Radiometer Calibrations at the ARM Southern Great Plains Radiometer Calibration Facility

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Introduction

The Atmospheric Radiation Measurement (ARM) Program needs the most accurate broadband shortwave solar irradiance measurements possible. Precise radiometer calibrations are critical for producing accurate and comparable measurements. The Radiometer Calibration Facility (RCF) at the ARM Southern Great Plains (SGP) Central Facility (CF) is a state-of-the-art project, established with the purpose of calibrating the pyranometers and pyrheliometers used in the Solar and Infrared Observing System(SIROS)/Solar Infrared Radiation Stations (SIRS) network.

The RCF is shown in Figure 1.

This paper describes four prominent aspects of the RCF: traceability, the physical structure, calibration software, and the calibration events.

Traceability

Calibrations for the ARM project must be thorough, performed annually, and maintain traceability to the World Radiometric Reference (WRR). To attain traceability, the reference cavity radiometers in use at the RCF must be referenced back to the WRR, which is maintained at the World Radiation Center in Davos, Switzerland. Toward this end, the ARM Program Reference cavity radiometer (AHF28968) participated in the 1995 International Pyrheliometer Comparison at Davos and has direct traceability to the WRR. The SGP Site Reference cavity (AHF28964), the Working Standard cavity (AHF30495), and the All-weather cavity (AHF29222) all undergo regular comparisons with the ARM Program reference and other directly traceable instruments during annual inter-comparisons at the National Renewable Energy Laboratory (NREL). This hierarchy is detailed in Figure 2.

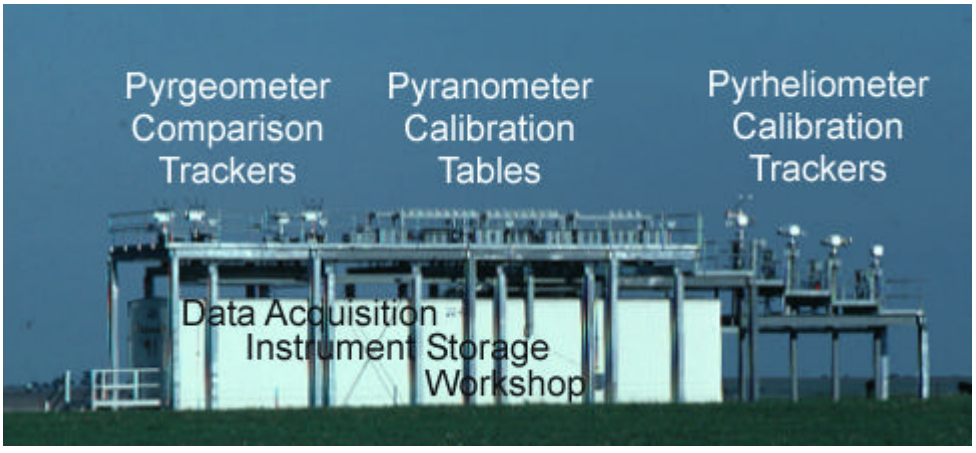

Figure 1. SGP RCF. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/ wilcox-98.pdf*.)

