

# ARM Pyrgometer Calibrations Update



**Broadband Radiometric  
Measurements Group**

**Tom Stoffel  
Ibrahim Reda  
Mark Kutchenreiter**

**29 March 2011**

# Solar Radiation Research Lab (SRRL)



Construction Project  
Scheduled Completion:  
June 2011



# Radiometer Infrastructure Upgrades

---

## SIRS

- New Mounting Fixtures
- Upgraded Data Loggers
- Replace Signal Cables/Connectors

## Radiometer Calibration Facility

- Replace Signal Cables/Connectors
- Implement Pyrgeometer Calibrations Traceable to World Infrared Standard Group (ECO-00781)



# SIRS Upgrades

Since ~1993



New A-Frame



# SIRS Upgrades

| SIRS Installations                                | QTY | Unit   | Unit Cost (\$) | Total Cost(\$)       | Vendor                  | Part No.  | Comments  |
|---|-----|--------|----------------|----------------------|-------------------------|-----------|---|
| Replace mounting fixtures with single A-frame     | 23  | each   | \$ 2,500.00    | N/A                  | N/A                     | N/A       | Purchased by SGP Site Ops.                              |
| Replace SW radiometer signal cables (Downwelling) | 75  | 25 ft  | \$ 114.00      | \$ 8,550.00          | Components Express, Inc | C1123-025 | per quote #20939_C 4wk ARO                              |
| Replace LW radiometer signal cables (Downwelling) | 25  | 25 ft  | \$ 245.00      | \$ 6,125.00          | Components Express, Inc | C1122-025 | per quote #20939_C 15wk ARO                             |
| Replace SW radiometer signal cables (Upwelling)   | 25  | 50 ft  | \$ 135.00      | \$ 3,375.00          | Components Express, Inc | C1123-050 | per quote #20939_C 4wk ARO                              |
| Replace LW radiometer signal cables (Upwelling)   | 25  | 50 ft  | \$ 327.00      | \$ 8,175.00          | Components Express, Inc | C1122-050 | per quote #20939_C 15wk ARO                             |
| Replace shortwave radiometer connectors           | 92  | each   | \$ 20.00       | N/A                  | N/A                     | N/A       | Connectors included with signal cable fabrication cost. |
| Replace longwave radiometer connectors            | 46  | each   | \$ 60.00       | N/A                  | N/A                     | N/A       | Connectors included with signal cable fabrication cost. |
| Replace data acquisition ground cables            | 23  | 10 ft  | \$ 10.00       | \$ 230.00            | Beldon                  | TBD       |   |
| Replace data cables (tower J box to SIRS box)     | 23  | 50 ft  | \$ 40.00       | \$ 920.00            | Beldon                  | TBD       |   |
| Replace flex conduits for power and data cables   | 23  | 15 ft  | \$ 30.00       | \$ 690.00            | Newark                  | TBD       |   |
| Replace data logger with CR3000                   | 24  | system | \$ 3,522.00    | \$ 84,528.00         | Campbell Sci. Inc.      | CR3000    |   |
| <b>Subtotal</b>                                   |     |        |                | <b>\$ 112,593.00</b> |                         |           |   |

