Acquisition

RCF DAS Upgrades₂

Status & Plans

- NREL System in Service 2007
- \$60K Hardware delivered to NREL
- HDW/SW System Integration
- Tested at NREL
- Installation next Spring

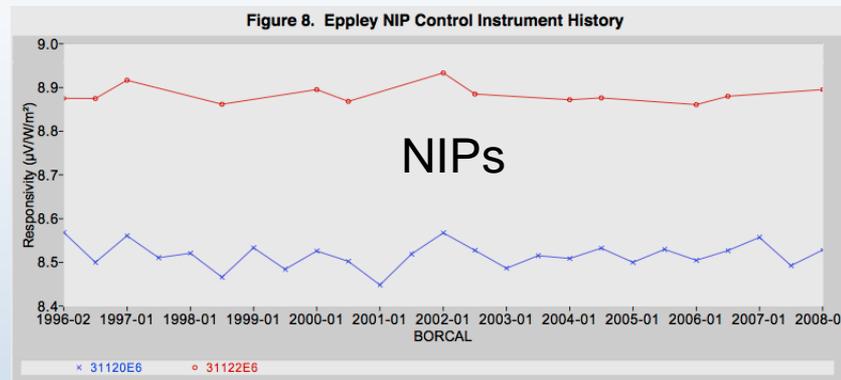


ECO-00642 Updates

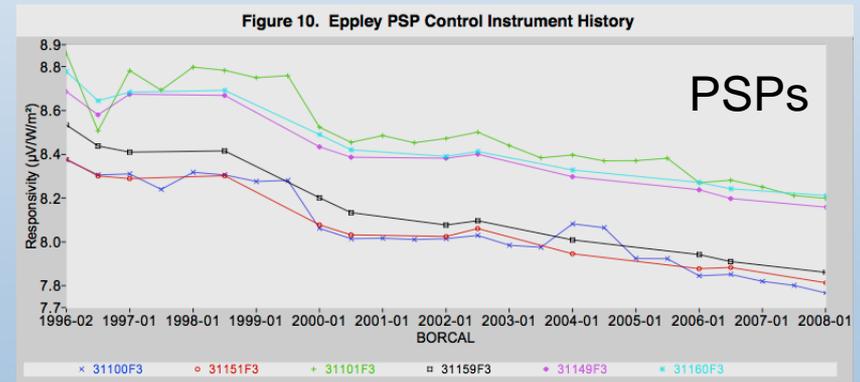
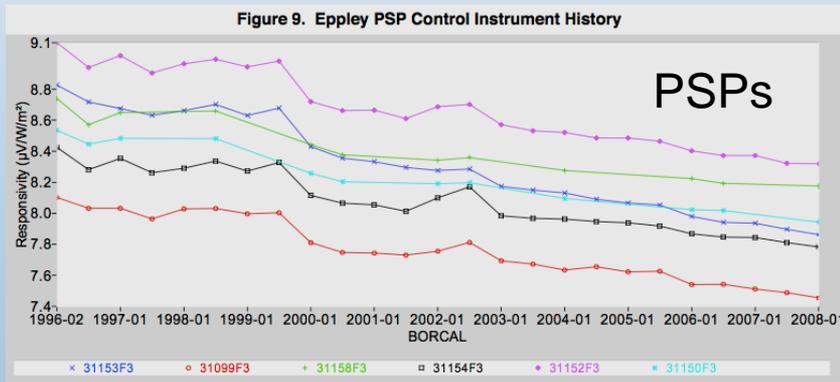
RCF DAS Upgrades₃

Test Results Based on Measurement Assurance Standards

22 instruments used only for BORCAL



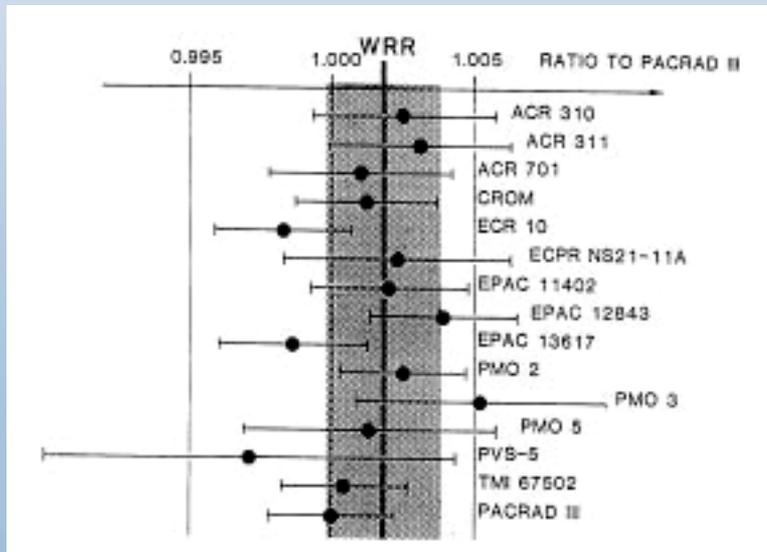
Alternating between SGP & NREL



PSP response trend = -0.3% per year

NREL Pyrheliometer Comparisons

- All ARM solar (shortwave) broadband radiometer calibrations are traceable to the **World Radiometric Reference (WRR)** via BORCAL
- Detector-based standard (6 radiometers)
- WRR uncertainty = $\pm 0.3\%$

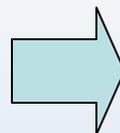


World Standard Group (WSG)

Calibration Traceability



5 yr International Pyrheliometer Comparisons



NREL/ARM Reference Standards



Annual NREL Pyrheliometer Comparisons

Transfer Standards

NREL Pyrheliometer Comparisons NPC-2008

22 September – 3 October



23 Participants from ARM, industry, DOE labs, academia, & WRC
36 Absolute Cavity Radiometers + 2 Pyrheliometers

NREL Pyrheliometer Comparisons NPC-2008

Transfer Group:

