ARM TR-023

Precision Infrared Radiometer (Pyrgeometer) Handbook

DRAFT

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1. General Overview

A pyrgeometer is a type of radiometer used to measure broadband longwave (infrared) irradiance on a planar surface. Accurate measurements of longwave irradiance are needed to understand the basic energy exchanges in the earth-atmosphere-ocean climate system. The ARM Program uses pyrgeometers for ground-based in-situ radiation measurements collected by the ground-radiation (GNDRAD), sky-radiation (SKYRAD), solar and infrared observation stations (SIROS), and solar infrared radiation station (SIRS) instrument platforms. (Note: for additional information on the pyrgeometer, see the SIRS page.)

2. Contacts

2.1 Mentor

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2.2 Instrument Developer

This section is not applicable to this instrument.

3. Deployment Locations and History

This section is not applicable to this instrument.

4. Near-Real-Time Data Plots

This section is not applicable to this instrument.

5. Data Description and Examples

Infrared irradiance values vary with location, season, time of day, and with atmospheric factors effecting the emission, transfer, and exchange of radiation.

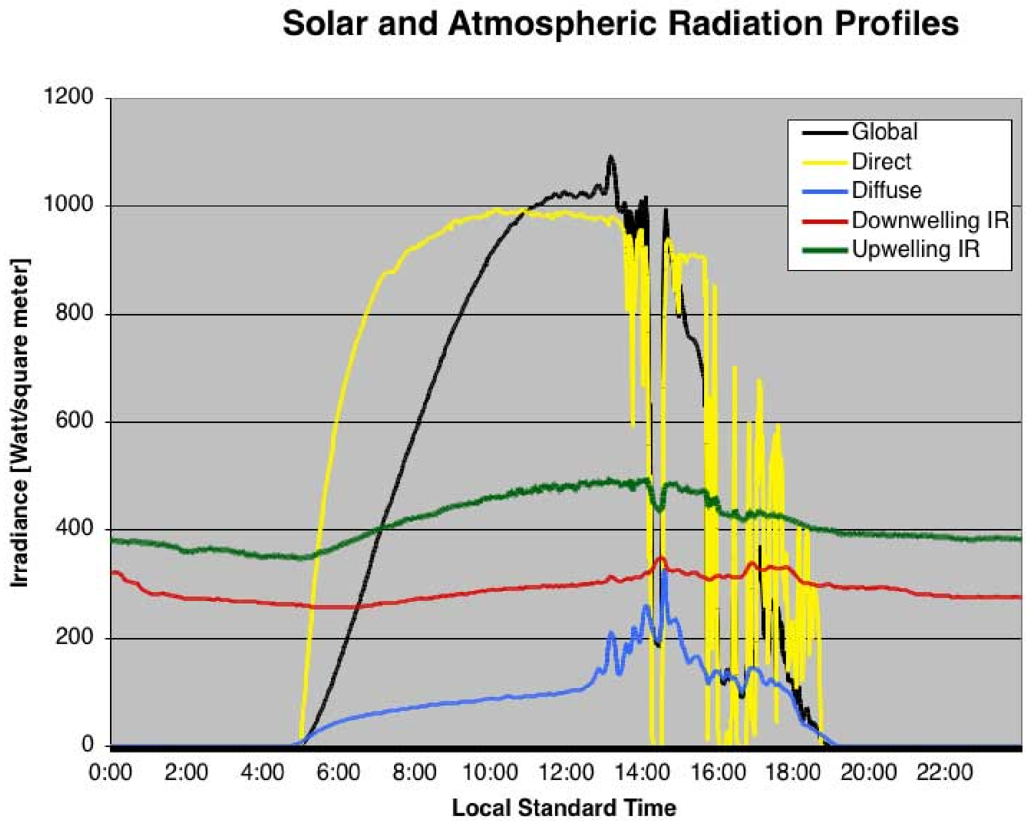

Figure 1. Solar and Atmospheric Radiation Profiles: Global, direct normal, diffuse horizontal, downwelling infrared and upwelling infrared time-series data

The time-series data were collected on May 7, 2004, and are representative of mid-latitude, continental conditions.

Steadily increasing amounts of shortwave (solar) irradiance data indicate the sky was clear from sunrise until about 13:00 when clouds began to interfere with the direct (beam) radiation. In the afternoon, clouds became opaque for brief periods and the sky remained partly cloudy until sunset.

