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Spectral Solar Radiation Data Base Documentation

Volume I

Carol J. Riordan
Daryl R. Myers
Roland L. Hulstrom

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PREFACE

This report documents the Solar Energy Research Institute's spectral solar radiation data base. Volume I describes the history, approach, content, and format of the data, and Volume II contains graphs of each of the spectral solar radiation curves and associated field notes.

This is the first public release of these data. Our intent is to make the data available as soon as possible so that others can use it. However, we also intend to create additional products and data subsets in the future to illustrate applications of the data for special purposes or analyses.

Comments or questions about these data should be directed to the Solar Energy Research Institute, Solar Electric Research Division, Resource Assessment and Instrumentation Branch, in Golden, Colorado, 80401.

ACKNOWLEDGMENTS

SERI would like to acknowledge the work of the Florida Solar Energy Center and the Pacific Gas and Electric Company in building this spectral solar radiation data base. Without their help, this data base would not have been possible.

SUMMARY

Objective

The objective of this report is to provide documentation for the spectral solar radiation data base at the Solar Energy Research Institute. The data reside on magnetic tape.

Discussion

Volume I of this report documents the history, approach, content, and format of the data base. Volume II contains graphs and field notes for each of the spectral data sets. Together, these two volumes should allow users to find and access any particular field of data or desired data subset contained on the magnetic tape.

Conclusions

These data are being released at this point to make the information available to those who have immediate uses or applications. We also intend to create other products and data subsets in the future to illustrate particular applications and analyses.

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1.0 INTRODUCTION

The Solar Energy Research Institute (SERI), Electric Power Research Institute (EPRI), Florida Solar Energy Center (FSEC), and Pacific Gas and Electric Company (PG&E) cooperated to produce a spectral solar radiation data base representing a range of atmospheric conditions (or climates) that is applicable to several different types of solar collectors. These data will help to characterize the natural variability in the spectral (color) content of outdoor solar radiation so that the sensitivity of spectrally selective solar devices (such as photovoltaics, "smart" windows, and biomass) to these variations can be studied quantitatively.

This report documents the history, approach, content, and format of the data base to make it useful to the scientific community. A second volume of this report contains graphs of each of the spectral solar radiation curves and associated field notes. The data are available on magnetic tape in ASCII format and consist of broadband[1] and spectral[2] solar radiation and meteorological measurements, daily field notes, quality control information, and measurement uncertainty. Questions about the data base should be directed to SERI, Solar Electric Research Division, Resource Assessment and Instrumentation Branch in Golden, Colorado.

[1]Broadband: integrated solar radiation, 0.3 to 3 μm.

[2]Spectral: solar radiation as a function of wavelength, 0.3 to 1.1 μm, at 0.002 μm intervals.

2.0 HISTORY

The need for spectral solar radiation data has been expressed in several forums [1-4]. The basic need is for data that can be used with solar collector spectral responsivity data to scientifically and quantitatively determine how the collector responds to natural variations in the spectral content of solar radiation, and thereby determine how its performance is affected. In the photovoltaic (PV) community, for example, there is no consensus on the magnitude of spectral effects because there are no standard procedures for evaluating outdoor spectral sensitivity of PV devices, the sensitivity is device dependent, and the quality and uncertainty of the spectral solar radiation data used in the analyses are unknown or undocumented [5]. In many cases, only one standard or reference spectrum is used to report the performance of a PV device, and the uncertainty associated with natural spectral variations is unknown.

To study the spectral sensitivity of a solar collector, its spectral response, quantum efficiency, or spectral absorption/transmission curve is multiplied by incident spectral solar radiation for a range of realistic outdoor conditions, and the results are integrated over the entire spectrum and the desired time period. All measurement uncertainty (in the spectral data and spectral response) must be evaluated to determine the statistical significance of any variations in the solar collector's performance that are attributed to spectral variations. To make this determination, spectral solar radiation data, with documented measurement uncertainty, are required.

In 1984, EPRI and SERI met to define a research project that would address the need for measured, outdoor spectral solar radiation data for a range of climate conditions. A formal project was initiated in 1985 in which EPRI provided funds to SERI to perform three tasks: (1) modify, calibrate, and deliver to EPRI two computer-controlled LI-COR, Inc. model LI-1800 spectroradiometers; (2) train EPRI-designated operators to use software that acquires spectral solar radiation and concurrent broadband solar radiation and meteorological data; and (3) develop data collection guidelines [6]. EPRI also initiated cooperative agreements with FSEC and PG&E to collect these data at their sites in Cape Canaveral, Fla., and San Ramon, Calif., respectively. In 1986, EPRI extended the agreement with SERI to use remaining project funds to assist with the start-up of measurements at FSEC and PG&E.

Spectral solar radiation and supporting data were collected at FSEC and PG&E and sent to SERI for quality-control processing and archiving [7]. SERI coordinated the data collection, periodically calibrated the spectroradiometers, added data to the data base, and documented and formatted the data base under the Department of Energy (DOE)/SERI Resource Assessment Program.

Data that are included in the data base were collected at FSEC from October 1986 to April 1988, and at PG&E from April 1987 to April 1988. FSEC operated one EPRI and one SERI spectroradiometer almost daily at Cape Canaveral (see Figure 2-1), which contributed nearly 2800 spectra to the data base. PG&E operated one EPRI spectroradiometer at San Ramon, Calif., (see Figure 2-2), as resources permitted, contributing nearly 300 spectra to the data base. SERI collected about 200 spectra in the Denver/Golden, Colo. (see Figure 2-3), area from November 1987 to February 1988 as part of a research project to study urban spectral solar radiation, and added these data to the data base [7].

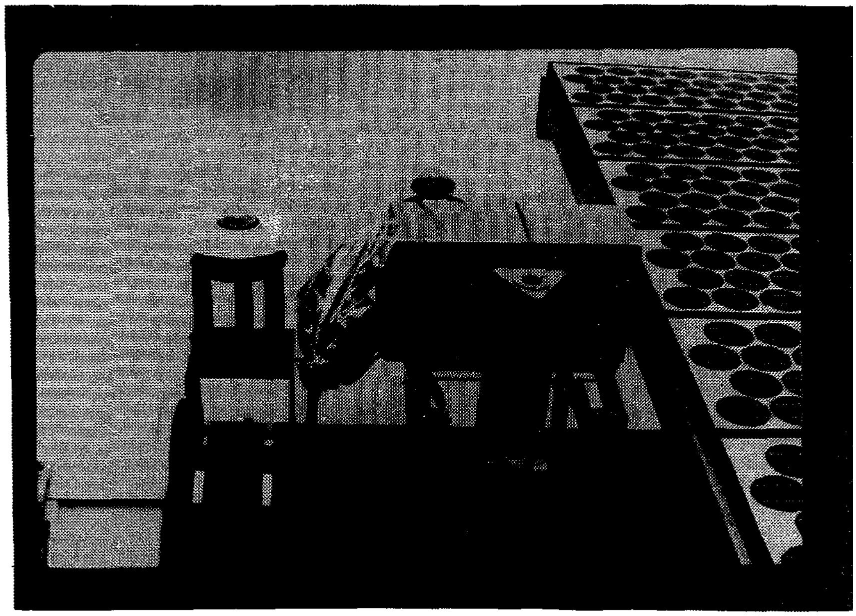


Figure 2-1. Spectral and broadband solar radiation collection at FSEC, Cape Canaveral, Fla., in conjunction with photovoltaic module data in the same plane

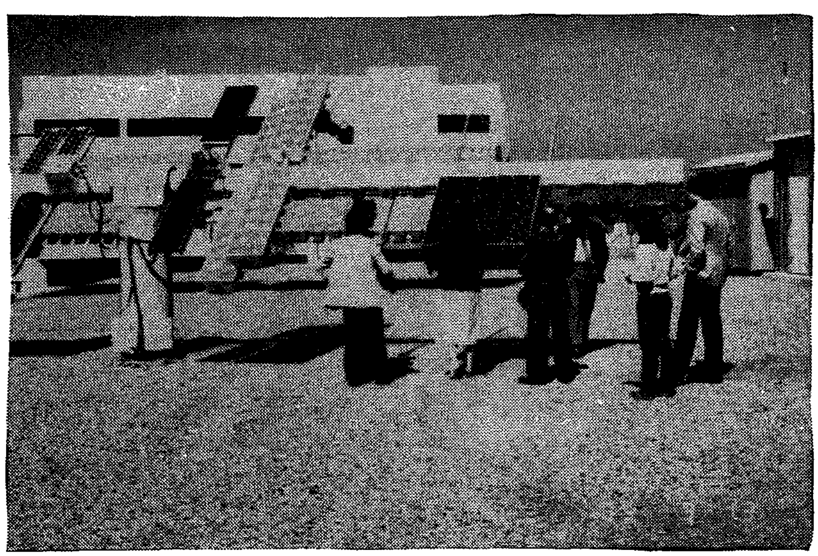


Figure 2-2. Data collection site at PG&E, San Ramon, Calif.

Figure 2-3. Data collection site at Welby, Colo., where SERI acquired research data to study air pollution effects on solar radiation

3.0 APPROACH

A detailed description of the approach for data collection is available in the Data Collection Plan [9]. The goals of this plan were to collect and to archive spectral solar radiation, broadband solar radiation, and meteorological data for a range of air masses and atmospheric conditions from various collector configurations.

A range of air mass values is important because air mass is the path length of the solar beam through the atmosphere (Figure 3-1). Air mass increases with increasing solar zenith angle and thus changes with location (latitude), season, and time of day. As air mass (the path length) increases, there is increased spectral absorption and scattering of solar radiation by atmospheric constituents, such as aerosols and water vapor, and the spectral content of solar radiation at the collector surface changes.