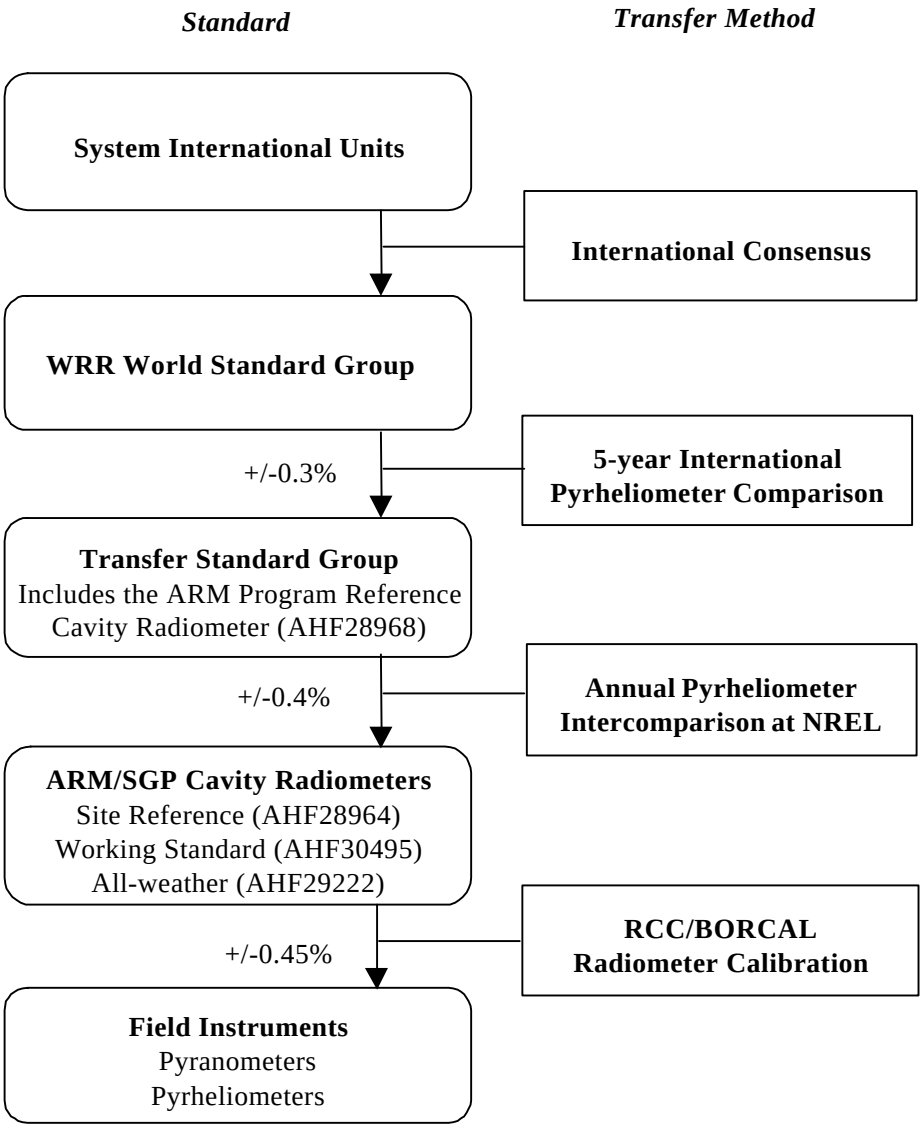

Figure 2. ARM cavity traceability to the WRR.

Physical Structure and Configuration

Besides the reference cavity radiometers, the RCF maintains four Brusag solar trackers, a data acquisition system, and an infrastructure that can handle 115 test instruments in each Broadband Outdoor Radiometer CALibration (BORCAL) event.

The RCF design includes an instrument mounting plane supported independently of both the calibration building and the platform access walkways. This maintains greater stability, minimizing potential platform tilt or tracker misalignment that can adversely affect calibration results. The instrument tables provide protection from hail damage by an innovative hail shield system that deploys quickly by one person when severe weather approaches.

The RCF also houses a pyrgeometer calibration system, data acquisition equipment, an instrument storage area, and a workshop for network support and maintenance.

Calibration Software

Radiometer Calibration and Characterization (RCC) was developed as an outgrowth of several years of procedures developed at NREL to calibrate radiometers. In the past, much of the data acquisition and data processing was done at various on-site locations using a variety of computer hardware with several software packages. RCC combines all functions of the calibration event into a single software package that runs on a personal computer. Beyond the data acquisition and reporting functions of the previous software, RCC provides the following enhancements:

- Generation of calibration vectors for pyranometers, reducing the uncertainty of measurements due to the non-linear response of many pyranometers in the domain of zenith angle. Each pyranometer is assigned a responsivity within ten solar zenith angle bins as shown in Figure 3.
- Real-time data error checking that alerts the operator to find and correct data acquisition problems when they occur. Diagnostics include physical limits, rate of change, and performance of control instruments.
- Monitoring of atmospheric and meteorological conditions that affect the results of a calibration event, allowing the filtering of data for optimal clear-sky conditions.
- A supporting instrument and calibration data base that stores information about each instrument under calibration, as well as completing a history of calibration events.
- Generation of a camera-ready printed report.