AHF 28968*

AHF 29220

AHF 30713

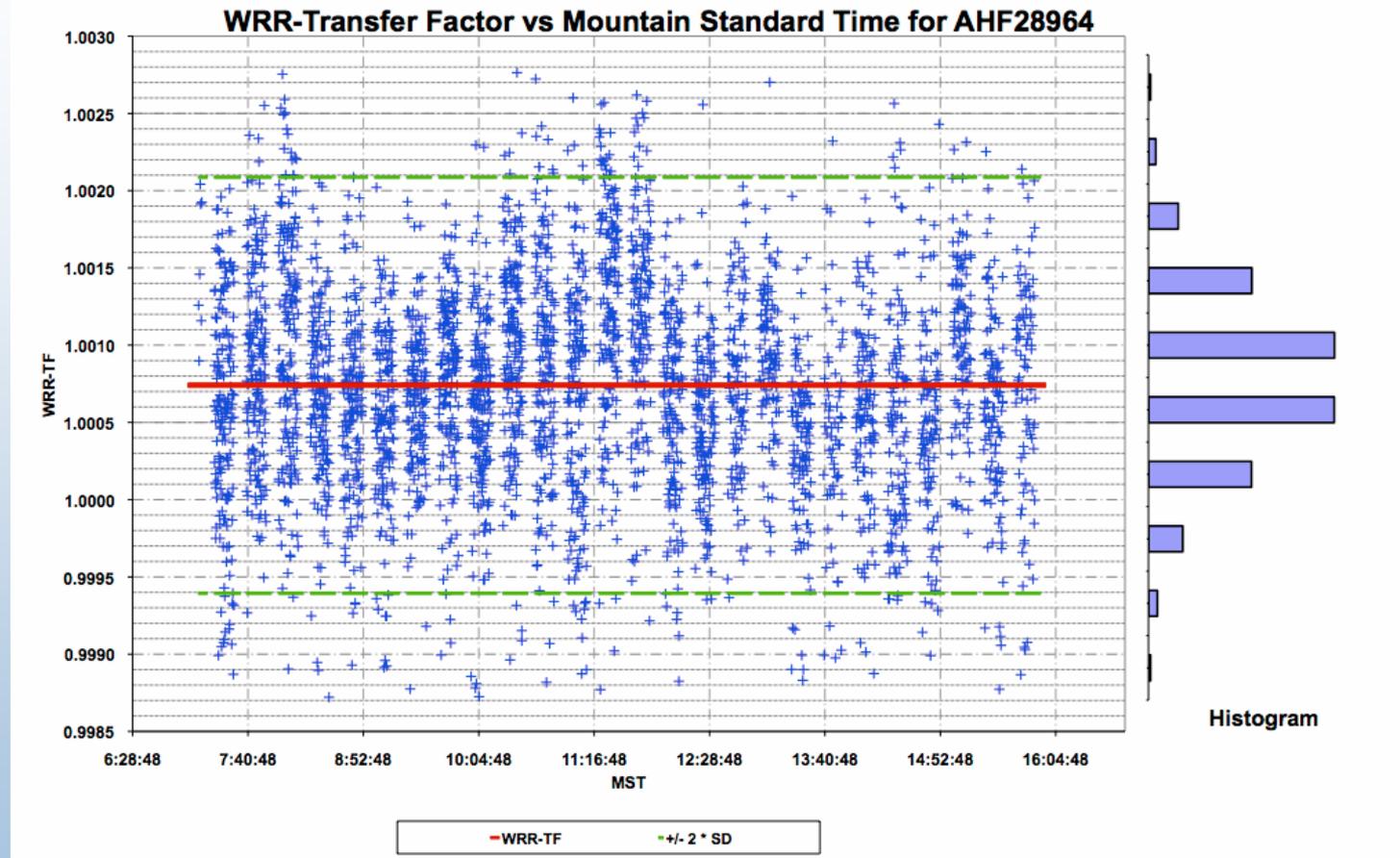
TMI 68018

*ARM Program
Reference



NPC-2008 Results: SGP Reference

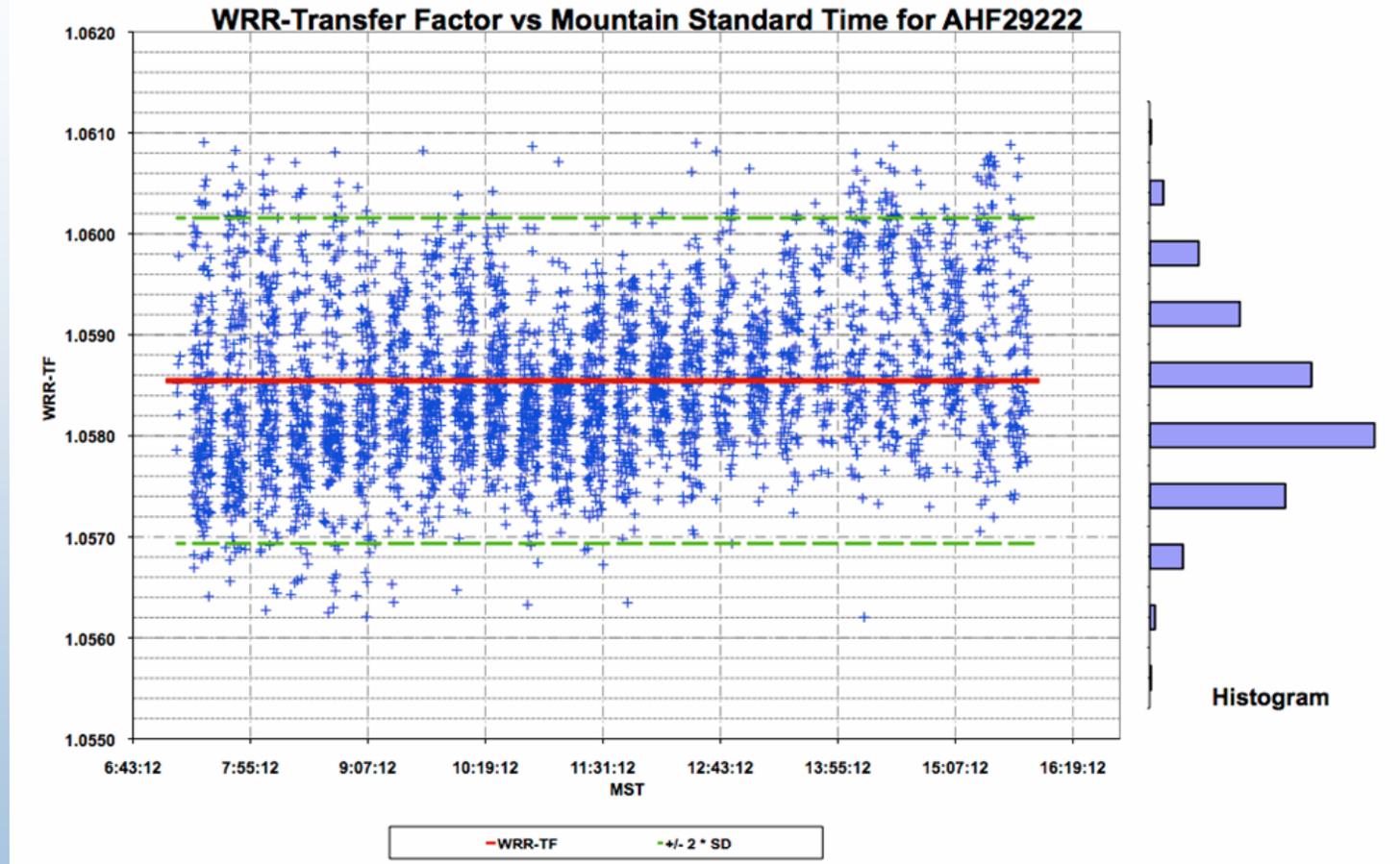
2σ
 $\pm 0.13\%$



Calibrate – Measure – Calibrate – Measure – Calibrate – Measure
6 min 37 @ 20 sec for > 1,000 readings over 5 days

