ARM TR-025

Solar Infrared Radiation Station
Handbook

July 2005

Atmospheric Radiation Measurement
Climate Research Facility
U.S. Department of Energy

Work supported by the U.S. Department of Energy
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Solar Infrared Radiation Station (SIRS) Handbook

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1. General Overview

The Solar Infrared Radiation Station (SIRS) provides continuous measurements of broadband shortwave (solar) and longwave (atmospheric or infrared) irradiances for downwelling and upwelling components. The following six irradiance measurements are collected from a network of stations to help determine the total radiative flux exchange within the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Climate Research Facility:

- Direct normal shortwave (solar beam)
- Diffuse horizontal shortwave (sky)
- Global horizontal shortwave (total hemispheric)
- Upwelling shortwave (reflected)
- Downwelling longwave (atmospheric infrared)
- Upwelling longwave (surface infrared)

Note: Beginning in 2004, The SKYRAD and GNDRAD measurement systems used in the Tropical Western Pacific and North Slope of Alaska sites are indentical to those used by SIRS in the SGP. SKYRAD and GNDRAD provide all downwelling and upwelling irradiances respectively.

Commercially available thermopile-based radiometers and supporting equipment (i.e., solar tracker, radiometer ventilator, and data acquisition system) comprise each SIRS installation as shown in Figure 1.

Figure 1. SIRS radiometers for downwelling irradiance measurements. (Pete Gotseff from National Renewable Energy Laboratory [NREL] inspecting the unshaded ventilated pyranometer used to measure global horizontal shortwave irradiance.)

An equipment summary is provided in Table 1.

Table 1. SIRS Equipment Summary

Measurement	Radiometer Type*	Model**	Supporting Equipment
Direct Normal	Pyrheliometer	Normal Incidence Pyrheliometer (NIP)	Kipp & Zonen Model 2-AP automatic solar tracker
Diffuse Horizontal	Pyranometer	Precision Spectral Pyranometer (PSP) [Replaced by Model 8-48 (Black & White) after Feb 2000]	Kipp & Zonen Model 2-AP automatic solar tracker and Eppley Model V1 ventilator
Global Horizontal	Pyranometer	Precision Spectral Pyranometer (PSP)	Eppley Model V1 ventilator
Upwelling Shortwave	Pyranometer	Precision Spectral Pyranometer (PSP)	Custom stainless steel sun shade for inverted radiometer case and 10 m tower
Downwelling Longwave	Pyrgeometer	Precision Infrared Radiometer (PIR)	Kipp & Zonen Model 2-AP automatic solar tracker and Eppley Model V1 ventilator
Upwelling Longwave	Pyrgeometer	Precision Infrared Radiometer (PIR)	Custom stainless steel sun shade for inverted radiometer case and 10 m tower

* All radiometers manufactured by The Eppley Laboratory, Inc., Newport, Rhode Island USA
** Shortwave (solar) radiometer spectral responses are 295 nm – 3000 nm and longwave (infrared) radiometer spectral responses are 3.5 µm – 50 µm

The current SIRS instrument suite was preceeded as the ARM operational broadband instrument suite by the Solar and Infrared Radiation Observation Station (SIROS) instruments which included the Multi-Filter Rotating Shadowband Radiometer (MFRSR). The change to SIRS occurred in 1997-1998 as described in the Table 2 below.

Table 2. SIRS Locations in the SGP (24 Extended Facilites – EF)

Site	Elevation (m)	Lat./Long.	SIRS Operational Date[1]
Ashton, Kansas: EF-9	386	37.133 N / 97.266 W	2/6/98
Byron, Oklahoma: EF-11	360	36.881 N / 98.285 W	8/20/97
Coldwater, Kansas: EF-8	664	37.333 N / 99.309 W	8/19/97
Cordell, Oklahoma: EF-22	465	35.354 N / 98.977 W	11/24/97
Cyril, Oklahoma: EF-24	409	34.883 N / 98.205 W	11/25/97
Earlsboro, Oklahoma: EF-27	300	35.269 N / 96.740 W	5/02/02[2]
Elk Falls, Kansas: EF-7	283	37.383 N / 96.180 W	10/31/97
El Reno, Oklahoma: EF-19	421	35.557 N / 98.017 W	6/16/98
Halstead, Kansas: EF-5	440	38.114 N / 97.513 W	11/6/97
Hillsboro, Kansas: EF-2	447	38.305 N / 97.301 W	11/6/97
Lamont, Oklahoma: EF-13	318	36.605 N / 97.485 W	8/25/97
Lamont, Oklahoma: EF-14	315	36.607 N / 97.488 W	1/15/97[3]
Larned, Kansas: EF-1	632	38.202 N / 99.316 W	11/20/97

Table 2. (cont'd)			
LeRoy, Kansas: EF-3	338	38.201 N / 95.597 W	11/4/97
Meeker, Oklahoma: EF-20	309	35.564 N / 96.988 W	2/11/98
Morris, Oklahoma: EF-18	217	35.687 N / 95.856 W	9/30/97
Okmulgee, Oklahoma: EF-21	240	35.615 N / 96.065 W	7/22/99
Pawhuska, Oklahoma: EF-12	331	36.841 N / 96.427 W	10/29/97
Plevna, Kansas: EF-4	513	37.953 N / 98.329 W	11/7/97
Ringwood, Oklahoma: EF-15	418	36.431 N / 98.284 W	8/23/97
Seminole, Oklahoma: EF-25	277	35.245 N / 96.736 W	10/01/97
(Removed 4/8/02)			
Towanda, Kansas: EF-6	409	37.842 N / 97.020 W	11/05/97
Tyro, Kansas: EF-10	248	37.068 N / 95.788 W	10/30/97
Vici, Oklahoma: EF-16	602	36.061 N / 99.134 W	8/21/97

Notes:

1. Date of conversion from SIROS to SIRS data acquistion systems except as noted.
2. Earlsboro, Oklahoma site resumes data following system removal from Seminole site.
3. Data of installation for the "SIRS Testbed" at the Central Facility.

2. Contacts

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2.2 Instrument Developers

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3. Deployment Locations and History

Currently, there are 23 operational SIRS in the network of SGP EF as summarized in Table 2. The SIRS radiometers are the same as those originally used by the the SIROS instrument suite to measure the identical irradiance components as SIRS. The SIROS instruments included the MFRSR and shared the data acquistion system. The SIRS offered data acquisiton improvements which increased data recovery and eliminated the need for in-line amplifiers on each broadband radiometer.

As shown in Figure 2, the spatial distribution of the SIRS network dictates bi-weekly maintenance of the equipment at each of the EF except at the Central Facility in Grant County where daily maintenance is performed.