The most important atmospheric variables that determine broadband and spectral solar radiation are cloud cover, atmospheric turbidity (aerosols), precipitable water vapor, and barometric pressure (number of air molecules in the path of the solar beam). To properly document the spectra, it is important to measure or characterize these variables. Several methods can be used, depending on the instruments available at the measurement sites:

- Cloud cover is measured in terms of
  - Opaque sky cover (tenths) and type as determined by an observer, an all-sky photograph, or both.
  - Kt, the atmospheric fractional transmittance of broadband global solar radiation on a horizontal surface (global-horizontal divided by extraterrestrial solar radiation on a horizontal surface); or D/GH, the ratio of direct-to-global broadband solar radiation on a horizontal surface; or both.
- Turbidity is measured in terms of
  - Atmospheric optical depth, due to aerosols, as calculated from narrow-wavelength spectral measurements taken with a sunphotometer or a spectroradiometer measuring direct-beam radiation [10; 11, pp. 118-122].
  - Kn, the atmospheric fractional transmittance of broadband direct-beam solar radiation; or D/GH, as described previously; or both.
- Precipitable water vapor is
  - Calculated from sunphotometer or spectroradiometer measurements [12].
  - Measured with a balloon radiosonde on-site or at a nearby National Weather Service station.
  - Calculated from measured relative humidity or dew-point temperature [13].

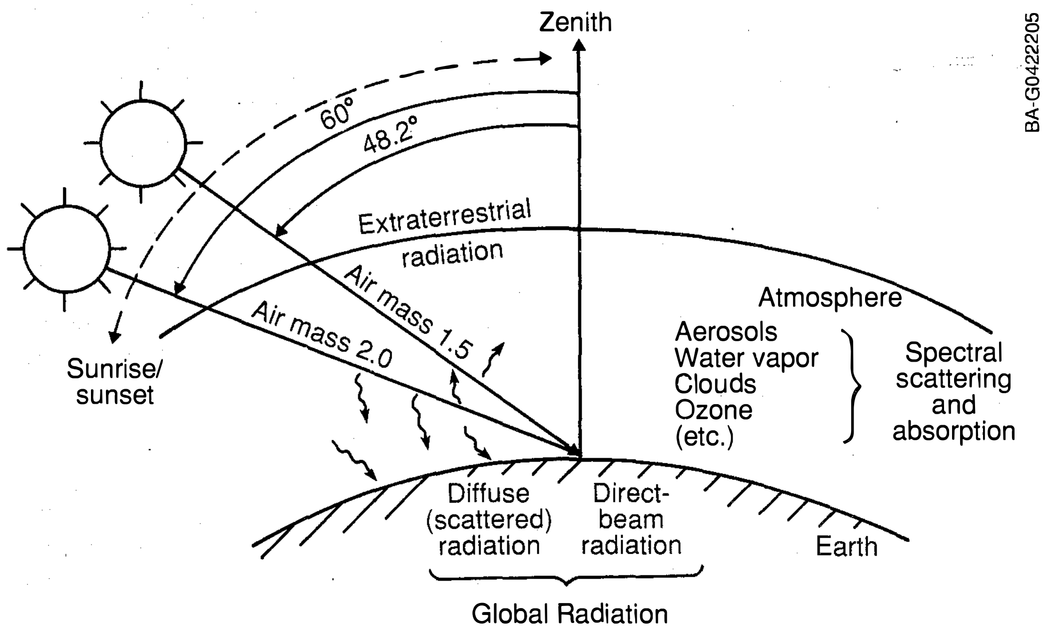


Figure 3-1. The atmosphere acts as a temporally and spatially variable filter on solar radiation. The path length (air mass) of direct-beam radiation increases with increasing solar zenith angle; scattering and absorption increase with longer path lengths. Global radiation on a horizontal plane (G_h) is equal to the direct-beam radiation (from the solar disk) normal to the surface (D_n), multiplied by the cosine of the solar zenith angle (z), plus scattered radiation from the sky (S). For a tilted (rather than horizontal) plane, D_n is multiplied by the cosine of the incidence angle. The surface also receives radiation reflected from the ground to the surface (R). These relationships are:

Direct normal	D_n
Global horizontal	$G_h = D_n \times \cos(z) + S$
Global tilt	$G_t = D_n \times \cos(\theta) + S + R$
Global normal	$G_n = D_n + S + R$

- Barometric pressure is
  - Measured with a barometer.
  - Calculated using site elevation [11, p. 100].

At least one of these options is used for each variable to document atmospheric conditions during the spectral solar radiation measurements. Redundant information is used for quality-control checks.

The spectral solar radiation measurements were made in several different measurement modes corresponding to solar collector configurations. Directnormal solar radiation (radiation from the solar disk in about a 5-deg field of view) is used by concentrating (focusing) collectors; global-normal (direct plus scattered radiation on a surface normal to the solar disk) is used by two-axis, sun-tracking, flat-plate collectors; and global-tilt is used by fixed-tilt flat plates, such as south-facing collectors tilted at the latitude angle, or single-axis tracking flat plates. Global-horizontal (direct plus scattered radiation on a horizontal surface) is used to develop and test models that convert global radiation to radiation on a surface of any orientation, such as building walls and windows; the photosynthetically active region of the spectrum is also important for biomass applications. The diffuse spectra (sky radiation, with the solar disk blocked) included in the data base were measured as part of SERI's research data collection to examine air pollution effects in the Denver/Golden area.

Spectral solar radiation data were acquired using spectroradiometers with the following characteristics:

- Holographic grating monochromator
- Wavelength range: 0.3 - 1.1 μm
- Bandwidth: 0.006 μm
- Scanning step size: 0.002 μm
- Scan time: 27 s.

Several modifications were made to these spectroradiometers by SERI [14]. A view-limiting tube was placed over the Teflon dome receiver (diffuser) to make direct-normal measurements (Figure 3-2). For global measurements, the Teflon dome was replaced by an integrating sphere (Figure 3-3), although the Teflon dome (Figure 3-4) was sometimes used for global-normal measurements. A temperature controller was added to each spectroradiometer to maintain the silicon detector temperature at 40°C.

The spectroradiometers were calibrated at SERI every six months against standard lamps traceable to the National Institute of Standards and Technology [NIST, formerly National Bureau of Standards (NBS)]. In this process, the spectroradiometers were calibrated in the laboratory and then compared with one another outdoors (Figure 3-5) to determine spectral uncertainty limits, precision (or repeatability) errors, and bias error estimates.

At the measurement sites, the instruments were checked monthly against a reference lamp (LI-COR Optical Radiation Calibrator) to monitor instrument stability; these results were reported to SERI. (Measurement uncertainty is reported in detail in references 15, 16 and a summary is given in Section 5.)

Table 3-1 lists the data collected to calculate or specify the atmospheric conditions and properly document each spectrum in the data base. The broadband solar radiation data were measured to correspond with the different spectroradiometer measurement modes and to calculate atmospheric descriptors, such as Kt. Ground albedo was included because it affects both solar radiation

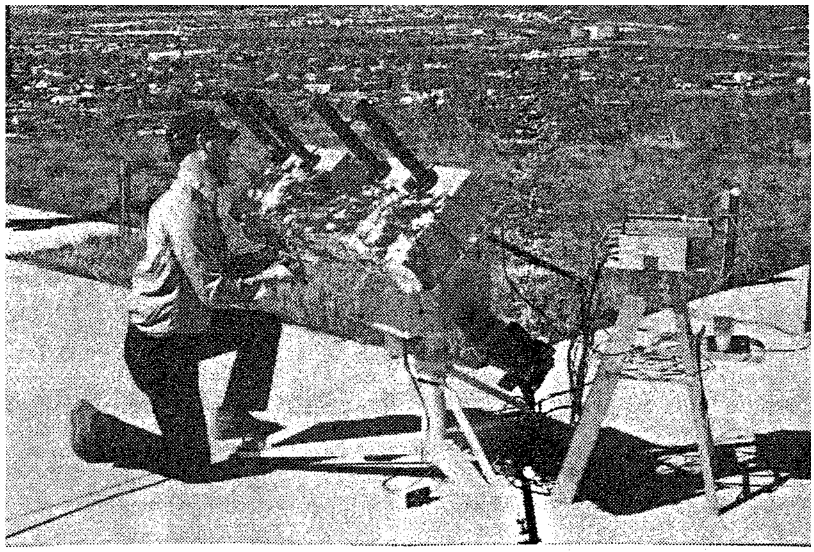


Figure 3-2. Spectroradiometers equipped with view-limiting tubes to acquire direct-normal solar radiation. Aluminum foil was placed over the instruments to reflect radiation and keep the instruments from overheating

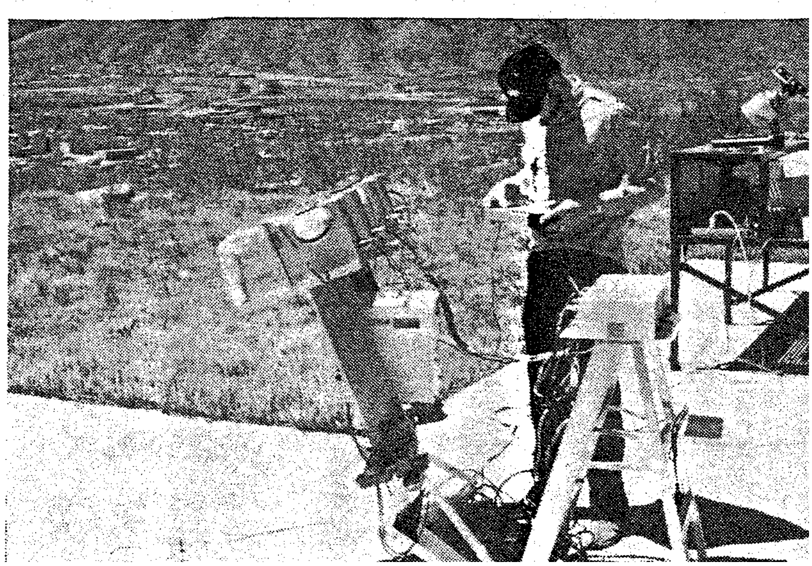


Figure 3-3. Spectroradiometers equipped with integrating spheres to measure global solar radiation

