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National Renewable Energy Laboratory
(formerly the Solar Energy Research Institute)
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Preface

This work was performed under the National Renewable Energy Laboratory's (NREL's) Solar Radiation Research Assessment Project Task Nos. RA210101 and RA310102. It provides summary information and describes hourly data sets for solar radiation and meteorological elements measured from 1981 to 1991 at NREL's Solar Radiation Research Laboratory (SRRL) .

We would like to first acknowledge the people that operate and maintain SRRL, for without their dedicated efforts this report would not be possible. Tom Stoffel has managed SRRL since its beginning in 1979. Assisting him with the operation, maintenance, and data collection include staff members Bob Hansen, Toula Ismailidis, Deborah Laudato, Jim Treadwell, and David Trudell. The need for a facility such as SRRL was recognized under the leadership of Roland Hulstrom, who was the program manager at that time.

We would also like to acknowledge Richard Perez (State University of New York at Albany), Frank Vignola (University of Oregon), and NREL staff members Carol Riordan, Dave Renné, Ted Cannon, Eugene Maxwell, Daryl Myers, and Tom Stoffel for their contributions to the report and their review. We would also like to thank Eric Hammond, Martin Rymes, and Steve Wilcox for assisting with data processing, Mary Anne Dunlap for technical editing, and Pam Gray-Hann and Terrie Webb for assisting with the manuscript.

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1.0 Introduction

As part of NREL's Solar Radiation Resource Assessment Project, researchers have been collecting, since 1981, solar radiation and meteorological data at the Solar Radiation Research Laboratory (SRRL). This report provides summary information on the data showing the site's solar resource, including seasonal and annual variability. It also describes hourly data sets contained on computer readable media for the period 1981 through 1991. NREL makes these data sets available to interested parties needing high quality measured data for evaluating solar energy technologies and for developing and validating solar radiation models.

The development of the SRRL began in 1979 at an interim site near the southern base of South Table Mountain, Golden, Colorado. In 1983, the SRRL was moved about 1.2 kilometers (0.75 miles) northwest and 90 meters (295 feet) higher to its present location on the top of South Table Mountain. Figure 1-1 shows the present and interim locations. The longitude and latitude of the present location is W105.18° and N39.74°, and the elevation is 1829 meters (6000 feet). SRRL enjoys a climate like that of much of the central Rocky Mountain region. The relative humidity is low, precipitation is low, and there is abundant sunshine.

For solar radiation monitoring purposes, the present location affords an excellent view of the sky. Only a small portion of the sky is obstructed. To the south and west, the foothills of the Rocky Mountains rise above the horizontal, but only a maximum of 5°. East of SRRL resides the Denver metropolitan area. Because of differences in elevation, the eastern horizon, when viewed from SRRL, is 1° below the horizontal.

The quantity, quality, and variety of SRRL's solar radiation and meteorological measurements make the facility one of the world's most complete outdoor laboratories devoted to solar radiation observations and research. Figure 1-2 provides an aerial view of SRRL.

The development and operation of the laboratory focus on the following objectives:

- Building a research data base that characterizes solar radiation and meteorological conditions for the various solar technologies.
- Providing a world-class facility for outdoor calibrations of radiometers traceable to international standards.
- Accommodating the varying research needs at NREL associated with the development and testing of improved solar radiation instruments, solar radiation models, and solar energy conversion devices.
- Establishing a long-term solar radiation and meteorological and climatological data base for South Table Mountain near Golden, Colorado.

This report addresses two of these objectives, the first and last, by providing summary information such as long-term averages and monthly and annual variability for key solar radiation elements, and by describing the hourly data sets for the period 1981-1991. The first part of this report describes the solar radiation and meteorological elements measured at SRRL and describes how the data were collected and processed into hourly values. Second, procedures used for quality assessment of the hourly data values are presented. Third, the position of the solar radiation and meteorological elements in the hourly data sets are defined and sample read statements are given. Fourth, summary information, such as long-term averages and monthly and annual variability for key solar radiation elements, is presented. An appendix is also included to show for each element when instruments and calibration factors were changed and the percentage of data that were collected and passed their quality assessment.

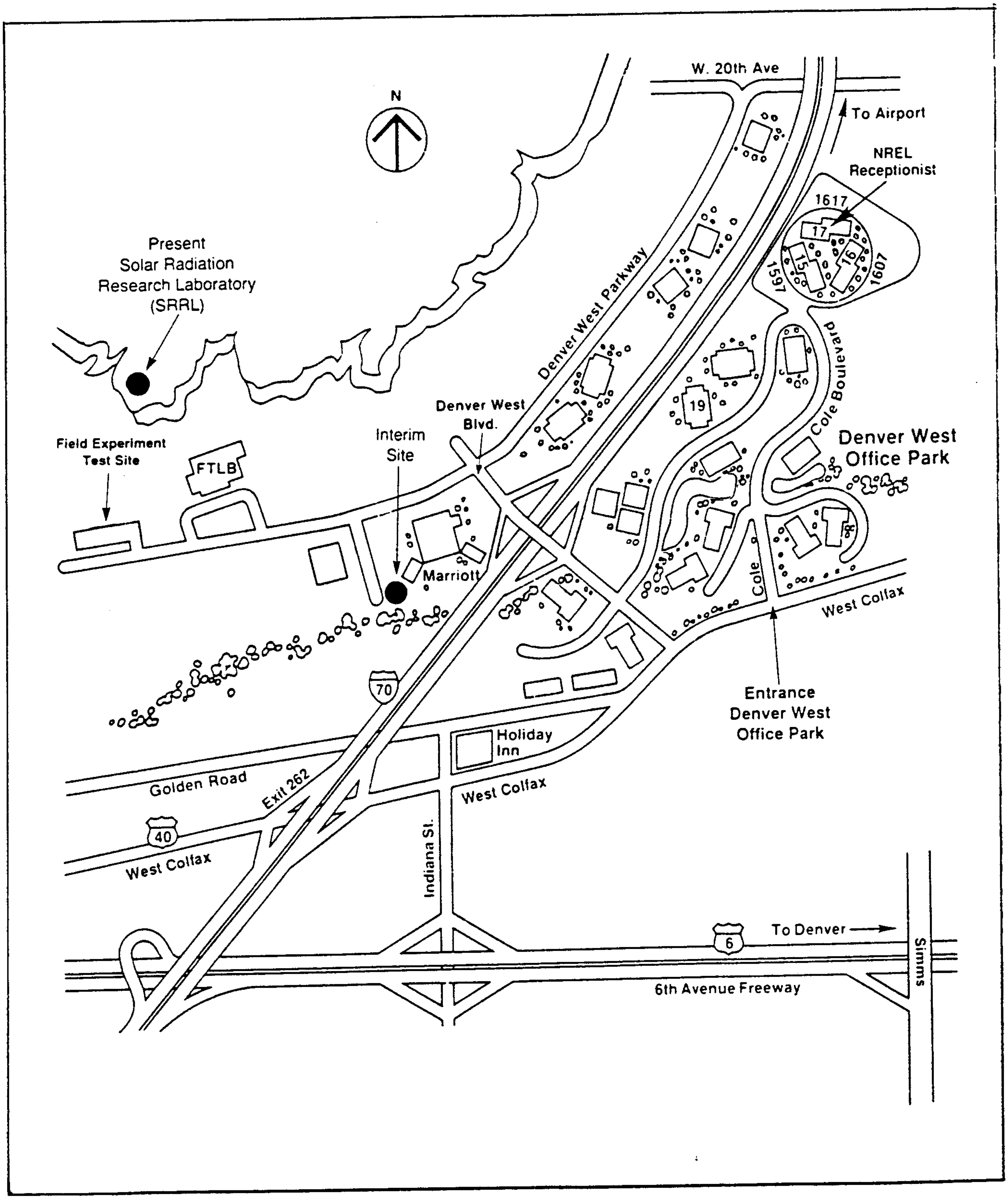

Figure 1-1. Present and interim locations of the Solar Radiation Research Laboratory

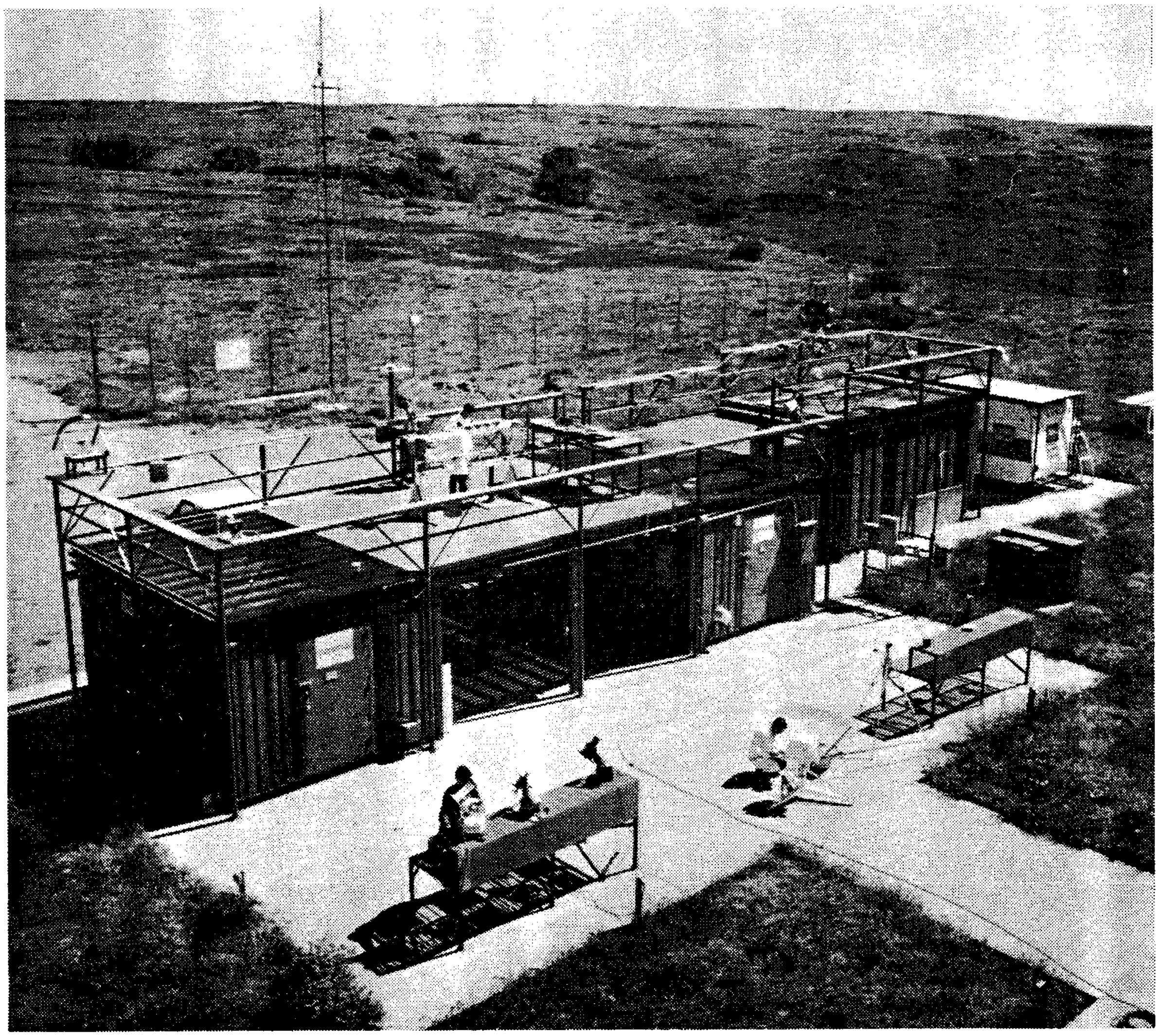

Figure 1-2. The Solar Radiation Research Laboratory located on South Table Mountain near Golden, Colorado

2.0 Data Collection and Processing

This section describes the solar radiation and meteorological elements measured at SRRL, instrument calibration methods, maintenance intervals and procedures, and how the hourly data values were generated.

2.1 Solar Radiation and Meteorological Elements

Over the years, the solar radiation and meteorological elements measured at SRRL changed to meet varying research needs. Consequently, some elements were measured less than a year, while fundamental elements such as global horizontal solar radiation and direct normal solar radiation were measured for the complete period of record.

Table 2-1 lists the solar radiation and meteorological elements, the instrument type, and the time period of the measurements. The four time periods correspond to changes in instrumentation. The dashed lines signify that the element was measured in the respective time period. From July 1, 1983 to October 25, 1984, data are not available because SRRL was moving from its interim site to its present location.

2.2 Maintenance and Instrument Calibration

Routine maintenance of the instruments and the data acquisition system is performed daily, except on weekends and holidays. (Exception: From January 1991 through June 1991 maintenance was performed seven days a week to accommodate special tests.) The maintenance includes cleaning the sensors of dirt, moisture, ice, or snow, checking and adjusting the shadowband for proper declination, checking the alignment of the sun trackers and adjusting if necessary, making a weather observation, and checking that the sensor outputs are reasonable for the prevailing conditions. A standard log form (Figure 2-1) records maintenance activities.

Instruments were generally calibrated once a year. However, there are several exceptions, depending on the instrument and the year. The appendix gives the dates for changes of instruments and calibration factors for each solar radiation and meteorological element. Pyranometers and pyrheliometers are calibrated at SRRL with an absolute cavity radiometer traceable to the World Radiometric Reference. The component summation technique (ASTM 1986) is used to calibrate pyranometers. Pyrheliometers are calibrated by directly comparing their output with that of the absolute cavity radiometer.

2.3 Data Processing

SRRL's data acquisition system scans the solar radiation and meteorological elements at 10-second intervals and stores average data values on audiocassette tapes. Prior to 1984, the data were collected with an Autodata Ten data logger, and values were stored as 1-minute averages. For 1984 and later, the data were collected with a Campbell Scientific data logger, and values were stored as 5-minute averages, with the exception of wind speed and wind direction that were instantaneous samples at 5-minute intervals. The data values were then downloaded from the audiocassette tapes to a VAX computer for storage and analysis.

To create the hourly data sets, the 1-minute and 5-minute data values were averaged over the preceding hour. If more than 10 minutes of data in an hour were missing, then the data element was assigned a value of 9900 to indicate missing data. Instead of simply averaging wind direction, a mean wind vector direction was determined for the hour. Diffuse horizontal radiation data were corrected for the presence of the shadowband by methods developed by Drummond for anisotropic skies (Iqbal 1983).

Table 2-1. SRRL Solar Radiation and Meteorological Elements

Element	Instrument[a]	7/15/81 to 6/30/83	10/25/84 to 4/14/85	4/15/85 to 2/29/88	3/15/88 to 12/31/91
Global Horizontal Radiation	PSP	———	———	———	———
Direct Normal Radiation	NIP	———	———	———	———
Ground-Reflected Radiation (for albedo)	PSP	———	———	———	———
Global Radiation on a 40° South-Facing Tilt	PSP	———		———	———
Global Horizontal Radiation	LI-COR	———			
Global Radiation on a 40° South-Facing Tilt	LI-COR	———			
Diffuse Horizontal Radiation (via shadowband)	PSP		———	———	———
Global Radiation on a 90° North-Facing Tilt Shielded from the Ground	PSP		———		
Ground-Reflected Radiation on a 90° North-Facing Tilt	PSP		———		
Global Radiation on a 90° North-Facing Tilt	PSP		———	———	
Global Radiation on a 90° East-Facing Tilt	PSP		———	———	
Global Radiation on a 90° South-Facing Tilt Shielded from the Ground	PSP		———		
Ground-Reflected Radiation on a 90° South-Facing Tilt	PSP		———		
Global Radiation on a 90° South-Facing Tilt	PSP		———	———	
Global Radiation on a 90° West-Facing Tilt	PSP		———	———	
Global Normal Radiation on a Two-Axis Tracking Surface	PSP			———	———
Direct Normal Near-Infrared Radiation	NIP				———
Global Horizontal Near-Infrared Radiation	PSP				———
Global Horizontal UV Radiation	TUVR				———
Wind Speed 10 Meters above Ground	TGT				———
Wind Direction 10 Meters above Ground	TGT				———
Dry Bulb Temperature	CSI				———
Relative Humidity	CSI				———
Atmospheric Pressure	YSI				———
Direct Normal UV Radiation	TUVR				b

[a]Instrument abbreviations:

CSI = Campbell Scientific, Inc., model 207 Probe
LI-COR = LI-COR Pyranometer, model LI-200
NIP = Eppley Laboratory Pyrheliometer, model NIP
PSP = Eppley Laboratory Pyranometer, model PSP
TGT = Teledyne-Geotech Wind System
TUVR = Eppley Laboratory Photometer, model TUVR
YSI = Yellow Springs Instrument Company

[b]Direct normal ultraviolet radiation measurements began on July 2, 1990.

Quality assessment routines assigned each hourly data value a flag ranging from 0 to 99 that indicates whether or not the hourly data value is reasonable. Section 3.0 describes the quality assessment procedures for each of the solar radiation and meteorological elements.