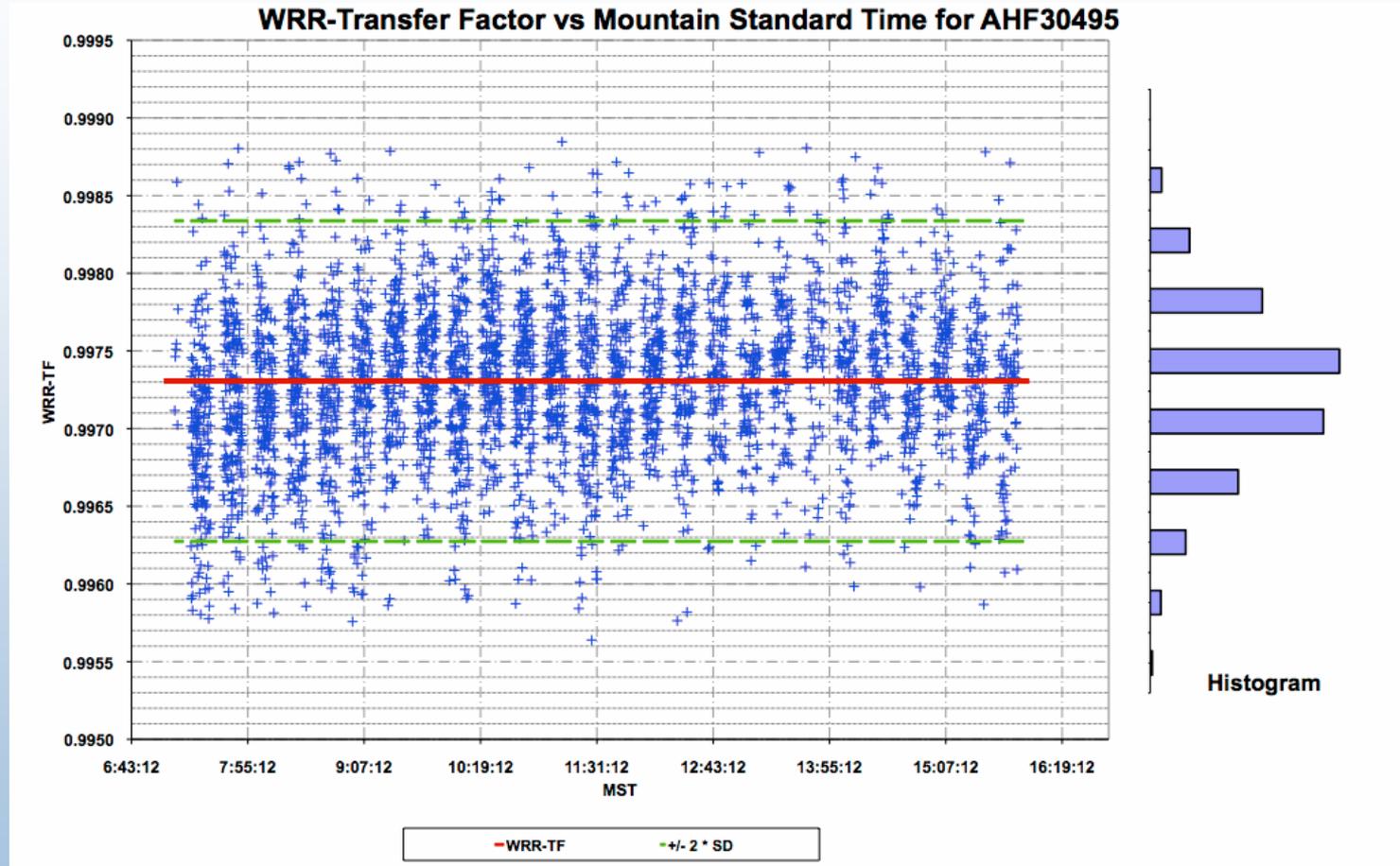
NPC-2008 Results₂ (Windowed XFR)

2σ
 $\pm 0.15\%$



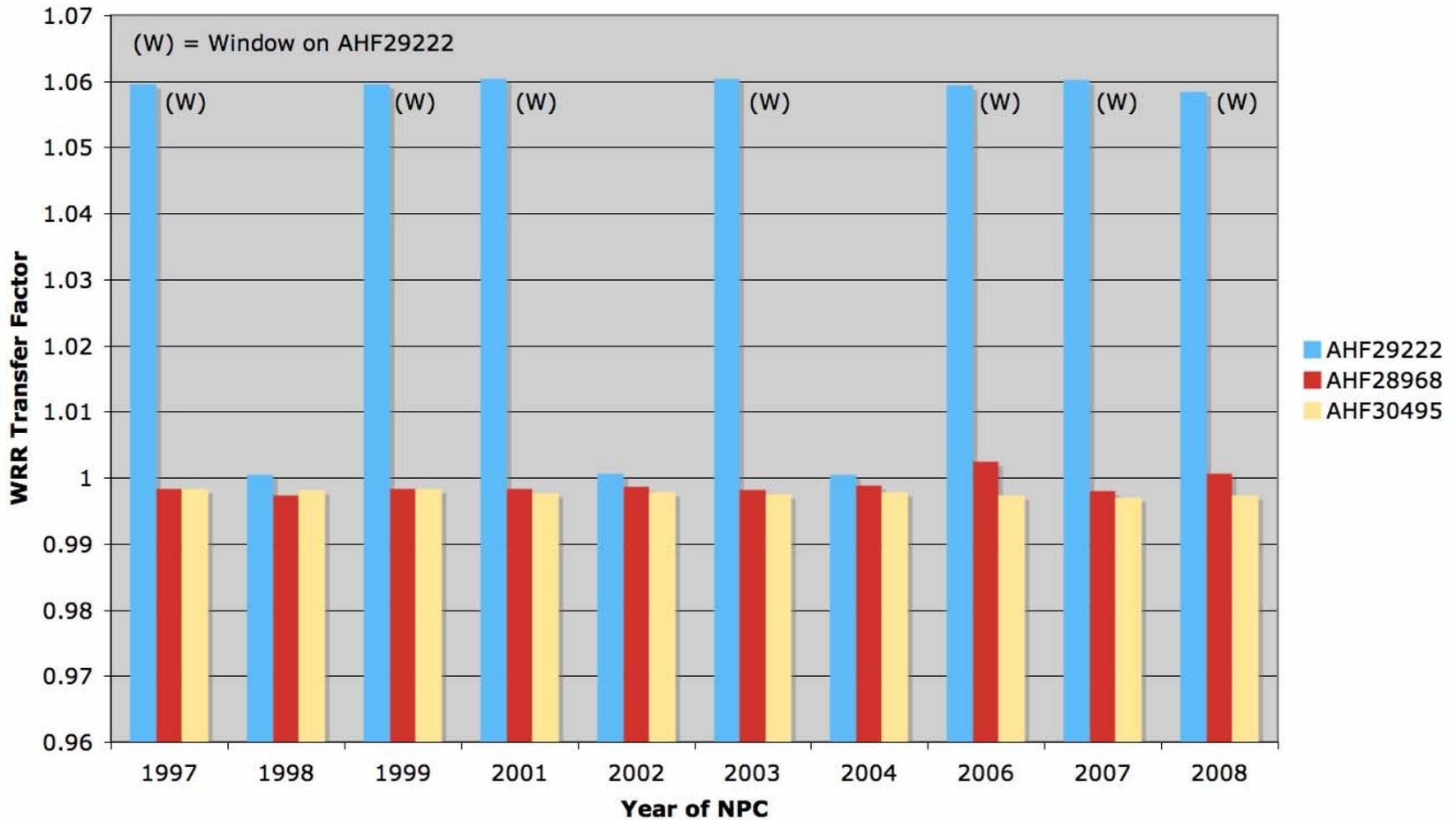
NPC-2008 Results₃ (Un-Windowed XFR)

2σ
 $\pm 0.12\%$



NPC-2008 Results (concluded)

NREL Pyrheliometer Comparison Results ARM Transfer Standard Absolute Cavity Radiometers