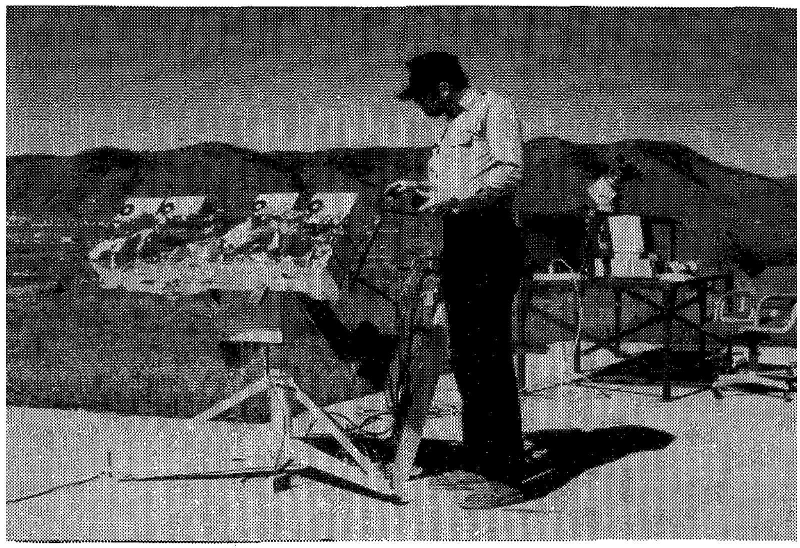


Figure 3-4. Spectroradiometers equipped with the Teflon dome receivers

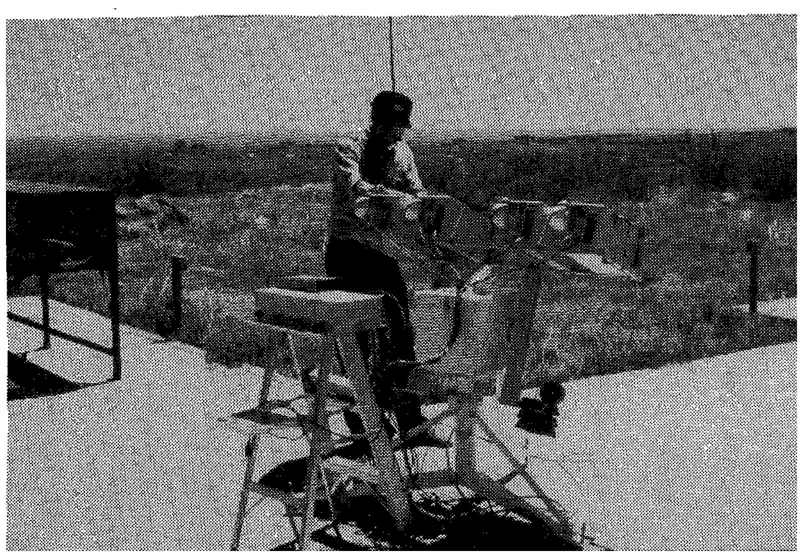


Figure 3-5. Outdoor intercomparison of four spectroradiometers

Table 3-1. Measurements and Documentation for Each File in the Spectral Solar Radiation Data Base

- Site identifier[a]
  - Four-letter code
  - Longitude (decimal)
  - Latitude (decimal)
  - Site elevation (m)
- Date[a]
  - Day number
  - Year
- Local standard time[a]
  - Hour
  - Minutes
- Collection mode for spectral irradiance scan(s)
  - Two-letter code:
    Global horizontal - GH
    Global normal - GN
    Global tilt - GT, use tilt angle from horizontal (e.g., 30 deg) and azimuth
    Direct normal - DN
- Direct-normal irradiance value (W/m^2)
- Global-normal irradiance value (W/m^2)
- Global-horizontal irradiance value (W/m^2)
- Global-tilt pyranometer value
  - Tilt angle of pyranometer from horizontal, and azimuth
  - Irradiance value (W/m^2)
- Irradiance-stability check (silicon pyrheliometer)[b]
- Irradiance-stability check (silicon pyranometer)[b]
- Spectroradiometer scan(s) (2-nm step size) (W/m^2-nm)
- Repeat of broadband irradiance measurements[b]
- Ambient temperature (°C)
- Surface pressure (mb)
- Relative humidity (%)
- Average wind speed (mph)
- Ground albedo (measured or estimated)[c] (%)
- Multiwavelength sunphotometer measurements (four-channel maximum)[d]
- Opaque cloud cover (tenths)
- National Weather Service water vapor value (cm)
- Comment field (15 characters)

[a]Location, date, and time are used to calculate air mass.

[b]The silicon pyrheliometer, silicon pyranometer, and repeated broadband solar radiation values are included to allow evaluation of irradiance stability during the spectral irradiance scan.

[c]Values should be representative of the dominant land-cover type or mixture in the vicinity of the spectroradiometer.

[d]Spectral measurements at several wavelengths are made using sunphotometers with narrow-band filters to calculate atmospheric turbidity and water vapor.

measured on tilted surfaces and ground-to-sky reflections (especially under cloud cover). Wind speed and ambient temperature were recorded because they may be useful, along with the spectral data, to predict collector performance. The broadband and meteorological sensors were maintained and calibrated by the measurement sites as documented in Section 5.

Broadband solar radiation measurements were made immediately (within 15 s) before and after the spectral solar radiation scan to allow evaluation of atmospheric stability at the time of the scan. In addition, the data-acquisition software was designed so that global-horizontal solar radiation was sampled six times during the spectral scan using a silicon-detector pyranometer; if global solar radiation varied by more than 2%, the spectral scan was not recorded. Three attempts were made to acquire a spectral scan during unstable conditions (such as partly cloudy skies). If a scan was not obtained after three tries, the broadband and meteorological data were recorded and then the data acquisition system waited until the next regularly scheduled data acquisition time (usually an hour) to attempt another spectral scan. Because of the stability monitoring during the spectral scans, we believe there are very few cases when the spectral scan was acquired during variable solar radiation conditions. We found three examples of distorted spectra (see Figure 3-6) that possibly were caused by unstable conditions.

Software to test the atmospheric stability and acquire the data in a specific format was integrated into the field operations by FSEC and PG&E. The format included fields for site identification, date and time, broadband solar radiation values, atmospheric data, spectral solar radiation data, and comments. In addition, an instrument description and configuration file was stored for each data file.

The data acquisition software was designed to accept manually entered data from sunphotometers, cloud-cover estimates, and National Weather Service precipitable water vapor measurements. However, the personnel, instruments, and measurements were generally not available to enter these data each hour at the measurement sites.

The schedule for data collection was flexible to accommodate individual site requirements and constraints. The goals, which were accomplished, were to collect data over at least one year at each site to capture seasonal variations and to cover a wide range of atmospheric conditions for each measurement configuration.

Measured spectra and supporting data were sent to SERI on floppy disks from PG&E and on magnetic tape from FSEC. Daily log sheets that describe the spectroradiometer operation and operator comments were included with the data. All-sky photographs corresponding to many of the FSEC spectral data sets were provided by the FSEC Fenestration Energy and Illumination Performance Research Program (Figure 3-7). All-sky photographs were also taken for each of the SERI spectral data sets (Figure 3-8). A camera system was installed at PG&E late in the data collection period, but no photographs are available.

At SERI, the data were processed through an interactive quality-control procedure during which the data were visually inspected for obvious problems. First, the instrument configuration file (see example in Figure 3-9) was examined against a template from the previous data set to check for any instrument changes or a change in the mode of operation. After the operator

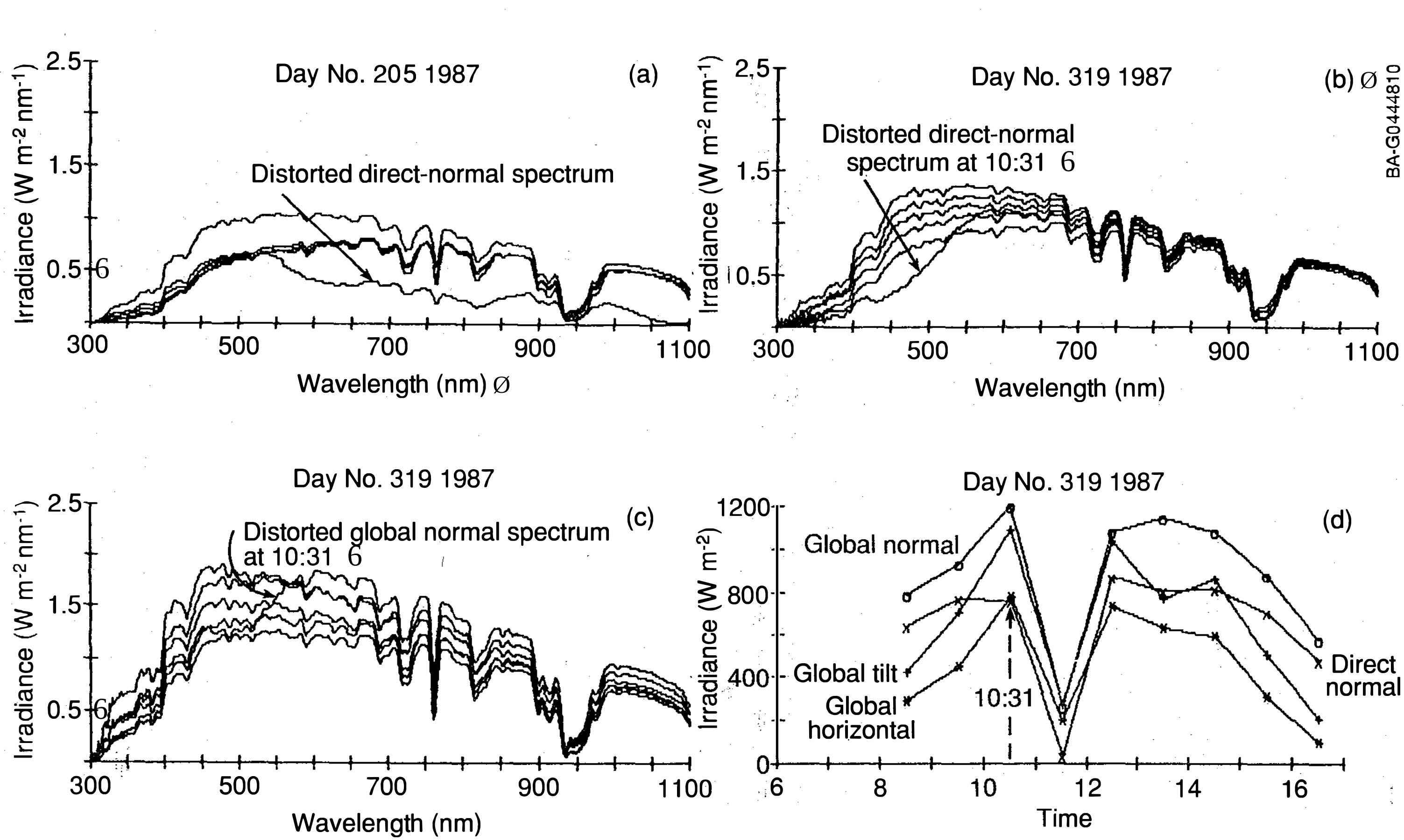


Figure 3-6. **Examples of the very few distorted spectra in the data base (a,b,c). Broadband solar radiation data (d), corresponding with the spectra in b and c, show that irradiance was decreasing at 10:31 due to partly cloudy conditions**