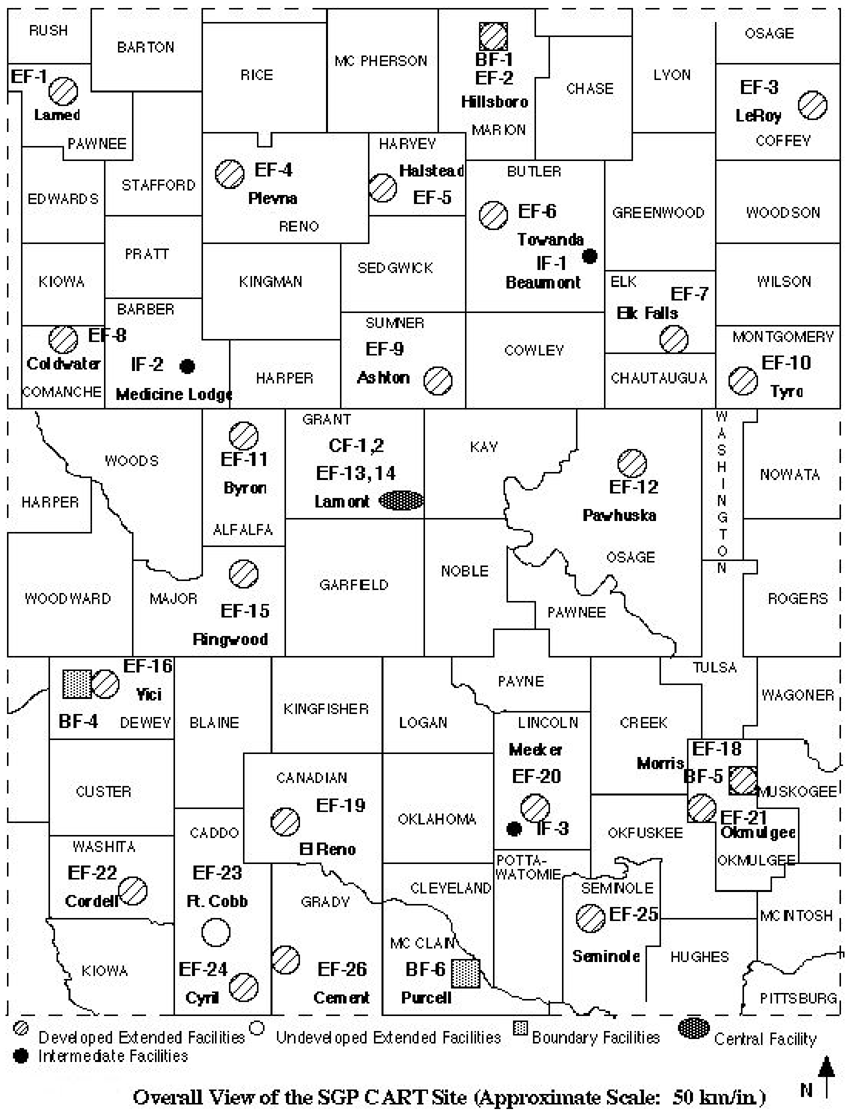

Figure 2. Measurement Facilities Map.

4. Near-Real-Time Data Plots

Daily Plots, from SGP Development System ?????????????????????

SGP Site Scientist Data Quality Assessment

General Quick Looks

5. Data Description and Examples

Typical SIRS Data Time-Series Plots

Irradiances measurements from the suite of six radiometers forming each SIRS is greatly influenced by the atmospheric conditions and ground cover. The examples given here represent the common range of shortwave (solar) and longwave (atmospheric) measurements encountered in the SGP.

Data in Figure 3 are typical of the clear-sky conditions at the SGP during the fall. Near solar noon, when the sun is highest in the sky and there is the least amount of atmosphere in the photons' path to the surface, the direct normal shortwave (beam) irradiance approaches 1000 Wm^{-2}, the global (total hemispheric) irradiance nears 800 Wm^{-2}, the diffuse (sky) irradiance remains nearly constant at about 50 Wm^{-2}, and the reflected shortwave reaches a peak of 155 Wm^{-2} (for a surface albedo, global/reflected, of about 19% which is typical for a vegetated surface). Heating of the surface and the atmosphere is evident from the increasing longwave (infrared) irradiance measurements. The peak longwave

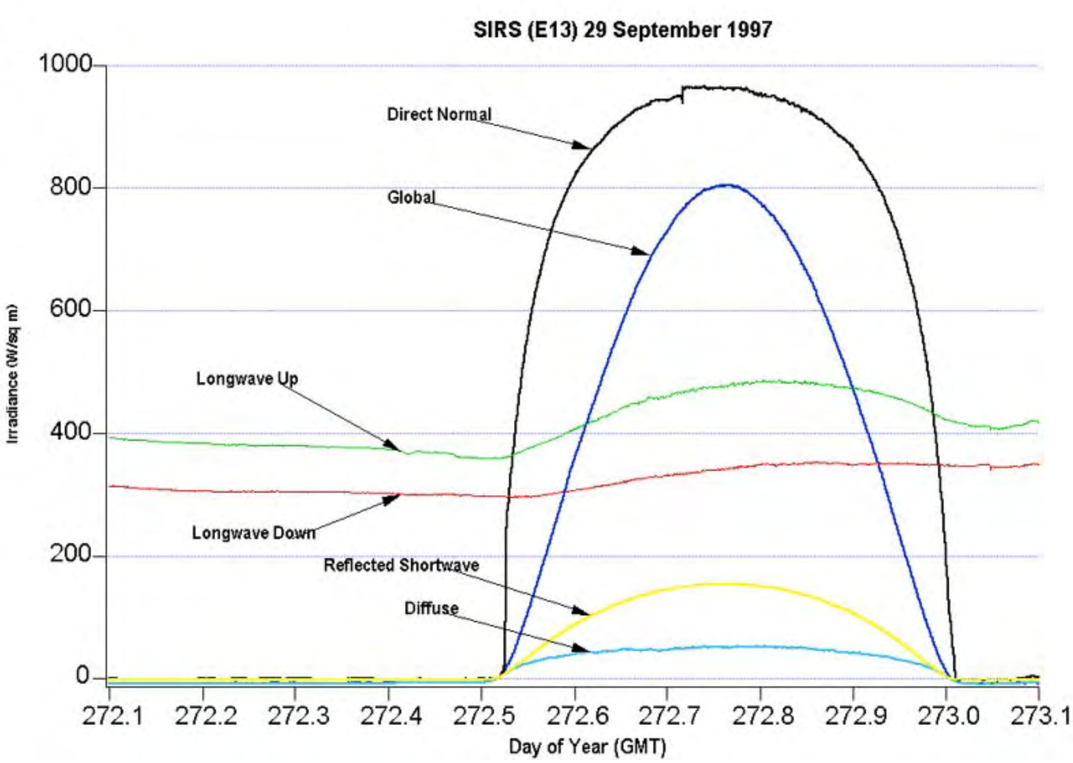

Figure 3. Clear-sky time-series plot of 1-minute SIRS measurements.

irradiances occur after solar noon, demonstrating the "thermal lag" of the earth-atmosphere system response to solar heating. The peak upwelling longwave irradiance on this day was 488 Wm^{-2} at 19:41 Greenwich Mean Time (GMT) (1:41 p.m. local standard time). The peak downwelling (atmospheric) longwave irradiance was 355 Wm^{-2} at about the same time, producing a net radiation of 133 Wm^{-2}. The effect of cleaning the pyrheliometer window is evident from the change in direct normal irradiance prior to local solar noon. Maintenance records show the pyrheliometer window was dry, but had light dust removed from the surface at 17:10 GMT. Comparing the direct normal data before and after the cleaning, 947.81 Wm^{-2} and 963.25 Wm^{-2} respectively, it suggests a decreased irradiance measurement of 1.6% due to the window contamination.

Data in Figure 4 are typical of cloudy sky conditions at the SGP during the fall. With completely overcast conditions, the direct normal shortwave (beam) irradiance remains near zero all day. Variable cloud thickness during the day allow the global (total hemispheric) and the diffuse (sky) irradiance to peak at about 256 Wm^{-2} at 18:20 GMT and a few hours later. The reflected shortwave reaches a peak of 45 Wm^{-2} (albedo of about 18%). The exchange of infrared radiation is nearly constant under these conditions, suggesting low clouds. The two SIRS pyrgeometers indicate 415 W^{-2} of longwave irradiance was consistently measured at the Central Facility on September 23, 1997.