SRRL MAINTENANCE & OPERATIONS LOG (Vol 23) Page 7

BA-G0539501

Observer: [illegible] Day: M T W T (F) (circle) Date: 6/11/[illegible] DOY: 1[illegible] Time: 5:40 (MST)
Solar Declination (δ): [illegible]

--RADIOMETERS/SENSORS-- --SUPPORT EQUIPMENT--

CR-21X Channel	Measured Parameter	Condition Code*	Reading		Condition Code*
1	GLOBAL HORIZONTAL WG7	✓	76 W/m2		
2	DIFFUSE (SB)	✓	94 W/m2	Shadow Band	✓
3	DIRECT NORMAL	✓	13[illegible] W/m2	Sun-Follower III	A
4	GLOBAL 40-SOUTH	✓	3[illegible] W/m2		
5	2-AXIS GLOBAL	✓	143 W/m2	Eppley ST-3 #1	✓
6	1-AXIS GLOBAL	✓	[illegible] W/m2	Eppley ST-3 #2	A
7	GLOBAL HORIZONTAL RG780	✓	17 W/m2		
8	DIRECT NORMAL RG780	✓	77 W/m2	Sun-Follower (See Above)	
9	TOTAL UV PHOTOMETER	✓	[illegible] W/m2		
10	ALBEDO	✓	[illegible] W/m2		
11	PHOTOMETER (500nm)	✓	[illegible] Volts	Sun-Follower (See Above)	
12	WIND SPEED	✓	3.3 m/s		
13	WIND DIRECTION	✓	216 deg	Other EPPLEY SMT-3 TRACKER	
14	DRY BULB TEMPERATURE	✓	20.[illegible] deg C	OK	
15	RELATIVE HUMIDITY	✓	35.7 %		
16	PRESSURE	✓	[illegible].76 mBar		

--DATA ACQUISITION SYSTEM (CR21X)--

Clock ✓ (Reset at ___:___ MST)
(slow/fast by ______)

Tape Counter 205

Changed Tape at –:– (MST)

--SURFACE WEATHER OBSERVATION---

Temperature: Current 67 F Max [illegible] F Min 44 F RH 31 %

Cloud Cover: Total 4/10 Type(s) Ac Opaque 5/10 Types(s) Ac

Distribution: TWO DARK LAYERS TO EAST [illegible] MOUNTAINS

Visibility: North 30 mi East 30 mi South 30 mi West 30 mi

Brown Cloud? MODERATE Mixing Layer Height 50 (% of Skyline)

--COMMENTS--

DENVER BROWN CLOUD DOES NOT EFFECT EASTERN VISIBILITY (CAN SEE OVER IT TO EASTERN HORIZON)

SUN BEHIND CLOUDS AT TIME OF READINGS

*Condition Code: ✓ = "OK" X = "Problem" 0 = "Fixed" A = "Adjusted"

Figure 2-1. Log used to record maintenance of instruments and the data acquisition system

3.0 Quality Assessment of Hourly Data

Quality assessment (QA), a post-data-collection procedure, indicates whether a data value is reasonable, too small, too large, or missing. It is not used to change data values and should not be confused with quality control or quality assurance. Quality control and quality assurance occur before and during data collection and include procedures such as the proper selection and installation of instruments and data acquisition equipment, and regular maintenance and calibration.

Quality assessment of the hourly data assigned a flag ranging from 0 to 99 to each of the hourly data elements. To select data for analysis purposes, the flags may be used to screen the data files for data meeting user-defined acceptance criteria.

Depending on the solar radiation or meteorological element being assessed, different techniques were used to assign the QA flags. Elements such as global horizontal, diffuse horizontal, and direct normal solar radiation can be rigorously assessed because they are physically related (global = diffuse + [cosine of the solar zenith angle] x direct normal). Other elements, such as wind speed, are not related to other elements and can only be assessed as to whether they fall between an expected minimum and maximum. Consequently, the QA flags for these elements impart less confidence that measured data values represent actual conditions. Data residing outside the upper and lower QA limits may be the result of data collected with sensors obstructed by dirt, water, snow, or ice, data collected with improperly installed or calibrated instruments, data collected with malfunctioning data acquisition equipment, or data collected under unexpected or unusual atmospheric conditions.

The rest of this section describes the QA procedures used for each of the hourly solar radiation and meteorological elements. Readers are encouraged to evaluate these procedures with respect to their applications, keeping in mind that because of the assumptions made it is likely that some "good" data may be flagged "bad," and vice versa.

3.1 QA for Global Horizontal, Diffuse Horizontal, and Direct Normal

Quality assessment of global horizontal, diffuse horizontal, and direct normal solar radiation data was performed using SERI QC, a procedural and software package developed by NREL (Maxwell et al. 1989). SERI QC defines ranges of acceptable data, depending on whether one, two, or all three hourly data elements are present. Ranges are defined based on dimensionless parameters normalized with respect to extraterrestrial radiation, where:

K_t = Clearness index or global horizontal transmittance
K_d = Diffuse horizontal transmittance
K_n = Direct normal transmittance.

Depending on the circumstances, SERI QC performs one-element, two-element, or three-element tests. First, it performs a one-element test by defining a range of acceptable values between zero and maximum values of K_t, K_d, or K_n, depending on the element being tested, based on three air mass regimes and month of the year.

Next, if the zenith angle (at the middle of the hour) is less than or equal to 80° and two elements passed the one-element test, SERI QC performs a two-element test by defining a range of acceptable values within boundaries such as shown in Figure 3-1. The boundaries in the figure are previously determined empirically for three different air mass regimes for each month using data collected at the site. With increasing cloud cover, the direct normal radiation decreases more rapidly than the global horizontal radiation. Consequently, data for cloudy skies are grouped toward the lower boundary. Clear sky data reside near the upper boundary. For some seldom

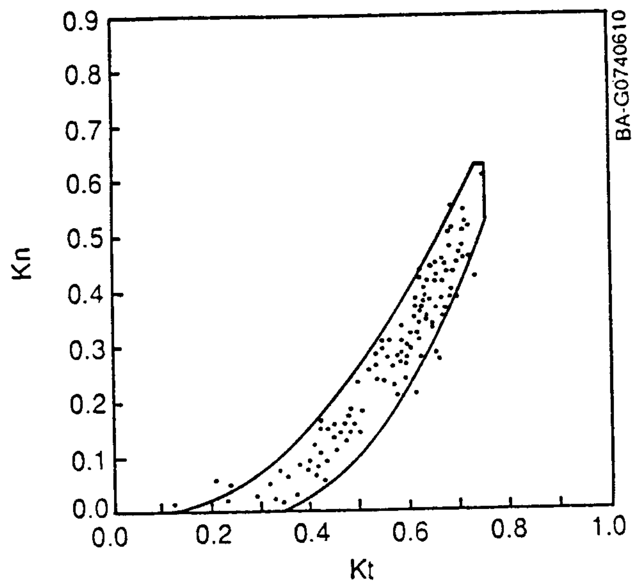

Figure 3-1. SERI QC data boundaries for two-element quality assessment

occurring conditions, data depicting real conditions may reside outside the boundaries and be flagged as bad data. For example, if the sun is near the edge of a cloud, some of the sun's rays can be reflected off the edge of the cloud and increase the global horizontal radiation and K_t without affecting the direct normal radiation and K_n. This shifts the data point to the right in Figure 3-1, and it may be to the right of the lower boundary if K_t is large enough.

Last, if all three of the elements are present, SERI QC performs a three-element test by defining a range of acceptable values so that the equation $K_t = K_d + K_n$ is satisfied within an arbitrary error limit of ±0.03, accounting for measurement uncertainties. Flags are assigned to the data according to the convention listed in Table 3-1.

Table 3-1. Flagging Convention for Global Horizontal, Diffuse Horizontal, and Direct Normal Solar Radiation

Flag	Description
0	Untested data
1	Passed one-element test; data within max-min limits of K_t, K_d, or K_n
2	Passed two-element test; data within 0.03 of boundaries
3	Passed three-element test; data within ±0.03 of satisfying $K_t = K_d + K_n$
7	Failed one-element test; data below allowed minimum
8	Failed one-element test; data greater than allowed maximum
9	Passed three-element test but failed two-element test by greater than 0.06
10-93	Failed two- or three-element test in one of four ways: To determine the test failed and the manner of the failure (high or low) examine the remainder of the calculation (flag + 2)/4 . <u>Remainder</u> — <u>Failure</u> 0 — Element too low by three-element test 1 — Element too high by three-element test 2 — Element too low by two-element test 3 — Element too high by two-element test The magnitude of the test failure (distance in K-units) is determined by the calculation: d = (INT (flag + 2)/4)/100
94-97	Data fall into a physically impossible region where $K_n > K_t$ 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)
99	Missing data

3.2 QA for Ground-Reflected Radiation (for Albedo)

An inverted pyranometer 1.5 meters above the ground measured the ground-reflected solar radiation. A one-element test assessed the data quality when the sun was below the horizon (nighttime), and a two-element test assessed the data quality when then sun was above the horizon (daytime). The one-element test checked for hourly data between -10 and +10 Wh/m^2, reasonable nighttime values for properly functioning instrumentation. The two-element test calculated the surface albedo by dividing the inverted pyranometer data by the global horizontal data, and then comparing the calculated albedo with expected values. Minimum and maximum expected albedos are given below and are based on reported values (Iqbal 1983):

June to September:	minimum	= 0.14 (wet grass, overcast skies)
	maximum	= 0.37 (wet grass, sunny)
October to May:	minimum	= 0.14 (wet grass, overcast skies)
	maximum	= 0.95 (new snow, overcast skies)

Table 3-2. Flagging Convention for Ground-Reflected Solar Radiation

Flag	Description
0	Untested data
1	Passed one-element test; data from -10 to +10 Wh/m^2
2	Passed two-element test; calculated albedo within minimum and maximum
7	Failed one-element test; data below -10 Wh/m^2
8	Failed one-element test; data greater than +10 Wh/m^2
94	Failed two-element test; calculated albedo below minimum expected
95	Failed two-element test; calculated albedo above maximum expected
99	Missing data

The two-element test was not performed when the global horizontal data were missing, not within ±0.05 of their boundaries during the two-element QA test, or not within ±0.05 of satisfying the equation $K_t = K_d + K_n$ during their three-element QA test. Flags were assigned to the data according to the convention listed in Table 3-2.

3.3 QA for Solar Radiation on Tilted and Tracking Surfaces

Quality assessment of solar radiation data for tilted and tracking surfaces was performed using a one-element test for data when the sun was below the horizon (nighttime), and using a three-element test for data when then sun was above the horizon (daytime). The one-element test checked for hourly data from -10 to +10 Wh/m^2, reasonable nighttime values for properly functioning instrumentation. The three-element test compared the measured values with estimates given using the Perez model (Perez et al. 1990). (Exception: 90° north and 90° south-facing tilted surfaces from October 25, 1984 to April 14, 1985, see Section 3.4)

The Perez model requires input variables of global horizontal and direct normal solar radiation, solar zenith angle, slope of the tilted surface, ground albedo, and solar incidence angle on the tilted surface. The model returns the diffuse radiation on the tilted surface, which can then be added to the direct normal radiation component for the tilted surface to obtain a modeled total solar radiation for the tilted surface. Measured data are compared to the modeled value and passes the three-element test if they are within ±75 Wh/m^2, a margin about two to four times the root-mean-square error reported for the Perez model (Perez et al. 1990; Muneer 1991; and Faiman et al. 1991).

Because the model requires valid input data, the three-element test was not performed if either the global horizontal data or direct normal data were: (1) missing, (2) not within 0.05 of their boundaries during the two-element QA test, or (3) not within ±0.05 of satisfying $K_t = K_d + K_n$ during their three-element QA test. Albedo was input to the model after calculating the albedo by dividing the ground-reflected radiation by the global horizontal radiation. Additionally, if the ground-reflected radiation did not pass its QA, an albedo of 0.2 was input to the model for data collected during June to September, and for data collected during October to May an albedo of 0.2 was input for a lower limit calculation and an albedo of 0.7 (possible snow conditions) was input for an upper limit calculation. Flags were assigned to the data according to the convention listed in Table 3-3.

Table 3-3. Flagging Convention for Solar Radiation on Tilted and Tracking Surfaces

Flag	Description
0	Untested data
1	Passed one-element test; data from -10 to +10 Wh/m^2
3	Passed three-element test; within ±75 Wh/m^2 of model estimate
7	Failed one-element test; data below -10 Wh/m^2
8	Failed one-element test; data greater than +10 Wh/m^2
94	Failed three-element test; data more than 75 Wh/m^2 below model estimate
95	Failed three-element test; data more than 75 Wh/m^2 above model estimate
99	Missing data

Figures 3-2 and 3-3 compare measured values with those estimated by the Perez model using data collected during 1991 for the two-axis tracking surface and for the south-facing surface tilted 40° from the horizontal. Data pass the three-element test if they reside between upper and lower limits. Measured data for the south-facing surface tilted 40° from the horizontal show better agreement with model estimates, except for a few data points residing on the y-axis. Apparently, the pyranometer was disconnected for a short period. These data were assigned a QA flag equal to 94.

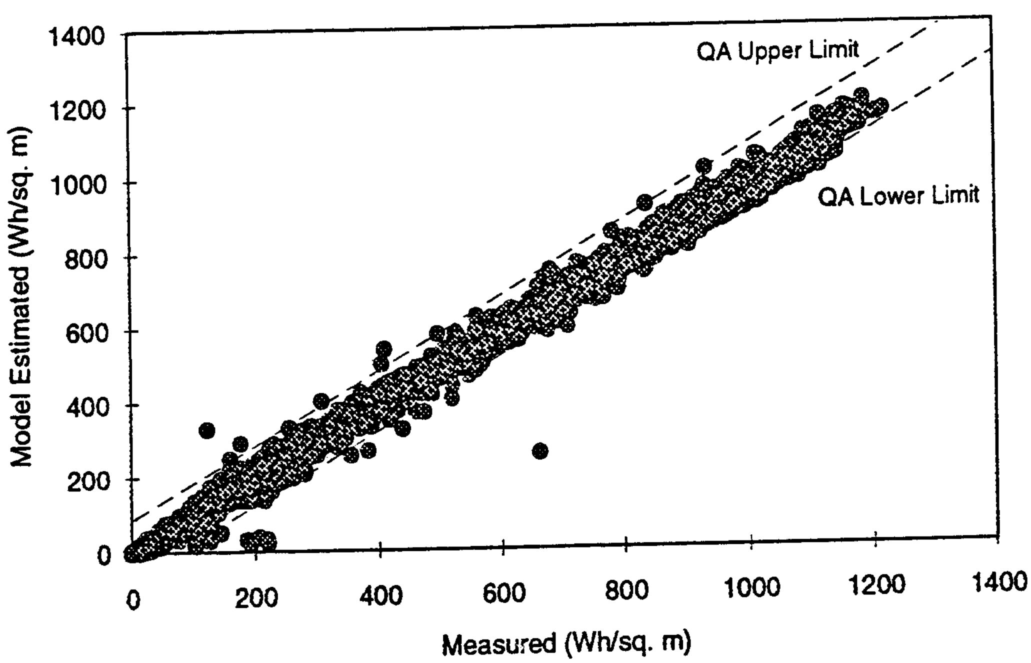

Figure 3-2. Model-estimated and measured two-axis tracking data for 1991

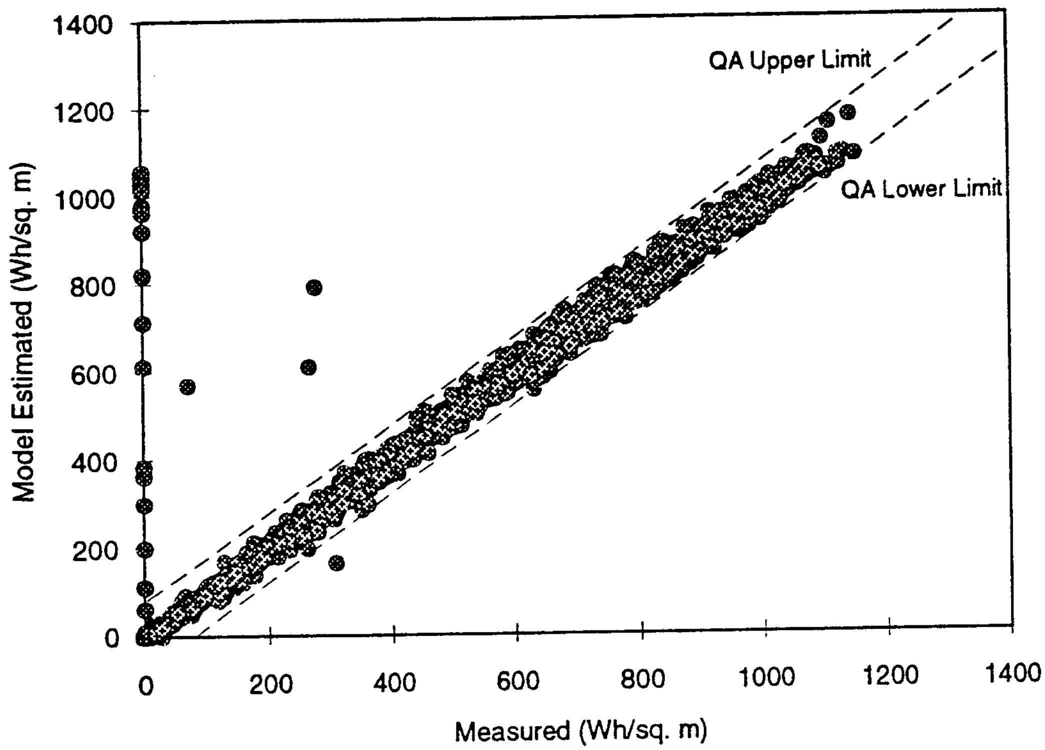

Figure 3-3. Model-estimated and measured 40° south-facing tilt data for 1991

The slightly poorer agreement between modeled and measured values for the two-axis tracking surface may be because its modeled values might have higher uncertainties. A greater percentage of the diffuse radiation for a two-axis tracking surface comes from circumsolar radiation and radiation reflected by nearby clouds, which is more difficult to model. Using different QA limits for different surface orientations could have been performed, but the single limit of ±75 Wh/m^2 proved satisfactory. The percentage of possible data passing QA shown in the Appendix for the two-axis tracking surface and for the south-facing surface tilted 40° from the horizontal are generally within 1% or 2% percent of each other.

3.4 QA for Solar Radiation on 90° North- and 90° South-Facing Tilted Surfaces from October 25, 1984 to April 14, 1985

From October 25, 1984 to April 14, 1985, data were collected for north- and south-facing surfaces tilted 90°, and separate measurements were also made showing the contribution of the global radiation when shielded from the ground and the amount of ground-reflected radiation. Quality assessment of these elements used only measured data (no model estimates such as Section 3.3) and was performed using a one-element test for data when the sun was below the horizon (nighttime) and a three-element test for data when then sun was above the horizon (daytime). The one-element test checked for data from -10 to +10 Wh/m^2, reasonable nighttime values for properly functioning instrumentation. The three-element test checked to see if the data satisfied the equation:

  Global Radiation on a 90° Tilted Surface Shielded from the Ground
\+ Ground-Reflected Radiation on a 90° Tilted Surface
\- Global Radiation on a 90° Tilted Surface = 0

If the residual of the above equation was from -10% to +10% of the global radiation value, the data passed the three-element test. The ±10% accounted for uncertainties in the pyranometer measurements. If one or more of the three elements were missing, no test was performed. Flags were assigned to the data according to the convention listed in Table 3-4.

Figure 3-4 shows the residuals versus the global radiation values for the set of three south-facing pyranometers for data collected from October 25, 1984 to April 14, 1985. Data pass the three-element test if they reside between upper and lower limits. The figure indicates a slight positive bias of the residuals. The calibration constants for the pyranometers, the positioning of the shields, and the cosine response of the pyranometers could create a bias of this type.