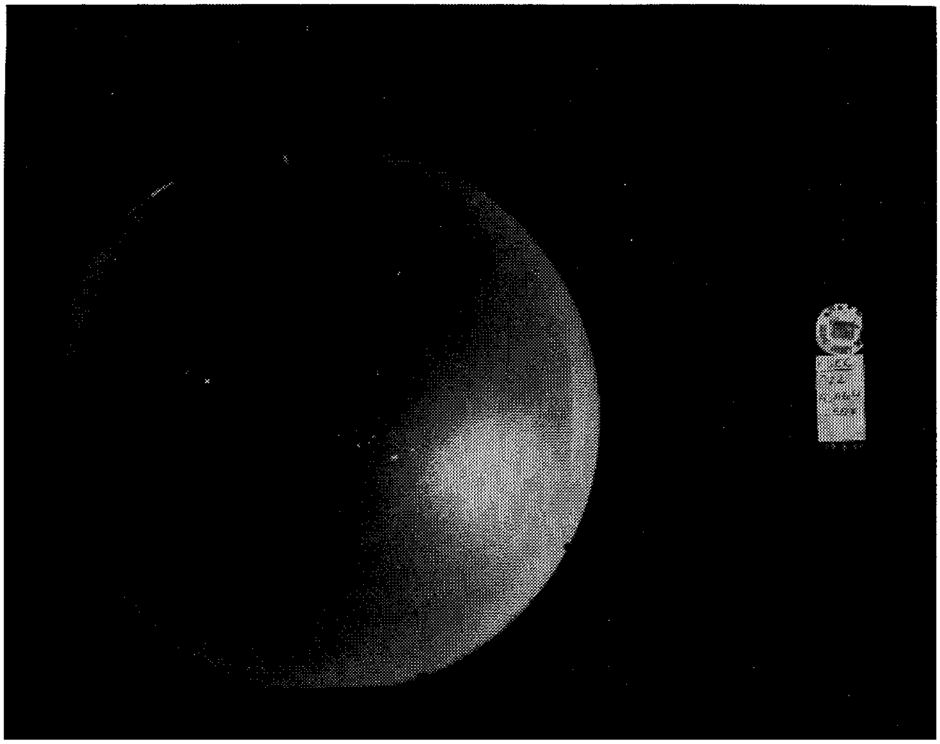


Figure 3-7. Example of all-sky photographs acquired at FSEC. These photographs provided evidence of rain, possible condensation on optics, and clouds

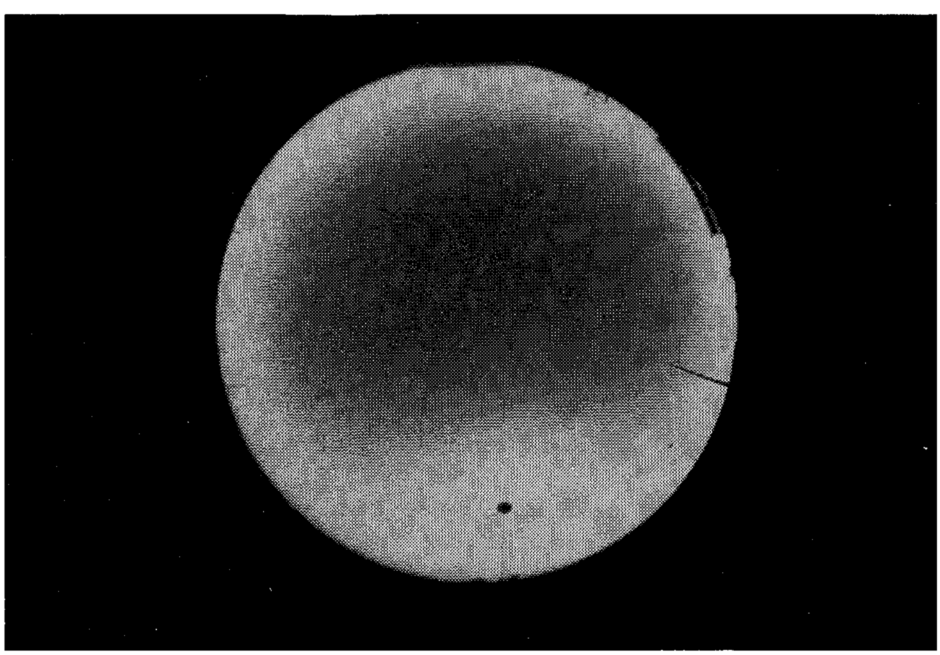


Figure 3-8. Example of all-sky photograph acquired at SERI with a disk blocking sun to show diffuse sky conditions

*(OK, I'll buy this.)   Press [Help] for help.

BA-G0444801

CHN NO	PARAMETER TYPE	INSTRUMENT MAKER	INSTRUMENT TYPE	INSTRUMENT SERIAL	CALIBRATION FACTOR	CALIBRATION DATE	OUTPUT UNITS	FOOT NOTES
1	Dir Norm	Eppley	NIP	17828E6	6.80	11-187	W/m^2	
2	Glo Norm	EPPLEY	PSPN	17863F3	8.11	11-187	W/m^2	
3	Glo Horz	Eppley	PSP	17863F3	8.11	11-187	W/m^2	
4	Glo Tilt	EPPLEY	PSPT	17863F3	8.11	1-187	W/m^2	
5	Dir N, Si	Unused	Unused	Unused	-99.00	-1-1-1	W/m^2	
6	Amb. Temp	TAYLOR	HG/GLASS	00718C	1.00	11-187	Deg. C	
7	Surf Pres	OBSERVER	ELEVATION	RIORDAN	-99.00	-1-1-1	Millibar	
8	Rel. Hum.	DC	DIGITAL	XXXXXC	1.00	-1-1-1	Percent	3
9	Wind Spd	OBSERVER	OBSERVD	STOFFEL	-99.00	-1-1-1	Meters/S	3
10	% Albedo	Unused	Unused	Unused	-99.00	-1-1-1	Percent	
11	Phot 380	SONOTEK	SUNPHOT	SPM7524	663.00	10-184	Counts	3
12	Phot 500	SONOTEK	SUNPHOT	SPM7524	775.00	10-184	Counts	3
13	Phot 860	SONOTEK	SUNPHOT	SPM7524	457.00	10-184	Counts	3
14	Phot 942	SONOTEK	SUNPHOT	Unused	-99.00	-1-1-1	Counts	1
15	Opq Cloud	OBSERVER	OBSERVER	STOFFEL	1.00	-1-1-1	Tenths	
16	H2O, NWS	NWS	SONDE	STAPLETON	1.00	-1-1-1	cm	
17	Spect #1	LICOR	LI1800	PRS158	1.00	9-187	W/sq m/nm	2
18	Spect #2	Unused	Unused	Unused	-99.00	-1-1-1	W/sq m/nm	
19	Glo H, Si	LICOR	SIPYRAN	PY1245	8.11	11-187	W/m^2	

Figure 3-9. Example of the instrument configuration data recorded with the measured data

approved the configuration table, the template was updated and the information was written to the data base.

Figure 3-10 shows an example of the computer terminal output during the second step of the quality-control session.

The information displayed (see circled numbers in Figure 3-10) included the following:

1. Site, date, day number, standard time, latitude, longitude, and number of attempts to acquire the spectrum, as controlled by the atmospheric stability monitor.

2. Plot of the spectrum, with the mode of operation printed below the plot.

3. Indication of stability, based on the before-scan and after-scan measurement of global-horizontal solar radiation from the silicon pyranometer (although the measurements by this instrument during the scan are actually used to test for atmospheric stability).

4. Graphic description of the azimuth and zenith angles of the sun.

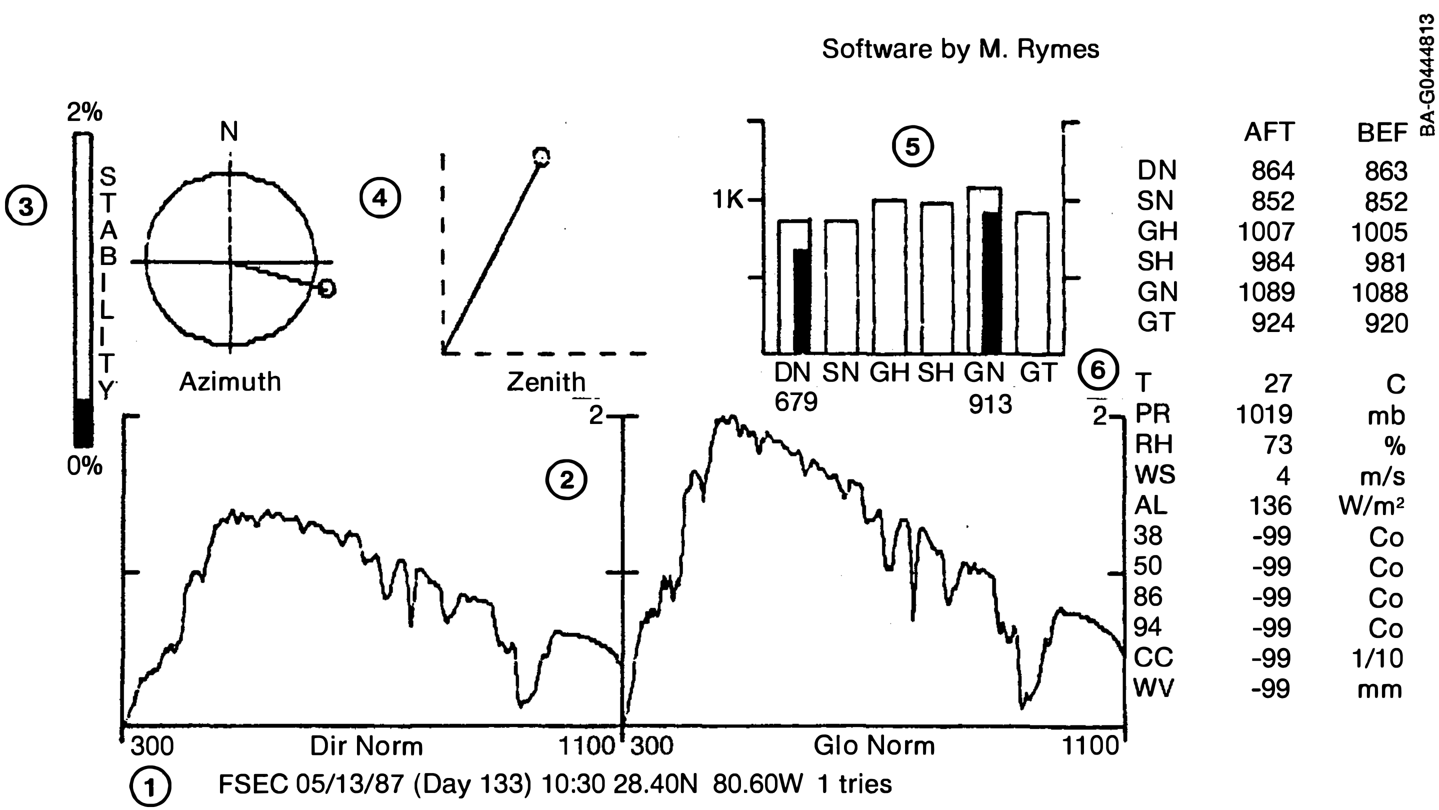


Figure 3-10. Example of the computer terminal output during a quality-control session