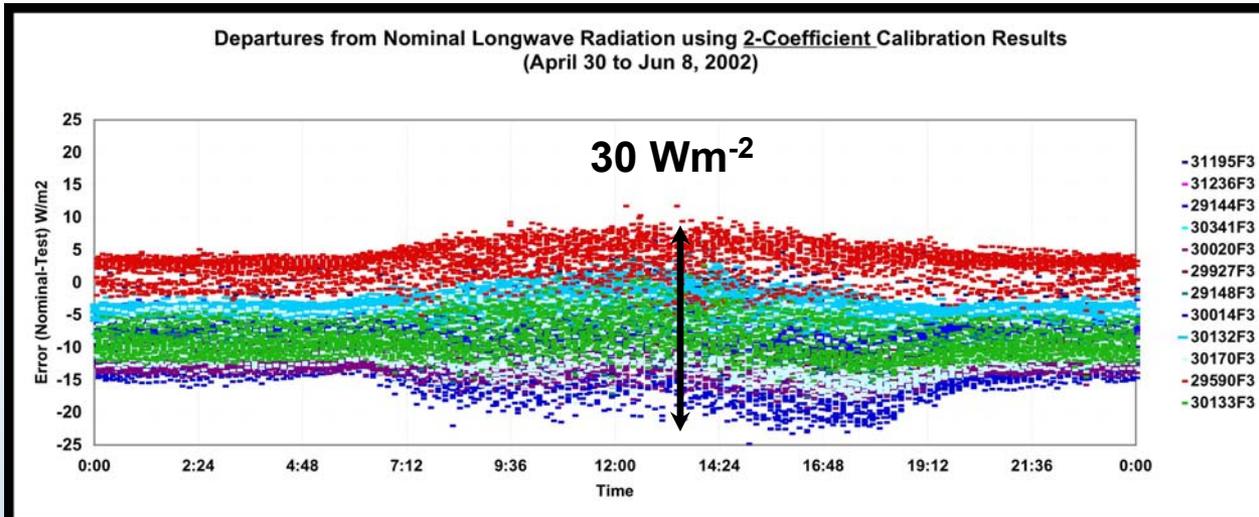
Pyrgometer Blackbody Calibration System



2 Systems: NREL/SRRL & SGP/RCF

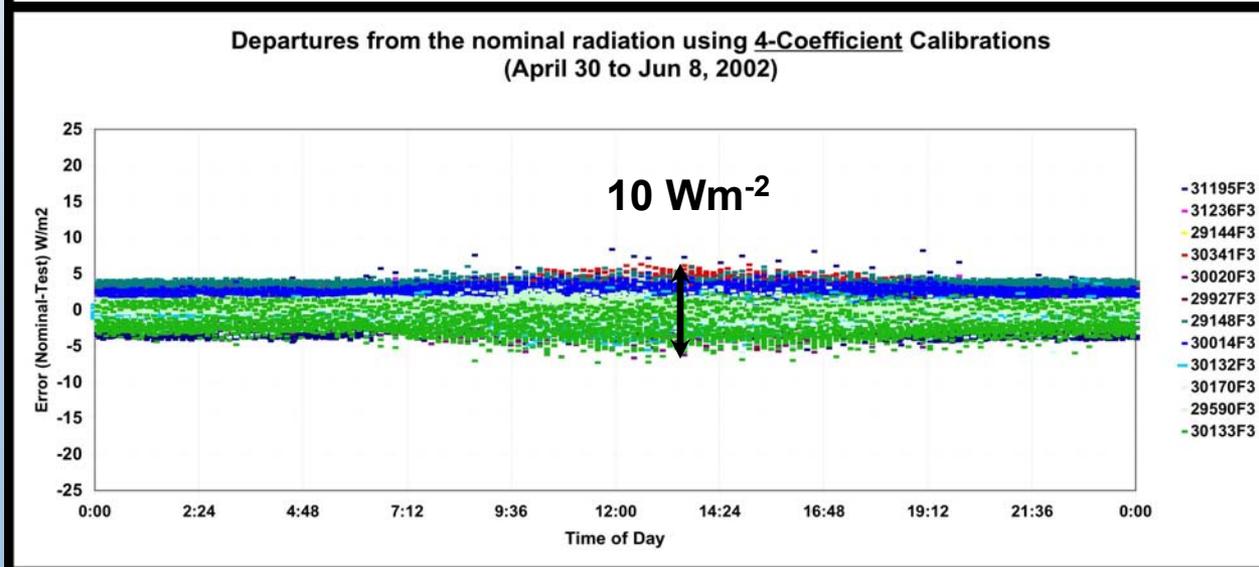
2002: Improved Precision*

EPLAB
Sensitivity
&
K3 = 4.0



12 PIRs
SGP
Outdoors
LW Down:
420 Wm^{-2}
To
240 Wm^{-2}

New BB
4-Coeff



Basis of
BCR-546

* WRT Group Mean

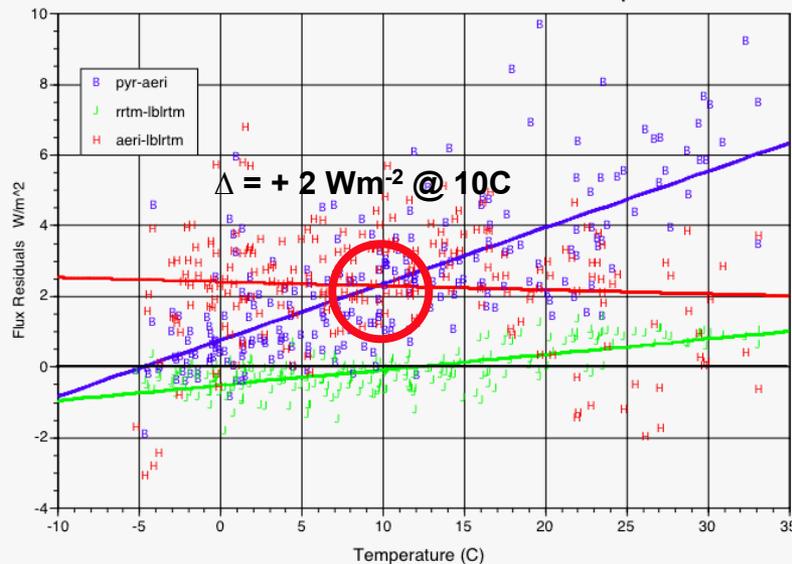
(Reda, et al., 2003)