Table 3-4. Flagging Convention for Solar Radiation on 90° North- and South-Facing Tilted Surfaces from October 25, 1984 to April 14, 1985

Flag	Description
0	Untested data
1	Passed one-element test; data from -10 to +10 Wh/m^2
3	Passed three-element test; residual from -10% to +10% of the global radiation
7	Failed one-element test; data below -10 Wh/m^2
8	Failed one-element test; data greater than +10 Wh/m^2
94	Failed three-element test; residual less than -10% of the global radiation
95	Failed three-element test; residual greater than +10% of the global radiation
99	Missing data

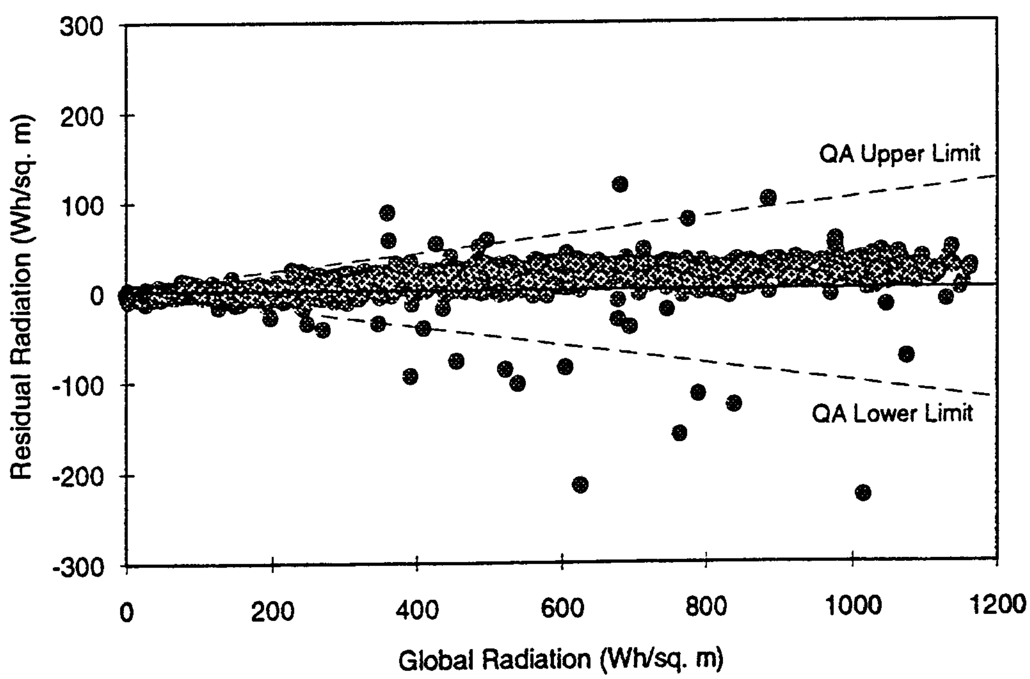

Figure 3-4. Residuals for global radiation on a 90° south-facing tilted surface

For data collected after April 14, 1985, for global radiation on a 90° tilted surface, the QA procedures shown in Section 3.4 were used because global radiation on a 90° tilted surface shielded from the ground and ground-reflected radiation on a 90° tilted surface were not measured.

3.5 QA for Direct Normal Near-Infrared Radiation

This element was measured with an Eppley NIP with an RG780 (red) filter placed in front of the instrument's window, measuring radiation in the near-infrared region from about 780 to 2800 nm. An unfiltered Eppley NIP, with a crystal quartz window, measures broadband radiation from about 200 to 4000 nm.

Quality assessment of direct normal near-infrared solar radiation data was performed using a one-element test for data when the sun was below the horizon (nighttime) and a two-element test for data when the sun was above the horizon (daytime). The one-element test checked for data from -10 to +10 Wh/m^2, reasonable nighttime values for properly functioning instrumentation. The two-element test checked to see if the near-infrared to broadband ratio (filtered NIP data value divided by the unfiltered NIP data value) was between 0.3 and 0.6 when the zenith angle was less than 65°, and between 0.3 and 0.9 when the zenith angle was 65° or greater. These limits were estimated based on previous work at NREL (Riordan and Myers 1990). For small data values, the calculated ratios were often outside these limits because the instrument error, as a percentage of the measured value, was larger. An increase in percentage of error at low values may be from a nonlinear response of the instrument or an offset error in the data acquisition system. Consequently, for this report, when the unfiltered NIP data were less than 50 Wh/m^2, the filtered NIP data were just checked to see that they did not exceed the unfiltered value. No test was performed if the unfiltered NIP data were: (1) missing, (2) not within 0.05 of their boundaries during their two-element QA test, or (3) not within ±0.05 of satisfying $K_t = K_d + K_n$ during their three-element QA test. Flags were assigned to the data according to the convention listed in Table 3-5.

Figure 3-5 shows ratios of the filtered NIP data value divided by the unfiltered NIP data value as a function of the sun's zenith angle for data collected during 1991. Data pass the two-element test if they reside between the upper and lower limits.

Table 3-5. Flagging Convention for Direct Normal Near-Infrared Radiation

Flag	Description
0	Untested data
1	Passed one-element test; data from -10 to +10 Wh/m^2
3	Passed two-element test; ratio from min to max; if NIP < 50 Wh/m^2, data < NIP
7	Failed one-element test; data below -10 Wh/m^2
8	Failed one-element test; data greater than +10 Wh/m^2
94	Failed two-element test; ratio less than min; if NIP < 50 Wh/m^2, data < -5 Wh/m^2
95	Failed two-element test; ratio greater than max; if NIP < 50 Wh/m^2, data > NIP
99	Missing data

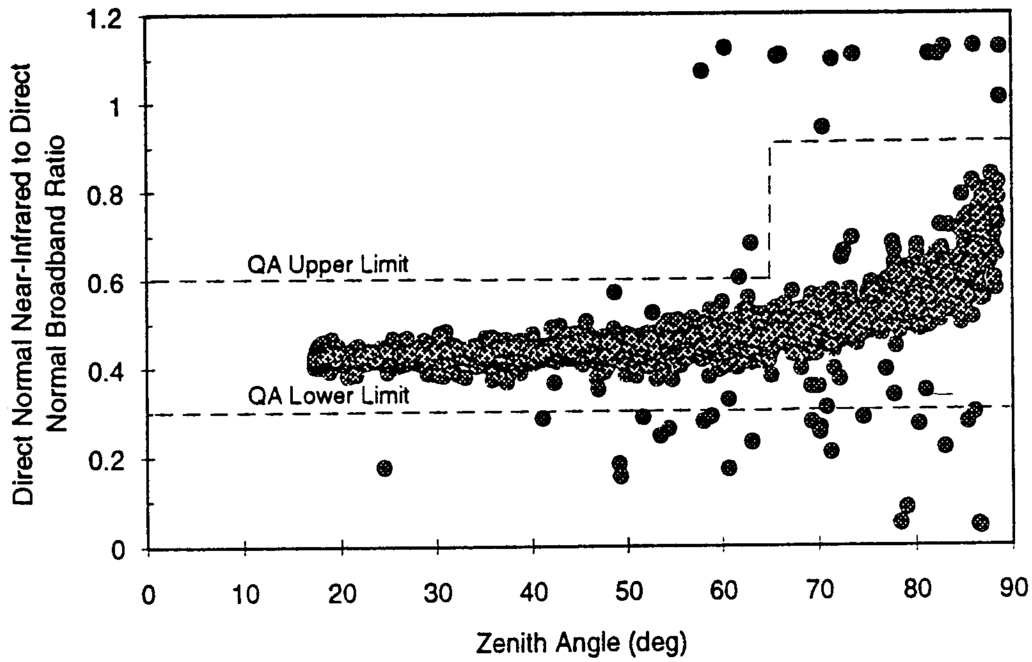

Figure 3-5. 1991 ratios of direct normal near-infrared radiation to direct normal broadband radiation versus zenith angle

3.6 QA for Global Horizontal Near-Infrared Radiation

This element was measured with an Eppley PSP with an RG780 (red) dome, measuring radiation in the near-infrared region from about 780 to 2800 nm. An unfiltered Eppley PSP with a WG7 dome measures broadband radiation from about 285 to 2800 nm. Quality assessment procedures for this element are similar to those presented in Section 3.5.

Quality assessment of global horizontal solar radiation data between 780 to 2800 nm was performed using a one-element test for data when the sun was below the horizon (nighttime) and a two-element test for data when the sun was above the horizon (daytime). The one-element test checked for data from -10 to +10 Wh/m^2, reasonable night time values for properly functioning instrumentation. The two-element test checked to see if the near-infrared to broadband radiation ratio (filtered PSP data value divided by the unfiltered PSP data value) was between 0.30 and 0.55. These limits were estimated based on previous work at NREL (Riordan and Myers 1990). For small data values, the calculated ratios were often outside these limits because the instrument error, as a percentage of the measured value, was larger. An increase in percentage of error at low values may be from a nonlinear response of the instrument or an offset error in the data acquisition system. Consequently, for this report, when unfiltered PSP data were less than 50 Wh/m^2, the filtered PSP data were just checked to see that they did not exceed the unfiltered values. No test was performed if the unfiltered PSP data were: (1) missing, (2) not within 0.05 of their boundaries during their two-element QA test, or (3) not within ±0.05 of satisfying $K_t = K_d + K_n$ during their three-element QA test. Flags were assigned to the data according to the convention listed in Table 3-6.

Figure 3-6 shows ratios of the filtered PSP data value divided by the unfiltered PSP data value as a function of the sun's zenith angle for data collected during 1991. Data pass the two-element test if they reside between the upper and lower limits.

Table 3-6. Flagging Convention for Global Horizontal Near-Infrared Radiation

Flag	Description
0	Untested data
1	Passed one-element test; data from -10 to +10 Wh/m^2
3	Passed two-element test; ratio from 0.30 to 0.55; if PSP < 50 Wh/m^2, data < PSP
7	Failed one-element test; data below -10 Wh/m^2
8	Failed one-element test; data greater than +10 Wh/m^2
94	Failed two-element test; ratio less than 0.30; if PSP < 50 Wh/m^2, data < 0
95	Failed two-element test; ratio greater than 0.55; if PSP < 50 Wh/m^2, data > PSP
99	Missing data

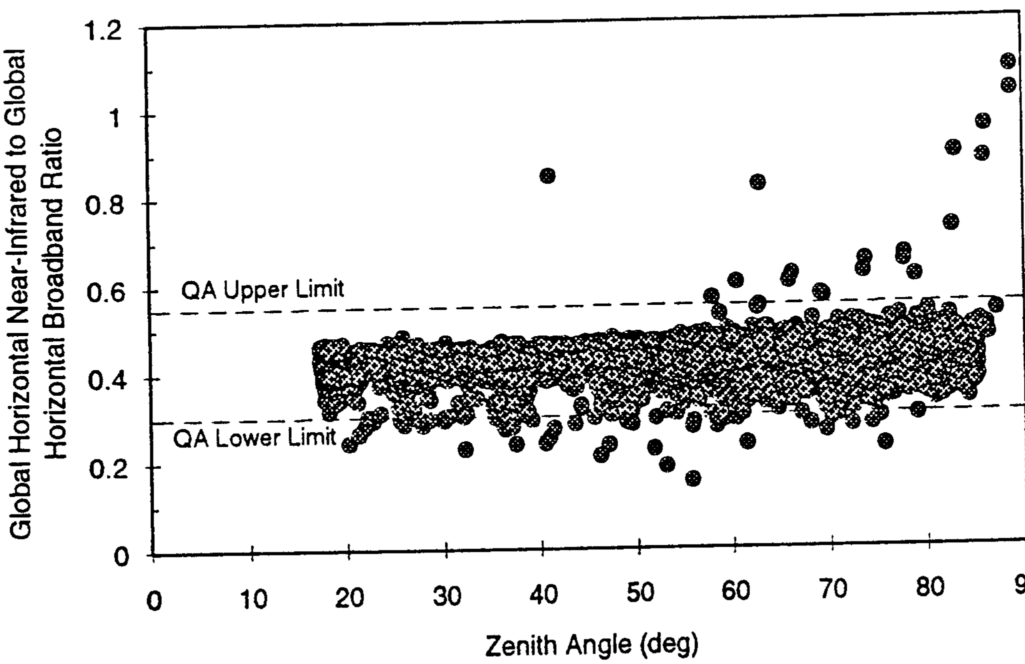

Figure 3-6. 1991 ratios of global horizontal near-infrared radiation to global horizontal broadband radiation versus zenith angle

3.7 QA for Direct Normal Ultraviolet Radiation

This element was measured with an Eppley Photometer model TUVR with a collimating tube added to restrict the field-of-view to 5.7°, which is the same field-of-view as an Eppley NIP. The TUVR measures radiation in the ultraviolet (UV) region from about 295 to 385 nm; the Eppley NIP measures broadband radiation from about 200 to 4000 nm.

Quality assessment of direct normal UV radiation data was performed using a one-element test for data when the sun was below the horizon (nighttime) and a two-element test for data when the sun was above the horizon (daytime). The one-element test checked for data between -2 and +2 Wh/m², reasonable nighttime values for properly functioning instrumentation. The two-element test checked to see if the direct normal UV to direct normal broadband radiation ratio (UV data value divided by the NIP data value) was between 0.004 and 0.080. These limits were estimated based on previous work at NREL (Riordan, Hulstrom, and Myers 1990 and Mehos, Pacheco, and Link 1992). For small data values, the calculated ratios were often outside these limits because the instrument error, as a percentage of the measured value, was larger. An increase in percentage of error at low values may be from a nonlinear response of the instrument or an offset error in the data acquisition system. Consequently, for this report, when the NIP data were less than 50 Wh/m² the UV data were just checked to see that they did not exceed 25% of the NIP value. No test was performed if the NIP data were: (1) missing, (2) not within 0.05 of their boundaries during their two-element QA test, or (3) not within ±0.05 of satisfying $K_t = K_d + K_n$ during their three-element QA test. Flags were assigned to the data according to the convention listed in Table 3-7.

Figure 3-7 shows ratios of the UV data value divided by the NIP data value as a function of the sun's zenith angle for data collected during 1991. Data pass the two-element test if they reside between the upper and lower limits. For zenith angles between 80° and 90°, there are data below the QA lower limit that are probably reasonable values, when taking into account the general distribution of the ratios versus zenith angles. It may be reasonable to lower the QA limit in this region. However, this region is of less interest because of the low radiation values present.

Table 3-7. Flagging Convention for Direct Normal UV Radiation

Flag	Description
0	Untested data
1	Passed one-element test; data from -2 to +2 Wh/m²
3	Passed two-element test; ratio from 0.004 to 0.080; if NIP < 50 Wh/m², data < NIP/4
7	Failed one-element test; data below -2 Wh/m²
8	Failed one-element test; data greater than +2 Wh/m²
94	Failed two-element test; ratio less than 0.004; if NIP < 50 Wh/m², data < -2 Wh/m²
95	Failed two-element test; ratio greater than 0.080; if NIP < 50 Wh/m², data > NIP/4
99	Missing data

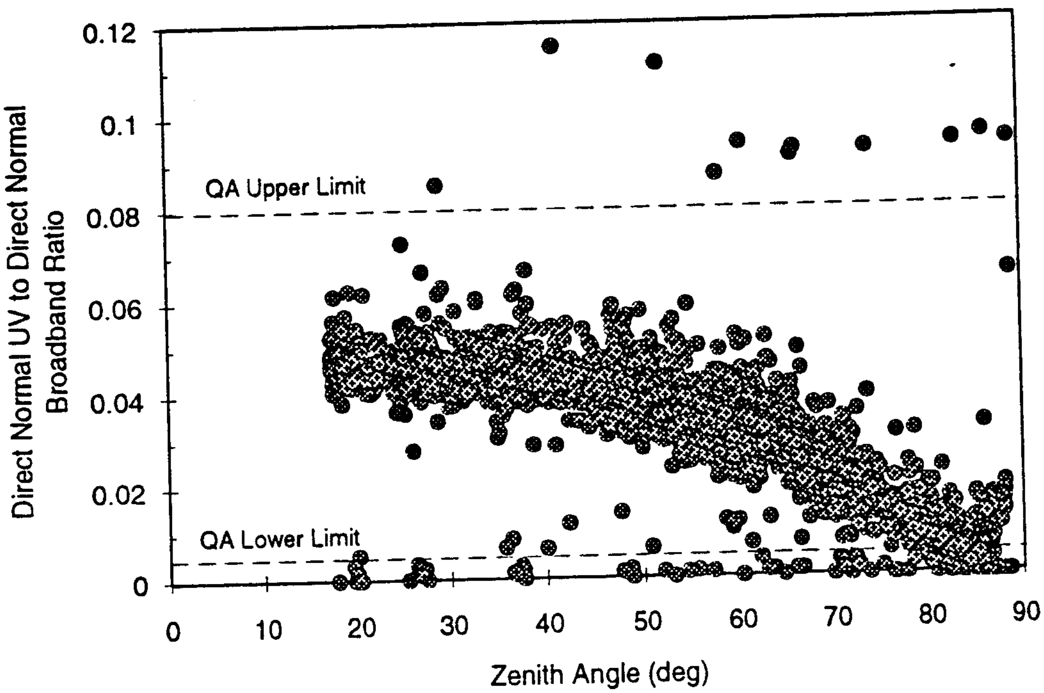

Figure 3-7. **1991 ratios of direct normal UV radiation to direct normal broadband radiation versus zenith angle**

3.8 QA for Global Horizontal Ultraviolet Radiation

This element was measured with an Eppley Photometer model TUVR that measures radiation in the UV region from about 295 to 385 nm. By comparison, an Eppley PSP measures broadband radiation from about 285 to 2800 nm. Quality assessment procedures for this element are similar to those presented in Section 3.7.