Calibration Events

RCF personnel completed two BORCAL events in 1997 involving 164 instruments. Each instrument in the SGP network is scheduled for calibration once per year. The network maintains a 50% overstock of instruments to allow

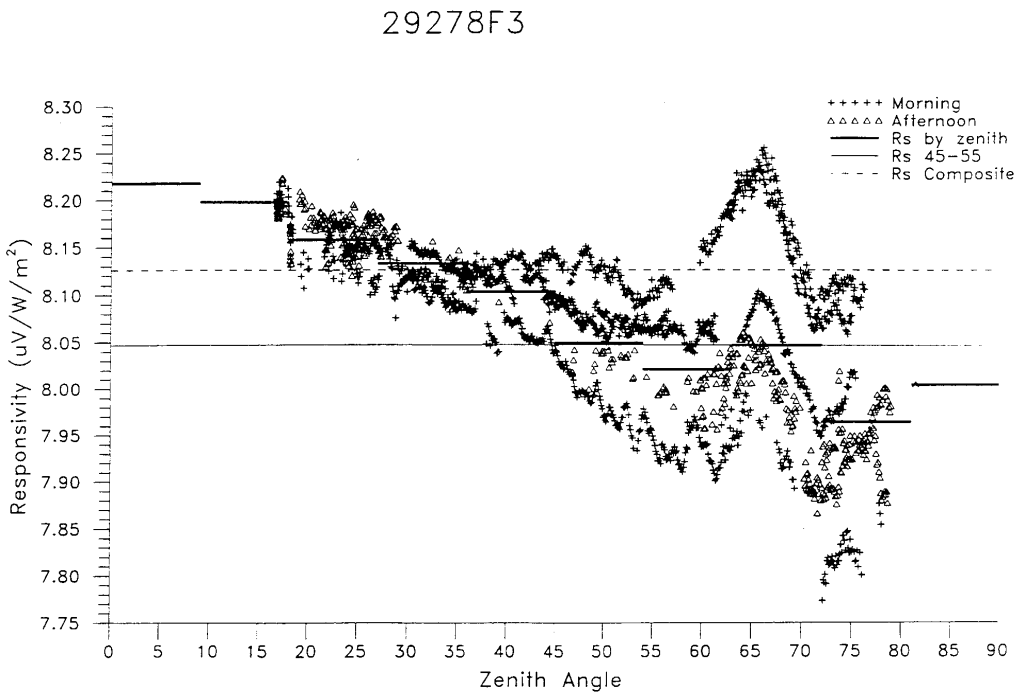

Figure 3. Precision spectral pyranometer responsivity profile from RCC report.

the recalibration of all instruments annually by scheduling two calibration events per year. Once instruments are calibrated, they are swapped into service at the sites, and the returning instruments are scheduled for a future calibration.

Data from all instruments are taken during clear-sky conditions over a period of several days to several weeks, depending on prevailing weather conditions. One or two cavity radiometers (one with a window and one without) are operated during the event, depending on wind conditions. Two pyranometers under shading disks provide a measurement of the diffuse sky radiation. The responsivity values for pyrheliometers are calculated using the cavity radiometer(s) as a reference. Pyranometers are calibrated from a global irradiance reference signal derived from the cavity radiometer and the two shading disk pyranometers. The global reference is calculated as the direct normal reference measurement multiplied by the cosine of the solar zenith angle, then that product added to the diffuse measurement.

The RCF BORCAL protocol includes 15 control and measurement assurance instruments that participate in every calibration event. Calibration results from these instruments are tracked from calibration to calibration to ensure consistency of the procedures. In addition, the measurement assurance instruments are calibrated at NREL each year to maintain an independent check of the calibration process at the RCF. To date, the interlaboratory calibrations suggest a nominal difference within the uncertainty of the calibration process.

The results of each BORCAL are documented in an RCF calibration report that is distributed to project principals. The instrument responsivity profiles shown in Figure 3 above, and the responsivity table shown in Table 1 are included in the report. In addition, the calibration responsivities and uncertainties for each instrument are transmitted to the Data and Science Integration Team for inclusion in the ARM project archive.

Table 1. RCC Instrument responsivities.