Decreasing levels of longwave (atmospheric) irradiance data suggest clearing sky conditions from midnight to sunrise and from sunset to the following midnight.

- Global: The sum of direct normal (beam) projected on a horizontal surface and the diffuse (sky) shortwave irradiance increases above the clear-sky value about 13:00 as the relative position of the sun and the clouds result in temporarily enhanced reflection of solar irradiance as measured by the unshaded pyranometer.

- Direct: Pyrheliometer measurements are consistent with the data from the shaded (Diffuse) and unshaded (Global) pyranometers. Variations of cloud opacity can be seen from the decreased direct irradiance levels from the clear-sky amounts.

- Diffuse: Shaded pyranometer measurements for this day are typical of clear blue sky conditions in the morning (10% - 15% of the unshaded pyranometer readings) and increase with the presence of bright white clouds.

- Downwelling IR: The infrared or longwave irradiance as measured by a pyrgeometer viewing the sky dome. The irradiance decreases from midnight until about sunrise. Increased air temperature due to solar heating and the sun's infrared radiance is captured by the pyrgeometer as seen by the slightly increasing irradiance levels from sunset until the sky is partly cloudy. The presence of "warm" clouds can be seen in the variations of irradiance between noon and sunset. Data approaching midnight, suggests the sky gradually cleared as seen by the slightly declining longwave irradiance values.

- Upwelling IR: The infrared irradiance as measured by an inverted pyrgeometer viewing the ground surface. Generally higher than downwelling longwave irradiance (the two components can be nearly equal under foggy conditions); the upwelling longwave irradiance levels for this day show the increased surface temperatures following sunrise. The effect on opaque clouds at about 14:00 on surface temperature is evident from the corresponding temporary decrease in upwelling longwave irradiance during this shaded period.

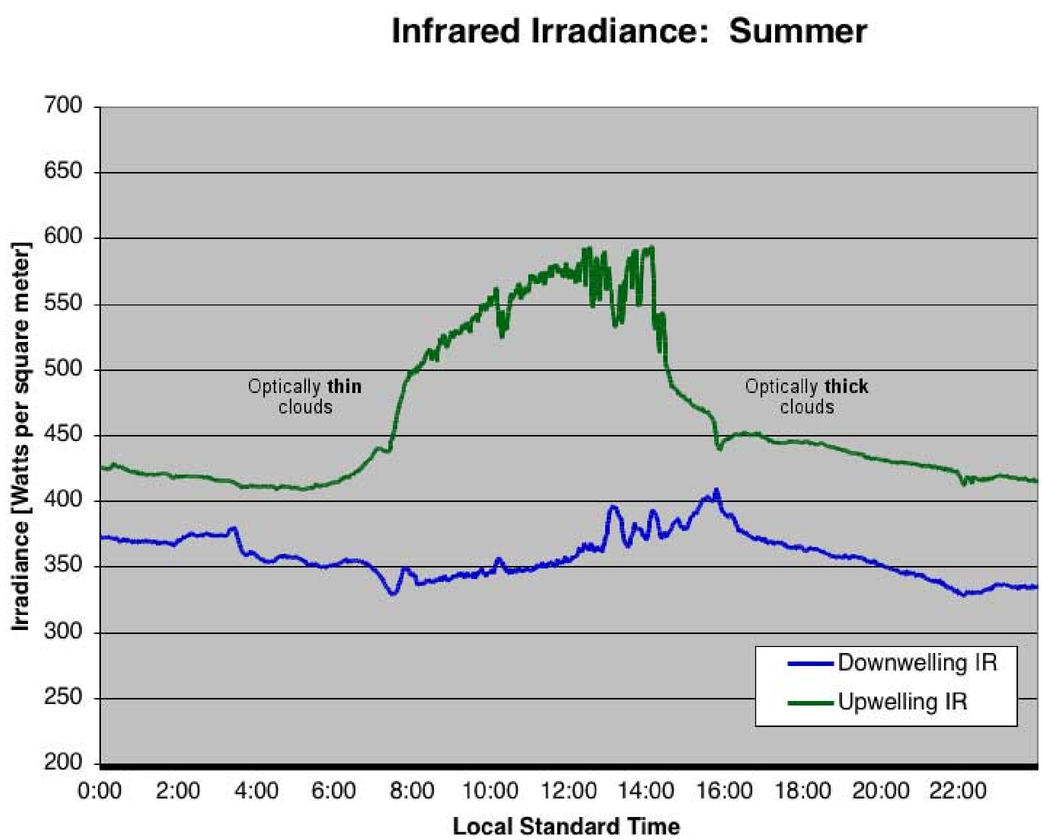

Figure 2. Infrared Irradiance: Influence of Clouds on Upwelling and Downwelling Components

The time-series data were collected on July 27, 2003, and are representative of mid-latitude, continental conditions.