Quality assessment of global horizontal UV radiation data was performed using a one-element test for data when the sun was below the horizon (nighttime) and a two-element test for data when the sun was above the horizon (daytime). The one-element test checked for data from -2 to +2 Wh/m^2, reasonable night time values for properly functioning instrumentation. The two-element test checked to see if the UV global to broadband global radiation ratio (UV data value divided by the PSP data value) was between 0.025 and 0.100. These limits were estimated based on previous work at NREL (Riordan, Hulstrom, and Myers 1990 and Mehos, Pacheco, and Link 1992). For small data values, the calculated ratios were often outside these limits because the instrument error, as a percentage of the measured value, was larger. An increase in percentage of error at low values may be from a nonlinear response of the instrument or an offset error in the data acquisition system. Consequently, for this report, when the PSP data were less than 50 Wh/m^2, the UV data were just checked to see that they did not exceed 25% of the PSP value. No test was performed if the PSP data were: (1) missing, (2) not within 0.05 of their boundaries during their two-element QA test, or (3) not within ±0.05 of satisfying $K_t = K_d + K_n$ during their three-element QA test. Flags were assigned to the data according to the convention listed in Table 3-8.

Figure 3-8 shows ratios of the UV data value divided by the PSP data value as a function of the sun's zenith angle for data collected during 1991. Data pass the two-element test if they reside between the upper and lower limits.

Table 3-8. Flagging Convention for Global Horizontal UV Radiation

Flag	Description
0	Untested data
1	Passed one-element test; data from -2 to +2 Wh/m^2
3	Passed two-element test; ratio from 0.025 to 0.100; if PSP < 50 Wh/m^2, data < PSP/4
7	Failed one-element test; data below -2 Wh/m^2
8	Failed one-element test; data greater than +2 Wh/m^2
94	Failed two-element test; ratio less than 0.025; if PSP < 50 Wh/m^2, data < 0
95	Failed two-element test; ratio greater than 0.100; if PSP < 50 Wh/m^2, data > PSP/4
99	Missing data

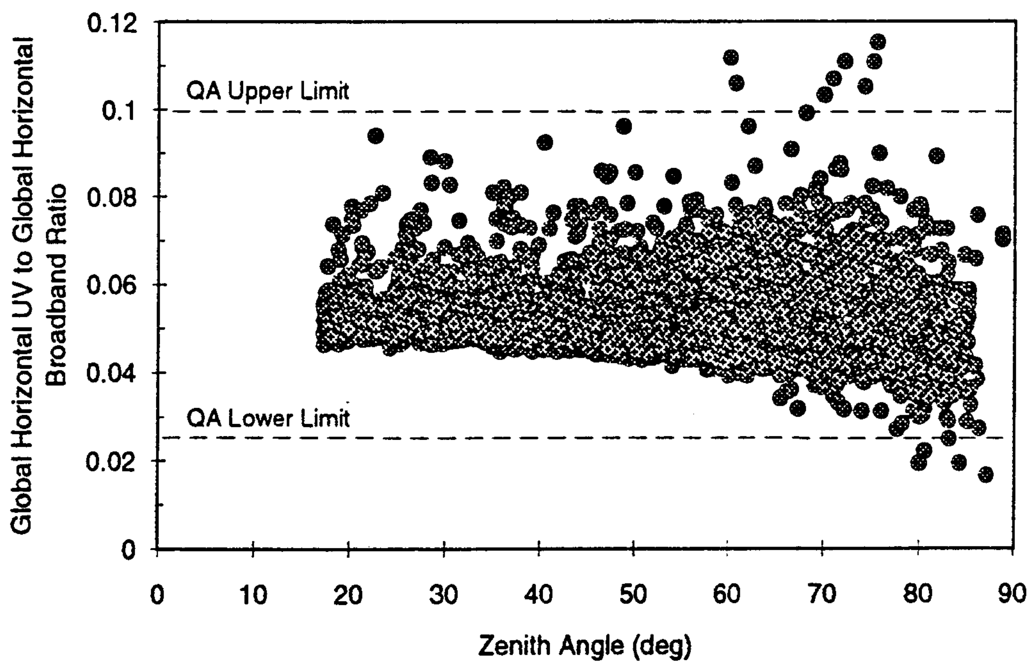

Figure 3-8. 1991 ratios of global horizontal UV radiation to global horizontal broadband radiation versus zenith angle

3.9 QA for Wind Speed and Mean Wind Vector Direction

Quality assessment of the wind speed and mean wind vector direction data was performed using one-element tests to see if the data resided between maximum and minimum values. Acceptable wind speed values were 0 to 40 m/s, and acceptable mean wind vector direction values were 0° to 360°. Flags were assigned to the data according to the convention listed in Table 3-9.

Table 3-9. Flagging Convention for Wind Speed and Mean Wind Vector Direction

Flag	Description
1	Passed one-element test; wind speed between 0 and 40 m/s, or mean wind vector direction between 0° and 360°
7	Failed one-element test; wind speed less than 0 m/s, or mean wind vector direction less than 0°
8	Failed one-element test; wind speed greater than 40 m/s, or mean wind vector direction greater than 360°
99	Missing data

3.10 QA for Dry Bulb Temperature, Relative Humidity, and Atmospheric Pressure

For these meteorological elements, quality assessment was performed using one-element tests to see if the data reside from minimum to maximum values. For dry bulb temperatures, the minimum and maximum were the record lows and highs, by month, for the Denver Stapleton airport. The acceptable range for relative humidity was 3% to 100%, and for atmospheric pressure the acceptable range was 750 to 930 mb. Flags were assigned to the data according to the convention listed in Table 3-10.

Table 3-10. Flagging Convention for Dry Bulb Temperature, Relative Humidity, and Atmospheric Pressure

Flag	Description
1	Passed one-element test; dry bulb temperature between record low and high, by month, or relative humidity from 3% to 100%, or atmospheric pressure from 750 to 930 mb
7	Failed one-element test; dry bulb temperature less than record low, by month, or relative humidity less than 3%, or atmospheric pressure less than 750 mb.
8	Failed one-element test; dry bulb temperature greater than record high, by month, or relative humidity greater than 100%, or atmospheric pressure greater than 930 mb.
99	Missing data

3.11 Summary Information on Quality Assessments

For each solar radiation and meteorological element, the Appendix includes summary information giving the percentage of data collected (not missing) and the percentage of data that passes its quality assessment. The percentage is based on the total daylight hours possible each month and is shown for each month of the period of record.

Except for the global horizontal, diffuse horizontal, and direct normal solar radiation elements, the passing criteria used to generate the tables in the Appendix was the same as described in this section and shown in Tables 3-2 through 3-10. SERI QC assigned quality assessment flags to the global horizontal, diffuse horizontal, and direct normal solar radiation data. The criteria were that the data be within 0.03 of its boundaries during their two-element QA test or within ±0.03 of satisfying the equation $K_t = K_d + K_n$ during their three-element QA test. Because of the measurement uncertainties associated with pyranometers, particularly due to cosine response at large incident angles, the pass criteria for these elements for this work was increased from 0.03 to 0.05 to account for instrument characteristics and to prevent flagging reasonable data as failed. Relaxing the criteria in this manner increased the data passing their quality assessment by about 10%; most of the changes occurred for data collected for solar zenith angles of greater than 70°.

4.0 Hourly Data Files

The SRRL hourly data set consists of four data files. The four data files correspond to time periods when different types and numbers of data elements were collected. Consequently, although the data files have a common structure, the line length for a particular data file depends on the number of data elements. This section describes the data format, identifies the location of each element in a line of data, provides sample read statements for three computer languages, and informs how the hourly data sets may be obtained.

4.1 File Format

Each line of the data file contains the time and the data elements with their respective QA flag. There is one line of data for each hour of the day. Hour values are from 1 to 24 (mountain standard time) and they correspond to data collected for the preceding hour. For example, an hour value of 16 is used for data averaged over the hour from 3 p.m. to 4 p.m. Within a file, data are presented for each hour and day from the beginning to the end of the file. If an element value was missing, a data value of 9900 and a QA flag value of 99 was assigned.

Figure 4-1 shows a sample printout of a portion of a data file. Although this data file contains only six data elements with QA flags, other data files may have up to 15 data elements with QA flags. The data values and flags are expressed as whole numbers.

				Element 1		Element 2		Element 3		Element 4		Element 5		Element 6	
YR	MO	DY	HR	Data	Fl	Data	Fl	Data	Fl	Data	Fl	Data	Fl	Data	Fl
83	1	1	1	-2	1	0	1	1	1	1	1	1	1	-1	1
83	1	1	2	-3	1	0	1	-1	1	1	1	1	1	-2	1
83	1	1	3	-2	1	0	1	0	1	1	1	1	1	-2	1
83	1	1	4	-2	1	0	1	1	1	1	1	1	1	-1	1
83	1	1	5	-3	1	0	1	0	1	1	1	1	1	-2	1
83	1	1	6	-2	1	0	1	0	1	1	1	1	1	-2	1
83	1	1	7	-3	1	0	1	-1	1	1	1	1	1	-2	1
83	1	1	8	15	1	80	1	17	95	56	3	18	1	53	3
83	1	1	9	132	2	435	2	130	95	349	3	129	2	345	3
83	1	1	10	273	2	652	2	260	95	644	3	268	2	632	3
83	1	1	11	387	2	753	2	349	2	851	3	380	2	833	3
83	1	1	12	446	2	801	2	393	2	959	3	444	2	938	3
83	1	1	13	449	2	804	2	394	2	964	3	449	2	941	3
83	1	1	14	393	2	753	2	340	2	862	3	393	2	838	3
83	1	1	15	278	2	658	2	244	2	673	3	291	2	640	3
83	1	1	16	144	2	454	2	130	2	378	3	150	2	361	3
83	1	1	17	25	1	81	1	25	95	70	3	28	1	65	3
83	1	1	18	-3	1	0	1	0	1	1	1	1	1	-2	1
83	1	1	19	-3	1	1	1	0	1	1	1	1	1	-2	1
83	1	1	20	-3	1	1	1	0	1	1	1	1	1	-2	1
83	1	1	21	-3	1	1	1	0	1	1	1	1	1	-2	1
83	1	1	22	-3	1	0	1	-1	1	1	1	1	1	-3	1
83	1	1	23	-3	1	1	1	0	1	1	1	1	1	-2	1
83	1	1	24	-2	1	0	1	0	1	1	1	1	1	-2	1

Figure 4-1. Sample format of data file SRRL1.DAT

4.2 Element Identification

Table 4-1 presents the order in which the time and the data elements and their QA flags occur in a line of data. Because each data file contains a different number of data elements, the order is different for each data file. Also included in the table are the units of measurement for each data element and the names of the four data files and their corresponding dates of measurement.

4.3 Sample Read Statements

The SRRL data files contain ASCII characters that are readable using various computer languages. Sample read statements for three computer languages are shown below for reading a line of data from the file SRRL1.DAT. For the other data files, change the final loop index from 6 to 12 (SRRL2.DAT), 10 (SRRL3.DAT), or 15 (SRRL4.DAT).

IBM BASIC

```
100 INPUT #1, YEAR, MON, DAY, HOUR
110 FOR I = 1 TO 6: INPUT #1, X(I), Y(I): NEXT I
```

FORTRAN

```
    READ(16,100) YEAR, MON, DAY, HOUR, ( X(I), Y(I), I = 1, 6 )
100 FORMAT( 4I3, 6 ( F5.0, I3 ) )
```

C

```
fscanf ( fp_in, "%d %d %d %d", &YEAR, &MON, &DAY, &HOUR );
for ( I = 1; I <= 6; I++ )  fscanf ( fp_in, "%f %d", &X[I], &Y[I] );
```

Where:

YEAR	=	Last two digits of year (89 = 1989)
MON	=	Month of year, 1 to 12
DAY	=	Day of month, 1 to 31
HOUR	=	Hour of day, 1 to 24
X(I)	=	Data value for Ith element, read as floating point number in FORTRAN and C
Y(I)	=	QA flag for Ith element, read as integer number in FORTRAN and C

4.4 Obtaining the SRRL Data Set

The SRRL hourly data set may be obtained by contacting the NREL Technical Inquiry Service at 303/231-7303. The data set is provided on two MS-DOS® formatted 1.44 MB floppy disks. The data files on the floppy disks are compressed to minimize their file size. Uncompressed, the four data files require a total of about 8.5 MB of disk space. The necessary program to uncompress the data files is included on the floppy disks. A "readme" file describes the procedure for uncompressing the data files and installing them on a computer's hard disk.

Table 4-1. Order of Data Elements and Their QA Flags

Element	Units	SRRL1.DAT (7/15/81 to 6/30/83)	SRRL2.DAT (10/25/84 to 4/14/85)	SRRL3.DAT (4/15/85 to 2/29/88)	SRRL4.DAT (3/15/88 to 12/31/91)
Global Horizontal Radiation	Wh/m^2	1	1	1	1
Direct Normal Radiation	Wh/m^2	2	3	3	3
Ground-Reflected Radiation (for albedo)	Wh/m^2	3	12	10	9
Global Radiation on a 40° S-Facing Tilt	Wh/m^2	4		4	4
Global Horizontal Radiation (w/LI-COR)	Wh/m^2	5			
Global Radiation 40° S-Facing Tilt(w/LI-COR)	Wh/m^2	6			
Diffuse Horizontal Radiation (via shadowband)	Wh/m^2		2	2	2
Global Radiation on a 90° N-Facing Tilt Shielded from the Ground	Wh/m^2		4		
Ground-Reflected Radiation on a 90° N-Facing Tilt	Wh/m^2		5		
Global Radiation on a 90° N-Facing Tilt	Wh/m^2		6	6	
Global Radiation on a 90° E-Facing Tilt	Wh/m^2		7	7	
Global Radiation on a 90° S-Facing Tilt Shielded from the Ground	Wh/m^2		8		
Ground-Reflected Radiation on a 90° S-Facing Tilt	Wh/m^2		9		
Global Radiation on a 90° S-Facing Tilt	Wh/m^2		10	8	
Global Radiation on a 90° W-Facing Tilt	Wh/m^2		11	9	
Global Normal Radiation on a Two-Axis Tracking Surface	Wh/m^2			5	5
Direct Normal Infrared Radiation	Wh/m^2				6
Global Horizontal Infrared Radiation	Wh/m^2				7
Global Horizontal UV Radiation	Wh/m^2				8
Wind Speed 10 Meters above Ground	m/s				10
Wind Direction 10 Meters above Ground, N = 0 or 360, E = 90, S = 180, W = 270	Degree				11
Dry Bulb Temperature	°C				12
Relative Humidity	%				13
Atmospheric Pressure	mb				14
Direct Normal UV Radiation	Wh/m^2				15[a]

[a]Direct normal UV radiation measurements began on July 2, 1990. For times prior, missing data values of 9900 and QA flag values of 99 were assigned.

5.0 Summary Data for Key Elements

Summary data were determined for four elements: global horizontal radiation, direct normal radiation, global radiation for a south-facing surface tilted 40° from the horizontal (SRRL latitude = N39.74°), and global normal radiation for a two-axis tracking surface. The summary data includes tables of average daily radiation by month and year, and graphs showing monthly variability, annual variability, and diurnal profiles. The SRRL data are also compared with data from two other data bases. This section begins with a discussion of how missing data and the measurement uncertainty of the instruments determine the uncertainty of the calculated monthly averages.

5.1 Missing Data and Data Uncertainties

When calculating the average daily radiation for a period, both missing data and the measurement uncertainty of the instruments that measured the radiation create an uncertainty in the calculated value.

The total measurement uncertainties of SRRL pyranometers and pyrheliometers have previously been established by Stoffel et al. (1987) by using the method of Abernethy and Ringhiser (1985). This root-sum-square method defines an uncertainty interval $\pm U_{RSS}$ having a 95% confidence level.

$$U_{RSS} = [\ (tR)^2 + B^2\ ]^{1/2} \qquad (1)$$

where:

t = student's T distribution factor, equals 2 for sample size greater than 30
R = random error
B = bias error.

For SRRL pyranometers, the total uncertainty was determined to be 4.4% (3.1% bias and 1.6% random), and for pyrheliometers the total uncertainty was determined to be 3.2% (1.8% bias and 1.3% random). These uncertainties apply to single measurements and include errors due to temperature response, cosine and azimuth response, linearity, spectral response, installation, sensor cleanliness, and data acquisition equipment. For this work, when summing measurements to calculate the average daily radiation for a month, the large number of measurements (sample rate of once every 10 seconds) cause the random errors to cancel each other. Consequently, only the bias error remains (3.1% for pyranometers and 1.8% for pyrheliometers).

Besides the instrument bias error, additional uncertainties in the calculation of the average daily radiation for a month exist if data are missing because of instrument or data acquisition system malfunction. For this analysis, data not meeting their quality assessment criteria are also considered missing. If data for a day are missing, we do not know what the data value should be, but we can expect it to be between a minimum and maximum value. For SRRL, these minimum and maximum values are shown in Table 5-1 and were determined by calculating the solar radiation for each day during the period of record when data were available. Because the period of record is different for the four elements shown in the Table 5-1, it may not be appropriate to compare the elements with each other.

The effect of missing data on the uncertainty of the calculated average daily radiation for a month is addressed by: (1) assuming the radiation for a missing day is the same as the average daily radiation calculated using the available data for the month, (2) assigning a random error to the assumed radiation value that is equal to the absolute difference between the assumed radiation value and the minimum or maximum value from Table 5-1, whichever is larger, and (3) combining the random error due to missing data with the bias error due to the instrument to determine the total uncertainty.

Table 5-1. SRRL Minimum and Maximum Daily Solar Radiation (kWh/m^2)

	Global Horizontal		Direct Normal		Global 40° S Tilt		Global 2-Axis Tracking	
Month	Min	Max	Min	Max	Min	Max	Min	Max
Jan	0.59	3.66	0	8.15	0.53	7.16	0.42	9.71
Feb	0.64	4.98	0	10.00	0.61	7.91	0.53	11.02
Mar	0.71	6.69	0	10.70	0.74	8.44	0.66	12.05
Apr	0.77	7.74	0	11.14	0.66	8.67	0.66	12.53
May	0.90	8.52	0	11.29	0.78	7.84	0.77	12.86
Jun	0.74	8.91	0	11.75	0.62	7.59	0.64	13.07
Jul	1.48	8.67	0	11.37	1.28	7.57	1.34	13.06
Aug	1.01	7.97	0	11.06	0.89	7.65	0.90	11.58
Sep	0.63	6.71	0	10.48	0.52	8.06	0.50	11.52
Oct	0.31	5.61	0	9.95	0.26	7.98	0.23	11.08
Nov	0.35	3.74	0	8.78	0.32	7.22	0.25	9.49
Dec	0.55	2.87	0	7.90	0.50	6.70	0.42	8.70

The random error due to missing data during a month can be evaluated by the method outlined by Holman (1971), where F is a given function of independent variables $X_1, X_2, \ldots X_n$.

$$F = F (X_1, X_2, \ldots X_n) \qquad (2)$$

Letting R be the uncertainty in the result and $R_1, R_2, \ldots R_n$ be the uncertainty in the independent variables:

$$R = \left[(R_1 \, \partial F/\partial X_1)^2 + (R_2 \, \partial F/\partial X_2)^2 + \ldots (R_n \, \partial F/\partial X_n)^2 \right]^{1/2} \qquad (3)$$

If the function F is defined as the average of n values, then the uncertainty in the average becomes:

$$R = (1/n) \left[(R_1)^2 + (R_2)^2 + \ldots (R_n)^2 \right]^{1/2} \qquad (4)$$

As applied to our need to determine the random error created by missing data, equation 4 can be expressed as:

$$R_m = 100 (R_i / I) [(1 - x)/m]^{1/2} \qquad (5)$$

where:

R_m = percentage of random error in calculated average daily radiation for the month
I = calculated average daily radiation for the month using data passing QA
R_i = random error associated with substituting the average daily radiation for the month for missing data. Equals the larger of (I - Min) or (Max - I). Min and Max from Table 5-1.
x = fraction of data during the month that passes their QA (from Appendix)
m = number of days during the month.