5. Bar graph of the before-scan broadband measurements of direct-normal (thermopile detector) DN, direct-normal (silicon detector) SN, global-horizontal (thermopile) GH, global-horizontal (silicon) SH, global-normal (thermopile) GN, and global-tilt (thermopile) GT solar radiation. The darkened bar graphs show the integral of the spectral solar radiation (0.3-1.1 μm), which is printed under the bar graph. Before-scan and after-scan broadband values are printed to the right of the bar graph.

6. Listing of the supporting data. The first five values are temperature T, pressure PR, relative humidity RH, wind speed WS, and ground-reflected solar radiation AL, used for albedo calculations. The remaining fields were not used for this data base, and were included for future data collection projects.

This quality-control process was performed shortly after the data arrived at SERI to flag obvious field problems. The operator could add comments to the data file after viewing the information in Figure 3-10. The software also calculated atmospheric descriptors, such as Kt, and then the data and descriptors were written to the data base. Quantitative quality control was applied in the post-processing of the data base (described in detail in the appendix).

We chose to include all data in the data base and to be as specific as possible about the measurement uncertainty, rather than set stringent criteria for excluding data sets. This allows users to select data based on their specific application and accuracy requirements, or to use portions of the data sets, such as broadband data or spectral solar radiation segments. None of the data should be used without referencing the measurement uncertainty.

4.0 CONTENTS OF THE DATA BASE

A total of 3,364 spectral data sets (16 Mb) are included in the data base:

- 1415 Direct normal
- 899 Global normal
- 542 Global horizontal
- 455 Global tilt
- 53 Diffuse.

If the data acquisition systems were operating, but the atmospheric conditions were too unstable to record a spectrum, the broadband and meteorological data were included in the data base, but no quality-control processing was applied.

FSEC normally operated two spectroradiometers simultaneously, one in the direct-normal mode and the other in one of the global modes. PG&E operated one spectroradiometer, and rotated through the different measurement modes. SERI collected direct-normal, global-horizontal, and diffuse-horizontal spectra, mostly during cloudless-sky conditions.

Examples of the spectra are shown in Figures 4-1 through 4-5. Figure 4-1 (a,b) shows examples of spectra measured at FSEC in the direct-normal and global modes on a clear day. As air mass increases, the direct-normal spectra (a) shift toward longer wavelengths (the red end of the spectrum). The global spectra (b) are slightly less affected by the red shift because the radiation scattered out of the direct beam is added back into the global spectra as diffuse radiation, thus returning a portion of the short-wavelength (blue) radiation. Figure 4-1(c) shows the broadband solar radiation corresponding to the spectra.

Figure 4-2 shows examples of spectra measured under cloudy skies. The direct-normal spectra (a) are almost zero, and the global-tilt spectra (b) have low values. The graph of corresponding broadband solar radiation (c) shows nearly zero direct normal; the global values approach each other because all of the irradiance is diffuse under cloudy skies.

Figure 4-3 shows examples of spectra measured on a partly cloudy day. The graph also shows an example of data dropout during data transfer. The shape of the spectral curve is quite different for low-intensity spectra measured under cloud cover (10:31, air mass 1.88; 13:31, air mass 1.73) versus the low-intensity spectrum at higher air mass values (16:31, air mass 5.48).

Figure 4-4 shows two examples of spectra that appear to correspond with sun reflections off of clouds, which causes a "bright spot" [17] and a focusing effect on the solar radiometers. The broadband solar radiation values can actually approach or exceed the extraterrestrial value of about 1338 on day number 132/133. The global solar radiation values approach each other, while the direct-normal radiation drops indicating that the solar disk is partially blocked by clouds.

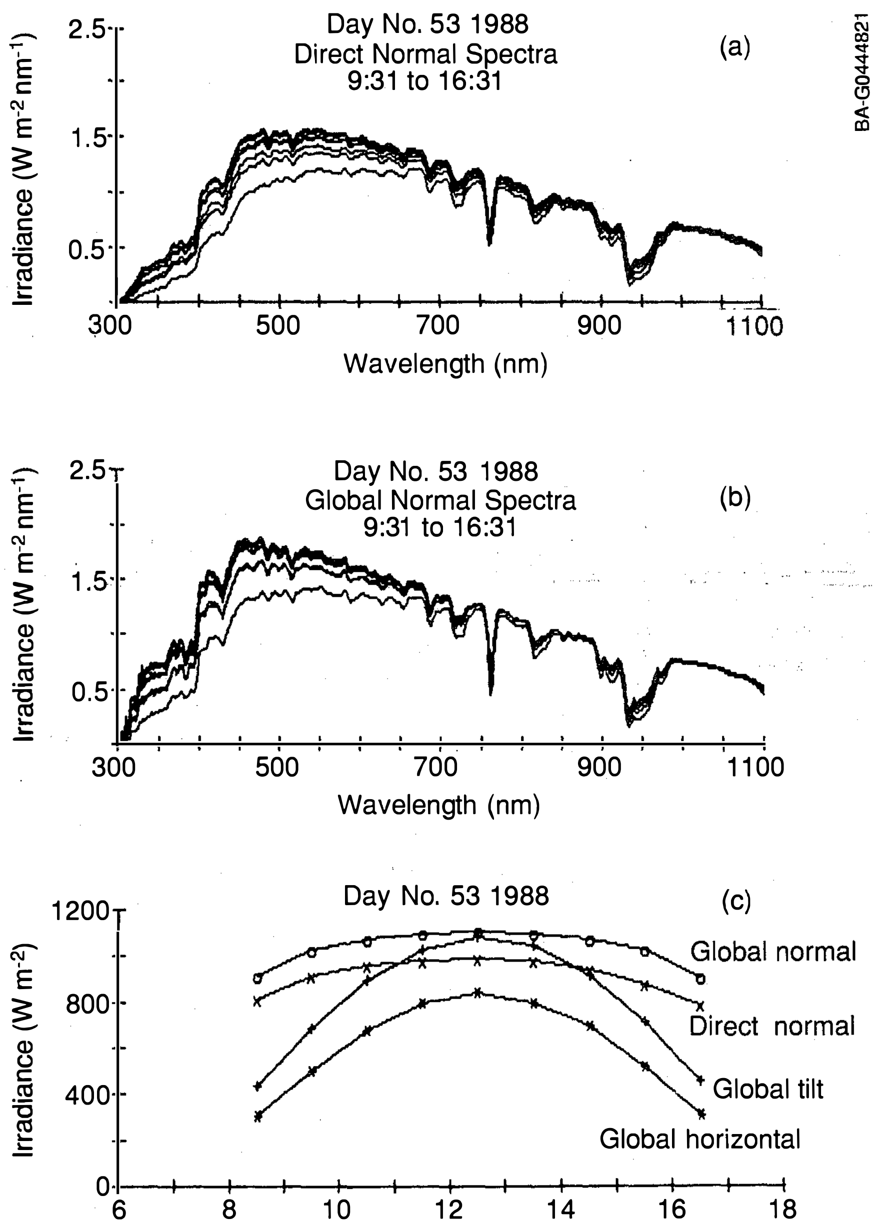


Figure 4-1. Examples of (a) direct-normal and (b) global-normal spectra and (c) broadband solar radiation measured at FSEC on a clear day