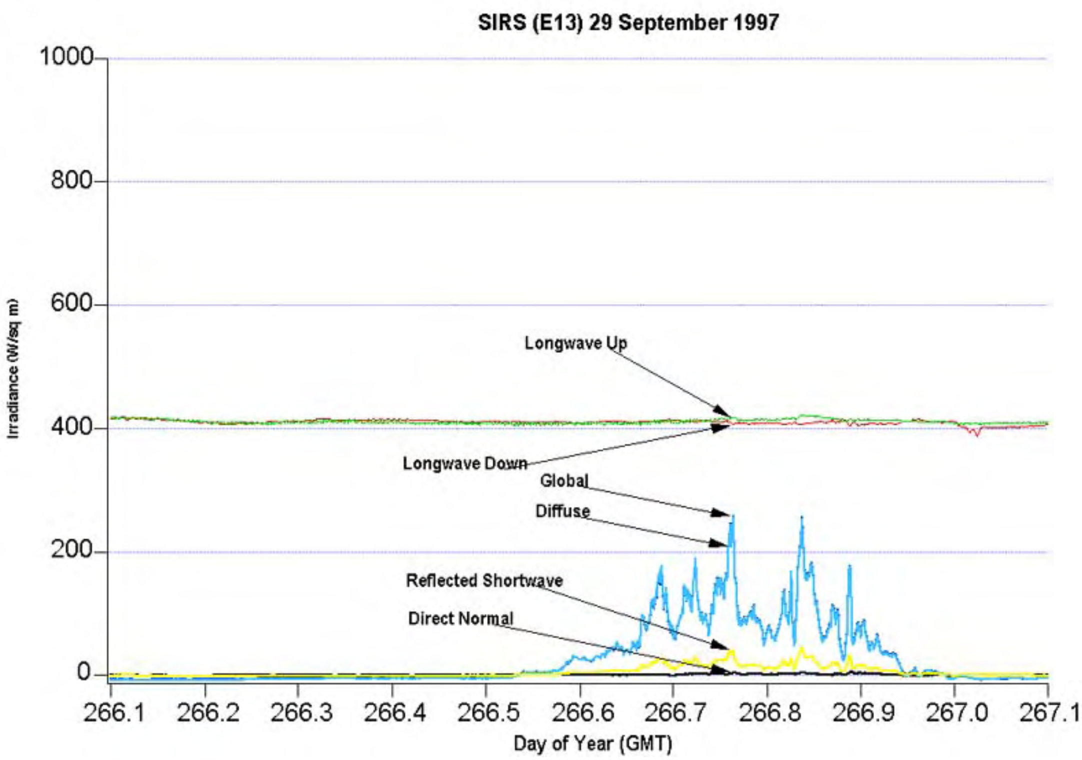

Figure 4. Overcast-sky time-series plot of 1-minute SIRS measurements.

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

The following *broadband* irradiance measurements are available from the SIRS platform:

DOWNWELLING SHORTWAVE (0.3 to 3.0 micrometers)

1. Direct Normal (beam) irradiance measured by a pyrheliometer with a 5.7 degree field of view.

2. Diffuse Horizontal (sky) irradiance measured by a shaded and ventilated pyranometer with a hemispherical field of view, but blocked from the direct normal irradiance by a tracking ball.

3. Total Hemispheric (global) irradiance measured by an unshaded and ventilated pyranometer.

DOWNWELLING LONGWAVE (4.0 to 50 micrometers)

4. Total Hemispheric (atmospheric) irradiance measured by a shaded and ventilated pyrgeometer with a hemispheric field of view.

UPWELLING SHORTWAVE (0.3 to 3.0 micrometers)

5. Reflected solar irradiance measured by an inverted pyranometer with a hemispheric field of view.

UPWELLING LONGWAVE (4.0 to 50 micrometers)

6. Irradiance measured by an inverted pyrgeometer with a hemispheric field of view.

Table 3. Primary Variables

Variable Name	Quantity Measured	Unit
short_direct_normal	Direct normal (beam) solar irradiance	Wm^{-2}
down_short_diffuse_hemisp	Diffuse horizontal (sky) solar irradiance	Wm^{-2}
down_short_hemisp	Total hemispheric (global) solar irradiance	Wm^{-2}
down_long_hemisp_shaded	Total hemispheric (atmospheric) infrared irradiance	Wm^{-2}
up_short_hemisp	Reflected solar irradiance	Wm^{-2}
up_long_hemisp	Upwelling longwave irradiance	Wm^{-2}

5.1.1.1 Definition of Uncertainty

All measurements are approximations and are incomplete without a quantitative uncertainty estimate. The *Guide to Measurement Uncertainty (GUM)* of the International Bureau of Weights and Measures (BIPM 1995) is the accepted international guide for performing a measurement uncertainty analysis. The GUM defines *Type A* uncertainty values as derived from statistical methods, and *Type B* sources as evaluated by “other means,” such as scientific judgment, experience, specifications, comparisons, or calibration data.

Each element of a measurement system contributes to the limits of uncertainty. When a result, R, is functionally dependent upon several variables, x_i, then the familiar propagation of error formula is used,

$$U^2 = \sum_i (\partial_{Xi} R \cdot e_{Xi})^2 \qquad \text{[eq. 1]}$$

where,

U	=	uncertainty in the resultant,
e_{xi}	=	estimated uncertainty in variable x_i, and
$\partial_{xi}R$	=	partial derivative of the response R with respect to variable $x_{i,}$ (also called the sensitivity function for variable x_i).

Radiometer measurement uncertainty analyses have historically treated sources of uncertainty in terms of "random" and "bias" components (Myers et al. 1989). Total uncertainty (U) was computed from:

$$U^2 = \Sigma\,(\text{Bias})^2 + \Sigma\,(2*\text{Random})^2 \qquad \text{[eq. 2]}$$

A factor of two was applied to the "random" or statistical uncertainty component, because this component usually represented a standard deviation. One standard deviation of a normal or Gaussian distribution encompasses only 37% of the measured values, and two standard deviations encompasses approximately 95% of the measured values. Thus, this method was considered to report uncertainty with a 95% "confidence interval." For example, the resulting uncertainty in the *calibration* of pyranometer responsivity and *field measurements* was ±2.4%, and ±5%, respectively.

The GUM replaces the factor of two with a "coverage factor," *k*, and determines the uncertainty from:

$$U^2 = \Sigma\,(\text{Type B})^2 + \Sigma\,(k*\ \text{Type A})^2. \qquad \text{[eq. 3]}$$

For small (n < 20) samples, from a Gaussian distribution of measurements, *k* may be selected from the student's t-distribution (Taylor and Kuyatt 1993) and U is the "Expanded Uncertainty" where *k* is usually in the range of 2 to 3, for confidence intervals of 95% and 99%, respectively. The following estimates of measurement uncertainty follow the GUM approach.

Estimating radiometer measurement uncertainties is a topic of continuing research. Based on experiences with these and similar instruments for renewable energy applications, the following estimated measurement uncertainties conservatively apply to SIRS measurements.

Table 4. Estimated Measurement Uncertainy of SIRS Irradiance Measurements

Measurement	Abbreviation	Radiometer Model	Typical Responsivity (μV/Wm^{-2})	Estimated Measurement Uncertainty*
Direct Normal (beam)	DNI	NIP	8.0	±3.0% or 4 Wm^{-2}
Diffuse Horizontal (sky)	DD	PSP	9.0	±6.0% or 20 Wm^{-2}
Downwelling Shortwave (global)	DS	PSP	9.0	±6.0% or 10 Wm^{-2}
Downwelling Longwave (atmospheric)	DIR	PIR	4.0	±2.5% or 4 Wm^{-2}
Upwelling Shortwave (reflected)	US	PSP	9.0	±6.0% or 15 Wm^{-2}
Upwelling Longwave (terrestrial)	UIR	PIR	4.0	±2.5% or 4 Wm^{-2}

*Field measurement uncertainties include the uncertainties associated with radiometer calibration and measurement system installation, operation and maintenance. Two standard deviations (95% coverage) were used to account for the random components of the total uncertainty estimates.