Expressing the total uncertainty U of the calculated average daily radiation for the month as a function of both the random error R_m due to missing data and the instrument bias error B:

$$U = (R_m^2 + B^2)^{1/2} \quad (6)$$

This method appears to work well (≈95% confidence level) as long as no more than 30% of the data during the month are missing or fail their QA. Global horizontal and direct normal radiation for two months, March and April of 1991, were examined. Virtually all data were present for these months, and their monthly averages of solar radiation represent values both above and below the long-term averages for SRRL. The uncertainty method was evaluated by selectively deleting days from the monthly data sets to see if the changes in calculated monthly averages from their real values (based on all data present) were within the random error limits calculated using equation 5.

Days were deleted sequentially, and the number of days deleted ranged from 1 to 29. Days for deletion could have been selected at random, but a sequential deletion was used because this is more representative of actual circumstances, particularly when large segments of data are missing. For example, an instrument or data logger failure may interrupt data collection for several days in a row before it is repaired. All possible variations of missing sequential days were checked to see when changes in monthly averages from missing data were within the calculated random error uncertainties. For a month with 30 days, there are 30 possible variations for one day of missing data, 29 for two days of missing data, 28 for three days of missing data, etc.

Until more than nine days (30%) of data are missing, the calculated random error uncertainties and the monthly averages for data sets with deleted data compare favorably with the true monthly average. For 10 or more days of missing data, the relationship was less favorable, particularly for direct normal radiation. Although we treat the missing data as a random error, solar radiation itself is not random and is influenced by season, geographical features, and climate. Consequently, when large segments of data are missing the error may not always be random.

Equation 5 can also be used to stress the importance of maximum data recovery when measuring solar radiation to calculate monthly averages for resource assessment. With only one day of global horizontal radiation data missing, the error introduced in the monthly average because of missing data can be as large as the bias error of the instrument. For direct normal radiation, the error in the monthly average because of missing one day of data can be twice as large as the bias error of the instrument. Direct normal radiation is more variable, and the pyrheliometer measuring it has less instrument error than the pyranometer measuring global solar radiation.

5.2 Average Daily Radiation

The average daily radiation by month and year are shown in Tables 5-2 through 5-5 for global horizontal radiation, direct normal radiation, global radiation for a south-facing surface tilted 40° from the horizontal, and global normal radiation for a two-axis tracking surface. The percentage uncertainty for each value was determined using equations 5 and 6 and is shown in parenthesis below the value. For months with more than 30% of the data missing or failing their QA, the greater than symbol (>) is used to show that the uncertainty is likely greater than determined. Also given in the table are the annual average daily radiation and the minimum, maximum, and average daily radiation for each calendar month. The percentage uncertainty for these values was determined using equations 4 and 6. To be conservative, values for months with more than 30% of the data missing or failing their QA were excluded when determining the minimum, maximum, and average daily radiation for each calendar month. Annual averages are only shown if all months during the year had 30% or less of the data missing or failing their QA.

Table 5-2. SRRL Average Daily Global Horizontal Radiation (kWh/m^2) (Percentage Uncertainty Shown in Parenthesis)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
81							6.32 (>11)	5.34 (3.4)	4.62 (3.4)	3.27 (4.3)	2.82 (4.2)	2.09 (5.3)	
82	1.86 (>13)	3.44 (7.5)	4.84 (5.4)	5.81 (4.4)	5.20 (6.3)	6.27 (4.5)	6.34 (7.3)	6.06 (>13)	3.81 (5.1)	3.39 (>12)	2.51 (3.7)	2.07 (5.0)	
83	2.19 (4.6)	3.23 (3.9)	3.80 (3.6)	5.07 (10.5)	5.41 (4.6)	6.47 (9.0)							
84										3.41 (>16)	2.61 (8.8)	2.25 (6.9)	
85	2.37 (4.3)	3.52 (4.7)	4.69 (3.6)	5.01 (5.1)	6.29 (>12)	6.79 (4.4)	5.76 (6.4)	6.00 (4.8)	4.67 (6.7)	4.19 (>15)	2.34 (>12)	2.23 (4.9)	
86	2.45 (5.7)	3.12 (7.0)	4.30 (3.6)	5.47 (5.0)	6.14 (5.0)	6.38 (5.0)	6.56 (>13)	5.40 (5.4)	4.23 (4.8)	3.42 (4.9)	2.42 (7.1)	2.27 (5.2)	
87	2.46 (5.5)	2.98 (4.1)	4.30 (4.2)	5.72 (6.1)	5.08 (5.6)	6.13 (8.0)	6.75 (6.3)	5.39 (5.4)	5.00 (4.2)	4.00 (>10)	2.63 (>11)	1.97 (4.7)	
88	2.45 (4.9)	3.49 (4.9)	4.85 (>11)	5.57 (5.0)	6.30 (6.6)	6.94 (7.9)	5.58 (>11)	5.83 (>10)	5.08 (4.5)	3.67 (4.5)	2.68 (5.2)	2.28 (>9)	
89	2.61 (6.7)	3.30 (5.2)	4.54 (4.7)	5.12 (5.5)	5.72 (7.2)	5.91 (5.8)	7.00 (5.0)	5.80 (5.8)	4.75 (4.3)	3.69 (5.5)	2.81 (6.4)	2.01 (5.4)	4.44 (3.4)
90	2.66 (4.4)	3.19 (4.1)	3.88 (4.3)	4.47 (4.3)	6.03 (4.0)	7.42 (4.7)	5.56 (4.8)	5.57 (4.9)	4.87 (3.6)	3.86 (4.0)	2.67 (4.3)	2.35 (4.2)	4.38 (3.3)
91	2.61 (4.7)	3.28 (3.4)	4.78 (3.2)	4.94 (4.1)	5.96 (4.3)	6.24 (4.6)	6.05 (4.8)	5.14 (6.2)	4.92 (3.8)	3.87 (4.7)	2.54 (7.2)	2.30 (5.0)	4.39 (3.3)
Min	2.19 (4.6)	2.98 (4.1)	3.80 (3.6)	4.47 (4.3)	5.08 (5.6)	5.91 (5.8)	5.56 (4.8)	5.14 (6.2)	3.81 (5.1)	3.27 (4.3)	2.42 (7.1)	1.97 (4.7)	
Max	2.66 (4.4)	3.52 (4.7)	4.84 (5.4)	5.81 (4.4)	6.30 (6.6)	7.42 (4.7)	7.00 (5.0)	6.00 (4.8)	5.08 (4.5)	3.87 (4.7)	2.82 (4.2)	2.35 (4.2)	
Ave	2.48 (3.4)	3.28 (3.4)	4.39 (3.3)	5.24 (3.5)	5.73 (3.5)	6.51 (3.6)	6.24 (3.7)	5.52 (3.5)	4.66 (3.3)	3.63 (3.4)	2.63 (3.6)	2.17 (3.4)	4.40 (3.2)

Table 5-3. SRRL Average Daily Direct Normal Radiation (kWh/m^2) (Percentage Uncertainty Shown in Parenthesis)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
81							6.04 (>13)	5.11 (2.7)	5.20 (2.4)	4.71 (3.9)	5.15 (3.6)	3.89 (6.2)	
82	1.57 (>51)	5.16 (8.5)	5.97 (5.4)	6.48 (4.0)	4.26 (11.1)	5.93 (4.0)	6.44 (8.9)	6.19 (>15)	3.94 (8.3)	4.15 (>18)	3.83 (3.2)	3.27 (7.8)	
83	2.91 (8.4)	4.00 (4.9)	2.98 (6.1)	3.97 (>22)	4.39 (7.5)	6.03 (9.8)							
84										6.27 (>17)	4.48 (9.7)	4.75 (8.2)	
85	3.95 (4.6)	5.11 (4.6)	5.30 (2.9)	5.24 (5.8)	6.48 (>13)	6.75 (4.0)	5.02 (9.7)	6.82 (4.8)	5.78 (7.1)	6.71 (>16)	3.37 (>21)	4.50 (5.3)	
86	4.91 (6.7)	3.84 (12.8)	5.01 (3.1)	5.45 (5.2)	5.77 (5.1)	5.92 (4.8)	7.49 (>16)	5.14 (6.6)	4.51 (6.0)	4.80 (4.8)	4.12 (8.7)	4.94 (5.9)	
87	4.47 (6.3)	3.89 (5.6)	4.84 (4.4)	6.59 (4.5)	4.36 (9.1)	4.66 (>23)	7.24 (7.6)	5.15 (6.6)	6.30 (3.8)	5.97 (3.6)	4.59 (>11)	3.17 (7.2)	
88	3.95 (5.6)	5.53 (5.0)	5.07 (>14)	5.70 (4.9)	6.09 (7.2)	7.20 (8.9)	5.68 (8.7)	5.88 (4.2)	6.67 (4.3)	5.46 (4.0)	4.64 (6.1)	4.66 (>11)	
89	5.29 (8.3)	4.14 (7.3)	5.35 (3.8)	4.71 (7.2)	4.83 (10.9)	4.93 (12.6)	7.51 (5.4)	6.27 (6.2)	6.35 (3.9)	5.79 (5.7)	5.42 (6.8)	3.43 (8.0)	5.34 (2.7)
90	5.51 (4.6)	4.85 (4.0)	4.24 (5.5)	3.84 (7.0)	5.68 (3.5)	8.22 (4.5)	4.97 (6.6)	5.80 (5.0)	6.27 (2.7)	6.14 (3.2)	4.82 (4.0)	5.03 (3.6)	5.45 (2.2)
91	4.78 (4.3)	5.09 (2.3)	6.27 (2.0)	4.21 (5.0)	5.29 (4.6)	5.90 (4.2)	6.22 (5.2)	5.17 (7.9)	5.87 (3.2)	5.63 (4.1)	3.87 (9.3)	4.03 (5.4)	5.20 (2.2)
Min	2.91 (8.4)	3.84 (12.8)	2.98 (6.1)	3.84 (7.0)	4.26 (11.1)	4.93 (12.6)	4.97 (6.6)	5.11 (2.7)	3.94 (8.3)	4.71 (3.9)	3.83 (3.2)	3.17 (7.2)	
Max	5.51 (4.6)	5.53 (5.0)	6.27 (2.0)	6.59 (4.5)	6.09 (7.2)	8.22 (4.5)	7.51 (5.4)	6.82 (4.8)	6.67 (4.3)	6.14 (3.2)	5.42 (6.8)	5.03 (3.6)	
Ave	4.47 (2.8)	4.62 (2.7)	5.00 (2.2)	5.28 (2.5)	5.08 (3.1)	6.36 (3.0)	6.15 (3.3)	5.73 (2.6)	5.65 (2.3)	5.50 (2.3)	4.54 (2.9)	4.11 (2.7)	5.33 (2.0)

Table 5-4. SRRL Average Daily Global Radiation (kWh/m^2) on a 40° South-Facing Tilt (Percentage Uncertainty Shown in Parenthesis)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
81							5.82 (>11)	5.32 (3.5)	5.37 (3.5)	4.58 (4.5)	4.93 (4.8)	4.03 (6.9)	
82	2.71 (>22)	5.20 (8.4)	5.81 (6.3)	5.73 (6.0)	4.69 (6.4)	5.47 (4.5)	5.73 (7.4)	6.00 (>13)	4.43 (5.3)	4.64 (>12)	4.23 (3.9)	3.90 (5.7)	
83	3.78 (5.3)	4.82 (4.1)	4.65 (4.6)	5.23 (>11)	5.01 (5.0)	5.83 (9.1)							
84													
85				4.41 (>14)	5.87 (11.6)	5.88 (4.5)	5.12 (6.5)	6.02 (4.9)	5.49 (7.0)	5.92 (>16)	4.01 (>13)	4.45 (5.4)	
86	4.70 (6.8)	4.56 (7.6)	5.39 (3.7)	5.70 (5.3)	5.67 (5.1)	5.55 (5.1)	6.09 (>13)	5.42 (5.6)	4.94 (4.9)	4.93 (5.0)	4.21 (7.7)	4.84 (6.2)	
87	4.66 (6.3)	4.54 (4.4)	5.47 (4.8)	6.23 (6.9)	4.40 (7.7)	3.50 (>19)	6.16 (6.6)	5.49 (5.6)	6.17 (4.3)	5.78 (>11)	4.38 (>13)	3.52 (5.8)	
88	4.41 (5.6)	5.55 (5.3)	5.84 (>12)	6.01 (5.1)	5.89 (6.8)	6.10 (8.4)	4.92 (>11)	6.17 (>10)	6.26 (4.7)	5.46 (4.6)	4.76 (6.3)	4.68 (>10)	
89	4.99 (8.4)	4.94 (5.9)	5.67 (4.9)	5.52 (5.9)	5.28 (7.6)	5.10 (8.5)	6.38 (5.1)	5.39 (>10)	5.91 (4.7)	5.53 (6.0)	5.19 (6.8)	3.63 (6.6)	
90	5.21 (4.9)	5.03 (4.3)	4.96 (4.5)	4.70 (4.4)	5.62 (4.1)	6.49 (4.8)	5.08 (4.9)	5.79 (5.0)	5.96 (3.9)	5.92 (4.0)	4.91 (4.8)	4.84 (4.5)	5.38 (3.2)
91	5.01 (5.2)	5.24 (3.5)	6.25 (3.2)	5.36 (4.5)	5.68 (4.5)	5.54 (4.7)	5.53 (4.9)	5.29 (6.4)	5.87 (5.5)	5.77 (5.0)	4.47 (7.7)	4.59 (5.6)	5.38 (3.3)
Min	3.78 (5.3)	4.54 (4.4)	4.65 (4.6)	4.70 (4.4)	4.40 (7.7)	5.10 (8.5)	5.08 (4.9)	5.29 (6.4)	4.43 (5.3)	4.58 (4.5)	4.21 (7.7)	3.63 (6.6)	
Max	5.21 (4.9)	5.55 (5.3)	6.25 (3.2)	6.23 (6.9)	5.89 (6.8)	6.49 (4.8)	6.38 (5.1)	6.02 (4.9)	6.26 (4.7)	5.92 (4.0)	5.19 (6.8)	4.84 (4.5)	
Avc	4.68 (3.7)	4.99 (3.5)	5.46 (3.4)	5.61 (3.6)	5.28 (3.6)	5.75 (3.7)	5.67 (3.7)	5.56 (3.5)	5.60 (3.4)	5.36 (3.5)	4.67 (3.7)	4.23 (3.6)	5.38 (3.2)

Table 5-5. SRRL Average Daily Global Normal Radiation (kWh/m²) on a Two-Axis Tracking Surface (Percentage Uncertainty Shown in Parenthesis)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
85				6.03 (>15)	9.05 (12.2)	9.23 (4.5)	7.57 (7.0)	8.96 (5.2)	7.21 (8.8)	7.76 (>16)	4.95 (>13)	5.61 (5.8)	
86	6.00 (7.4)	5.55 (8.8)	6.99 (4.2)	7.77 (5.7)	8.19 (5.5)	8.50 (5.4)	9.32 (>14)	7.41 (6.0)	6.44 (5.1)	6.18 (5.1)	5.30 (8.3)	6.20 (6.3)	
87	5.86 (7.4)	5.52 (5.4)	7.07 (5.6)	8.40 (6.8)	6.28 (8.3)	6.79 (>15)	9.34 (7.2)	7.58 (5.9)	8.06 (7.3)	7.54 (>11)	5.71 (>13)	4.40 (6.7)	
88	5.69 (6.8)	7.25 (6.4)	7.59 (>12)	8.16 (5.4)	8.78 (7.2)	9.71 (8.8)	7.90 (>12)	8.58 (>11)	8.54 (4.9)	7.10 (4.9)	5.95 (7.2)	5.68 (>11)	
89	6.57 (9.0)	6.24 (6.9)	7.46 (5.3)	7.29 (6.0)	7.49 (8.4)	7.64 (9.1)	9.92 (5.4)	7.65 (>11)	7.90 (4.7)	7.40 (6.6)	6.60 (7.2)	4.58 (6.9)	
90	6.83 (5.1)	6.58 (4.6)	6.37 (4.7)	6.29 (4.9)	8.47 (4.1)	10.79 (5.2)	7.53 (5.3)	7.95 (5.3)	8.03 (3.6)	7.57 (4.2)	6.16 (4.7)	6.06 (4.7)	7.39 (3.3)
91	6.16 (5.4)	6.64 (3.8)	8.08 (3.3)	6.85 (4.7)	8.00 (5.3)	8.67 (5.2)	8.60 (5.3)	7.51 (7.2)	8.13 (4.6)	7.45 (6.7)	5.51 (8.8)	5.80 (6.9)	7.29 (3.4)
Min	5.69 (6.8)	5.52 (5.4)	6.37 (4.7)	6.29 (4.9)	6.28 (8.3)	7.64 (9.1)	7.53 (5.3)	7.41 (6.0)	6.44 (5.1)	6.18 (5.1)	5.30 (8.3)	4.40 (6.7)	
Max	6.83 (5.1)	7.25 (6.4)	8.08 (3.3)	8.40 (6.8)	8.78 (7.2)	10.79 (5.2)	9.92 (5.4)	8.96 (5.2)	8.54 (4.9)	7.57 (4.2)	6.60 (7.2)	6.20 (6.3)	
Ave	6.19 (4.0)	6.30 (3.8)	7.19 (3.5)	7.46 (3.7)	7.87 (3.9)	9.09 (3.9)	8.59 (3.9)	7.88 (3.8)	7.76 (3.6)	7.14 (3.7)	5.90 (4.3)	5.44 (3.8)	7.34 (3.2)

Figure 5-1 shows the average daily radiation for each calendar month and the average annual daily radiation. The annual radiation for direct normal and for a south-facing surface tilted 40° from the horizontal are approximately equal, wheras the global normal radiation for a two-axis tracking surface is about 36% greater (based on the common data collection period 1990-1991). During June the two-axis tracking surface receives, on the average, 57% more radiation than the south facing surface tilted 40° from the horizontal, but only 29% more during December (based on the common data collection period 1985-1991).