## NEW

- Signal Cables
- Power Cables
- Conduits
- Campbell Loggers CR-3000

# RCF Upgrades

| Radiometer Calibration Facility                           | QTY | Unit   | Unit Cost (\$) | Total Cost(\$)      | Vendor                  | Part No.                  | Comments  |
|---|-----|--------|----------------|---------------------|-------------------------|---------------------------|---|
| <b>Longwave Radiometer Calibrations IRCAL</b>             |     |        |                |                     |                         |                           |   |
| Signal Cables with PIR Connectors and Precision Resistors | 12  | 50 ft  | \$ 327.00      | \$ 3,924.00         | Components Express, Inc | CC1122-050                | per quote #20939_C 15wk ARO   |
| Data Acquisition Digital Multimeter                       | 2   | each   | \$ 4,000.00    | \$ 8,000.00         | Agilent                 | 34420A                    | Contact Ibrahim.Red@nrel.gov for model number-P/N.                                    |
| Data Acquisition Scanner                                  | 1   | system | \$16,400.00    | \$ 16,400.00        | Data Proof              | 320B Opt2-F4-32 and Q320b | per quote #291216 7wk ARO<br>Contact Ibrahim.Red@nrel.gov regarding Rack Mount Option |
| GPIB-USB-HS Cable   | 1   | each   | \$ 550.00      | \$ 550.00           | National Instruments    | NI-488.2 for Windows/XP   |   |
| 1.0 m L-COM GPIB cable                                    | 2   | each   | \$ 100.00      | \$ 200.00           | National Instruments    | CIB24-1M                  |   |
| 2.0 m L-COM GPIB cable                                    | 2   | each   | \$ 105.00      | \$ 210.00           | National Instruments    | CIB24-2M                  |   |
| 3.0 m L-COM GPIB cable                                    | 1   | each   | \$ 115.00      | \$ 115.00           | National Instruments    | CIB24-3M                  |   |
| 2.0 m L-COM USB extension cable                           | 1   | each   | \$ 15.00       | \$ 15.00            | National Instruments    | CSMUAX-2M                 |   |
| L-COM GPIB connector shielding cover                      | 8   | each   | \$ 6.50        | \$ 52.00            | National Instruments    | CIB24CB                   |   |
| <b>Subtotal</b>   |     |        |                | <b>\$ 29,466.00</b> |                         |                           |   |
| <b>Shortwave Radiometer Calibrations (BORCAL)</b>         |     |        |                |                     |                         |                           |   |
| Cavity radiometer signal cables & connectors              | 4   | 65 ft  | \$ 400.00      | \$ 1,600.00         | Eppley Laboratory, Inc  | TBD                       | Contact Ibrahim.Red@nrel.gov for more information.                                    |
| Pyranometer and Pyrhelimeter signal cables and connectors | 126 | 65 ft  | \$ 150.00      | \$ 18,900.00        | Components Express, Inc | TBD                       | Non-Thermistor Cables   |
| Pyranometer and Pyrhelimeter signal cables and connectors | 10  | 65 ft  | \$ 200.00      | \$ 2,000.00         | Components Express, Inc | TBD                       | Extra conductors for Thermistor Cables  |
| Data Acquisition PC                                       | 1   | each   | \$ 1,850.00    | \$ 1,850.00         | TBD                     | TBD                       | Contact Ibrahim.Red@nrel.gov for more information regarding GBIB and/or Serial Ports. |
| Note: New BORCAL DAS acquired in FY08                     |     |        |                |                     |                         |                           |   |
| <b>Subtotal</b>   |     |        |                | <b>\$ 24,350.00</b> |                         |                           |   |

- BORCAL (Shortwave)
  - BORCAL (Longwave = PYRG-CAL)
- New Hardware & **PROCESS**

# Pyrgeometer Calibration Process

World Reference

WISG

NREL Reference



NREL Transfer Standards  
( $\pm 2 \text{ W/m}^2$  agreement with NOAA/GMD)