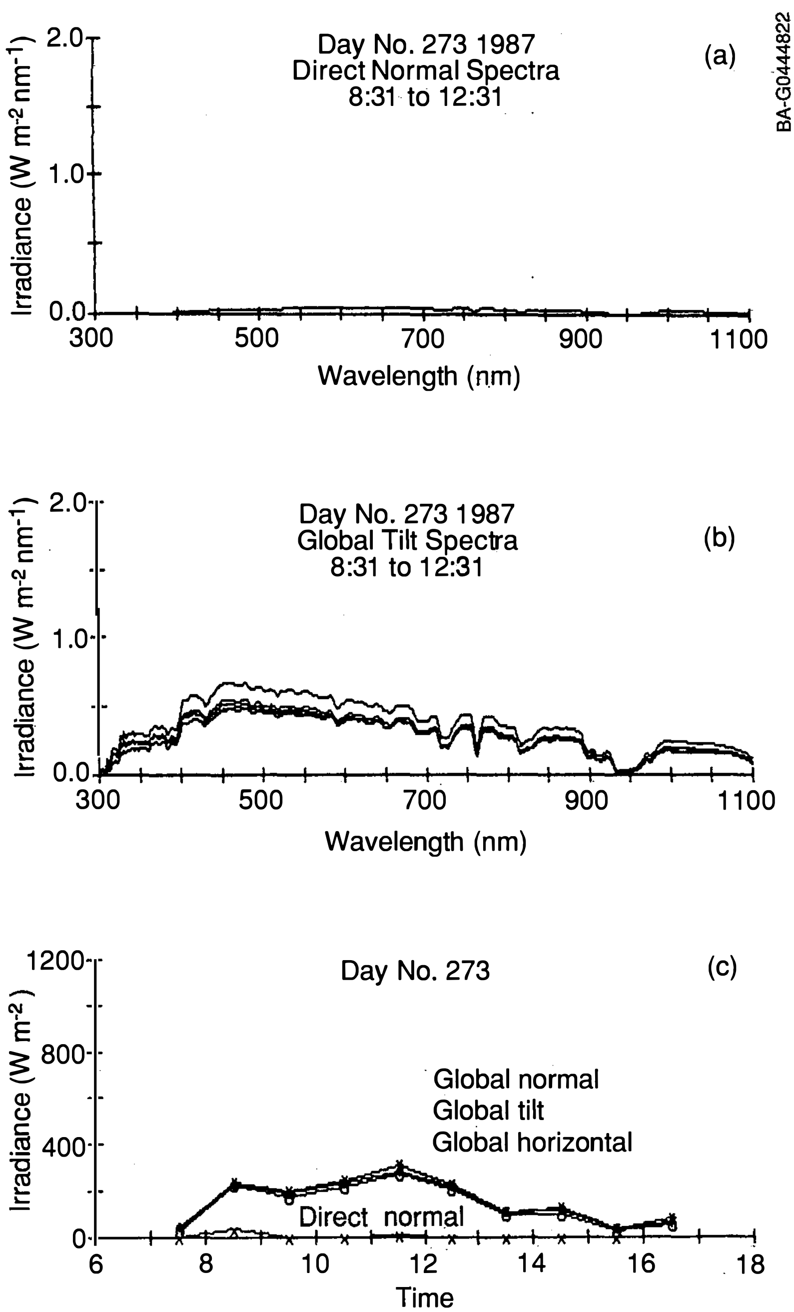
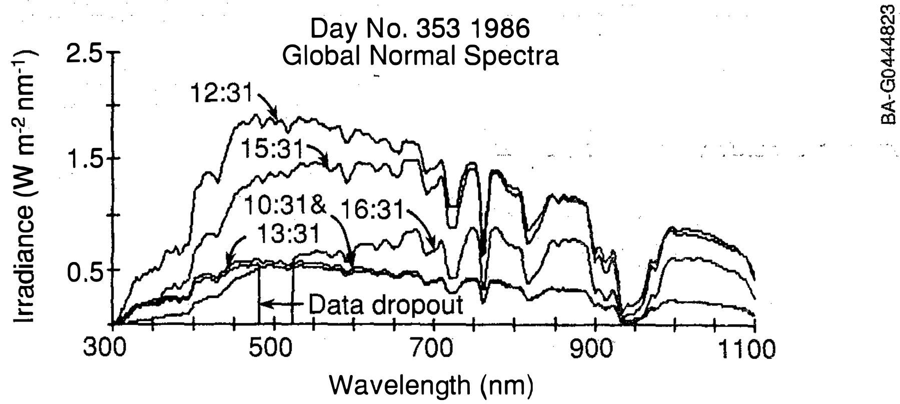


Figure 4-2. Examples of (a) direct-normal and (b) global-tilt spectra and (c) broadband solar radiation measured at FSEC on a cloudy day



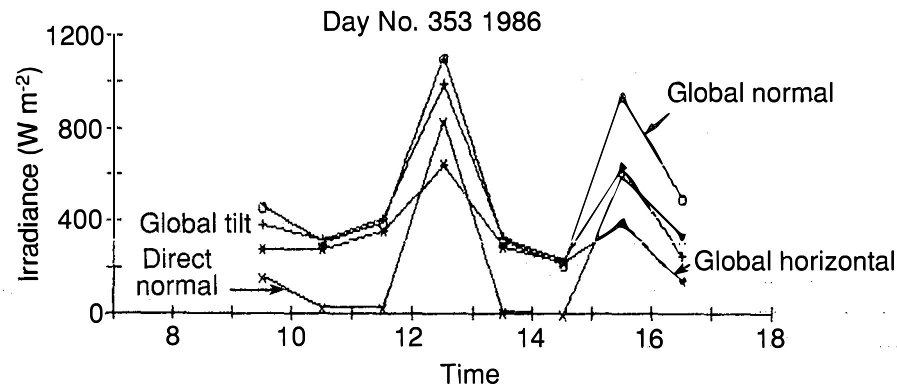


Figure 4-3. Examples of global-normal spectra (upper) and broadband solar radiation (lower) measured at FSEC on a partly cloudy day. The spectrum at 16:31 shows data dropout during data transfer

Figure 4-5 shows examples of direct-normal, global-horizontal, and diffuse-horizontal spectra measured by SERI. The diffuse radiation is mostly concentrated in the short-wavelength (visible) region of the spectrum (blue sky). The global-horizontal spectrum is equal to the direct-normal spectrum multiplied by the cosine of the zenith angle, plus the diffuse spectral radiation.

The cumulative number of these spectra versus air mass; the atmospheric descriptors Kt, Kn, D/GH; and relative humidity are shown in Figures 4-6 (a-f). The large number of spectra at low air mass values is caused by the operation of the spectroradiometers during normal working hours at mid-latitudes, and by the larger air mass values occurring near sunrise and sunset which occupy a relatively small fraction of the day. The large number of spectra during relatively clear-sky conditions is due to selection of clear days for the data taken at SERI, the requirement for atmospheric stability during spectral scans, and perhaps climate types at the three sites. Figure 4-6 (c) shows that relative humidity measurements were missing for about 25 global-normal spectra. The diffuse spectra associated with D/GH ratios near 1.0 indicate very clear conditions where diffuse measurements are probably within the measurement uncertainty.

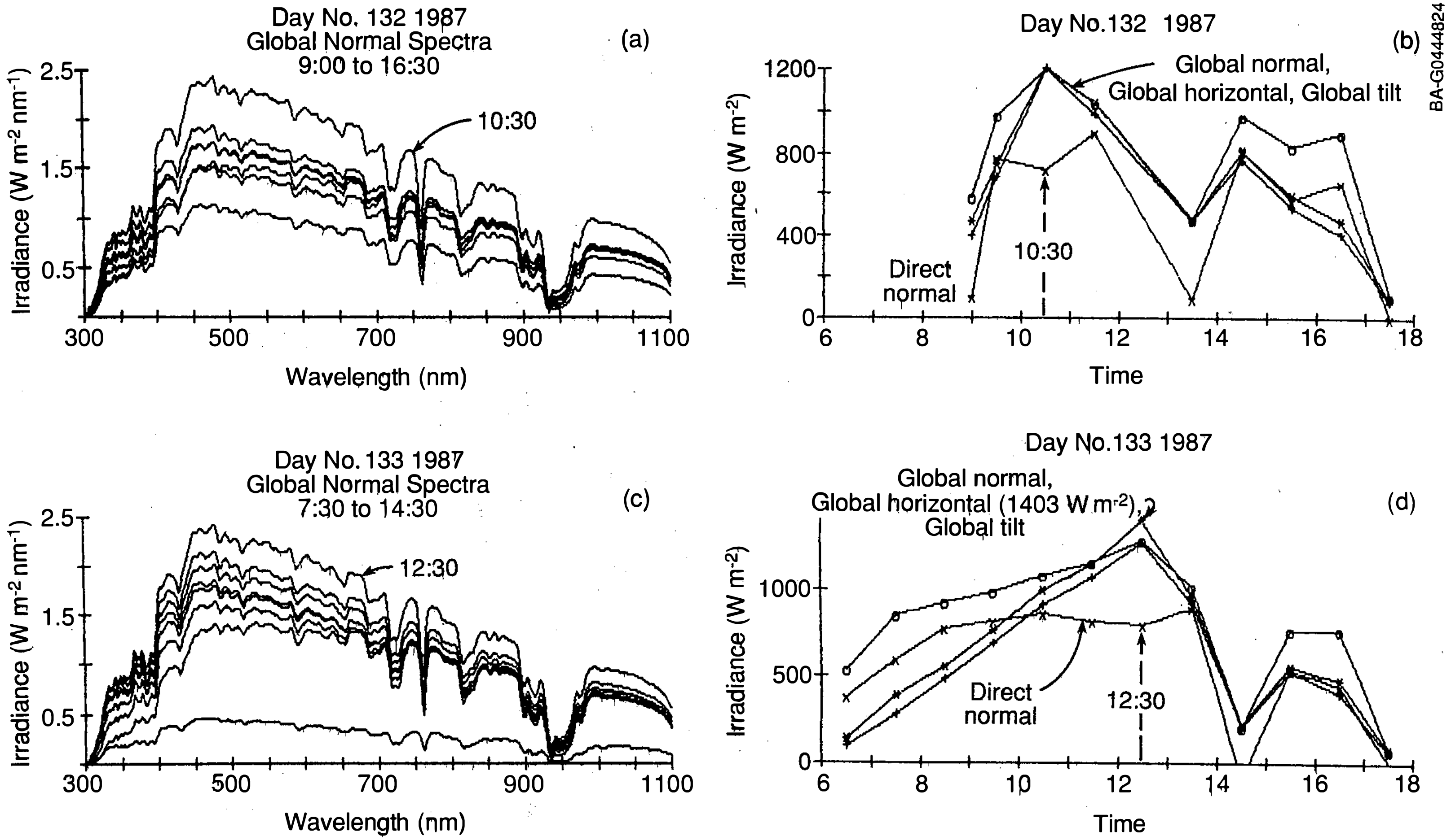


Figure 4-4. Examples of solar spectra enhanced by cloud bright spots (a) at 10:31 on day 132 and (c) at 12:30 on day 133, and corresponding [(b) and (d) respectively] broadband solar radiation