From midnight until local noon, clear to partly-cloudy sky conditions result in a relative maximum difference between the upwelling (approaching 600 Wm-2) and the downwelling (fairly stable near 350 Wm-2) irradiances of about –250 Wm-2.

The onset of more uniform and optically thicker clouds decreases this difference (also called the Net Longwave Irradiance) to less than 50 Wm-2 near 15:00.

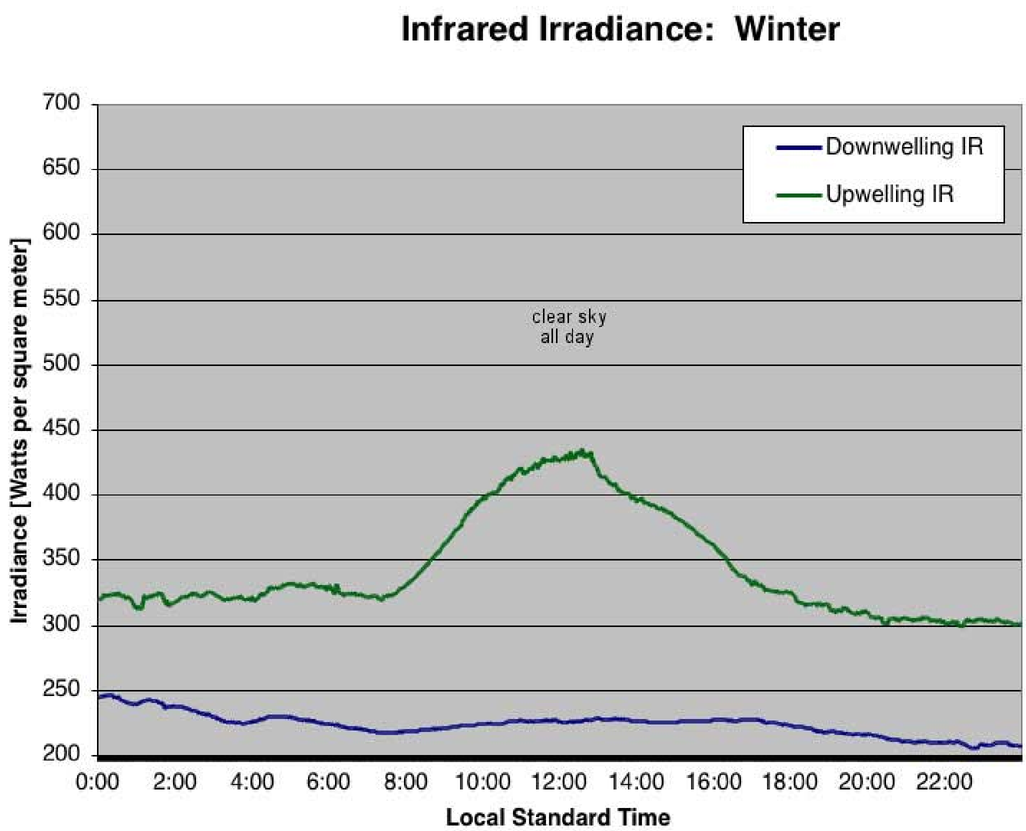

Figure 3. Seasonal Differences: Typical Winter Diurnal Profile

The time-series data were collected on January 11, 2004, and are representative of mid-latitude, continental conditions.

Comparing these data with the summer measurements shown in Figure 2, the colder ground surface and atmospheric temperatures are evident from the lower irradiance levels available on this clear-sky day in January.

The maximum upwelling irradiance near local noon [about 440 Wm-2] is nearly 150 Wm-2 less than the summer values. Similarly, the wintertime downwelling irradiances can be more than 100 Wm-2 less than the summertime values at this mid-continental location.

During the Second International Pyrgeometer and Absolute Sky-Scanning Radiometer Comparisons (IPASRC II) in Barrow, the minimum downwelling longwave irradiances were near 125 Wm-2.