5.1.2 Secondary/Underlying Variables

Table 5. Secondary Variables

Variable Name	Quantity Measured	Unit
short_direct_normal_std	Direct Normal (Beam) Solar Irradiance, Standard Deviation	Wm^{-2}
short_direct_normal_max	Direct Normal (Beam) Solar Irradiance Maxima	Wm^{-2}
short_direct_normal_min	Direct Normal (Beam) Solar Irradiance Minima	Wm^{-2}
down_short_diffuse_hemisp_std	Diffuse Horizontal (Sky) Solar Irradiance, Standard Deviation	Wm^{-2}
down_short_diffuse_hemisp_max	Diffuse Horizontal (Sky) Solar Irradiance Maxima	Wm^{-2}
down_short_diffuse_hemisp_min	Diffuse Horizontal (Sky) Solar Irradiance Minima	Wm^{-2}
down_short_hemisp_std	Total Hemispheric (Global) Solar Irradiance, Standard Deviation	Wm^{-2}
down_short_hemisp_max	Total Hemispheric (Global) Solar Irradiance Maxima	Wm^{-2}
down_short_hemisp_min	Total Hemispheric (Global) Solar Irradiance Minima	Wm^{-2}
down_long_hemisp_shaded_std	Total Hemispheric (Atmospheric) Infrared Irradiance, Standard Deviation	Wm^{-2}
down_long_hemisp_shaded_max	Total Hemispheric (Atmospheric) Infrared Irradiance Maxima	Wm^{-2}
down_long_hemisp_shaded_min	Total Hemispheric (Atmospheric) Infrared Irradiance Minima	Wm^{-2}
up_short_hemisp_std	Reflected Solar Irradiance, Standard Deviation	Wm^{-2}
up_short_hemisp_max	Reflected Solar Irradiance Maxima	Wm^{-2}
up_short_hemisp_min	Reflected Solar Irradiance Minima	Wm^{-2}
up_long_hemisp_std	Upwelling longwave irradiance, Standard Deviation	Wm^{-2}
up_long_hemisp_max	Upwelling longwave irradiance, Maxima	Wm^{-2}
up_long_hemisp_min	Upwelling longwave irradiance, Minima	Wm^{-2}

????? Add thermistors ???????

5.1.3 Diagnostic Variables

The battery voltage is recorded at 1-minute intervals to confirm adequate electrical power was available to the Campbell Scientific, Inc. data logger. Nominally 13 Vdc, the acceptable minimum voltage is approximately 10 Vdc to assure proper operation (especially regulated excitation voltage need for thermistor measurements).

5.1.4 Data Quality Flags

Each 1-minute irradiance value is assigned a two-digit data quality flag (00 – 99) based on the results of automated assessments developed by the National Renewable Energy Laboratory (NREL). Shortwave irradiance tests are based on the *SERI-QC* process developed by the Solar Energy Research Institute – SERI (now NREL). A description of this automated quality assessment tool can be found at the NREL Renewable Resource Data Center.

The ARM Program has incorporated the *SERI-QC* concepts and upgraded the automated capabilities to include the upwelling shortwave and all longwave irradiances thereby addressing each of the SIRS data elements. Information about the resulting *Data Quality Management System Version 3*.0 *(DQMS-3)* can be found at http://www.dqms.com/dqmspart.htm.

Additional elements of DQMS-*3* are used for assessing SIRS data quality and providing the means for correcting known instrumentation responses:

1. *DQMS-3* converts 1-minute broadband shortwave irradiance data from flux densities in Watts per square meter to non-dimensional units normalized to the coincident extraterrestrial (exoatmospheric) values:

   K_T = Total Hemispheric / Extraterrestrial = DS / ETR

   K_N = Direct Normal / Extraterrestrial Normal = DNI / ETRN

   K_D = Downwelling Diffuse / Extraterrestrial = DD / ETR

   Resulting in the relationship among the three measured shortwave components:

$$K_T = K_N + K_D \qquad \text{[eq. 4]}$$

Failing the above "3-component" test, pairs of irradiance data can be evaluated using the transformation.

When presented in K-Space, the data can be evaluated based on acceptable limits determined by physical limits, internal consistency, and careful inspection of historical data.

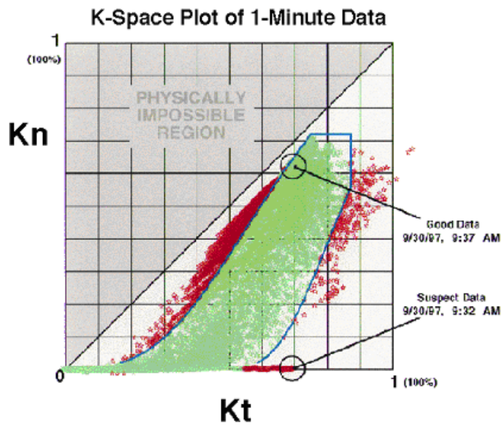

Figure 5. Typical acceptable bounds of Normalized Total Hemispheric and Direct Normal irradiance.

DQMS-3 assigns a two-digit quality flag to each irradiance data element based on the location in the appropriate K-Space coordinates.

Table 6. *DQMS-3* Flagging Convention (based on *SERI_QC* methodology).

Flag	Description
00	Untested (raw data)
01	Passed one-component test; data fall within max-min limits of Kt, Kn, or Kd
02	Passed two-component test; data fall within 0.03 of the Gompertz boundaries
03	Passed three-component test; data come within ±0.03 of satisfying Kt=Kn+Kd
04	Passed visual inspection; *not used* by SERI_QC
05	Failed visual inspection; *not used* by SERI_QC
06	Value estimated; passes all pertinent SERI_QC tests
07	Failed one-component test; lower than allowed minimum
08	Failed one-component test; higher than allowed maximum
09	Passed three-component test but failed two-component test by > 0.05 (K-units)
10-93	Failed two- or three-component tests in one of four ways. To determine the test failed and the manner of failure (high or low), examine the remainder of the calculation (flag + 2) / 4. Rem Failure: 0 Parameter too low by three-component test (Kt = Kn + Kd) 1 Parameter too high by three-component test (Kt = Kn + Kd) 2 Parameter too low by two-component test (Gompertz boundary) 3 Parameter too high by two component test (Gompertz boundary) The magnitude of the test failure (distance in K-units) is determined from: D = INT ((flag + 2) / 4) / 100.
94-97	Data fall into a physically impossible region where Kn > Kt by K-space distances of 0.05 to 0.10 (94), 0.10 to 0.15 (95), 0.15 to 0.20 (96), and ≥0.20 (97)
98	Not used
99	Missing data

More detailed information about *SERI-QC* is available from the Renewable Resource Data Center: http://rredc.nrel.gov.

Additional information may also be found at 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

Incorrect Metadata

When SIRS radiometers are changed for recalibration or other reasons, the site operators immediately enter the new serial numbers and calibrations in to the Campbell Scientific, Inc., dataloggers (CDLs) dedicated to the SIRS. If this is done properly, the values for the observed geophysical parameters immediately have the correct calibration coefficients applied. These values are ingested in the 60-s data and no further processing is necessary to produce the estimates in geophysical units with correct calibrations. The 20-s data consist of raw values and are not affected by the choice of calibration coefficients or serial numbers. However, the metadata for the 60-s data are not updated with the new calibration coefficients and serial numbers until a special file produced daily near midnight GMT by the CDL are read at that time by the site data system. Hence, it is possible that up to nearly 24 hours of partially incorrect metadata will be generated. This problem could be overcome by a procedure of turning off the data ingest and correcting it whenever the sensors are replaced. All SIRS data collected to date have this problem, because such a procedure has not been implemented. The amount of time and effort to take such actions does not seem to be justified for this fairly minor source of misinformation. Additionally, the information needed to account for this discrepancy can be found by the interested data user on the Operations Management Information System (OMIS) site (http://??????????????????).