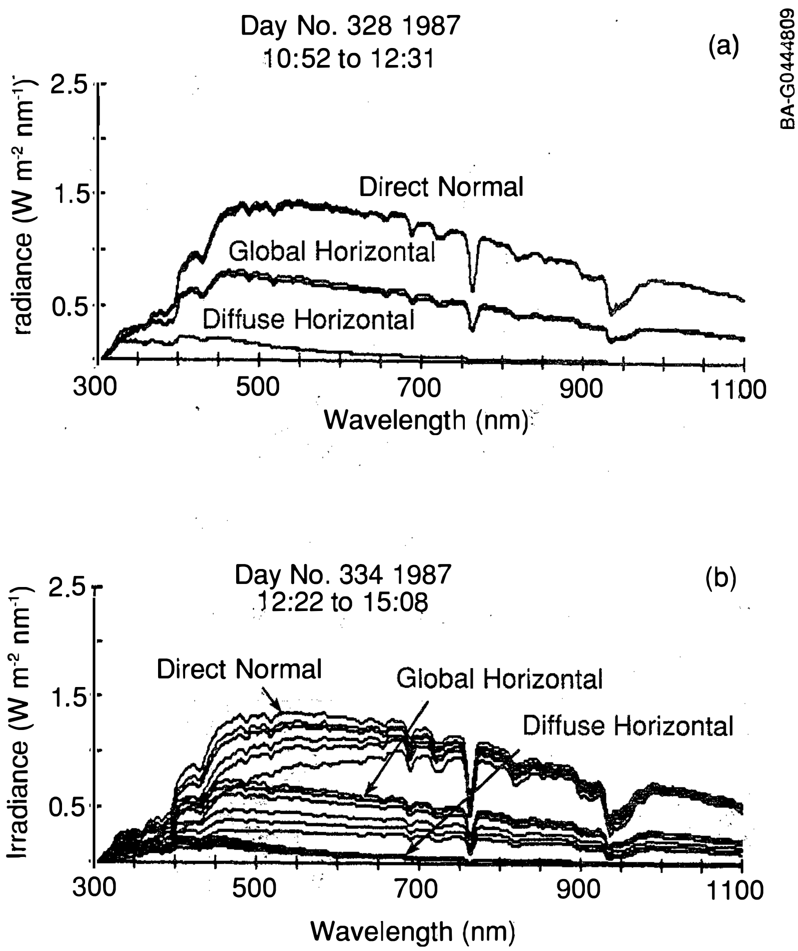


Figure 4-5. Examples of direct-normal, global-horizontal, and diffuse-horizontal spectra measured by SERI on two days

Included on the data tape are daily field notes, quality control information, and measurement uncertainty. This information alerts the user to problems such as data dropouts (as seen in Figure 4-3) and noise in the spectrum (Figure 4-7). This information should always be reviewed when any spectral data sets are used.

Photographs or slides corresponding to many of the spectral data sets are available at SERI. The daily field notes that are included with the data base document the existence and quality of the photos/slides.

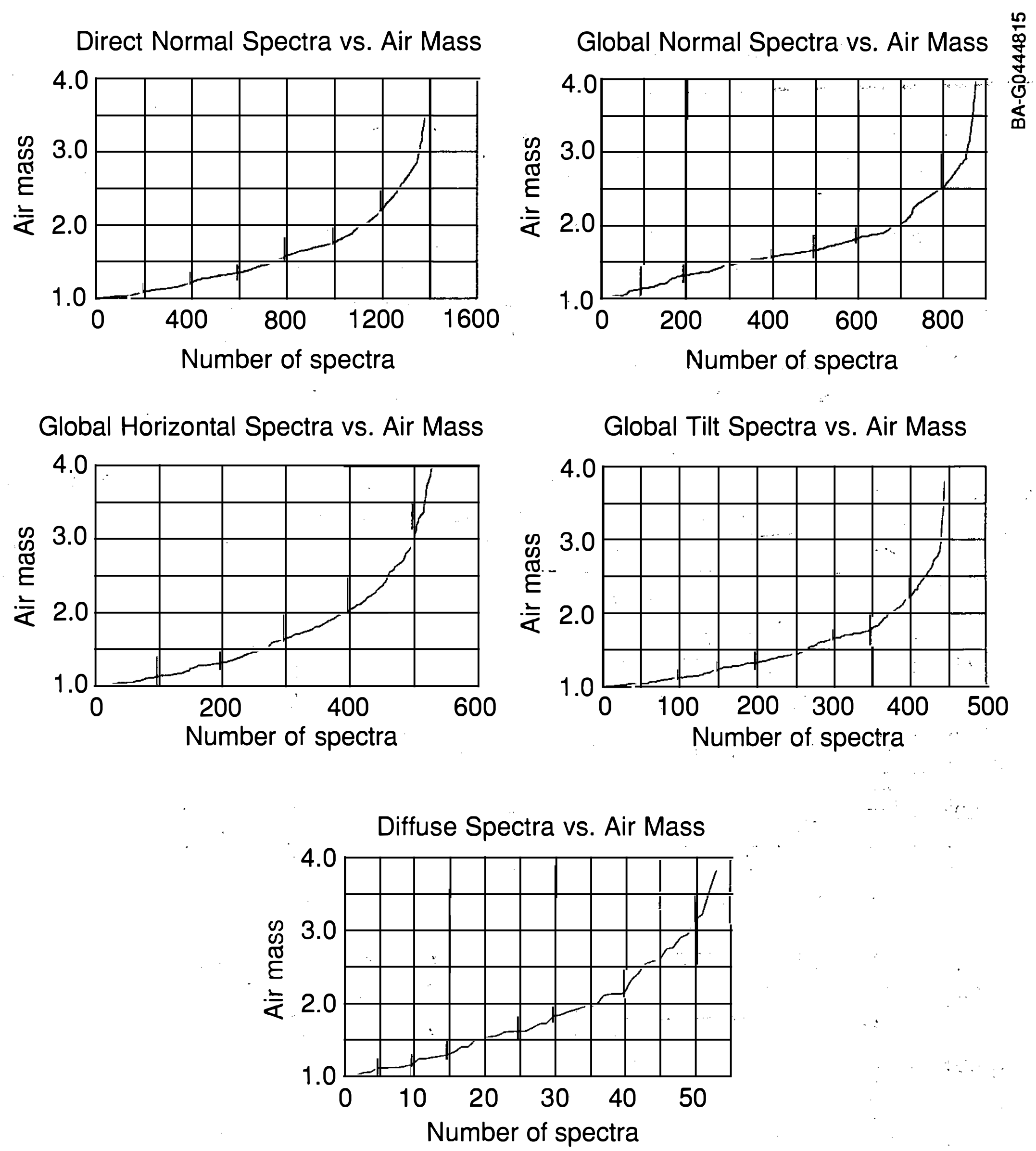


Figure 4-6 (a). The cumulative number of spectra (horizontal axis) measured over a range of air mass and atmospheric descriptors (vertical axis)

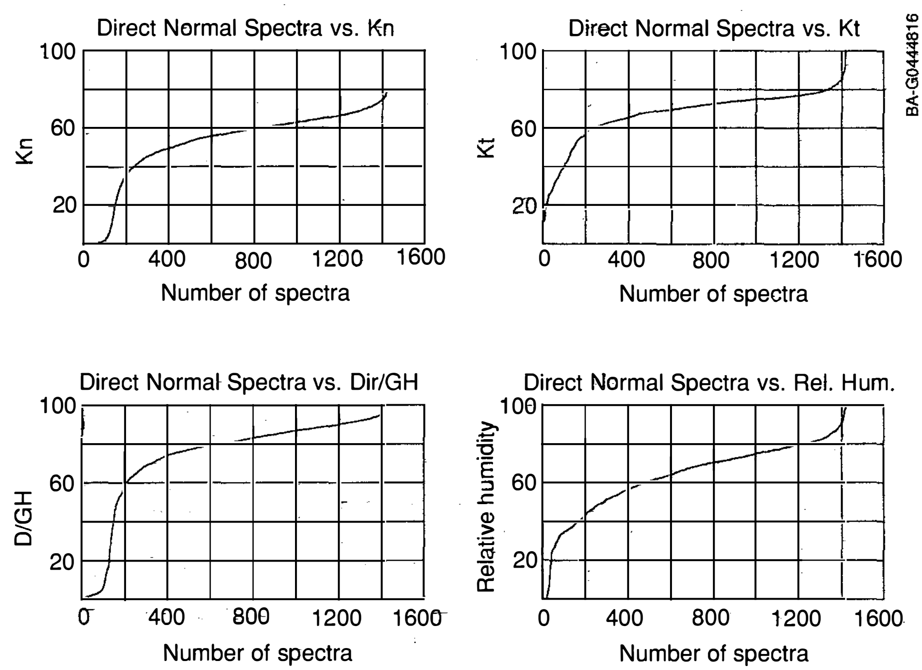


Figure 4-6 (b). The cumulative number of spectra (horizontal axis) measured over a range of air mass and atmospheric descriptors (vertical axis)

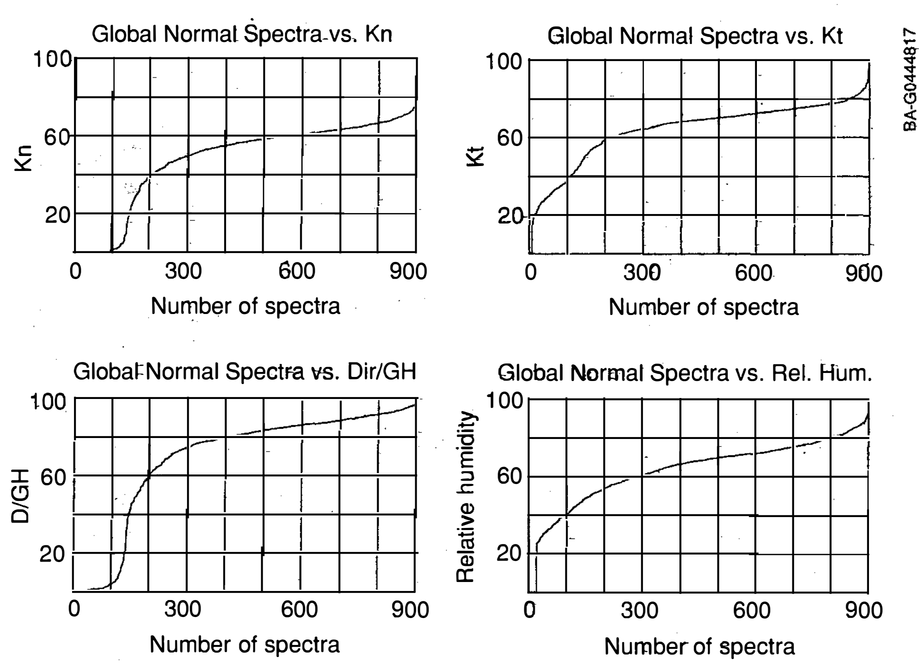


Figure 4-6 (c). The cumulative number of spectra (horizontal axis) measured over a range of air mass and atmospheric descriptors (vertical axis)