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

Depending on sensor orientation and mounting system, a pyrgeometer can be used to measure longwave or infrared irradiances (Watts per square meter):

1. Downwelling Infrared (DIR): A pyrgeometer mounted on a stable horizontal platform will provide measurements of the "atmospheric" longwave irradiance.
2. Upwelling Infrared (UIR): When inverted (i.e., mounted with the detector pointed at the ground) a pyrgeometer will measure the amount of longwave irradiance emitted and reflected by the surface.

5.1.1.1 Definition of Uncertainty

PIR pyrgeometers are capable of providing 1-minute averages of downwelling and upwelling longwave irradiance measurements within +/- 5% or +/- 5 Watts per square meter, whichever is larger, at the 95% confidence level. This estimate assumes the instrument has been calibrated with a blackbody reference, was properly installed, and is adequately maintained. A detailed analysis of the response characteristics contributing to the measurement uncertainty estimate is provided in the "Theory of Operation" section.

There are a number of conditions under which PIR measurements may be incorrect. The data user should examine the data quality flags (described in "Explanation of Flags Applied During Data Ingest) and data quality reports (DQR) to determine whether significant malfunctions have occurred due to problems with a pyrgeometer. The more frequent sources of error are described briefly here.

Contaminated optical surfaces can reduce or enhance the apparent infrared flux at the detector. Accumulations of dew, frost, dust, snow, or ice on the dome are generally reduced or eliminated by the use of a ventilator or when the pyrgeometer is mounted in the inverted position. Reduction of the dome transmittance due to contamination will decrease the signal from a pyrgeometer. Under some circumstances, the presence of dew, frost, snow or ice can enhance the amount of longwave radiation reaching the pyrgeometer detector. Any extraneous thermal influences on the dome or case will affect pyrgeometer measurement performance.

5.1.2 Secondary/Underlying Variables

This section is not applicable to this instrument.

5.1.3 Diagnostic Variables

This section is not applicable to this instrument.

5.1.4 Data Quality Flags

See SIRS Data Object Design Changes for ARM netCDF file header descriptions.

5.1.5 Dimension Variables

This section is not applicable to this instrument.

5.2 Annotated Examples

This section is not applicable to this instrument.

5.3 User Notes and Known Problems

This section is not applicable to this instrument.

5.4 Frequently Asked Questions

How do you pronounce "pyrgeometer"?

Websters' dictionary gives the first pronunciation as "peer`-je-om-et-ur", from the Greek, fire/earth/measure.

What is the typical relationship between Upwelling and Downwelling longwave irradiances?

As deployed for ARM Program measurements, pyrgeometers respond to infrared radiation from the atmosphere (Downwelling Irradiance) or the ground (Upwelling Irradiance). The amount of longwave radiation reaching the pyrgeometer is then basically a function of the sky or ground temperature and emissivity. Because the effective sky temperature is generally much lower than for the ground, Upwelling Infrared (UIR) is typically greater then the corresponding Downwelling Infrared (DIR) values. In the presence of very low clouds (Nimbostratus), fog, or rainy weather, the two irradiance fields can be very similar.

How often should the dome be cleaned?

Frequently enough to keep dome contamination due to dust, insects, birds, and all forms of precipitation from affecting the transmission of radiation to the detector and/or changing the effective dome temperature. The ARM Program uses electrically-powered ventilators to keep the domes clear of contamination. A “Cleaning Study” is currently in progress to access the effectiveness of the semi-monthly preventative maintenance schedule based on the daily maintenance performed at the Central Cluster (E-13).

What is the maximum signal cable length?

100 to 150 feet. The maximum thermopile signal is typically 3-5 millivolts DC. The temperature measurements require thermistor excitation voltages (2.5 Vdc), but are made with 4-wire connections to reduce the effects of “long” conductors.

When should the desiccant be changed?

When the indicating silica crystals are not blue when viewed through the window on the desiccant chamber. The desiccant turns pink when the pyrgeometer case has become damp (>60% RH) and white when the desiccant has become saturated with moisture.

Why are pyrgeometers installed on automatic solar trackers?

Although the pyrgeometer dome is designed to reject all shortwave radiation (wavelengths less than about 4 microns), the coating of this hemispherical interference filter may “leak,” allowing some shortwave radiation to reach the detector. Although the pyrgeometers used in the ARM Program have been carefully tested and do not exhibit this problem, all pyrgeometers for downwelling irradiance measurements are mounted next to the shaded pyranometers used to measure the diffuse (sky) irradiance. Both radiometers are thus shaded from the direct rays of the sun.