On Time Formats and Values of Downward Shortwave Hemispheric Radiation (P011004.2)

All SIRS data are recorded in Universal Time Corrindates (UTC). This means local sunset will occur after 24:00 UTC in the summer as can be found, for example, in the data file sgpsirsC1.a1.20000601.000000.cdf. The large positive values are valid for the afternoon period. The negative values after sunset (and throughout the night, depending on the cloud cover) are typical of single-black thermopile detectors used in the SIRS network (see Dutton, EG et al., “Measurement of Broadband Diffuse Solar Irradiance Using Current Commercial Instrumentation with a Correction for Thermal Offset Errors.” Journal of Atmospheric and Oceanic Technology, Vol 18, March 2001, pages 297-306.) Prior to the use of Eppley Laboratory, Inc. Model 8-48 in February 2001, the diffuse shortwave and, to a lesser extent, the global irradiance can be corrected for thermal offsets. In any event, I would treat the small (<15 Watts per sq meter) nighttime shortwave irradiances as "0.0" when computing the daily total irradiation values. We have programmed the Campbell Scientific, Inc. Model CR10X data loggers to output the measurements using the convention where midnight is recorded as 00:00:00 and the date reflects the start of a new 24 hour day. In Campbell-ese, the 4-digit code for "Time Options" is 1110 for the SIRS program. SIRS 1-minute data for a particular date is then recorded from 00:00 to 23:59. For example, the data recorded for 10:05 are the averages, minima, maxima, and standard deviations of the 2-second samples beginning 10:04:02 and ending 10:05:00.

Pyranometer Thermal Offsets

Broadband downwelling shortwave diffuse (sky) irradiance measurements available from SIRS prior to February 22, 2001 may require adjustment for thermal offsets. After this date, all SIRS were providing diffuse irradiance data as measured with an Eppley Laboratory, Inc., Model 8-48 (black and white) pyranometer. The operational date of each SIRS in 1997/98 and the date and time of Model 8-48 installation in February 2001 can be found in Table 3.

As described in the above Description of Observational Specifications, these thermal, or "zero" offsets refer to the generally reduced output signals from a shaded pyranometer due to the exchange of longwave (infrared) irradiance between the single black thermopile detector, the protective glass domes surrounding the detector, and the atmosphere. Originally considered an acceptable nighttime response of thermopile-type pyranometers, the generally negative bias is now recognized to significantly effect the accuracy of SIRS diffuse irradiance data during daylight periods.

Studies of the Eppley Laboratory, Inc. Model Precision Spectral Pyranometer (PSP), used for the SIRS measurements of diffuse irradiance, suggest the thermal offset correction can range from near 0, to as much as 30 Watts per square meter, depending on the coincident net longwave, or infrared irradiance (1, 2). Under very clear-sky conditions, the diffuse irradiance from a shaded PSP can be less than the minimum physical limit defined by radiative transfer model estimates based only on Rayleigh scattering effects.

A correction method has been developed for adjusting SIRS diffuse irradiance data [3]. The resulting Value Added Product (VAP) will be applied to SIRS data for the period of this Data Quality Report (DQR). The VAP will not be applied to SIROS data collected before the instrument platform was converted to SIRS.

Additionally, the Model PSP radiometer has been replaced by a Model 8-48 which uses a black and white thermopile detector known to reduce the thermal offset errors to less than 2 Watts per square meter [3]. The radiometer replacement at this SIRS location was completed on the date shown in Table 7.

Table 7. SIRS Upgrade: Model 8-48 Pyranometer Installation for Diffuse Irradiance, 4-19-01, Tom Stoffel[1].

Site	SIROS to SIRS[2]	Model 8-48 Installation	Data Logger "OFF" (GMT)[3]	Returned to Service (GMT)[4]
C1	01-15-97	02-22-01	20:50	21:00
E1	11-20-97	02-13-01	20:15	20:25
E2	11-06-97	02-15-01	15:47	16:02

Table 7. (contd)				
E3	11-04-97	02-14-01	19:30	19:50
E4	11-07-97	02-14-01	15:10	16:06
E5	11-06-97	02-14-01	19:45	20:03
E6	11-05-97	02-15-01	15:30	15:50
E7	10-31-97	02-13-01	19:25	19:45
E8	08-19-97	02-13-01	18:15	18:41
E9	02-06-98	02-13-01	15:40	16:00
E10	10-30-97	02-14-01	15:00	15:10
E11	08-20-97	02-20-01	20:40	21:05
E12	10-29-97	02-20-01	16:55	17:15
E13	08-25-97	02-22-01	20:21	20:35
E15	08-23-97	02-20-01	17:30	17:40
E16	08-21-97	02-21-01	16:20	16:50
E18	09-30-97	02-20-01	22:20	22:40
E19	06-16-98	02-22-01	15:35	15:48
E20	02-11-98	02-20-01	18:50	19:10
E21	07/22/99	02-20-01	21:00	21:35
E22	11-24-97	02-21-01	20:00	20:20
E24	11-25-97	02-22-01	16:15	16:35
E25	10-01-97	02-21-01	16:00	16:15

1 Information provided by Dan Nelson 2 Mar 99 and revised by Bev Kay 11 Apr 01 using OMIS.
2 Date SIRS was fully operational (Assume 00:00 GMT).
3 Ending time for DQR describing shaded PSP thermal offset remains uncorrected.
4 Time of data collection beginning with a new shaded Model 8-48 for Downwelling Diffuse (DD).

References:

Cess, R. D., X. Jing, T. Qian, and M. Sun. 1999. Validation Strategies Applied to the Measurement of Total, Direct and Diffuse Shortwave Radiation at the Surface. *J. Geophys. Res*.

Dutton, E.G., J.J. Michalsky, T. Stoffel, B.W. Forgan, J. Hickey, D.W. Nelson, T.L. Alberta, and I. Reda. 2001. Measurement of Broadband Diffuse Solar Irradiance Using Current Commercial Instrumentation with a Correction for Thermal Offset Errors. *J. Atmospheric & Oceanic Technology*, Vol. 18, No. 3, pp. 297-314.

Gulbrandsen, A. 1978. On the Use of Pyranometers in the Study of Spectral Solar Radiation and Atmospheric Aerosols. *J. Appl. Meteorol*., 17, 899-904.

5.4 Frequently Asked Questions

This section is not applicable to this instrument.

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 VAPs. Despite extensive instrumentation deployed at the ARM Cloud and Radiation Testbed 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

The following radiometers manufactured by The Eppley Laboratory, Inc., in Table 8 re used at each SIRS.

Table 8.				
Measurement	**Radiometer Model**	**Mounting Arrangement**	**Typical Responsivity ($\mu V/Wm^{-2}$)**	**Typical Calibration Uncertainty***
Direct Normal	NIP	Solar Tracker	8.0	±2.5% or 2 Wm^{-2}
Diffuse Horizontal	PSP	Shaded & Ventilated	9.0	±3.0% or 10 Wm^{-2}
Downwelling Shortwave	PSP	Unshaded & Ventilated	9.0	±3.0% or 10 Wm^{-2}
Downwelling Longwave	PIR	Shaded & Ventilated	4.0	±2% or 2 Wm^{-2}
Upwelling Shortwave	PSP	Inverted w/o ventilation	9.0	±3.0% or 10 Wm^{-2}
Upwelling Longwave	PIR	Inverted w/o ventilation	4.0	±2% or 2 Wm^{-2}
*Field measurement uncertainties are larger and include the uncertainties associated with instrument calibration, installation, operation and maintenance.				

Additional information is available from http://www.nrel.gov/srrl/.

7.1.2 System Configuration and Measurement Methods

Depending on the irradiance measurement, SIRS radiometers are mounted on either an automatic solar tracker or a stationary surface. The following abbreviations are used to describe the SIRS instrumentation and their relative locations shown in Figure 5:

DNI = Direct Normal (beam) Shortwave Irradiance
DD = Downwelling Diffuse (sky) Shortwave Irradiance
DS = Downwelling Total Hemispheric (global) Shortwave Irradiance
DIR = Downwelling Infrared (atmospheric) Irradiance
US = Upwelling Shortwave (reflected) Irradiance
UIR = Upwelling Infrared (terrestrial) Irradiance.

The data acquisition system is a Campbell Scientific, Inc. Model CR10X-1M with AM416 Multiplexer, 4 Mb memory card, and modem. These components are inside a weather-resistant enclosure mounted above ground. The system is designed to operate over the full range of environmental conditions anticipated for the network of SIRS stations (see http://www.campbellsci.com for detailed measurement and environmental specifications).