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

Flux Residuals vs. SMOS 320 m Temperature

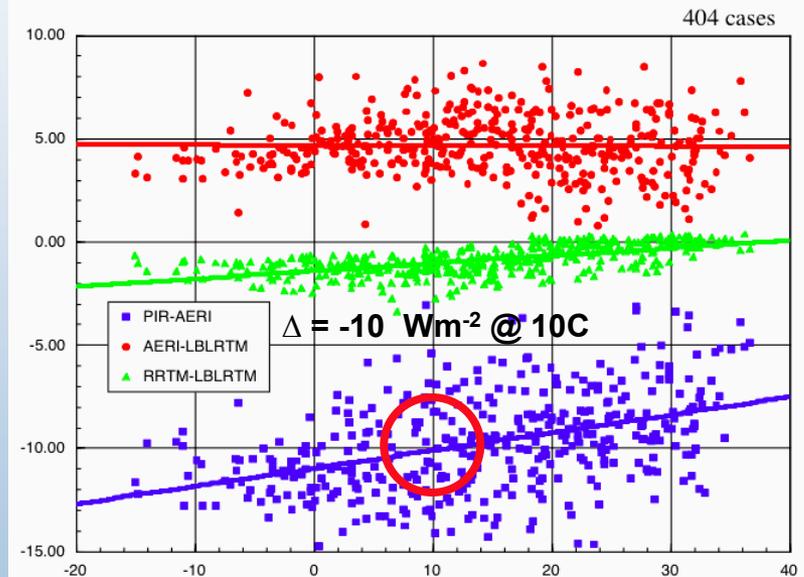


Slope of pyr - aeri vs. T (blue line) = 0.16 W/m²/K

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

AERI and SIRS Data from 2004

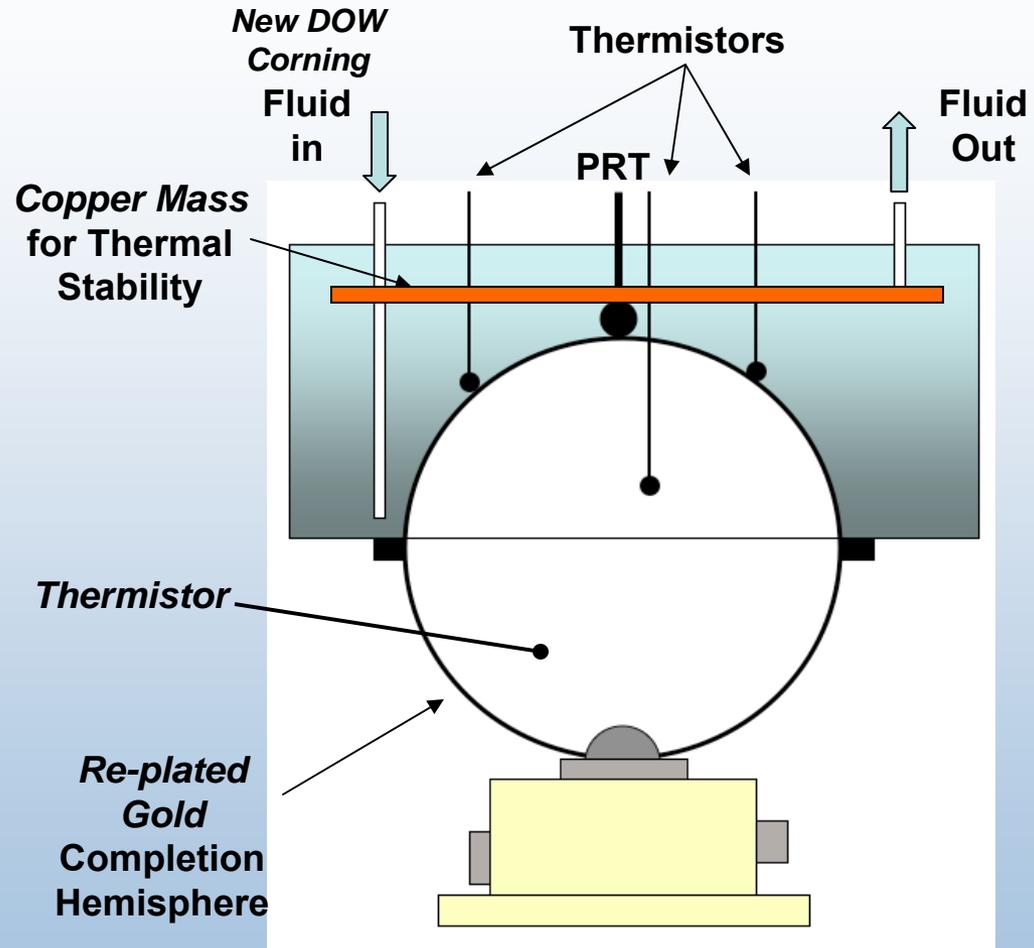
2004 LW QME (PIRs use 4-coefficient calibration)



Slope of PIR-AERI vs. T is 0.09 W/m²/K

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

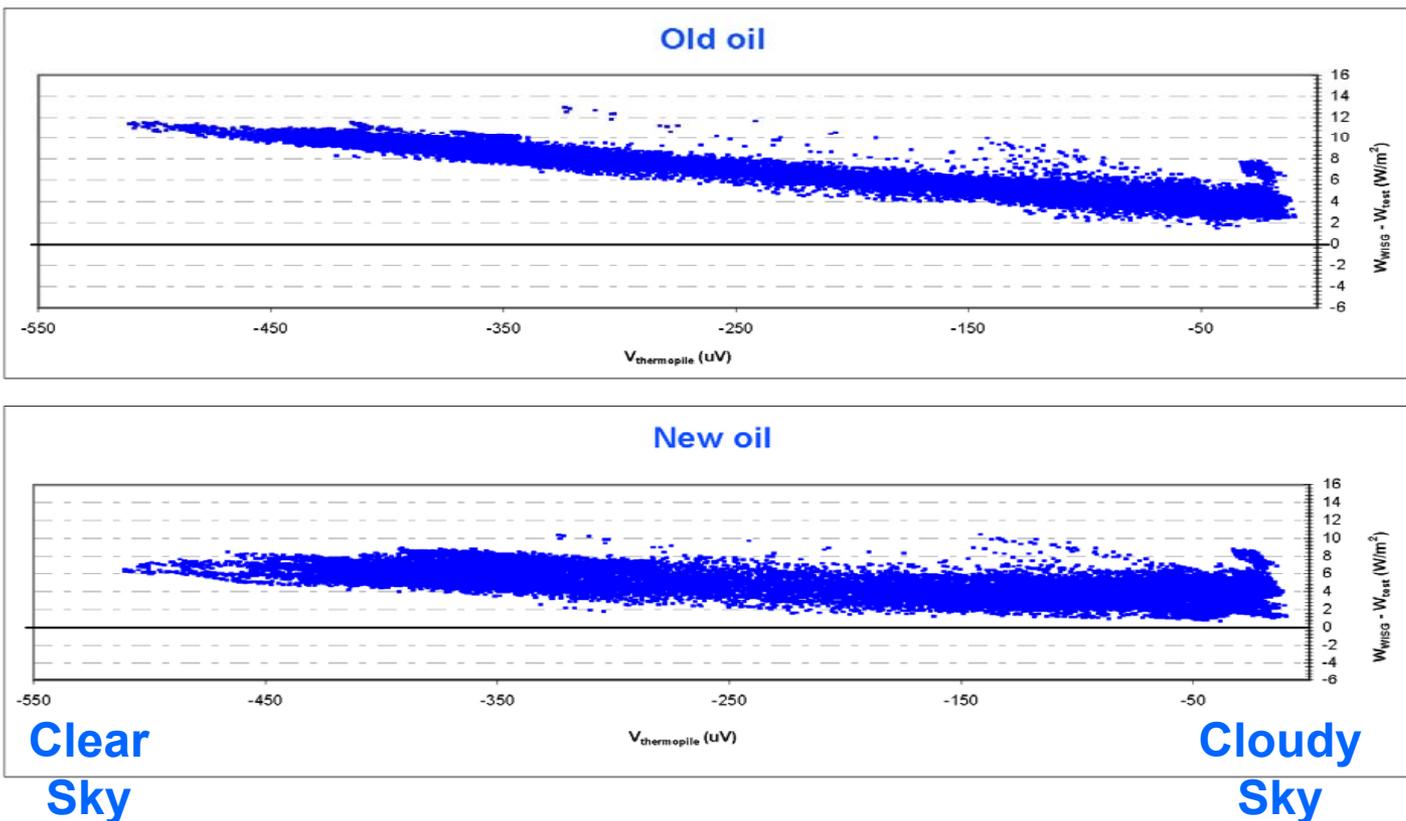
Blackbody Calibration Improvements



Improvements reduced BB temperature gradients at -35°C
From 3° to 0.8° , improved emissivity & BB irradiance
 6 Wm^{-2} 1 Wm^{-2} 4 Wm^{-2}

Difference between the reference irradiance and the irradiance measured by 30557F3 using NREL-BB-Coefficients (Old vs. New oil)

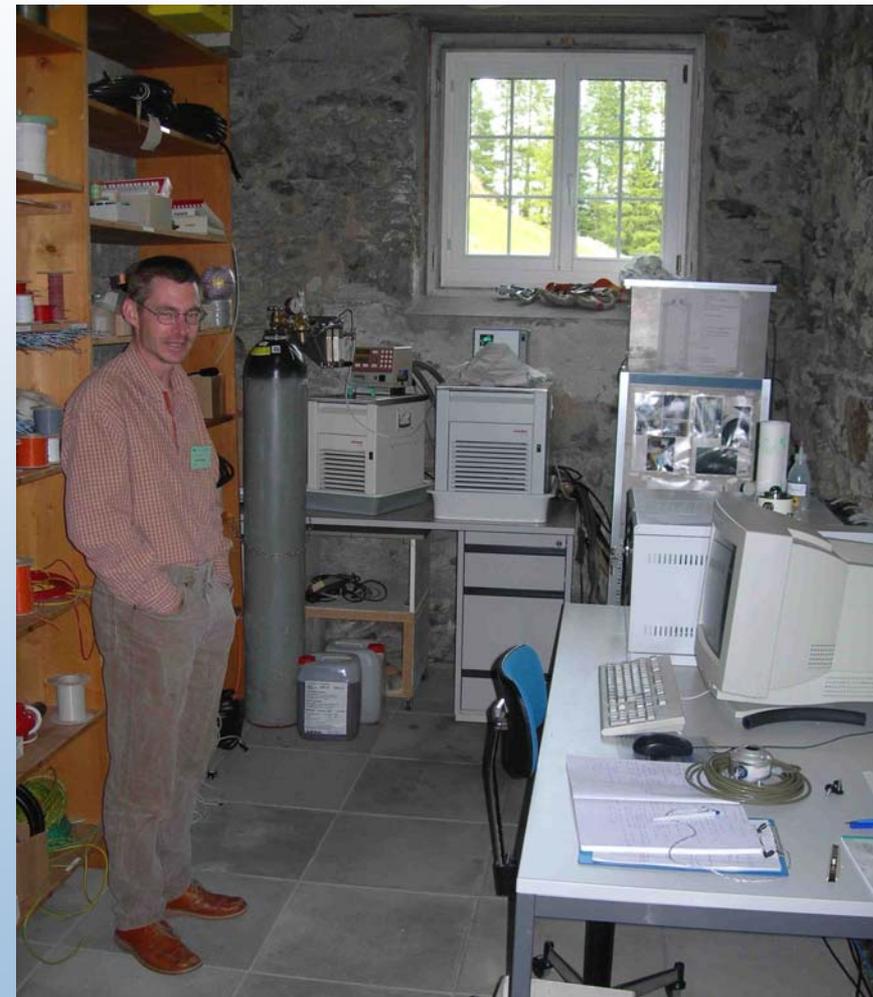
Without e_G correction



Decreased dependence on sky conditions

Interim World IR Standard Group (WISG)