What is the maximum irradiance expected from a pyrgeometer measurement?

Downwelling longwave irradiance for an effective sky temperature near freezing (cloudless and low levels of precipitable water vapor) is about 250 Watts per square meter. Upwelling longwave irradiance for an effective ground temperature near 25°C is about 350 Watts per square meter.

Where can I send a pyrgeometer for recalibration?

The radiometer manufacturer. The ARM Program has developed a pyrgeometer calibration system based on a temperature-controlled blackbody chamber and outdoor characterizations at the Radiometer Calibration Facility. The results of this method, developed by NREL and EPLAB, have been compared with two International Pyrgeometer and Absolute Sky-scanning Radiometer Comparisons (IPASRC-I and IPASRC-II).

How often should a pyrgeometer be recalibrated?

Full characterization is recommended prior to deployment with annual recalibrations until the stability of each pyrgeometer has been established and the measurement uncertainty goals have been confirmed.

Is it necessary to remove a pyrgeometer from service for calibration?

A traveling standard could be used in the field for side-by-side measurement comparisons. The ARM Program, however, has designed 50% spares for each measurement station and requires the pyrgeometer be removed and sent to the manufacturer or the Radiometer Calibration Facility for recalibration.

How do blackbody calibrations of pyrgeometers compare with conditions found outdoors?

This question remains part of an on-going study by the ARM Program at NREL. The issue is, "How similar are the infrared spectral distributions achieved in a blackbody chamber to those encountered outdoors under a range of atmospheric conditions"? Preliminary analyses suggest the measurement uncertainties due to this difference is less than 3 Watts per square meter.

What are the effects of ventilators on pyrgeometer performance?

Ventilators help to prevent dome contamination by forcing air at ambient temperature over the pyrgeometer dome. Because the irradiance measurement from a pyrgeometer is computed from the measured thermopile output and the case and dome temperatures, the ventilator has no measurable effect on the pyrgeometer data.

Does it matter how I install a pyrgeometer?

>level (tolerance)
>Air gap at base (heat transfer)
>mounting material(s)

Does it matter where I install a pyrgeometer?

>free horizon (solar access)
>Non-reflective surfaces
>Shaded by poles, roof vents, elevator shafts, trees, etc.

Does the amount of circumsolar (forward scattering around the solar disk) effect pyrgeometer measurements?

What effects do rapidly changing cloud scenes have on pyrgeometer measurements?

What is the difference between measurements made with an Infrared Thermometer (IRT) and a pyrgeometer?

6. Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results.

- DQ HandS (Data Quality Health and Status)
- NCVweb for interactive data plotting using.

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

This section is not applicable to this instrument.

6.3 Data Assessments by Site Scientist/Data Quality Office

All DQ Office and most Site Scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM Program are met through the analysis and processing of existing data products into "value-added" products or VAPs. Despite extensive instrumentation deployed at the ARM CART sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the program. Conversely, ARM produces some VAPs not in order to fill unmet measurement needs, but instead to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces "best estimate" VAPs. A special class of VAP called a Quality Measurement Experiment (QME) does not output geophysical parameters of scientific interest. Rather, a QME adds value to the input datastreams by providing for continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between measurement with modeled results, and so forth. For more information, see the VAPs and QMEs web page.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

A pyrgeometer is the lowest component-level device used by an ARM instrument platform. Please refer to GNDRAD, SKYRAD, SIROS, or SIRS for a description of how pyrgeometers are used in these systems.

7.1.2 System Configuration and Measurement Methods

The ARM Program uses The Eppley Laboratory, Inc. Model PIR (Precision Infrared Radiometer) pyrgeometer for shortwave irradiance measurements. The PIR comprises a multi-junction wire-wound Eppley thermopile that can withstand severe mechanical vibration and shock. Its receiver is coated with Parson's black lacquer providing non-wavelength selective absorption. The instrument is supplied with a removable precision ground hemisphere to protect the thermopile detector and limit the transmission of radiant energy to the infrared wavelength region. The silica hemisphere is coated to serve as an interference filter, restricting the energy reaching the detector to the infrared (4.0 to 50-m). A YSI 44031 thermistor is cemented to the interior of the silica dome to provide a temperature measurement of this component. The instrument has a cast bronze body with a second thermistor for monitoring "case" temperature. A white enameled guard disk (sun shield) protects the pyrgeometer body from large thermal gradients. A spirit level is attached to the body for accurately determining the horizontal orientation with adjustable leveling screws. A removable desiccator is secured in the pyrgeometer body and can be readily inspected.