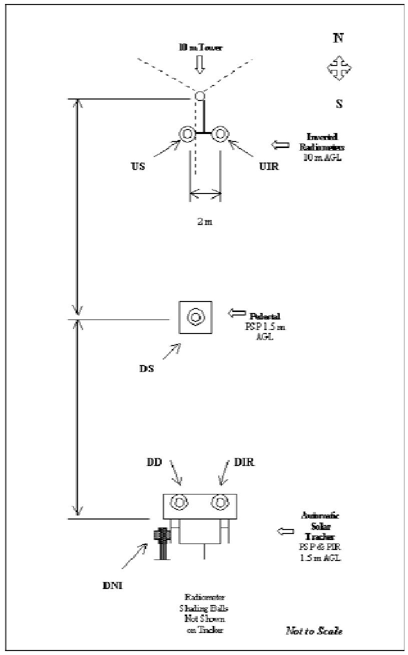

Figure 6. Plan View of SIRS Instrument Locations

The system is programmed to sample ten inputs listed below every 2-seconds and output the average, standard deviation, minimum, and maximum values of the six geophysical elements, described above, at the end of each minute. Appended to each 1-minute data output record are the instantaneous values sampled at 20 seconds, 40 seconds, and 60 seconds within the 1-minute interval. These “instantaneous” data actually require 0.272 milliseconds to complete the analog to digital conversion of each measurement. Additionally, at 23:59:02 each day, the instrument serial numbers and calibration factors used by the data logger program are appended to the last record of the day. The system is designed to store up to two weeks of measured data and statistics, but the data are generally collected by telephone modem every 3-hours. Data stored on the 4 Mb memory card at each station are physically removed as part of the routine SIRS maintenance every two weeks and made available to the SGP Data System.

Measurements collected by the CR10X-1M logger are listed below with a sample data record for reference. All data files are reformatted in NETcdf for distribution.

Measurement Dictionary

1. DSTp = DS unshaded pyranometer thermopile output voltage (mV)
2. USTp = US inverted pyranometer thermopile output voltage (mV)
3. DDTp = DD shaded pyranometer thermopile output voltage (mV)
4. DNITp = DNI pyrheliometer thermopile output voltage (mV)
5. DIRTp = DIR pyrgeometer thermopile output voltage (mV)
6. DIRCr = DIR pyrgeometer case thermistor resistance (Kohm)
7. DIRDr = DIR pyrgeometer dome thermistor resistance (Kohm)
8. UIRTp = UIR pyrgeometer thermopile output voltage (mV)
9. UIRCr = UIR pyrgeometer case thermistor resistance (Kohm)
10. UIRDr = UIR pyrgeometer dome thermistor resistance (Kohm)

Excerpts from SIRS data file for 28 April 1997

Typical 60-sec output record:

Note: For improved readability, a space has been added after each comma in the original CSV Campbell data logger output file.

199, 1997, 108, 1831, 459.01, 344.61, 204.24, 186.11, 738.7, 839.92, 1.363, .74, .755, 1.302, 10.25, 9.06, 462.3, 345.6, 205.9, 189.1, 758, 857, 456.8, 342.4, 203.2, 184.5, 722, 825, 9.8011, 9.9781, 9.0405, 8.7893, .08167, -.52838, 1.9969, 1.7249, 6.3005, 7.1103, 9.8011, 9.9781, 9.0599, 8.7893, .08034, -.52738, 1.9874, 1.7117, 6.2098, 7.059, 9.8012, 9.9585, 9.0212, 8.7894, .09334, -.51988, 1.9829, 1.7183, 6.3546, 7.1512, 13.14

Penultimate 60-sec output record of the day has **last valid irradiance data**:

199, 1997, 108, 2359, 423.04, 330.79, 77.44, 61.688, 541.83, 181.26, .661, .626, .525, 2.231, 25.03, 5.988, 424, 332.2, 78.3, 64.46, 569.2, 188.3, 421.9, 329.9, 76.5, 57.16, 488.7, 169.1, 10.492, 10.592, 9.5264, 9.2535, -.04884, -.54438, .75906, .58593, 4.773, 1.5735, 10.492, 10.592, 9.5068, 9.2535, -.05017, -.54472, .75307, .56289, 4.5574, 1.5175, 10.492, 10.592, 9.5068, 9.2535, -.0505, -.54305, .74609, .52833, 4.1591, 1.4303, 13.16

Last 60-sec output record of the day has instrument serial numbers and calibration factors:

(Note: All measurement elements are invalid due to timing restriction.)

199, 1997, 108, 2359, 397.49, 315.72, 72.17, 65.84, 321.97, 272.75, 40.17, 19.63, 95.1, 76.1, 352.5, 335.9, 471.3, 393.9, 400.8, 215.2, 948, 980, 350.3, 291.2, -7.88, -1.427, -4.451, -6.624, 10.492, 10.592, 9.5264, 9.2535, -.04884, -.54438, .75906, .58593, 4.773, 1.5735, 10.492, 10.592, 9.5068, 9.2535, -.05017, -.54472, .75307, .56289, 4.5574, 1.5175, 10.492, 10.592, 9.5068, 9.2535, -.0505, -.54305, .74609, .52833, 4.1591, 1.4303, 13.16, 30783, 245.7, 30696, 268.82, 29618, 102.5, 30802, 108.19, 29737, 117.51, 30891, 118.2

				Range	
Pos	**Element**	**Value**	**Units**	**Min**	**Max**
01	Site Identifier	199	n/a	1	511
02	Year	1997	Years	1997	2052
03	Day of Year	145	n/a	1	366
04	Time (hh:mm)	1345	UTC	0	2359
	----Begin 60-sec Averages of 2-sec samples for the time ending above----				
05	UIR	459.01	W/sq m	100	800
06	DIR	344.61	W/sq m	50	800
07	DD	204.24	W/sq m	-10	600
08	US	186.11	W/sq m	-10	1100
09	DNI	738.7	W/sq m	-10	1100
10	DS	839.92	W/sq m	-10	1400

---Begin 60-sec Standard Deviations of 2-sec samples for the time ending above----

11	UIR	1.363	W/sq m	0	600
12	DIR	0.74	W/sq m	0	600
13	DD	0.755	W/sq m	0	500
14	US	1.302	W/sq m	0	400
15	DNI	10.25	W/sq m	0	1000
16	DS	9.06	W/sq m	0	1000

---Begin 60-sec Maxima of 2-sec samples for the time ending above----

17	UIR	462.3	W/sq m	100	800
18	DIR	345.6	W/sq m	50	800
19	DD	205.9	W/sq m	-10	600
20	US	189.1	W/sq m	-10	1100
21	DNI	758	W/sq m	-10	1100
22	DS	857	W/sq m	-10	1400

---Begin 60-sec Minima of 2-sec samples for the time ending above----

23	DIR	456.8	W/sq m	100	800
24	UIR	342.4	W/sq m	50	800
25	DD	203.2	W/sq m	-10	600
26	US	184.5	W/sq m	-10	1100
27	DNI	722	W/sq m	-10	1100
28	DS	825	W/sq m	-10	1400

----Begin 20-sec Instantaneous samples for 20-sec into the time ending above----

29	UIRDr	9.8011	KOhms		
30	UIRCr	9.9781	KOhms		
31	DIRDr	9.0405	KOhms		
32	DIRCr	8.7893	KOhms		
33	UIRTp	.08167	mv	-0.2	7.5
34	DIRTp	-.52838	mv	-0.2	7.5
35	DDTp	1.9969	mv	-0.2	15.0
36	USTp	1.7249	mv	-0.2	15.0
37	DNITp	6.3005	mv	-0.2	15.0
38	DSTp	7.1103	mv	-0.2	15.0

----Begin 20-sec Instantaneous samples for 40-sec into the time ending above----

39	UIRDr	9.8011	:
40	UIRCr	9.9781	:
41	DIRDr	9.0599	: << as above for 20-sec interval >>
42	DIRCr	8.7893	:
43	UIRTp	.08340	:
44	DIRTp	-.52738	:
45	DDTp	1.9874	:
46	USTp	1.7117	:
47	DNITp	6.2098	:
48	DSTp	7.059	:

----Begin 20-sec Instantaneous samples for 60-sec into the time ending above----

49	UIRDr	9.8012	:	
50	UIRCr	9.9585	:	
51	DIRDr	9.0212	:	
52	DIRCr	8.7894	: <<as above for 40-sec interval>>	
53	UIRTp	0.09334	:	
54	DIRTp	-.51988	:	
55	DDTp	1.9829	:	
56	USTp	1.7183	:	
57	DNITp	6.3546	:	
58	DSTp	7.1512	:	
59	BATT	13.14	V	9.2 14.0

Once daily at 23:59:02 the radiometer serial numbers and calibration factors are output AFTER a bogus (insufficient sample size) record as above for positions 1-59.