ARM/SGP Transfer Standards



ARM Field Pyrgeometers



# Pyrgometer Calibration Action Items

---

## **(6) Frequency:**

Two Year Cycle using outdoor method

## **(7a) EPLAB Re-cal for 10 PIRs for comparison with original results:**

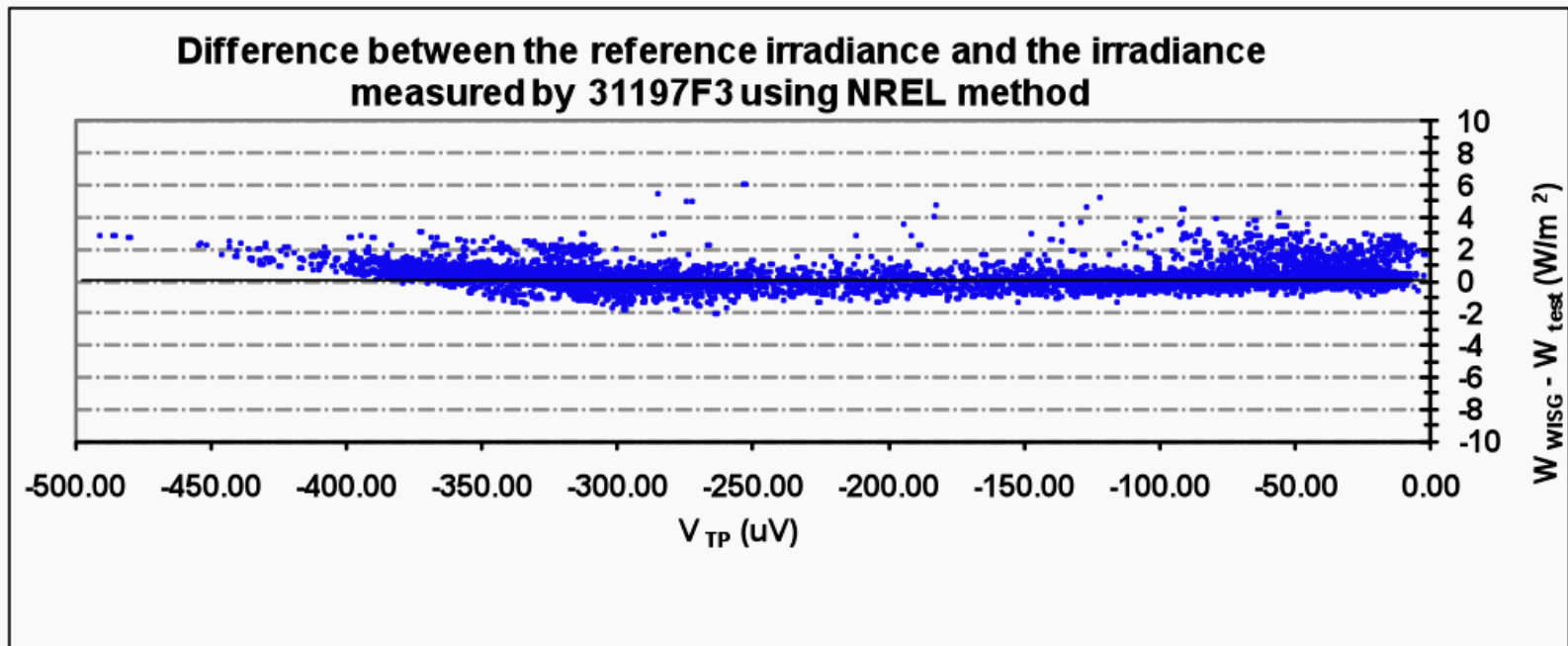
Six (6) SIRS PIRs going to EPLAB as we speak