This thermoelectric device (see "Theory of Operations" for details) produces electrical current proportional to the broadband longwave irradiance reaching the detector. A shielded, twisted three-pair, copper wire signal cable connects the PIR to a data logger. The data logger is generally programmable and provides 1-minute statistics of analog to digital conversions made every few seconds (see other instrument platforms for details, e.g., SIRS).

Pyrgeometers are located to provide maximum hemispheric access (i.e., the local horizon is unobstructed to the extent possible). The "Downwelling Infrared" pyrgeometer is mounted in a ventilator that is in turn secured to a horizontal surface on an automatic solar tracker about 2 meters above the ground. The pyrgeometer/ventilator system is carefully leveled and positioned under a tracking shade mechanism to block direct shortwave (solar) irradiance from the detector. The ventilator provides a continuous stream of air over the outer optical surface of the pyrgeometer to prevent dew, frost, or dust accumulation. The pyrgeometer is shaded from the sun to prevent any shortwave “leakage” to the thermopile detector that could occur in the silica dome.

The “Upwelling Infrared” pyrgeometer is mounted several meters above the ground, typically on a meteorological tower mast, and inverted over a surface representative of local ground cover. An inverted pyrgeometer is generally not mounted in a ventilator as this orientation naturally protects the instrument's optical surfaces from contamination. Ventilation is used, however, when severe icing or frost accumulations are possible (e.g., at the North Slope of Alaska sites).

Methods of measurements are further described under "Theory of Operation" and under "Frequently Asked Questions (FAQs)".

7.1.3 Specifications

This section is not applicable to this instrument.

7.2 Theory of Operation

This section is not applicable to this instrument.

7.3 Calibration

7.3.1 Theory

Introduction

In the absence of a recognized calibration standard, ARM has developed a Pyrgeometer Blackbody Calibration System (PBCS). The system (see Figure 4) was designed and built by The Eppley Laboratory, Inc., with support from the National Renewable Energy Laboratory (NREL) to meet the needs for routine calibration of pyrgeometers used in the SIRS, SKYRAD, and GNDRAD measurement platforms. The

PBCS meets the performance goals recommended by the World Meteorological Organization's Baseline Surface Radiation Measurement Network (BSRN)[1]. Pyrgeometers are calibrated and characterized based on the ability of the PBCS to provide stable and accurate temperatures for a blackbody source and the pyrgeometer body.

In order to calibrate pyrgeometers in large quantities, a collection of five conventional pyrgeometers, calibrated in the PBCS, have been selected to establish the NREL Pyrgeometer Transfer Reference Group (NPTRG)[2]. The calibration of field pyrgeometers is then made outdoors using the NPTRG as the transfer standard. The Radiometer Calibration Facility at the Southern Great Plains Central Facility has the same equipment and capabilities for the routine calibration of pyrgeometers.

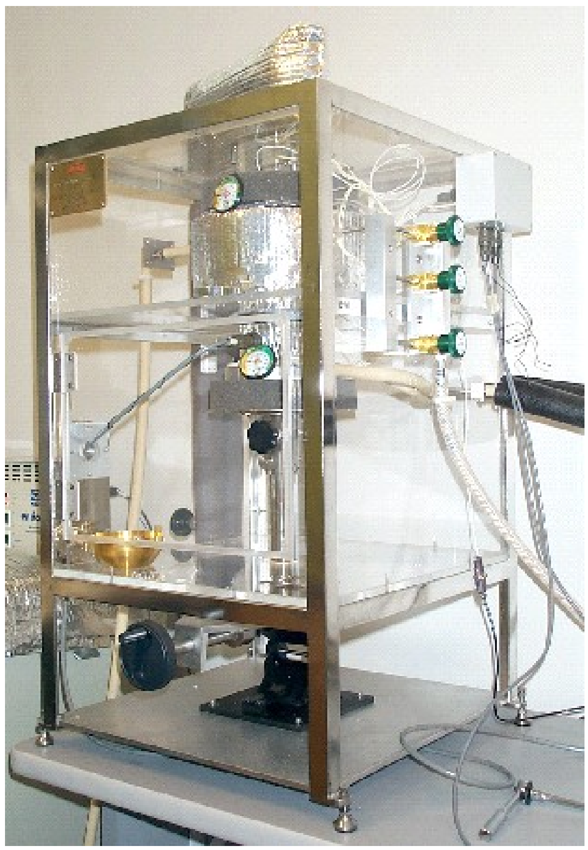

Figure 4. The calibration chamber portion of the Pyrgeometer Blackbody Calibration System.