60	UIR Serial No.	30783	“F3” implied
61	UIR Calibration Factor	245.7	W/sq m per mv
62	DIR Serial No.	30696	“F3” implied
63	DIR Calibration Factor	268.82	W/sq m per mv
64	DD Serial No.	29618	“F3” implied
65	DD Calibration Factor	102.5	W/sq m per mv
66	US Serial No.	30802	“F3” implied
67	US Calibration Factor	108.19	W/sq m per mv
68	DNI S/N	29737	“E6” implied
69	DNI Calibration Factor	117.51	W/sq m per mv
70	DS S/N	30891	“F3” implied
71	DS Calibration Factor	118.2	W/sq m per mv

Note: All PIR and PSP serial numbers are “xxxxx.F3.” All NIP s/n are “xxxxx.E6”

Reconstructing the 1-Minute Averages from Three 20-Second Samples

Use the average of the three samples for each of the elements described below to compute an average irradiance (W/sq m). The data acquisition system program uses these same procedures to compute the 1-minute statistics from the 2-second scans.

1. Global
   DS = DSTp (mV) * DS Cal Factor (W/sq m per mV)

2. Upwelling Shortwave
   US = USTp (mV) * US Calibration Factor (W/sq m per mV)

3. Diffuse
   DD = DDTp (mV) * DD Calibration Factor (W/sq m per mV)

4. Direct Normal
   DNI = DNITp (mV) * DNI Calibration Factor (W/sq m per mV)

5. Down / Upwelling Infrared (DIR or UIR)

   Step 1. Compute Temperature (K) from thermistor resistance (KOhm)

   $T = 1 / [A + BX + CX^3]$
   where,

   T = Temperature (K)
   A = 10.425E-04
   B = 2.37E-04
   C = 1.64E-03
   X = 5 * Ln(10) + Ln(R/100), and R = Resistance (KOhm)

   Step 2. Compute Irradiance from PIR Temperatures (K) and Thermopile Voltages (mV)

   $Irrad = T_p * C1 + Sig * T_c^4 - C2 * Sig *(T_d^4 - T_c^4)$
   where,

   Irrad = Irradiance (W/sq m)
   T_p = PIR thermopile voltage (mV)
   T_c = PIR case temperature (K)
   T_d = PIR dome temperature (K)
   C1 = PIR Calibration Factor (W/sq m per mV)
   C2 = PIR Dome Correction Factor (4.0 = default for all PIRs)
   Sig = Stephan-Boltzman Constant = 5.67E-08 $W/m^2 K^4$)

7.1.3 Specifications

Selected theoretical measurement parameters of the SIRS radiometers are listed below in Table 9.

Table 9.

Measurement	Radiometer Field of View	Wavelength Range (microns)	Minimum Irradiance (Wm^{-2})	Maximum Irradiance (Wm^{-2})
Direct Normal (beam) [DNI]	5.7°	0.3 to 3.0	0.0	1100
Diffuse Horizontal (sky) [DD]	2π sr	0.3 to 3.0	0.0	600
Downwelling Shortwave (global) [DS]	2π sr	0.3 to 3.0	0.0	1400
Downwelling Longwave (atmospheric) [DIR]	2π sr	4.0 to 50	50	800
Upwelling Shortwave (reflected) [US]	2π sr	0.3 to 3.0	0.0	1100
Upwelling Longwave (terrestrial) [UIR]	2π sr	4.0 to 50	100	800

Field of View and Angular Response

The SIRS pyrheliometer (Eppley Laboratory, Inc. Model NIP) field of view was designed to meet the World Meteorological Organization's (WMO) design requirements circa 1960. Without the scattering effects of a clear atmosphere, the solar disc would appear to be about 0.5° at the earth's surface. The NIP geometry allows for solar tracker alignment tolerances possible at the time of the WMO specification and includes, therefore, an amount of circumsolar (forward scatter) radiation.

The SIRS pyranometers (Eppley Laboratory, Inc. Model PSP) have unique angular response characteristics that can be determined and verified with calibration (see separate section). The angular response of the pyranometer is a major contributor to the estimated measurement uncertainty for the various shortwave irradiance elements.

Spectral Response

The spectral response of the SIRS radiometers listed above are nominal values. The precise values vary with instrument model. Figures 2 & 3??

<<Insert John's Spectral Response Plot here>>

Thermal Offsets

Shortwave radiometers should produce a null signal in the absence of solar radiation. However, all commercially available pyranometers based on thermoelectric transducers, exhibit a non-zero output signal in the absence of solar radiation. These signals are believed to be a result of thermal gradients within the pyranometer.

The Eppley Laboratory, Inc. Model PSP is a thermoelectric, single-black detector design with well-established performance characteristics (Thekaekara 1972, Hulstrom 1989, McCluney 1994). As shown in Figure 4, the two Schott Glass hemispheres protect the thermopile detector from the weather. These inner and outer domes are used to also reduce the thermal exchange between the detector, or thermopile "hot" junction, and the environment. The body of the instrument is a relatively massive bronze casting that is used to control the "cold" or reference junction of the thermopile. Recent studies of this and other models of pyranometers suggest thermal offsets are producing as much as 30 Wm^{-2} during clear-sky, nighttime conditions. Similarly, daytime measurements of downwelling diffuse shortwave irradiance must be corrected for thermal offsets. ARM will use a correction method based on correlations with the net infrared and observed diffuse irradiances [Dutton, et al 2001].

7.2 Theory of Operation

Shortwave Irradiance

Three pyranometers are positioned to measure the hemispheric irradiance fields:

- DS Unshaded, ventilated, and mounted in horizontal orientation
- US Inverted, unventilated and mounted 10 m above the ground level
- DD Shaded, ventilated, and mounted on automatic solar tracker in horizontal orientation.

A single pyrheliometer is mounted on an automatic solar tracker and aligned to the sun's disc.

The following relationships are expected from the SIRS measurement system for the various broadband shortwave irradiance elements.

$$DS = DNI * Cos(Z) + DD$$

$$US = DS * \rho$$

$$DS \leq ETR$$

$$DNI \leq ETRN$$

where,

DS = Downwelling Hemispheric Shortwave (Global) Irradiance
DNI = Direct Normal Shortwave (Beam) Irradiance
Z = Solar Zenith Angle (sunrise/sunset = 90°)
DD = Downwelling Diffuse Shortwave (sky) Irradiance
US = Upwelling Diffuse Shortwave (reflected) Irradiance
ρ = Surface Shortwave Albedo (typically 0.2 for vegetation, 0.8 for fresh snow)
ETR = Extraterrestrial (exo-atmospheric) Radiation on horizontal surface
ETRN = Extraterrestrial Radiation Normal (beam) to the sun (1366 ±5 Wm^{-2} [REF??]).