Figure 5-2 shows how the average daily radiation varies by month over a three-year period from January 1989 to December 1991. Global horizontal radiation varies the most from winter to summer. Changes in global normal radiation for a two-axis tracking surface parallel changes in direct normal radiation. For the two-axis tracking surface, direct normal radiation is the major component. Changes in global radiation for a south-facing surface tilted 40° from the horizontal do not parallel changes in direct normal radiation because the contribution of direct normal radiation changes throughout the year due to the changing position of the sun with season.

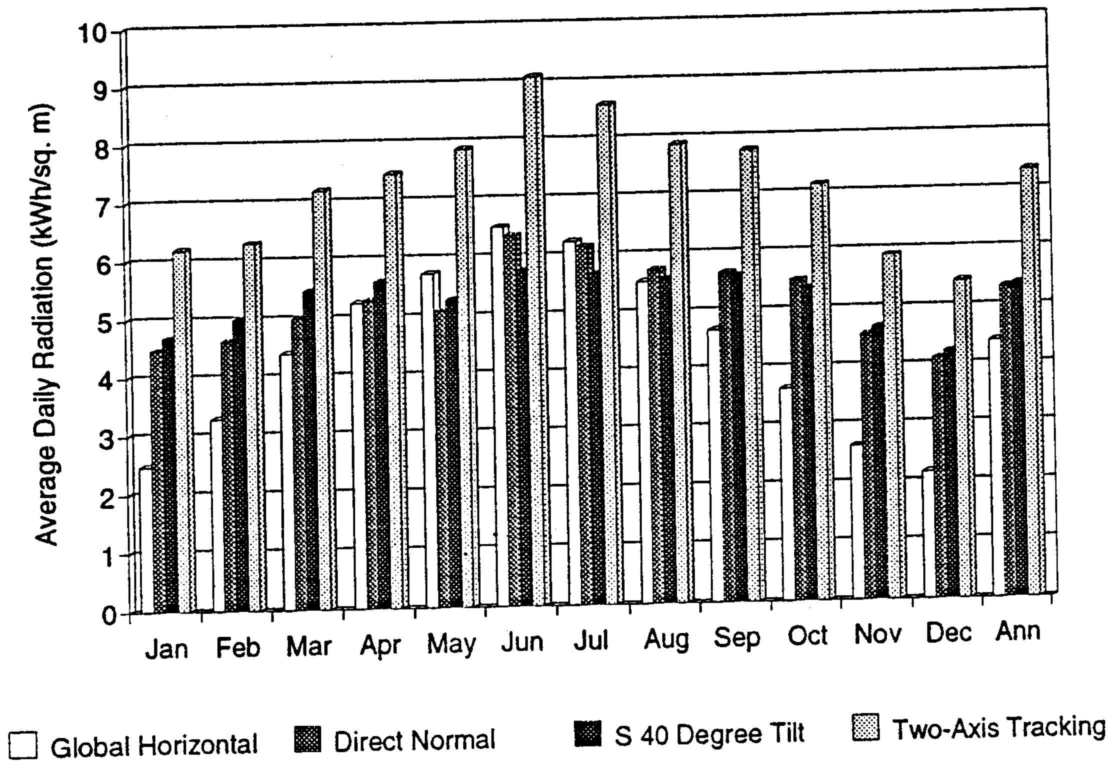

Figure 5-1. SRRL average solar radiation

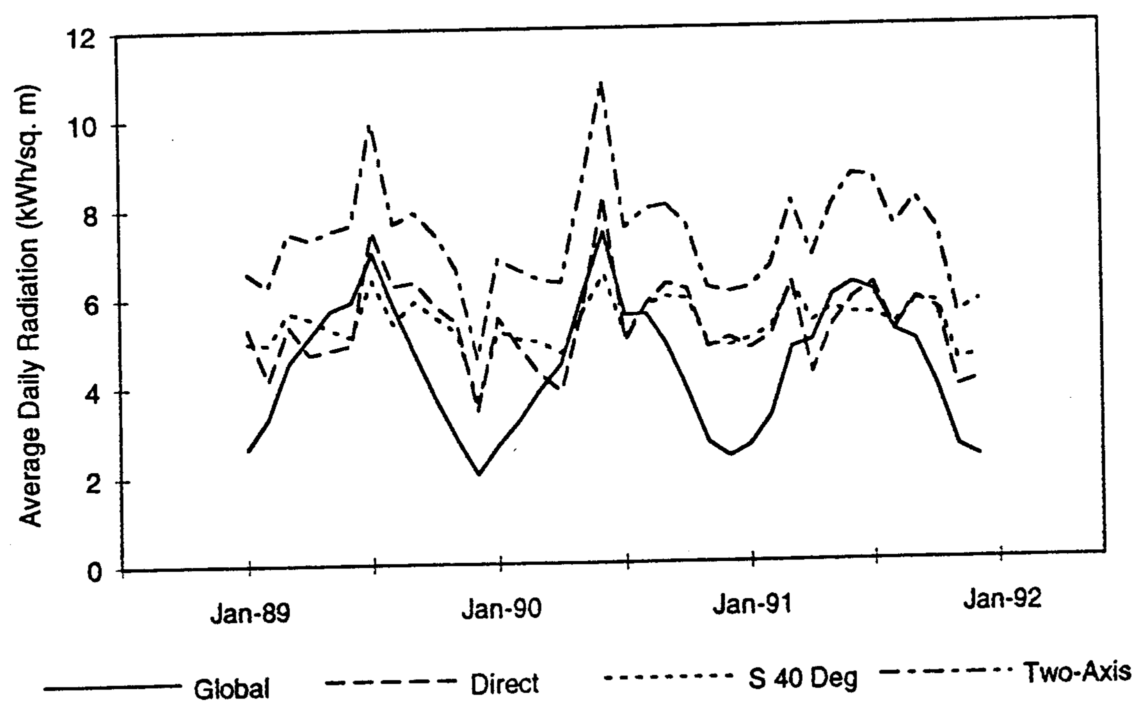

Figure 5-2. SRRL average solar radiation from January 1989 to December 1991

5.3 Comparison with Other Data Bases

Besides the SRRL data at Golden, two other sources of nearby solar radiation data are the ERSATZ data for Denver and the National Solar Radiation Data Base (NSRDB) data for Boulder. The ERSATZ data contains modeled data from 1952 to 1975, and the NSRDB data contains measured and modeled data from 1961 to 1990. Although they cover different time spans, it is informative to compare the average monthly and annual values of the three data bases. This comparison is shown in Figures 5-3 and 5-4 for global horizontal radiation and direct normal radiation. ERSATZ values are greater than the SRRL values. On an annual basis they are 12% greater for global horizontal radiation and 20% greater for direct normal radiation. SRRL and NSRDB compare better; NSRDB annual averages are only a few percent greater than those for SRRL. Other measurement sites also have observed poor agreement between their measurements and the modeled ERSATZ data. In fact, this was one of the main arguments for establishing the NSRDB.

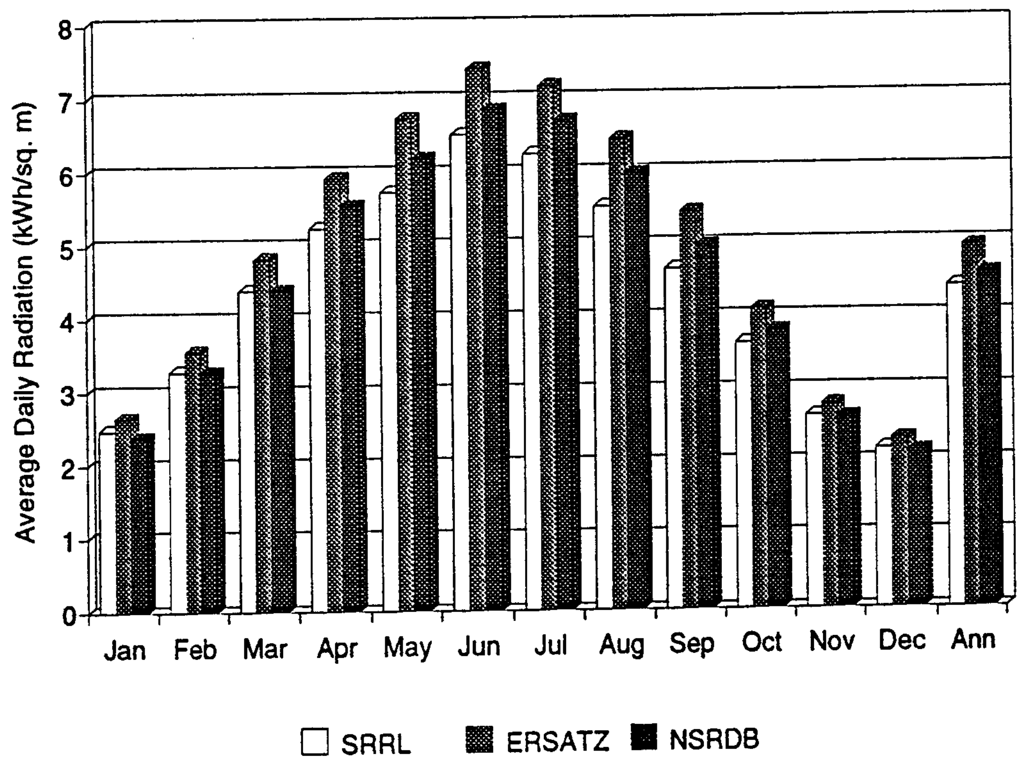

Figure 5-3. Comparison of SRRL, ERSATZ, and NSRDB global horizontal radiation

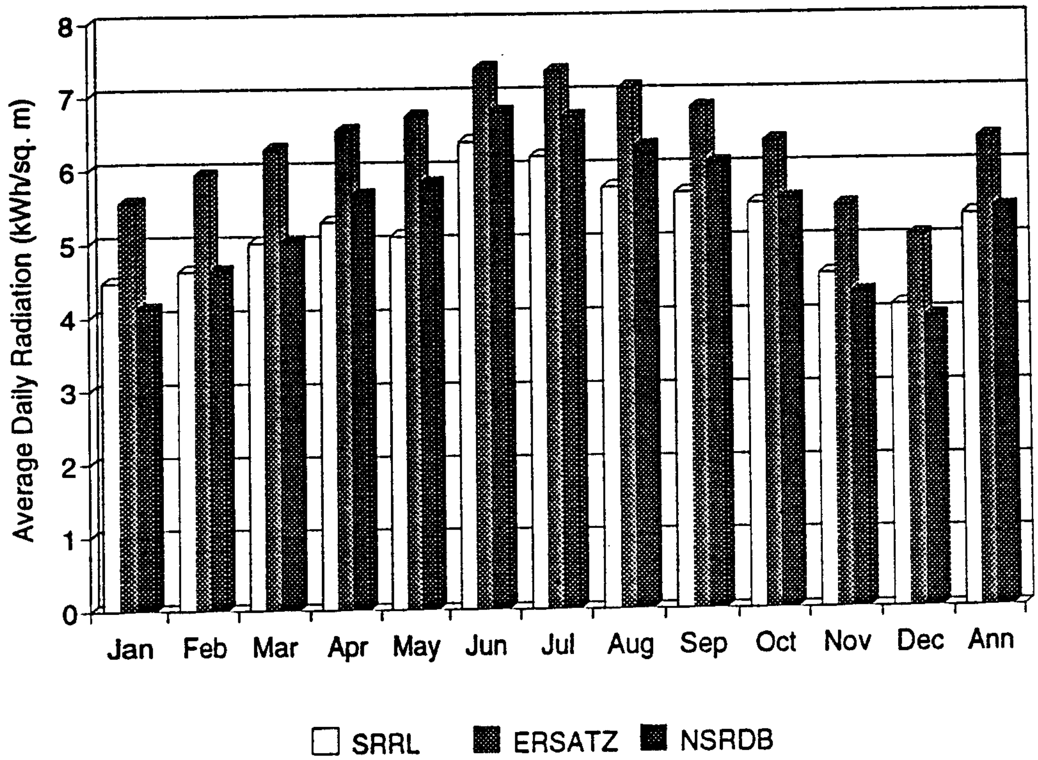

Figure 5-4. Comparison of SRRL, ERSATZ, and NSRDB direct normal radiation

5.4 Monthly and Annual Variability

Monthly variability for global horizontal radiation, direct normal radiation, global radiation for a south-facing surface tilted 40° from the horizontal, and global normal radiation for a two-axis tracking surface are shown in Figures 5-5 through 5-8. The figures show the ratio of radiation for a particular month to the average radiation for that month recorded over the period of record. Values greater than one indicate that more radiation than average was received.

Direct normal radiation shows the largest monthly variability. The variations were generally within ±25%, except for late 1982 and early 1983. Low radiation values during this period resulted from two events: the eruption of El Chichon in Mexico in March of 1982 and an El Niño. Volcanic eruptions spew large amounts of dust into the atmosphere that increase the scattering and absorption of radiation. Several years may elapse before all the volcanic dust falls out of the atmosphere and the effects are no longer seen. An El Niño results from large bodies of warm water in the western Pacific that disrupt weather patterns; consequently, increases in cloudiness may result, and the amount of solar radiation may be reduced. Recent volcanic activity includes the eruption of Mt. Pinatubo in the Philippines in June 1991. This was one of the larger eruptions of this century, and its full effect will be shown in data collected during 1992 and 1993.

Global horizontal radiation shows the least monthly variability; variations are generally within ±15%. Monthly variability for global radiation for a south-facing surface tilted 40° from the horizontal and for global normal radiation for a two-axis tracking surface was greater than for global horizontal radiation but less than that for direct normal radiation. Because global normal radiation for a two-axis tracking surface has a larger component of direct normal radiation than the global radiation for the south-facing tilted surface, it shows a larger monthly variability.