Elements of Pyrgeometer Calibration

We will limit our discussion to the pyrgeometer design characteristics of the Eppley Laboratory, Inc., Model PIR. This instrument uses thermistors to monitor the temperatures of the dome and case (instrument body) and a wire-wound thermopile element for detecting radiative flux.

Accurate calibration of the case and dome thermistors is extremely important to achieve consistent results in measuring longwave radiation. However, it is equally important to use an accurate and precise blackbody to calculate the pyrgeometer responsivity, case emittance, and dome correction factor. See Figure 5.

Figure 5. The PIR positioned below the PBCS completion hemisphere. During calibration, the PIR dome is fully inserted into the blackbody by means of the adjustable support mechanism.

The *Single Calibration Factor* Approach

The longwave radiation, or infrared radiant flux, can be determined from the available output parameters of the pyrgeometer as described by Albrecht and Cox[3]:

$$W_{in} = K_1 * V + K_2 * W_c + K_3 * (W_d - W_c) \qquad [1]$$

Where,

K_1 = Factory determined thermopile responsivity [$\mu V/Wm^{-2}$]

K_2 = 1.0 , if not calibrated in the PBCS

K_3 = -4.0, if not calibrated in the PBCS

W_c = Pyrgeometer case radiation equal to $\sigma * T_c^4$, where T_c is the case temperature[K]

W_d = Pyrgeometer dome radiation equal to $\sigma * T_d^4$, where T_d is the dome temperature[K]

Historically, the manufacturer determines the thermopile sensitivity (K_1) for each pyrgeometer using a temperature-controlled blackbody and the dome correction factor (K_3) has been assumed to be -4.0 for all instruments.

The *Four-Coefficient Calibration* Approach

Improved measurement performance can be achieved using the NREL/Hickey method [2] for computing longwave irradiance from the pyrgeometer:

$$W_{in} = K_0 + K_1 V + K_2 W_r + K_3 (W_d - W_r) \quad [2]$$

Where,

W_{in} = Incoming longwave radiation (Wm^{-2})

$K_{i=0-3}$ = Pyrgeometer calibration coefficients computed using linear regression of 7 data points for 7 temperature plateaus in the PBCS
Note that K_3 is always negative

V = Pyrgeometer thermopile output (μV)

W_r = Pyrgeometer receiver radiation equal to $\sigma * T_r^4$

Where,

$$T_r = T_c + \alpha V,$$

And,

T_c = Pyrgeometer case temperature [K]

σ = Stefan-Boltzman constant ($5.6697 * 10^{-8}$ $W/m^2/K^4$)

α = $1/(S * n * E)$

S = Seebeck coefficient (39 $\mu V/K$])

n = number of thermopile junctions (56)

E = thermopile efficiency factor (.65)

W_d = Pyrgeometer dome radiation equal to $\sigma * T_d^4$, where T_d is the dome Temperature[K].

Blackbody Calibration

A properly designed blackbody calibration system can reduce the majority of errors introduced by the thermistor calibration uncertainties assigned to the pyrgeometer case and dome temperature values. This can be achieved by the following:

- The *blackbody temperature sensor* is calibrated to ± 0.01 ºC or better.
- The range of *blackbody* temperatures is consistent with the climatological limits of the intended site for pyrgeometer installation.
- The range of *pyrgeometer case* temperatures is consistent with the climatological limits for ambient air temperature.
- The thermistor coefficients used during the blackbody calibration are the same coefficients used to process the outdoor pyrgeometer measurements.

Substituting the actual blackbody flux, $W_{bb} = \sigma T_{bb}^4$ (where T_{bb} is the measured blackbody temperature in Kelvin) for the incoming irradiance (W_i), we use equation [2], to determine the calibration coefficients (K_{0-3}). Using the temperature plateaus shown in Table 1, the data from each pyrgeometer at each controlled-temperature condition are used to compute the four pyrgeometer calibration coefficients:

- K_0 accounts for all measurement offsets.
- K_1 is proportional to the thermopile responsivity.
- K_2 will include the emittance of the pyrgeometer case, a factor that is proportional to the errors resulting from the thermistor location, and a factor that is proportional to the errors resulting in the precise conversion of thermistor resistance to temperature.
- K_3 will include the correction coefficient of the dome temperature, a factor proportional to errors resulting from the case and dome thermistor locations, and a factor that is proportional to errors resulting from the thermistor resistance-to-temperature conversion.