Longwave Irradiance

Elements of the pyrgeometer measurements are used to compute the infrared:

$$IR = T_{tp} * C_1 + \sigma T_C^4 - C_2 \sigma (T_d^4 - T_c^4)$$

where,

IR = Infrared Irradiance (W/sq m)
T_{tp} = PIR thermopile voltage (mV)
T_c = PIR case temperature (K)
T_d = PIR dome temperature (K)
C_1 = PIR Calibration Factor (W/sq m per mV)

C_2 = PIR Dome Correction Factor (4.0 = default for all PIRs)
σ = Stephan-Boltzman Constant = 5.67E-08 W/m^2 K^4.

7.3 Calibration

7.3.1 Theory

The calibration of all SIRS *shortwave* radiometers (pyrheliometers and pyranometers) is traceable to the World Radiometric Reference (WRR) maintained by the World Radiation Center (WRC) for the WMO. Calibrations are performed at the SGP Radiometer Calibration Facility (RCF-see separate entry) using the Broadband Outdoor Radiometer CALibration (BORCAL) methods developed at NREL. A group of three electrically self-calibrating absolute cavity radiometers is maintained by NREL as the reference standards for the U.S. Department of Energy (DOE) and ARM. WRR calibration traceability of these reference standards is maintained for all DOE programs by participation in the International Pyrheliometer Comparisons held every five years at the WRC. NREL Pyrheliometer Comparisons are held annually at the Solar Radiation Research Laboratory in Golden to transfer the WRR to participating instruments and ensure the measurement performance of the reference standards.

The calibration of all SIRS *longwave* radiometers (pyrgeometers) are traceable to temperature standards maintained by the National Institute of Standards and Technology. SIRS pyrgeometers are to be calibrated in the new Pyrgeometer Blackbody Calibration System developed by The Eppley Laboratory, Inc. for the ARM Program and/or by outdoor comparisons with transfer standards. Standard operating procedures are currently under development at NREL for later use at the RCF to provide routine pyrgeometer calibrations.

Shortwave Radiometer Calibrations

The *Component* Summation *Method* used for all BORCAL events is a modified version of the shading method described in the American Society for Testing and Materials Standard E913-82, "Standard Method for Calibration of Reference Pyranometers with Axis Vertical by the Shading Method."

The direct normal (beam) irradiance is measured with one or two absolute cavity radiometers, and the diffuse (sky) irradiance is measured with one or two pyranometers shaded with a tracking disk (Figure 6) The two pyranometers providing the reference diffuse irradiance are calibrated by a shade/unshade method involving only the absolute cavity radiometer as a reference (Figure7). The output voltage of these standards and the radiometers under test are measured at approximate 30-second intervals throughout each day during clear-sky conditions (no clouds near the solar disk).

The responsivity for a pyrheliometer is calculated for each data point by dividing the value of the instrument's output signal (microvolts) by the mean value of the absolute cavity radiometer(s) output (W/sq m).

The responsivity for a pyranometer is calculated by dividing the value of the instrument's output signal (microvolts) by the computed reference global horizontal irradiance (W/sq m). The computed reference irradiance is the sum of the diffuse radiation and the vertical component of the direct beam irradiance (cavity radiometer irradiance multiplied by the cosine of the solar zenith angle at the time of measurement). This assumes that the pyranometer has a perfect angular response. The solar zenith angle calculations are corrected for atmospheric refraction effects at the calibration facility.

During a calibration event, one or more pyranometers (The Eppley Laboratory, Inc. Model PSP) and pyrheliometers (The Eppley Laboratory, Inc. Model NIP) are used as control standards to monitor the calibration process.

Figure 6. Component Summation Calibration

Figure 7. Shade/Unshade Calibration

Longwave Radiometer Calibrations

As of January 2001, all SIRS pyrgeometers have the calibration factors assigned by the manufacturer. A new blackbody calibration system has been developed for the recalibration of all SIRS pyrgeometers and is under test and evaluation at NREL. The specifications relative to the temperature ranges to be attained by the blackbody source and the PIR instrument were adapted from the WMO's Baseline Surface Radiation Network (BSRN) operating specifications.

The model PIR pyrgeometer is an instrument for measuring infrared radiation from the atmosphere, or from the ground if used in an inverted position. It defines the radiative transfer relative to the longwave irradiance. A PIR can be calibrated using a blackbody radiator with temperatures in the range given in the cited specification. The blackbody radiator itself is a copper hemisphere mounted in a fluid containing vessel, which is insulated. The geometry is such that the PIR will be in the "up-looking" position when it is inserted into the radiator. The surface of the hemispherical cavity is coated with Parson's black paint over a layer of Parson's black primer. This should yield a surface emissivity greater than 0.98. When the PIR instrument is inserted in the hemispherical cavity the effective emissivity approaches 1.0, due to the cavitation and enhancement from reflection of its own radiation. The reason for this approach is that the PIR instrument has a 180° Field of view. While this concept is simple in principle it is not as straight forward in operation. One reason is that for temperature differences between blackbody radiator and the PIR instrument thermal conduction and convection interfere with achieving the strictly radiative heat transfer desired for a calibration.

In nature, the ambient temperature determines the temperature of the PIR to a high degree. The cold radiative temperatures of the sky are actually affecting the instrument temperature to a high degree. It has been reported that solar radiation heats the hemisphere and/or hemisphere collar during some field use. However, some investigators use ventilation and / or shading to reduce this effect. Correction terms have been added to the data reduction algorithms to reduce such effects. The prototype PIR calibration system offered an opportunity to assess some of these effects. There is a history of relatively good agreement among different calibration laboratories as reported elsewhere. It was intended that information gathered by use of the prototype would allow development of the production units.

The prototype system was based on the system used at Eppley Laboratory for over 20 years. The main differences for the new systems:

1. Operates over a larger temperature range (see discussion of BSRN spec.)
2. Is to be fully automatic for a number of functions and all measurements
3. The temperature of the PIR is controlled (EPLAB system at ambient).

To understand the design and operation of the calibrator, the actual desired result must be defined. The radiation measured by a PIR is calculated from the measurement of the parameters of the instrument. The primary parameters are:

1. The thermopile output signal
2. The case temperature (approximation of the cold junction temperature)
3. The silicon hemisphere temperature.

Note that some users also measure a quantity termed the pyrgeometer output signal. This is a modified output signal from the PIR by virtue of a radiation compensation circuit which act like an analog computer which automatically corrects for the outgoing (emitted) radiation from the thermopile surface.

Generally speaking, investigators define the calibration as the determination of the sensitivity of the thermopile and the correction parameters associated with the temperatures and temperature differences experienced. A thermopile signal is related to the NET radiation at its receiver. This leads to the fact that the outgoing radiation must be assessed to calculate the incoming radiation, which is the desired result of the measurement. This is accomplished by calculating the outgoing radiation using the measured case temperature and making such corrections as deemed necessary. The measured hemisphere (or dome) temperature is also used to calculate correction terms related to other effects due to temperature gradients in the instrument during calibration and/or use.

Figure 7. Photo of PIR BB Production 0809Unit Blackbody Unit in Enclosure front view.

Figure 7 shows the PIR BB system enclosure consists of 2 chambers: upper Blackbody chamber and lower PIR chamber which are separately purged with dry gas. Dry air is also directed to the Blackbody hemisphere. The lower section with lab jack for height adjustment is outside the purged volume.

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

Pyranometers and pyrheliometers are re-calibrated annually at the SGP RCF. Calibration results and instrument deployment records are available from NREL's ARM Instrument Management System at http://www.nrel.gov/aim/.

7.4 Operation and Maintenance

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

In order to provide research-quality irradiance measurements, the SIRS radiometers are re-calibrated annually. The existing radiometer inventory allows for 50% spares, reducing the down time for station operation due to calibration. Maintenance of the SIRS equipment is performed during the biweekly maintenance visits to the SGP facilities. Detailed information is available from the OMIS at http://ops.sgp.arm.gov.

7.5 Glossary

See the ARM Glossary.

7.6 Acronyms

See the ARM Acronyms and Abbreviations.

7.7 Citable References

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