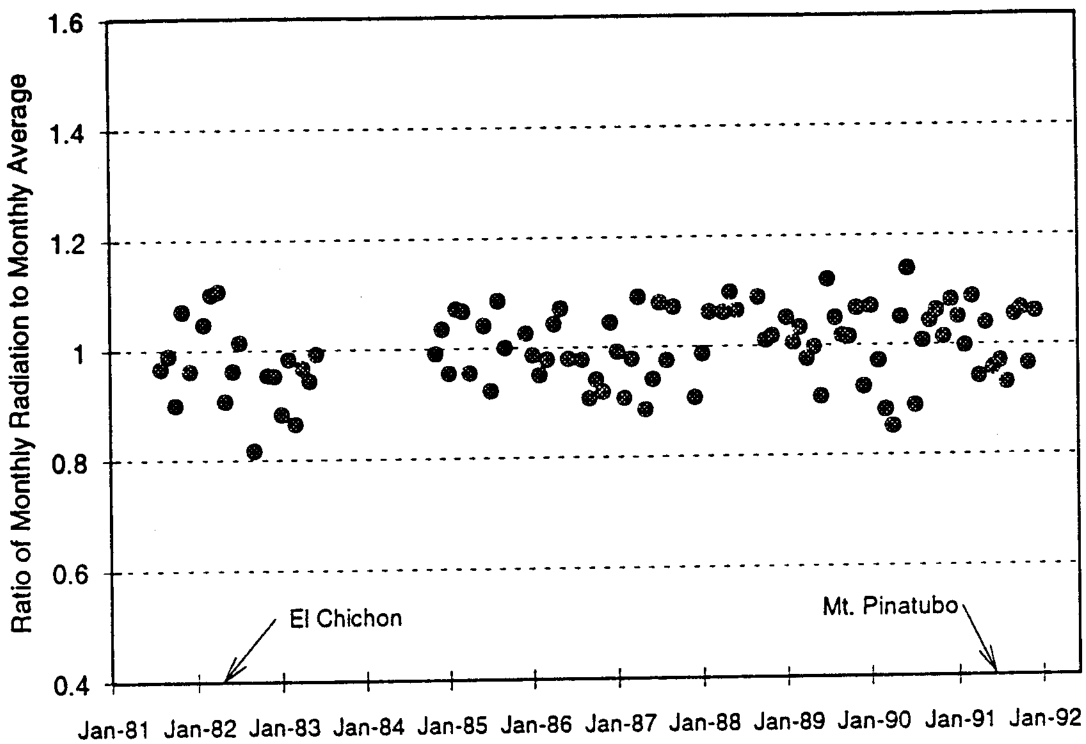

Figure 5-5. Monthly variability of SRRL global horizontal radiation

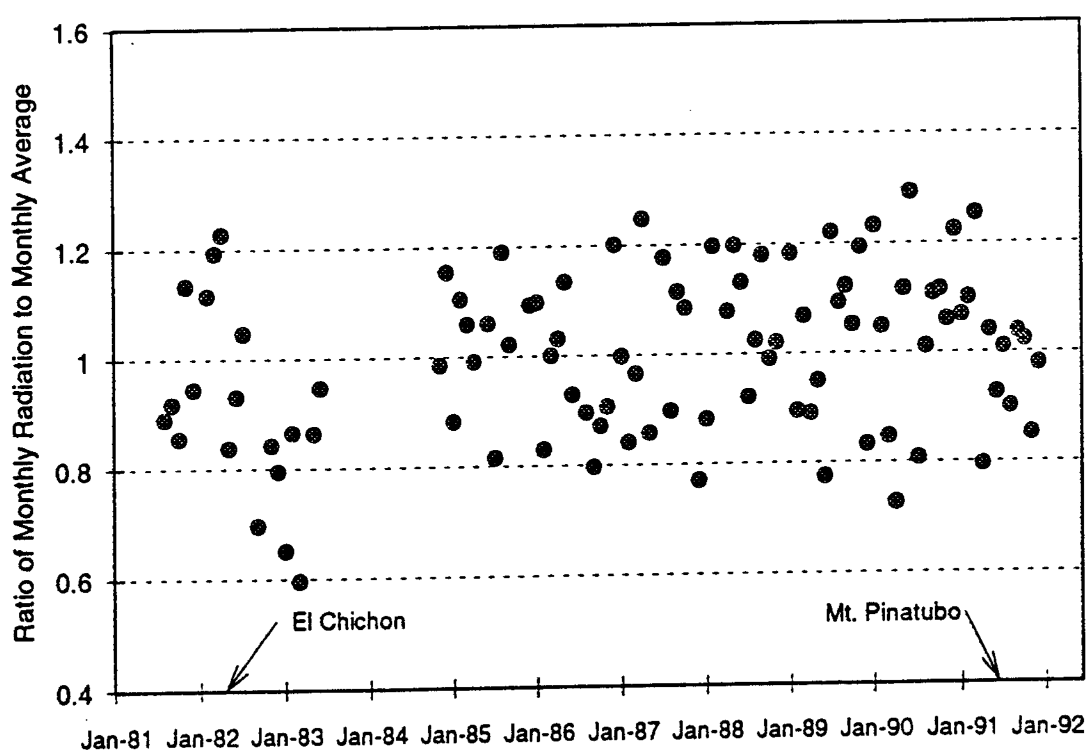

Figure 5-6. Monthly variability of SRRL direct normal radiation

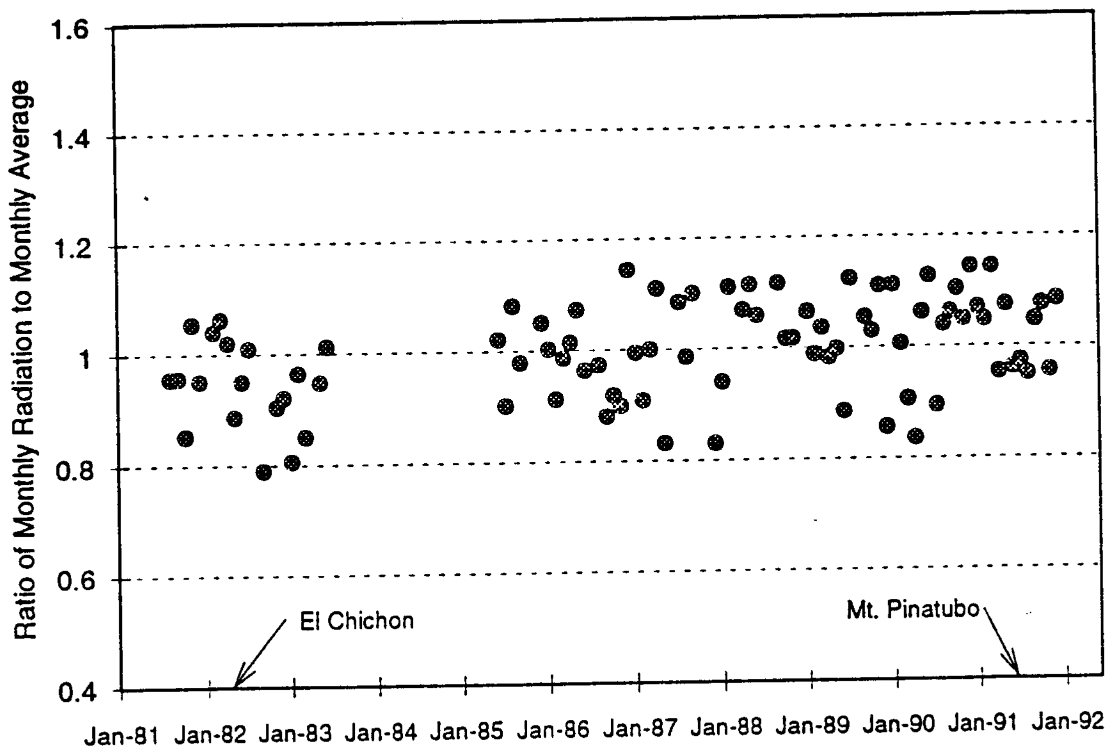

Figure 5-7. Monthly variability of SRRL global radiation on a 40° south-facing tilt

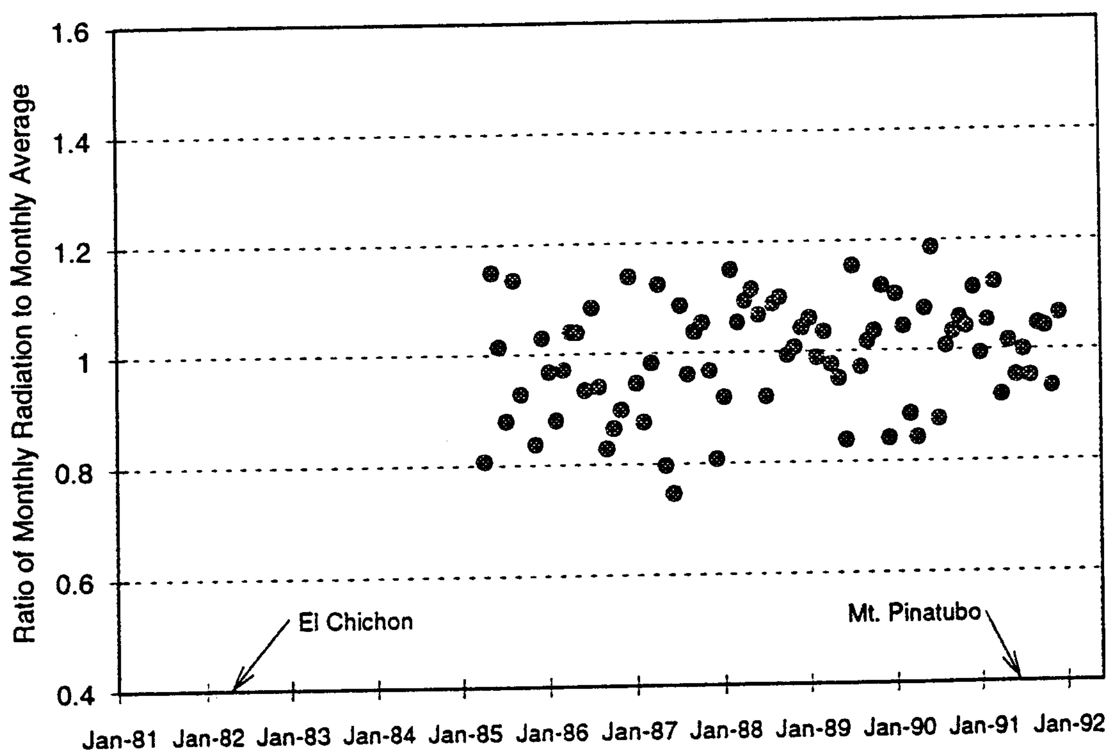

Figure 5-8. Monthly variability of SRRL global normal radiation on a two-axis tracking surface

Because prior to 1989 there were some months during the year when more than 30% of the data were missing, annual averages were only calculated for 1989 to 1991 data. Consequently, there is not a clear picture of the annual variability. From the available data, annual variability is much less than the monthly variability and is greatest for direct normal radiation.

5.5 Average Daily Profile for August 1990

For some solar energy applications, the timing of the delivery of the generated energy is as important as the total quantity of energy delivered. For example, utility engineers may want to know if the output of a solar electric power plant could reliably and economically help meet their daytime electric demand. Using average hourly values for August 1990, Figure 5-9 shows how the solar radiation for three different collector types varies throughout the day. August 1990 data were used for this figure because the data values are close to the average for August. The data points in the figure represent data collected over the preceding hour. The radiation profiles are representative of existing weather conditions for that time of year: relatively clear morning, with increasing cloudiness during the afternoon. Consequently, more solar radiation is available during the morning than in the afternoon, and tracking collectors would also be more beneficial in the morning (when compared with collectors facing south having a fixed tilt). If desired, the hourly data sets can be used to determine hourly profiles for other months and years for SRRL.

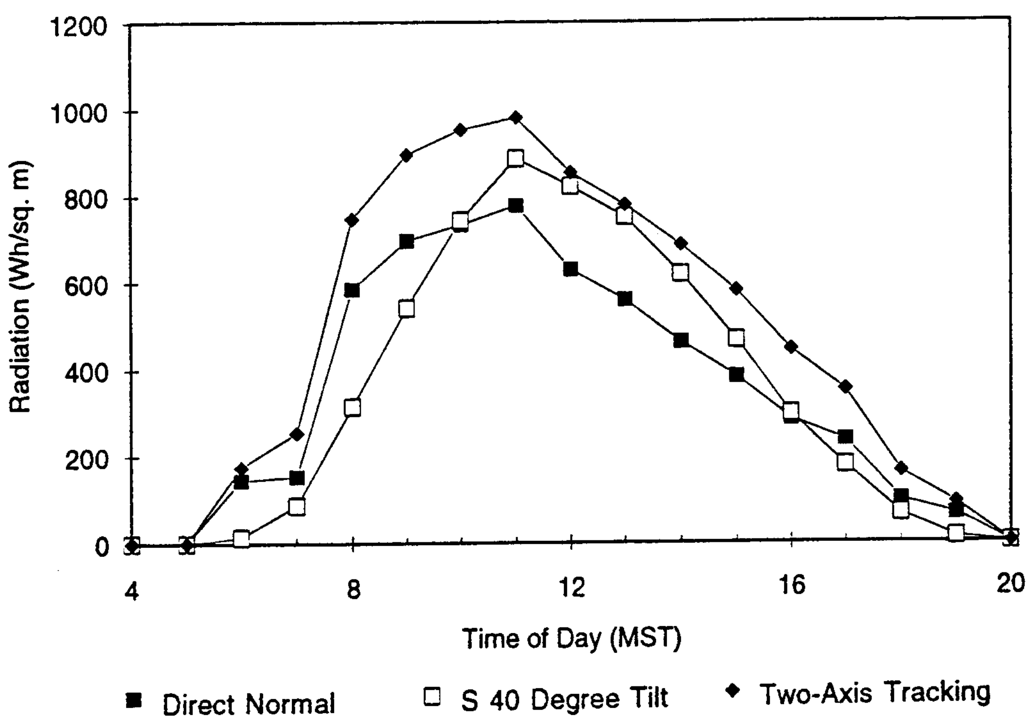

Figure 5-9. SRRL average daily radiation profiles for August 1990

6.0 References

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Appendix

Instrument and Quality Assessment Summaries

Table of Contents

Introduction

This appendix contains tables showing, for each solar radiation and meteorological element, when instruments and calibration factors were changed and the quality assessment summary for daylight hours for each month of the period of record.

The quality assessment summary tables give two numbers for each month: (1) the percentage of possible data collected and (2) the percentage of data that passes their quality assessment (shown as bold face numbers in the tables). The percentages are based on the total daylight hours possible for each month. Section 3.11 provides additional discussion on how these tables were derived.

A.1 Global Horizontal Radiation

Sensor Instrument: Eppley Laboratory pyranometer, model PSP

Table A-1. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
7/15/81	18039F3	8.43
10/25/84	20079F3	10.20
7/16/87	20079F3	9.93
9/19/88	20079F3	9.86
10/8/90	25825F3	9.80

Table A-2. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
81							53 **52**	99 **99**	100 **99**	100 **97**	98 **97**	100 **90**
82	75 **53**	82 **80**	92 **92**	96 **96**	88 **86**	97 **96**	77 **77**	31 **31**	94 **93**	54 **53**	99 **98**	95 **91**
83	96 **93**	98 **97**	100 **98**	59 **58**	100 **95**	73 **73**						
84										18 **17**	74 **73**	82 **80**
85	99 **95**	100 **95**	100 **98**	99 **93**	53 **49**	100 **96**	88 **83**	100 **94**	88 **86**	23 **22**	57 **51**	100 **92**
86	100 **88**	95 **83**	100 **98**	98 **94**	99 **93**	97 **94**	28 **24**	100 **91**	100 **94**	100 **95**	100 **83**	100 **90**
87	100 **89**	100 **97**	99 **97**	94 **89**	98 **90**	99 **79**	100 **85**	100 **91**	100 **97**	68 **66**	91 **58**	99 **93**
88	100 **92**	98 **94**	55 **54**	97 **94**	89 **86**	83 **80**	44 **40**	65 **61**	99 **96**	99 **96**	100 **93**	77 **68**
89	100 **82**	99 **92**	99 **95**	99 **92**	100 **82**	100 **91**	97 **92**	93 **89**	100 **96**	100 **92**	100 **88**	99 **89**
90	100 **95**	99 **97**	100 **96**	100 **96**	100 **97**	100 **95**	96 **92**	100 **93**	99 **99**	99 **98**	99 **97**	100 **96**
91	100 **94**	100 **99**	100 **100**	100 **97**	100 **96**	100 **96**	99 **93**	100 **86**	99 **98**	99 **95**	93 **83**	93 **92**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.2 Direct Normal Radiation

Sensor Instrument: Eppley Laboratory pyrheliometer, model NIP

Table A-3. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
7/15/81	19791E6	8.53
1/10/83	17834E6	8.39
5/18/83	19791E6	8.49
6/3/83	17834E6	8.17
10/25/84	17836E6	8.26
9/19/88	17836E6	8.38
1/3/90	17836E6	8.47

Notes concerning instrument operation:

1. NIP 19791E6 was replaced on 1/10/83 because of moisture contamination.
2. NIP 17834E6 was replaced on 5/18/83 because of moisture contamination.
3. NIP 19791E6 was replaced on 6/3/83 because of moisture contamination.

A.2 Direct Normal Radiation (continued)

Table A-4. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
81							53 **52**	99 **99**	100 **99**	100 **97**	98 **97**	100 **90**
82	75 **54**	82 **81**	92 **92**	96 **96**	88 **86**	97 **96**	77 **77**	31 **31**	94 **93**	54 **53**	99 **99**	95 **91**
83	96 **94**	98 **97**	100 **98**	59 **58**	99 **93**	73 **73**						
84										18 **17**	74 **73**	82 **80**
85	99 **95**	100 **95**	100 **98**	99 **93**	53 **49**	100 **96**	88 **83**	100 **94**	88 **86**	23 **22**	57 **52**	100 **92**
86	99 **87**	95 **83**	100 **98**	98 **94**	99 **93**	97 **94**	28 **24**	100 **91**	100 **94**	100 **95**	100 **83**	100 **90**
87	100 **89**	100 **97**	99 **97**	100 **95**	98 **90**	53 **33**	100 **83**	100 **90**	100 **97**	100 **97**	99 **66**	99 **93**
88	100 **92**	98 **94**	55 **54**	97 **94**	89 **85**	80 **77**	80 **78**	100 **96**	99 **95**	99 **96**	96 **90**	77 **67**
89	99 **80**	99 **93**	99 **97**	99 **92**	100 **80**	87 **76**	97 **92**	93 **89**	100 **96**	100 **91**	100 **87**	99 **89**
90	100 **95**	99 **97**	100 **96**	100 **96**	100 **97**	100 **95**	96 **93**	100 **93**	99 **99**	99 **98**	99 **96**	100 **97**
91	100 **95**	100 **99**	100 **100**	100 **98**	100 **96**	100 **96**	99 **93**	100 **86**	99 **98**	99 **96**	93 **84**	93 **92**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.3 Ground-Reflected Radiation

Sensor Instrument: Eppley Laboratory pyranometer, model PSP (inverted to face ground)

Table A-5. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
7/15/81	18036F3	7.91
10/25/84	18035F3	8.45
7/16/87	18035F3	8.34
9/19/88	18035F3	8.35

Table A-6. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
81							53 **45**	99 **92**	100 **89**	100 **84**	98 **85**	100 **78**
82	75 **41**	82 **70**	92 **80**	96 **94**	88 **79**	97 **85**	77 **65**	31 **21**	94 **49**	54 **45**	99 **94**	95 **79**
83	96 **84**	98 **92**	100 **84**	59 **54**	100 **91**	73 **64**						
84										18 **17**	74 **70**	82 **74**
85	99 **88**	100 **85**	100 **94**	46 **42**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**
86	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**	0 **0**
87	100 **79**	100 **86**	99 **83**	100 **76**	98 **84**	98 **34**	100 **75**	100 **82**	100 **87**	100 **59**	99 **52**	99 **85**
88	100 **85**	98 **89**	55 **50**	97 **89**	90 **81**	83 **74**	81 **35**	99 **56**	99 **83**	99 **89**	100 **86**	77 **63**
89	100 **73**	99 **88**	99 **89**	100 **85**	100 **69**	100 **78**	97 **82**	93 **30**	100 **0**	100 **0**	100 **0**	99 **0**
90	100 **0**	99 **0**	100 **0**	100 **0**	100 **0**	100 **0**	96 **0**	100 **0**	99 **0**	99 **0**	99 **0**	100 **0**
91	100 **0**	100 **0**	100 **0**	100 **21**	100 **85**	100 **82**	99 **82**	100 **76**	99 **87**	99 **87**	93 **72**	93 **84**

Notes:
1. Top number is percentage of possible data collected; boldface number is percentage of data passing QA.
2. From May 1985 to December 1986 and from August 1989 to April 1991 the pyranometer was disconnected or inoperative. Data for this period is flagged missing or failed QA.