Cylindrical Blackbody Characterization



Physikalisch-Meteorologisches Observatorium Davos (PMOD)
World Radiation Center (WRC)

Interim World IR Standard Group (WISG)₂

Original* Absolute Sky-Scanning Radiometer (ASR)



* Rolf Philipona



International Pyrgometer &
Absolute Sky-Scanning
Radiometer Comparisons
(IPASRC)
IPASRC I – Sept 1999 SGP
IPASRC II – March 2001 NSA

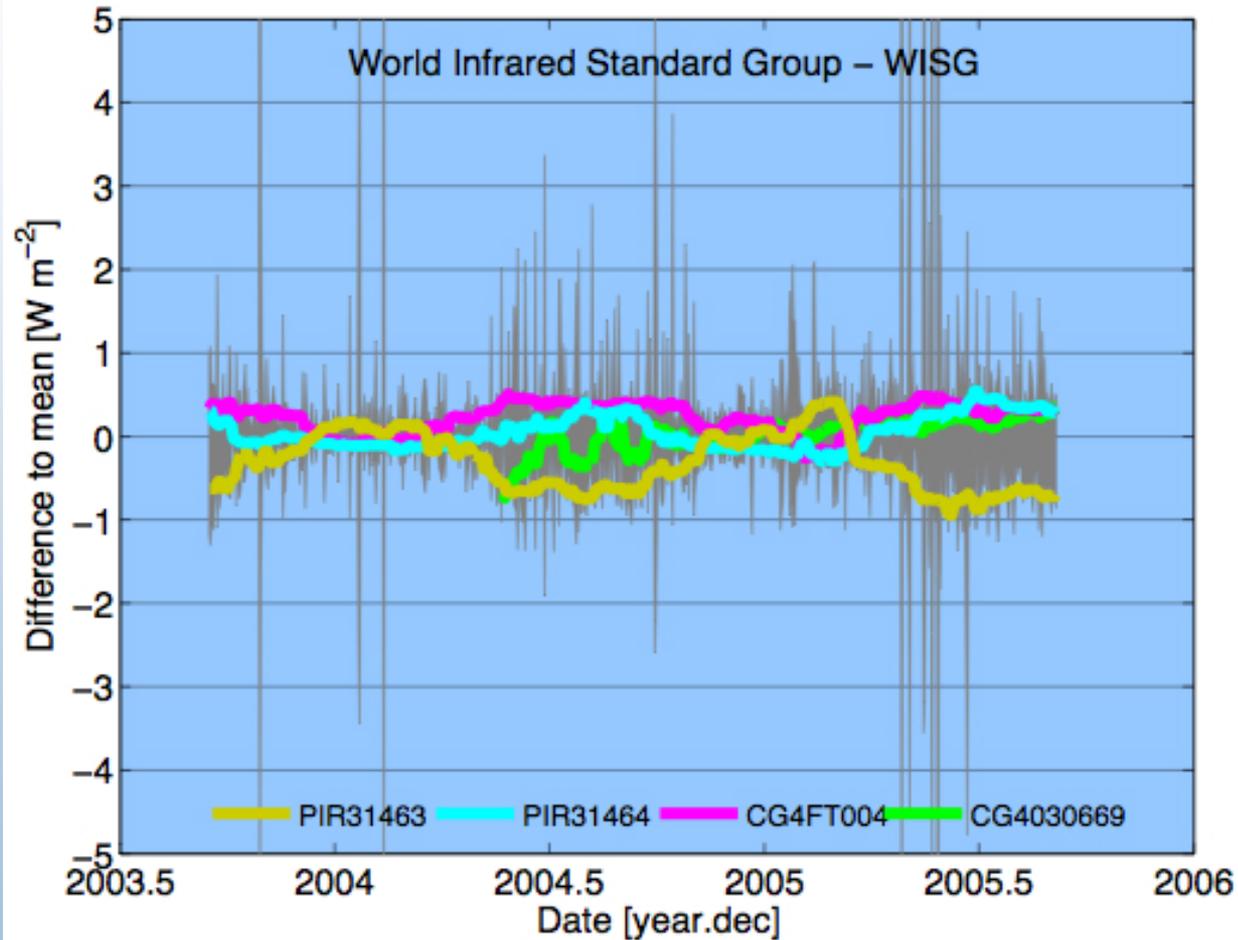
Interim World IR Standard Group (WISG)₃

Detector-based Standard
Pyrgeometers with IPASRC
and PMOD/WRC Blackbody
Characterizations



2 CG4s + 2 PIRs Adjusted to
Davos Sky Conditions...

World Infrared Standard Group



WISG Traceability

World Infrared Standard Group



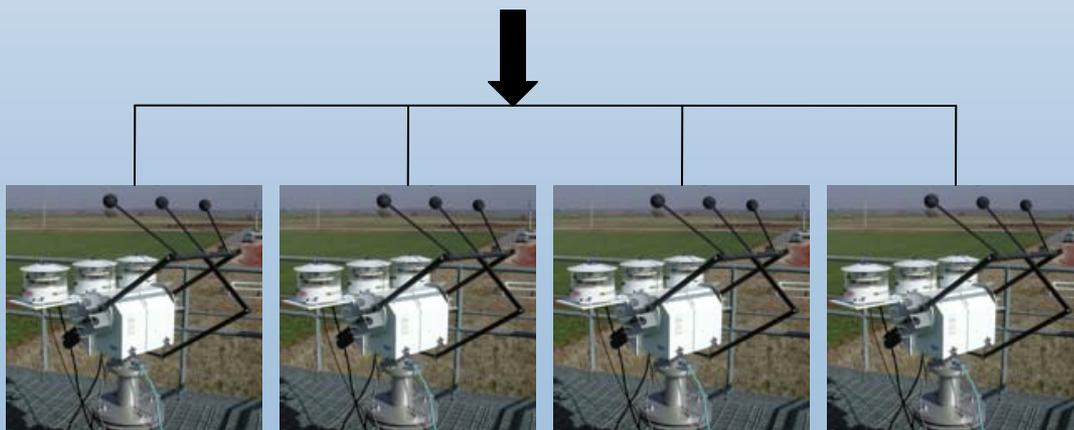
ARM/NREL Reference Group



Transfer Standard Group



SIRS, SKYRAD & GNDRAD PIRs at RCF

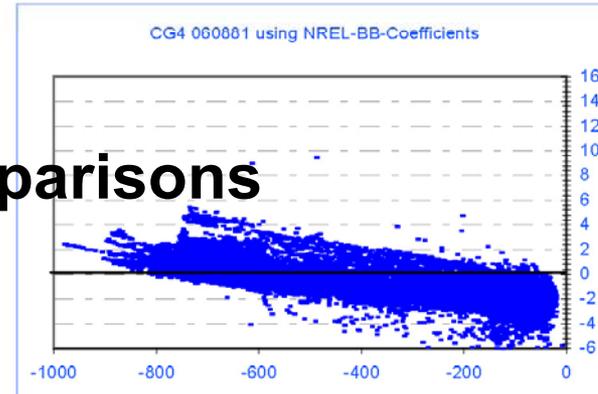
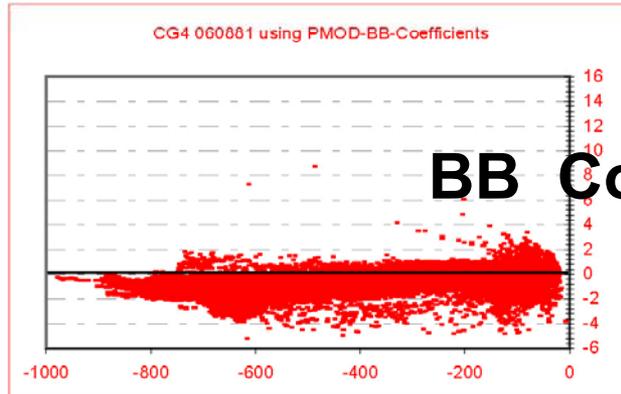