# Compare WISG with NREL Calibrations

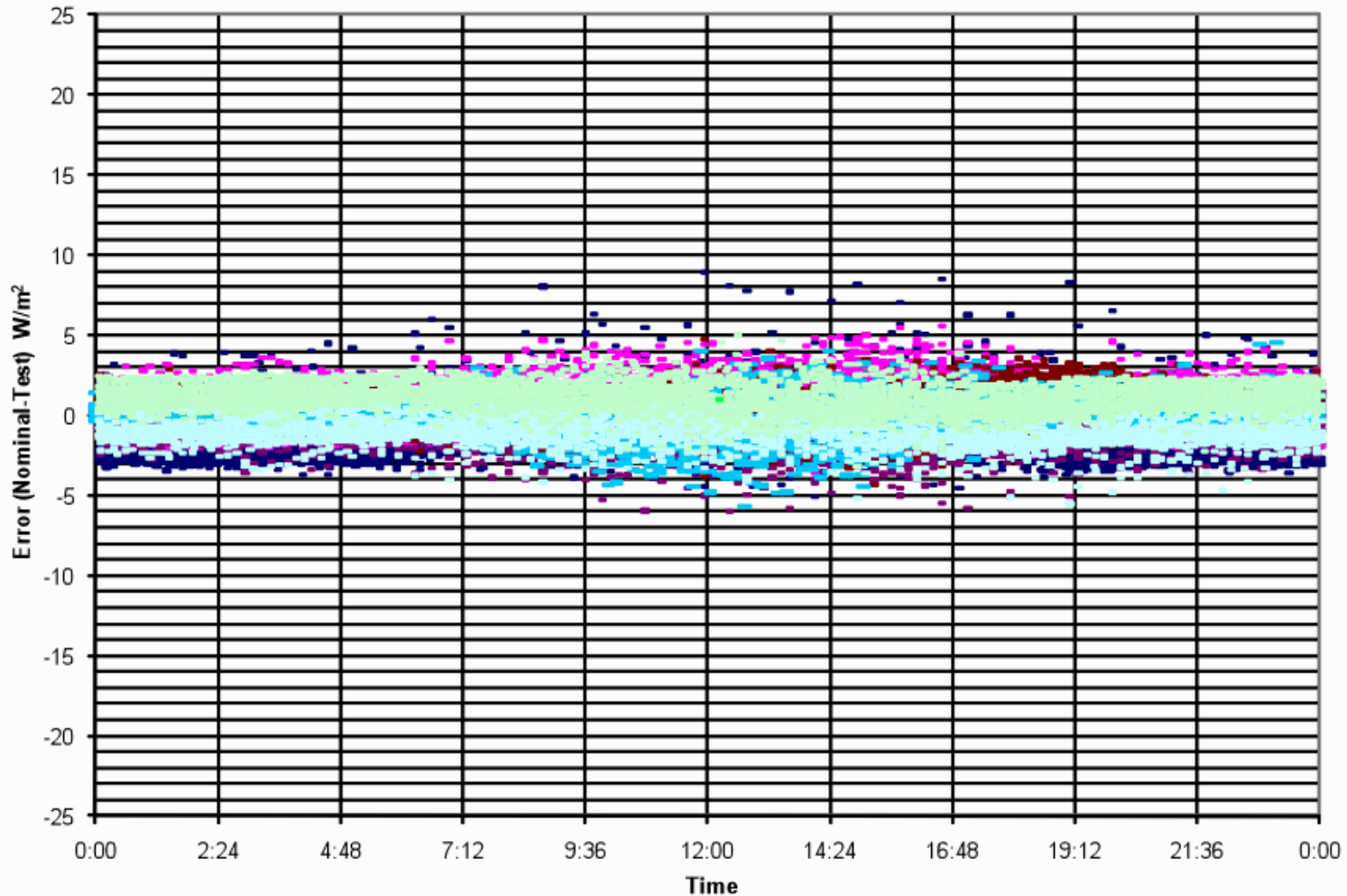
## NREL Calibration Method Validation

- At least 40 pyrgeometers were calibrated using NREL method with uncertainty  $U_{95} < \pm 3 \text{ W/m}^2$  with respect to WISG, for all sky conditions, e.g.