BROADBAND OUTDOOR RADIOMETER CALIBRATION REPORT
BORCAL 1997-01

Summary Statistics for Instruments submitted by
ARM/CART Site (Dan Nelson)

Cavity Radiometer: EPPLEY H-F #29222 WRR Factor: 0.9994 Window Factor: 1.0709
Cavity Radiometer: EPPLEY H-F #30495 WRR Factor: 0.9976 No Window Mounted
Diffuse Pyranometer: 31096F3 Responsivity: 9.27
Diffuse Pyranometer: 31098F3 Responsivity: 8.51
Calibration Dates: 7/14/97 7/23/97 7/24/97 7/25/97 7/26/97 7/27/97 7/31/97

Instrument	14862F3			29251F3			29278F3		
N/StdDev	2722/0.074			2695/0.027			2713/0.050		
Bin	Rs	Uncert	Pct	Rs	Uncert	Pct	Rs	Uncert	Pct
45-55	8.371	0.28	3.4	8.237	0.19	2.3	8.047	0.21	2.7
Composite	8.460	0.58	6.9	8.280	0.32	3.9	8.126	0.35	4.3
Zen 00-09	8.594*	----	---	8.354*	----	---	8.218*	----	---
Zen 09-18	8.575	0.14	1.7	8.341	0.14	1.6	8.198	0.13	1.6
Zen 18-27	8.537	0.20	2.3	8.317	0.16	1.9	8.158	0.16	2.0
Zen 27-36	8.493	0.22	2.6	8.299	0.15	1.9	8.133	0.16	2.0
Zen 36-45	8.447	0.25	2.9	8.276	0.15	1.8	8.103	0.16	2.0
Zen 45-54	8.374	0.28	3.3	8.238	0.19	2.3	8.049	0.21	2.6
Zen 54-63	8.300	0.33	3.9	8.197	0.20	2.5	8.021	0.25	3.1
Zen 63-72	8.226	0.44	5.4	8.170	0.25	3.0	8.047	0.30	3.7
Zen 72-81	8.062	0.45	5.5	8.087	0.22	2.7	7.965	0.28	3.5
Zen 81-90	8.270	0.11	1.3	7.975	0.10	1.3	8.005	0.10	1.3

Instrument	29554E6			29556E6			29617F3		
N/StdDev	2302/0.043			2300/0.044			2706/0.071		
Bin	Rs	Uncert	Pct	Rs	Uncert	Pct	Rs	Uncert	Pct
45-55	-----	----	---	-----	----	---	9.332	0.28	3.0
Composite	8.134	0.20	2.5	8.211	0.21	2.5	9.407	0.49	5.2
Zen 00-09	-----	----	---	-----	----	---	9.513*	----	---
Zen 09-18	-----	----	---	-----	----	---	9.491	0.15	1.6
Zen 18-27	-----	----	---	-----	----	---	9.447	0.20	2.1
Zen 27-36	-----	----	---	-----	----	---	9.412	0.21	2.3
Zen 36-45	-----	----	---	-----	----	---	9.381	0.22	2.4
Zen 45-54	-----	----	---	-----	----	---	9.334	0.28	3.0
Zen 54-63	-----	----	---	-----	----	---	9.282	0.32	3.4
Zen 63-72	-----	----	---	-----	----	---	9.306	0.33	3.6
Zen 72-81	-----	----	---	-----	----	---	9.168	0.43	4.7
Zen 81-90	-----	----	---	-----	----	---	9.414	0.12	1.3

N/StdDev: N = Sample size of entire data set; StdDev = Standard Deviation in uV/W/m^2 (45-55 data for pyranometers; All data for pyrheliometers)
Bin Rs: Responsivity (uV/W/m^2)
Bin Uncert: Measurement uncertainty (plus/minus uV/W/M^2)
Bin Pct: Measurement uncertainty (plus/minus percent of Responsivity)
45-55: Responsivity and uncertainty for the 45-55 zenith bin
Composite: Responsivity and uncertainty (Pyranometers: weighted by cosine of the bin center zenith angle when all bins have data; Pyrheliometers: all data)
Zen nn-nn: Responsivity and uncertainty for zenith angle bin (nn-nn = bin range)
* Indicates the responsivity is interpolated or extrapolated