Difference between the reference irradiance (WISG) and the irradiance measured by the test pyrgeometer at PMOD/WRC between July and December 2007.

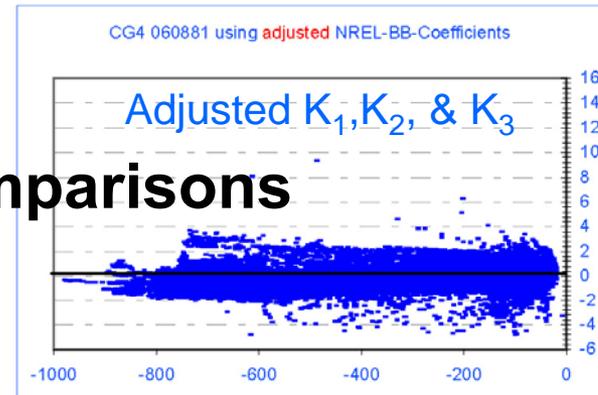
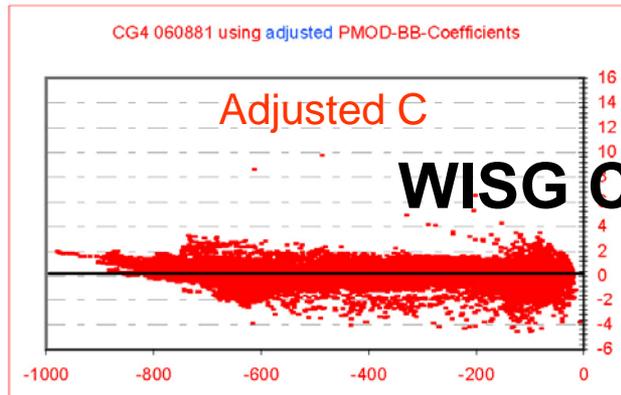
CG4

PMOD BB-Calibration

NREL BB-Calibration



BB Comparisons



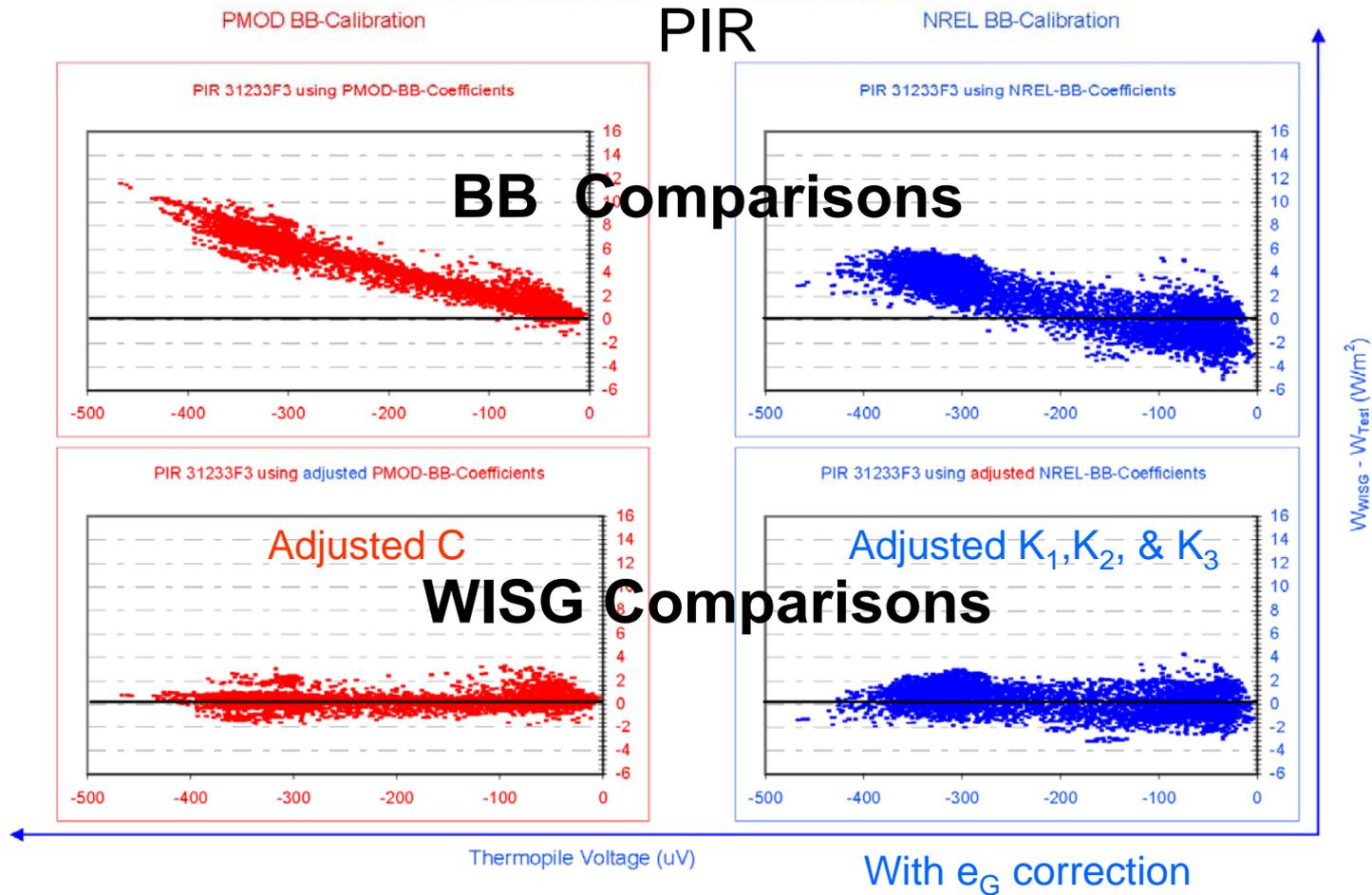
WISG Comparisons

Thermopile Voltage (uV)