Table 1. Temperature Plateaus[1] for Pyrgeometer Calibrations at NREL

No.	Blackbody Temperature T_{bb}(°C)	PIR Case Temperature T_c (°C)	Typical Dome & Case Temperature Difference T_d-T_c (°C)
1	35	15	1.1
2	10	25	-0.7
3	-5	25	-1.6
4	-5	10	-0.5
5	-20	10	-1.4
6	-20	-5	-0.5
7	-35	-5	-1.0
8	35	15	1.1

[1] Temperatures determined according to BSRN protocol based on the climatic normals for the pyrgeometer installation site (above values apply to SGP).

Comparison of the Two Methods

NREL collected a series of outdoor measurements at the Solar Radiation Research Laboratory in Golden, Colorado (http://www.nrel.gov/srrl) using 12 pyrgeometers calibrated with the PBCS. The longwave downwelling irradiances were computed using both the 1- and 4-coefficient methods for each pyrgeometer. Data from 30 April to 8 June 2002 formed the basis of this comparison. Sky conditions during this period ranged from clear to mostly cloudy. The pyrgeometers were installed on automatic solar trackers, shaded from direct shortwave irradiance, and mounted in ventilators.

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

This section is not applicable to this instrument.

7.4 Operation and Maintenance

This section is not applicable to this instrument.

7.4.1 User Manual

This section is not applicable to this instrument.

7.4.2 Routine and Corrective Maintenance Documentation

This section is not applicable to this instrument.

7.4.3 Software Documentation

ARM netCDF file header descriptions may be found at SIRS Data Object Design Changes.

7.4.4 Additional Documentation

This section is not applicable to this instrument.

7.5 Glossary

Atmospheric Radiation
Blackbody
Broadband
Emittance
Infrared Radiation
Irradiance
Longwave Irradiance
Transmittance

Also see the ARM Glossary.

7.6 Acronyms

AHF: Automatic Hickey-Frieden. The model name for an absolute cavity radiometer manufactured by The Eppley Laboratory, Inc.

ARCS: Atmospheric Radiation and Cloud Station.

BORCAL: Broadband Outdoor Radiometer Calibration. The summation method of pyrgeometer calibration as performed at NREL and the SGP/RCF.

GNDRAD: Ground Radiation

NREL: National Renewable Energy Laboratory. One of the eight national laboratories operated for the US Department of Energy.

PIR: Precision Infrared Radiometer. The model name for the pyrgeometer manufactured by The Eppley Laboratory, Inc.

RCC: Radiometer Calibration and Characterization. The hardware and software implementation developed by NREL for automating a BORCAL.

RCF: Radiometer Calibration Facility. Located at the SGP Central Facility, the RCF is designed to perform calibrations of all broadband longwave and shortwave radiometers used by the ARM Program. Calibrations are traceable to international standards through the Metrology Laboratory and the Solar Radiation Research Laboratory at NREL.

SGP: Southern Great Plains.

Also see the ARM Acronyms and Abbreviations.

7.7 Citable References

Albrecht, B., M. Peollet, and S. Cox. 1977. Procedures for improving pyrgeometer performance. *J. of Applied Meteorology*, Vol. 16, p. 188-197.

McArthur L.J.B. 1998. *Baseline Surface Radiation Network (BSRN)*. Operations Manual, WMO/TD-No. 879, WCRP/WMO.

Payne, R.E., and S.P. Anderson. 1999. A new look at calibration and use of Eppley Precision Infrared Radiometers, Part II: Calibration and use of the Woods Hole Oceanographic Institution improved meteorology precision infrared radiometer. *J. of Atmospheric and Oceanic Technology*, Vol. 16, p. 741.

Reda, I., J.R. Hickey, T. Stoffel, and D. Myers. 2002. Pyrgeometer Calibration at the National Renewable Energy Laboratory (NREL). *J. of Atmospheric and Solar-Terrestrial Physics*, Vol. 64, p. 1623-1629. Pergamon Press.