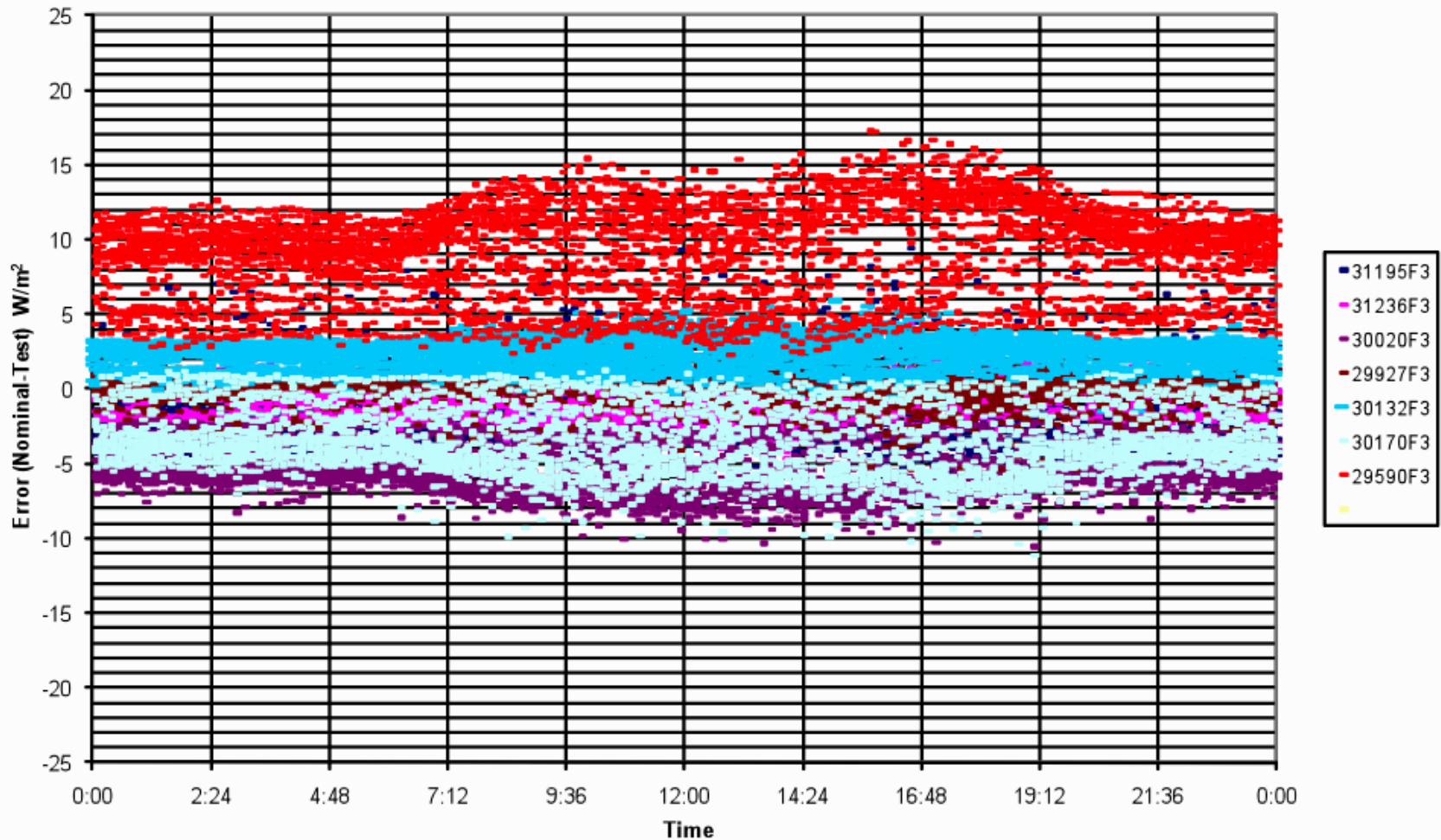
# Compare WISG with NREL Calibrations

Outdoor errors from the nominal radiation using NREL equation from April 30 to Jun 8, 2002 at SGP



# Compare WISG with EPLAB Calibrations

Outdoor errors from the nominal radiation using 2-Ks derived from the manufacturer calibration  
from April 30 to Jun 8, 2002 at SGP



# Joe's Validation of NREL Equation

## Accuracy of Ground-based Infrared Irradiance Measurements in the NOAA/BSRN Network

J. J. Michalsky<sup>1</sup>, E. G. Dutton<sup>1</sup>, J. A. Augustine<sup>1</sup>, C. R. Cornwall<sup>1</sup>,  
D. W. Nelson<sup>1</sup>, T. Stoffel<sup>2</sup>, and I. Reda<sup>2</sup>

<sup>1</sup>Global Monitoring Division/Earth System Research Laboratory/NOAA

<sup>2</sup>National Renewable Energy Laboratory

- Temperature measurements and equations in pyrgeometry
- Issues in the Atmospheric Radiation Measurement (ARM) program
- Calibration techniques and comparisons
- Field transfer of calibration



Albrecht & Cox (*J. Appl. Meteorol.* 1977)

$$E = \frac{U_{emf}}{C} + \sigma T_B^4 - k_3 \sigma (T_D^4 - T_B^4)$$

Philipona et al. (*Appl. Opt.* 1995)

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

Reda et al. (*J. Atmos. Sol. Terr. Phys.* 2002)

$$E = k_0 + \frac{U_{emf}}{C} + k_2 \sigma T_R^4 - k_3 \sigma (T_D^4 - T_R^4)$$

$$\text{where } \rightarrow T_R = T_B + 0.7044 U_{emf}; [U] == mv$$

# Conclusions

- Good blackbody calibrations with experimentally-determined dome/case correction term yields uncertainties of about  $4 \text{ W/m}^2$ ; shading lowers this uncertainty
- Outdoor calibrations using either Reda or Philipona eqns produce uncertainties  $\sim 1 \text{ W/m}^2$
- This is predicated on the assumption of the standard in use being tied to an absolute standard

# Pyrgeometer Calibration Action Items

---

**(7b) Compare PIRs with new (WISG) ARM calibrations with original EPLAB calibrations using 2-coefficient formula:**

- \_Original Cal and case-dome coeff = 4.0**
- \_Original Cal and new case-dome coeff**
- \_New Cal and new case-dome coeff**
- \_New Cal and 3-Coeff formula**
- \_Compare above to see differences...**