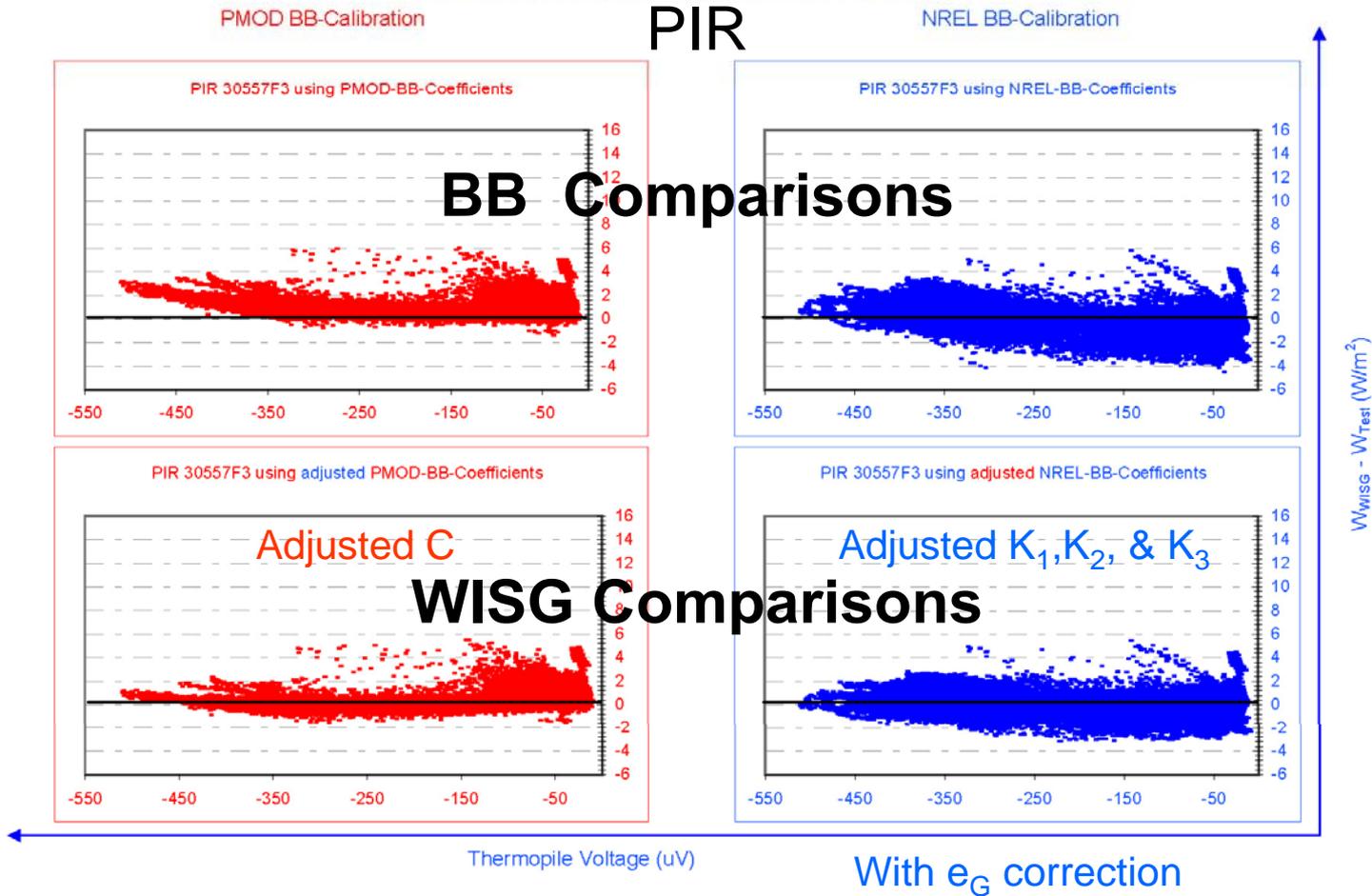
With e_G correction

$W_{WISG} - W_{Test} (W/m^2)$

Difference between the reference irradiance (WISG) and the irradiance measured by the test pyrheliometer at PMOD/WRC between July and December 2007.

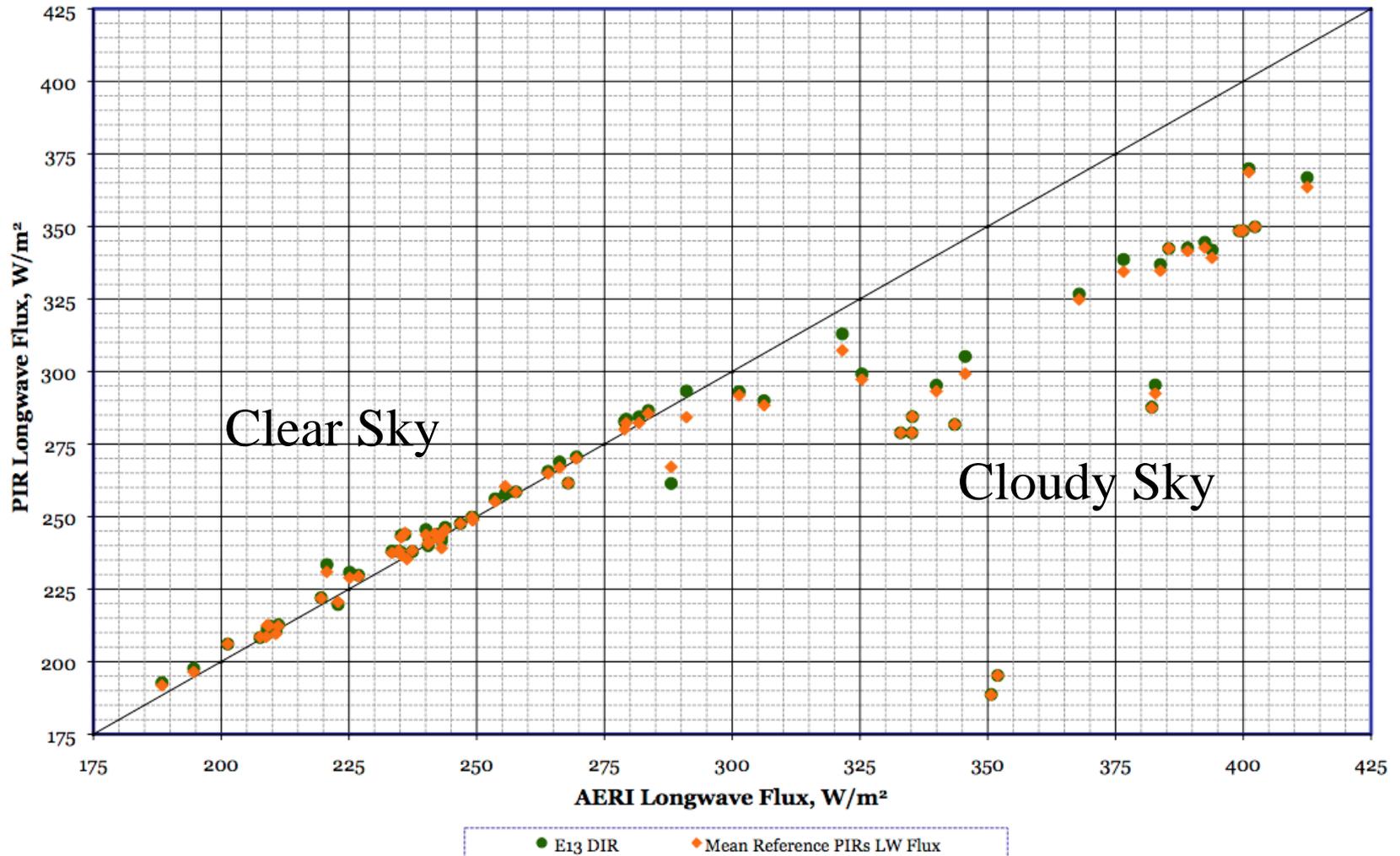


Difference between the reference irradiance (WISG) and the irradiance measured by the test pyrgeometer at PMOD/WRC between July and December 2007.



LW QME Comparisons to WISG

Downwelling Longwave Flux Comparison,
12/15/2006 - 1/31/2007



ARM Pyrgeometer Calibrations Traceable to the WISG

- **Close ECO-00559 – BB improvements**
- **No Changes to BB at SGP/RCF**
 - ✓ Continue PSP thermal offset measurements
- **Submit BCR for
Outdoor Infrared Calibration (IRCAL)
of all PIRs for SIRS, SKYRAD, GNDRAD**

Renewable Energy Needs



Fixed Tilt Flat Plate Collectors



2-Axis Tracking Flat Plate Collectors



Flat Plate Collector



1-Axis Tracking Concentrating Collectors



2-Axis Concentrating Collectors