A.4 Global Radiation on a 40° South-Facing Tilt

Sensor Instrument: Eppley Laboratory pyranometer, model PSP

Table A-7. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
7/15/81	17798F3	8.43
4/15/85	20068F3	10.57
7/16/87	20068F3	10.12
9/18/88	20068F3	10.05
9/1/89	20068F3	9.91
7/17/90	25822F3	9.60
5/17/91	20068F3	9.94

Table A-8. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
81							53 **52**	99 **99**	100 **99**	100 **96**	98 **95**	100 **85**
82	75 **48**	82 **78**	92 **88**	96 **90**	88 **86**	97 **96**	77 **77**	31 **30**	94 **93**	54 **53**	99 **98**	95 **91**
83	96 **93**	98 **97**	100 **95**	59 **58**	100 **93**	73 **73**						
84												
85				53 **46**	53 **49**	100 **96**	88 **82**	100 **94**	88 **86**	24 **22**	57 **51**	100 **92**
86	100 **86**	95 **82**	100 **98**	98 **93**	99 **93**	97 **94**	28 **24**	100 **90**	100 **94**	100 **95**	100 **83**	100 **89**
87	100 **88**	100 **97**	99 **95**	100 **86**	98 **77**	99 **28**	100 **83**	100 **90**	100 **97**	100 **66**	99 **47**	99 **91**
88	100 **91**	98 **94**	55 **54**	97 **94**	90 **85**	83 **77**	79 **40**	98 **61**	99 **95**	99 **96**	100 **89**	77 **67**
89	100 **76**	99 **91**	99 **94**	100 **90**	100 **79**	100 **76**	97 **92**	92 **62**	99 **95**	100 **91**	100 **87**	99 **86**
90	100 **95**	99 **97**	100 **96**	100 **96**	100 **97**	100 **95**	96 **92**	100 **93**	99 **98**	99 **98**	99 **96**	100 **96**
91	100 **93**	100 **99**	100 **100**	100 **96**	100 **96**	100 **95**	99 **93**	100 **86**	99 **93**	99 **95**	93 **83**	93 **91**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.5 Global Horizontal Radiation

Sensor Instrument: LI-COR pyranometer, model LI-200

Table A-9. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor (µV/W/m^2)
7/15/81	PY1366	8.33

Table A-10. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
81							53 **52**	99 **99**	100 **99**	100 **98**	98 **97**	100 **90**
82	75 **55**	82 **81**	92 **92**	96 **96**	88 **86**	97 **96**	77 **77**	31 **31**	94 **93**	54 **53**	99 **98**	95 **91**
83	96 **93**	98 **97**	100 **98**	59 **59**	100 **95**	73 **73**						

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.6 Global Radiation on a 40° South-Facing Tilt

Sensor Instrument: LI-COR pyranometer, model LI-200

Table A-11. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
7/15/81	PY1245	8.54

Table A-12. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
81							53 **52**	99 **99**	100 **98**	100 **96**	98 **97**	100 **83**
82	75 **48**	82 **80**	92 **91**	96 **96**	88 **86**	97 **96**	77 **77**	31 **30**	94 **93**	54 **53**	99 **97**	95 **90**
83	96 **93**	98 **97**	100 **95**	59 **57**	100 **93**	73 **72**						

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.7 Diffuse Horizontal Radiation

Sensor Instrument: Eppley Laboratory pyranometer, model PSP with a shadowband

Table A-13. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
10/25/84	18040F3	8.70
7/16/87	18040F3	8.55
9/19/88	18040F3	8.52
9/1/89	18040F3	8.44
7/17/90	18041F3	7.21
6/18/91	18041F3	7.21

Table A-14. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18 **17**	74 **73**	82 **80**
85	99 **95**	100 **95**	100 **98**	99 **93**	53 **49**	100 **96**	88 **83**	100 **94**	88 **86**	24 **22**	57 **52**	100 **92**
86	100 **87**	95 **83**	100 **98**	98 **94**	99 **93**	97 **94**	28 **24**	100 **90**	100 **94**	100 **95**	100 **83**	100 **90**
87	100 **89**	100 **97**	99 **97**	94 **89**	98 **90**	60 **40**	100 **84**	100 **91**	100 **97**	100 **97**	99 **67**	99 **95**
88	100 **85**	98 **94**	55 **54**	97 **94**	90 **86**	83 **80**	44 **41**	65 **61**	99 **96**	99 **96**	100 **93**	77 **69**
89	100 **82**	99 **93**	99 **94**	99 **92**	100 **83**	100 **91**	97 **92**	60 **55**	99 **96**	100 **85**	100 **86**	99 **90**
90	100 **91**	99 **97**	100 **97**	100 **96**	100 **97**	100 **95**	96 **93**	100 **93**	99 **99**	99 **98**	99 **97**	100 **97**
91	100 **97**	100 **99**	100 **100**	100 **97**	100 **96**	100 **95**	99 **93**	100 **86**	99 **98**	99 **97**	93 **83**	93 **92**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.8 Global Radiation on a 90° North-Facing Tilt Shielded from the Ground

Sensor Instrument: Eppley Laboratory pyranometer, model PSP with a shield placed to prevent measuring radiation reflected from the ground

Table A-15. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
10/25/84	17799F3	8.51

Table A-16. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18 **16**	74 **61**	82 **58**
85	99 **72**	100 **72**	100 **56**	46 **38**								

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.9 Ground-Reflected Radiation on a 90° North-Facing Tilt

Sensor Instrument: Eppley Laboratory pyranometer, model PSP with a shield placed so only radiation reflected up from the ground is measured.

Table A-17. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
10/25/84	17800F3	9.15

Table A-18. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18 **16**	74 **61**	82 **58**
85	99 **72**	100 **72**	100 **56**	46 **38**								

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.10 Global Radiation on a 90° North-Facing Tilt

Sensor Instrument: Eppley Laboratory pyranometer, model PSP

Table A-19. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
10/25/84	18039F3	8.28
7/16/87	18039F3	8.08

Table A-20. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18	74	82
										16	**61**	**58**
85	99	100	100	99	53	100	88	100	88	23	57	100
	72	**72**	**56**	**85**	**49**	**96**	**83**	**94**	**86**	**22**	**51**	**92**
86	100	95	100	98	99	97	28	100	100	100	100	100
	87	**83**	**98**	**94**	**93**	**94**	**24**	**91**	**94**	**95**	**83**	**90**
87	100	100	99	100	98	99	100	100	100	100	99	99
	87	**97**	**92**	**88**	**90**	**31**	**83**	**90**	**97**	**66**	**58**	**92**
88	100	98										
	89	**94**										

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.11 Global Radiation on a 90° East-Facing Tilt

Sensor Instrument: Eppley Laboratory pyranometer, model PSP

Table A-21. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
10/25/84	18078F3	10.09
7/16/87	18078F3	9.80

Table A-22. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										2 **2**	74 **66**	82 **70**
85	99 **88**	100 **87**	100 **92**	99 **89**	53 **48**	100 **96**	88 **81**	100 **88**	88 **79**	24 **18**	57 **50**	100 **90**
86	100 **83**	95 **77**	100 **92**	98 **92**	99 **91**	97 **94**	28 **24**	100 **90**	100 **91**	100 **92**	100 **81**	100 **90**
87	100 **86**	100 **91**	99 **88**	100 **86**	98 **89**	99 **32**	100 **82**	100 **90**	100 **93**	100 **63**	99 **49**	99 **86**
88	100 **88**	98 **87**										

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.12 Global Radiation on a 90° South-Facing Tilt Shielded from the Ground

Sensor Instrument: Eppley Laboratory pyranometer, model PSP with a shield placed to prevent measuring radiation reflected from the ground

Table A-23. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor (μV/W/m^2)
10/25/84	17798F3	8.22

Table A-24. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18 **18**	74 **68**	82 **73**
85	99 **92**	100 **88**	100 **90**	46 **38**								

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.13 Ground-Reflected Radiation on a 90° South-Facing Tilt

Sensor Instrument: Eppley Laboratory pyranometer, model PSP with a shield placed so only radiation reflected from the ground is measured.

Table A-25. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
10/25/84	17863F3	8.35

Table A-26. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18 **18**	74 **68**	82 **73**
85	99 **92**	100 **88**	100 **90**	46 **38**								

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.14 Global Radiation on a 90° South-Facing Tilt

Sensor Instrument: Eppley Laboratory pyranometer, model PSP

Table A-27. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor (μV/W/m^2)
10/25/84	17879F3	9.01
7/16/87	17879F3	8.73

Table A-28. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18 **18**	74 **68**	82 **73**
85	99 **92**	100 **88**	100 **90**	99 **81**	53 **45**	100 **94**	88 **82**	100 **92**	88 **84**	23 **21**	57 **49**	100 **90**
86	100 **80**	95 **77**	100 **87**	98 **85**	99 **87**	97 **92**	28 **23**	100 **89**	100 **92**	100 **92**	100 **80**	100 **88**
87	100 **84**	100 **92**	99 **85**	100 **83**	98 **90**	99 **33**	100 **83**	100 **87**	100 **91**	100 **63**	99 **55**	99 **88**
88	100 **85**	98 **86**										

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.15 Global Radiation on a 90° West-Facing Tilt

Sensor Instrument: Eppley Laboratory pyranometer, model PSP

Table A-29. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor (μV/W/m²)
10/25/84	18036F3	7.90
7/16/87	18036F3	7.72

Table A-30. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84										18 **16**	74 **71**	82 **74**
85	99 **89**	100 **91**	100 **97**	99 **93**	53 **48**	100 **95**	88 **80**	100 **93**	88 **85**	24 **21**	57 **45**	100 **88**
86	100 **85**	95 **81**	100 **98**	98 **93**	99 **92**	97 **92**	28 **24**	100 **89**	100 **94**	100 **94**	100 **81**	100 **81**
87	100 **83**	100 **92**	99 **91**	100 **88**	98 **88**	99 **32**	100 **81**	100 **89**	100 **96**	100 **66**	99 **56**	99 **89**
88	100 **85**	98 **90**										

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.16 Global Normal Radiation on a Two-Axis Tracking Surface

Sensor Instrument: Eppley Laboratory pyranometer, model PSP

Table A-31. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
4/15/85	17860F3	7.81
5/23/85	17861F3	7.92
7/16/87	17861F3	7.70
9/19/88	17861F3	7.51
9/1/89	17861F3	7.36
1/30/90	17861F3	7.36
7/17/90	13674F3	10.45
5/17/91	17861F3	7.37

Table A-32. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
85				53	52	100	88	100	85	23	57	100
				46	**49**	**96**	**82**	**93**	**76**	**21**	**50**	**91**
86	100	95	100	98	99	97	28	100	100	100	100	100
	84	**80**	**97**	**92**	**92**	**93**	**24**	**89**	**94**	**94**	**81**	**89**
87	100	100	99	100	96	99	100	100	100	100	99	99
	84	**95**	**92**	**87**	**83**	**31**	**82**	**90**	**85**	**64**	**46**	**89**
88	100	98	55	97	90	83	75	95	99	99	100	77
	87	**90**	**52**	**93**	**84**	**77**	**40**	**61**	**95**	**95**	**86**	**62**
89	100	99	99	100	100	100	97	86	99	100	100	99
	75	**87**	**93**	**90**	**77**	**74**	**92**	**56**	**96**	**89**	**86**	**86**
90	100	99	100	100	100	100	96	100	99	99	99	100
	94	**96**	**95**	**95**	**97**	**94**	**91**	**93**	**99**	**97**	**96**	**95**
91	100	100	100	100	100	100	99	100	99	99	93	93
	93	**98**	**99**	**95**	**93**	**94**	**92**	**83**	**96**	**88**	**77**	**86**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.17 Direct Normal Near-Infrared Radiation

Sensor Instrument: Eppley Laboratory pyrheliometer, model NIP with a RG780 filter

Table A-33. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor (µV/W/m²)
3/15/88	17837E6	8.32
9/19/88	17837E6	7.59

Table A-34. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55 **54**	97 **87**	90 **78**	83 **73**	81 **77**	100 **89**	99 **90**	99 **95**	100 **84**	77 **60**
89	100 **79**	99 **92**	99 **94**	100 **83**	100 **62**	100 **75**	97 **88**	93 **73**	100 **95**	100 **91**	100 **87**	99 **88**
90	100 **93**	99 **96**	100 **93**	100 **95**	100 **96**	100 **43**	96 **89**	98 **91**	93 **87**	99 **97**	99 **94**	100 **93**
91	100 **92**	100 **98**	100 **97**	100 **96**	100 **92**	100 **93**	99 **92**	100 **83**	99 **97**	99 **94**	93 **83**	93 **91**

Notes:
1. Top number is percentage of possible data collected; boldface number is percentage of data passing QA.
2. Transmittance of RG780 filter checked annually and replaced every two years.

A.18 Global Horizontal Near-Infrared Radiation

Sensor Instrument: Eppley Laboratory pyranometer, model PSP with a RG780 dome

Table A-35. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
3/15/88	25766F3	9.82
9/19/88	25766F3	9.70
7/3/90	25766F3	9.75
5/17/91	17880F3	8.77

Notes concerning instrument operation:

1. RG780 dome replaced on 1/9/90. Transmittance of old dome was approximately 4% greater than the new dome.
2. Transmittance of RG780 filter checked annually and replaced every two years.

Table A-36. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55	97	90	83	80	100	99	99	100	77
			52	**90**	**81**	**73**	**36**	**57**	**88**	**91**	**89**	**64**
89	100	99	99	100	100	100	97	93	100	100	100	99
	78	**89**	**91**	**57**	**6**	**77**	**83**	**67**	**87**	**85**	**82**	**85**
90	100	99	100	100	100	97	96	100	99	99	99	100
	92	**90**	**91**	**87**	**91**	**27**	**77**	**89**	**89**	**92**	**90**	**92**
91	100	100	100	100	100	100	99	100	99	99	93	93
	92	**93**	**95**	**89**	**89**	**81**	**83**	**82**	**90**	**89**	**80**	**89**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.19 Global Horizontal UV Radiation

Sensor Instrument: Eppley Laboratory photometer, model TUVR, 295-385 nm

Table A-37. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
3/15/88	18181	148.6
9/19/88	18181	148.6

Table A-38. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55 **52**	97 **92**	90 **84**	83 **79**	80 **38**	99 **60**	99 **90**	99 **93**	100 **91**	77 **67**
89	100 **81**	99 **91**	99 **93**	100 **90**	100 **78**	100 **85**	97 **85**	93 **87**	100 **91**	100 **88**	100 **85**	99 **88**
90	100 **94**	99 **94**	100 **94**	100 **94**	100 **93**	100 **92**	96 **83**	100 **92**	99 **93**	99 **94**	99 **94**	100 **94**
91	100 **91**	100 **95**	100 **97**	100 **95**	100 **92**	100 **90**	99 **86**	100 **85**	99 **93**	99 **91**	93 **82**	93 **92**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.20 Wind Speed 10 Meters above Ground

Sensor Instrument: Teledyne-Geotech Wind System

Table A-39. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor
3/19/88	058	7.986 m/s/V
9/19/88	059	7.96 m/s/V - 0.276 m/s

Table A-40. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55 **55**	97 **97**	90 **90**	83 **83**	81 **81**	100 **100**	99 **99**	99 **99**	100 **100**	77 **77**
89	100 **100**	99 **99**	99 **97**	100 **100**	100 **100**	100 **100**	97 **97**	93 **93**	100 **100**	100 **98**	100 **100**	99 **99**
90	100 **100**	99 **99**	100 **100**	100 **100**	100 **100**	100 **100**	96 **96**	100 **100**	99 **99**	99 **99**	99 **99**	100 **100**
91	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	99 **99**	100 **100**	99 **99**	99 **99**	93 **93**	93 **93**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.21 Wind Direction 10 Meters above Ground

Sensor Instrument: Teledyne-Geotech Wind System

Table A-41. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor (degree/V)
3/18/88	080	72
9/19/88	081	72

Table A-42. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55 **55**	97 **97**	90 **90**	83 **83**	81 **81**	97 **97**	99 **99**	99 **99**	100 **100**	77 **77**
89	100 **100**	99 **99**	99 **99**	100 **100**	100 **100**	100 **100**	97 **97**	93 **93**	100 **100**	100 **100**	100 **100**	99 **99**
90	100 100	99 99	100 100	100 100	100 100	100 100	96 96	100 100	99 99	99 99	99 99	100 100
91	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	99 **99**	100 **100**	99 **99**	99 **99**	93 **93**	93 **93**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.22 Dry Bulb Temperature

Sensor Instrument: Campbell Scientific, Inc., model 207 probe

Table A-43. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor
3/18/88	N/A	1

Table A-44. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55 **55**	20 **20**	4 **4**	43 **43**	80 **80**	96 **96**	99 **98**	99 **99**	100 **100**	77 **77**
89	100 **100**	99 **99**	99 **92**	100 **100**	100 **100**	100 **100**	97 **97**	93 **93**	100 **100**	100 **100**	100 **100**	99 **99**
90	100 **100**	99 **99**	100 **100**	100 **100**	100 **100**	100 **100**	96 **94**	100 **100**	99 **99**	99 **99**	99 **99**	100 **99**
91	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	99 **99**	100 **100**	99 **99**	99 **99**	93 **93**	93 **93**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.23 Relative Humidity

Sensor Instrument: Campbell Scientific, Inc., model 207 probe

Table A-45. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor
3/18/88	D30206	1
12/27/91	E13601	1

Table A-46. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55 **0**	20 **3**	3 **3**	42 **42**	80 **80**	96 **96**	99 **99**	99 **99**	100 **100**	77 **77**
89	100 **100**	99 **99**	99 **99**	100 **99**	100 **100**	100 **100**	97 **97**	93 **93**	100 **100**	100 **100**	100 **100**	99 **99**
90	100 **100**	99 **99**	100 **100**	100 **100**	100 **100**	100 **100**	96 **96**	100 **100**	99 **99**	99 **99**	99 **99**	100 **100**
91	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	100 **100**	99 **99**	100 **100**	99 **99**	99 **99**	93 **93**	93 **93**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.24 Atmospheric Pressure

Sensor Instrument: Yellow Springs Instrument Company

Table A-47. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor (mb/V + 728.8 mb)
3/18/88	1193	67.58
9/19/88	1193	67.58
11/14/90	18454	67.58
3/14/91	18329	67.58

Table A-48. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88			55 **55**	97 **20**	90 **4**	83 **43**	81 **80**	100 **96**	99 **99**	99 **99**	100 **100**	77 **77**
89	100 **100**	99 **99**	99 **99**	100 **100**	100 **100**	100 **100**	97 **97**	93 **93**	100 **100**	100 **98**	100 **100**	99 **99**
90	100 **74**	99 **0**	100 **55**	100 **41**	100 **0**	100 **0**	96 **86**	100 **98**	99 **96**	99 **97**	99 **99**	100 **100**
91	100 **100**	100 **100**	100 **100**	100 **99**	100 **100**	100 **100**	99 **97**	100 **98**	99 **99**	99 **98**	93 **93**	93 **93**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

A.25 Direct Normal UV Radiation

Sensor Instrument: Eppley Laboratory photometer model TUVR with collimating tube, 295-385 nm

Table A-49. Record of Instrument Changes and Calibration Factors

Date	Serial Number	Calibration Factor ($\mu V/W/m^2$)
3/18/88	18116	99.0

Table A-50. Percent of Possible Daytime Data Collected and Percent Possibly Passing QA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
90							78 **67**	54 **45**	99 **79**	99 **87**	99 **86**	100 **87**
91	100 **86**	100 **96**	100 **96**	100 **96**	99 **87**	100 **95**	99 **91**	100 **81**	99 **96**	99 **92**	93 **78**	82 **75**

Note: Top number is percentage of possible data collected; boldface number is percentage of data passing QA.

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