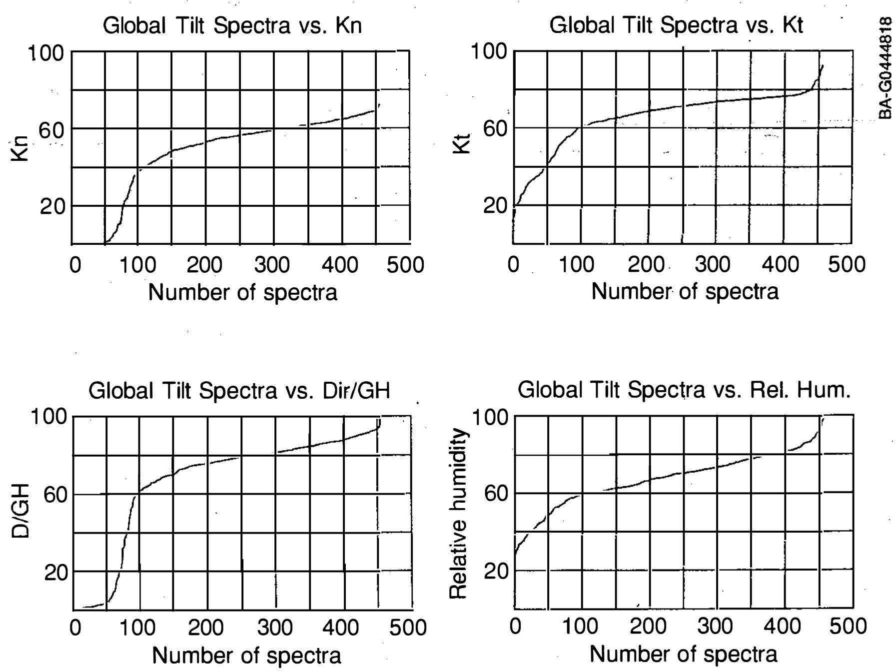


Figure 4-6 (d). The cumulative number of spectra (horizontal axis) measured over a range of air mass and atmospheric descriptors (vertical axis)

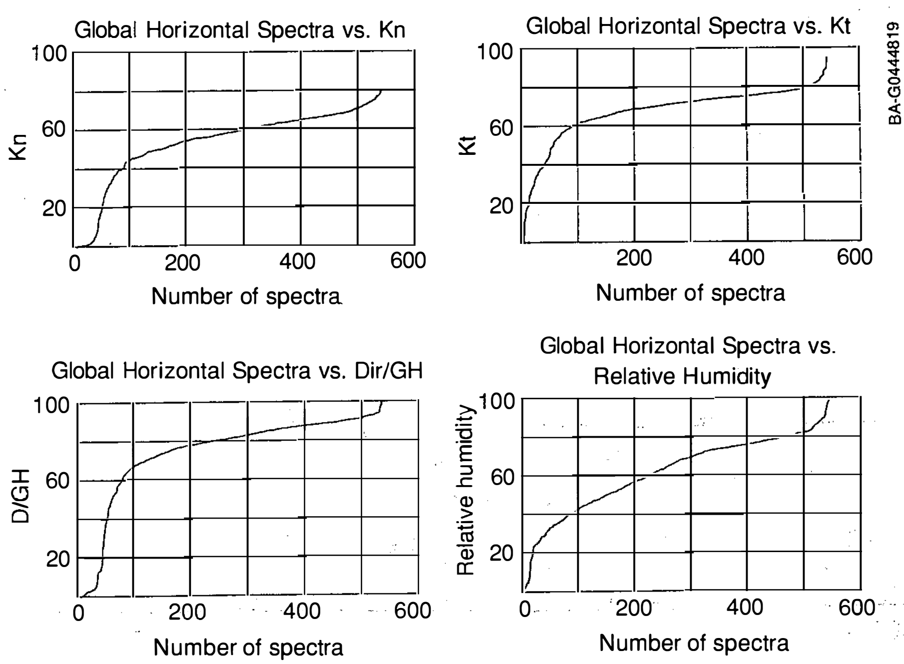


Figure 4-6 (e). The cumulative number of spectra (horizontal axis) measured over a range of air mass and atmospheric descriptors (vertical axis)

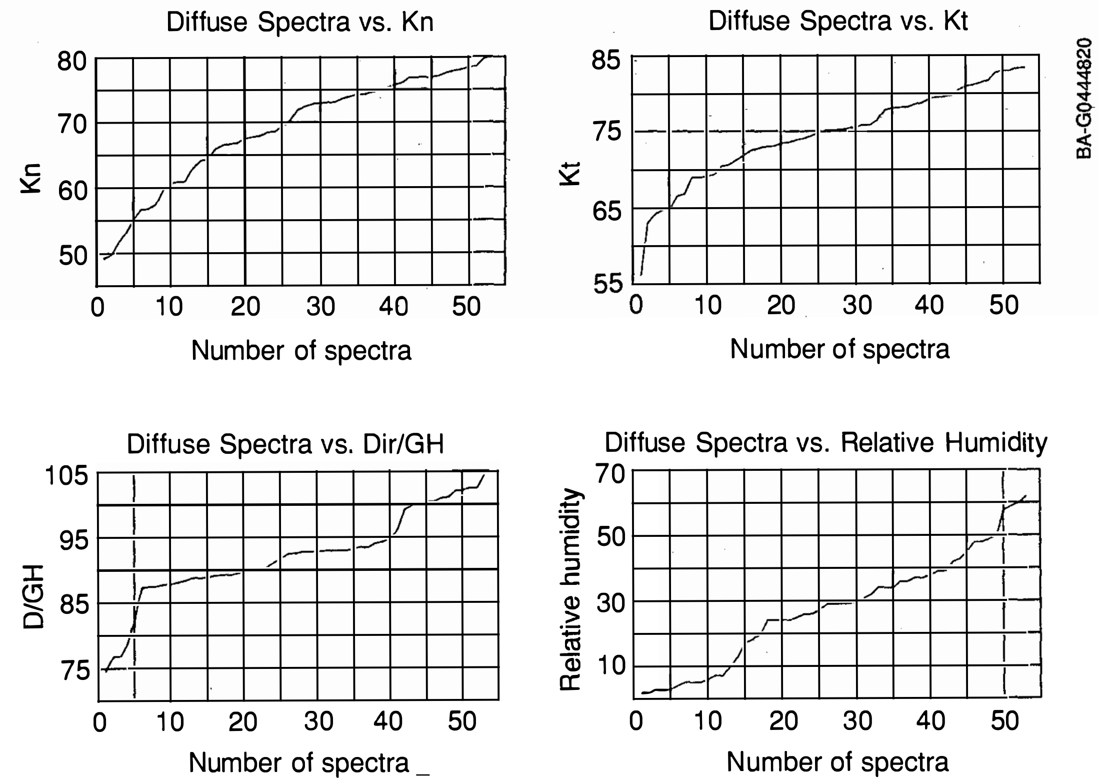


Figure 4-6 (f). The cumulative number of spectra (horizontal axis) measured over a range of air mass and atmospheric descriptors (vertical axis)

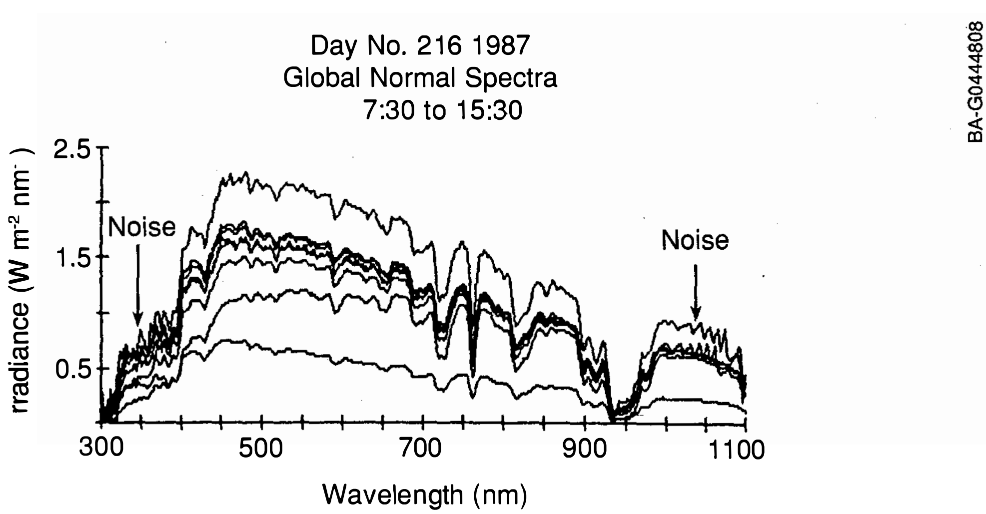


Figure 4-7. Examples of spectra showing noisy data in the ultraviolet (300-400 nm) and near-infrared (1000-1100 nm) regions

5.0 MEASUREMENT UNCERTAINTY

(Note: This section contains only a brief summary of the total uncertainty. The detailed reports [15,16] on the methods used to estimate total spectral measurement uncertainty should be consulted when using this data base.)

The data set described in this document is the best set of measurements possible with the personnel, equipment, methods, and calibration procedures available to us. We found that making continuous measurements with complex, sensitive equipment, and accounting for all sources of error in order to specify total measurement uncertainty were not trivial tasks.

The estimated total uncertainty (95% confidence interval) for each of the spectroradiometers and each of the measurement modes is shown in Figure 5-1. The upper and lower spectral uncertainty limits are symmetrical, except when global-tilt or global-horizontal spectra were measured using the integrating sphere, and when a strong, direct-beam component was present ($K_t > 60\%$). We added an 8% maximum bias to the lower uncertainty limits for these cases based on results of experiments in which we mapped the integrating sphere response under bright sun with the image of the sun in different locations on the inside of the sphere. During these experiments, we observed variations of up to -8% compared to the calibration point.

The high uncertainty in the absolute value of the spectral measurements less than 0.45 µm was caused by low spectral irradiance for the calibration lamps, which resulted in a low signal-to-noise ratio for the spectroradiometer calibrations (Figure 5-2). In addition, we experienced a change (i.e., loss of response) in the ultraviolet (UV) response of the instruments when using the integrating spheres.

Total uncertainty is a combination of an estimated total spectral bias error and total spectral random error. The final estimated total uncertainty for a 95% confidence interval is calculated as the root-sum-square of the bias (B) error, plus two times the random (R) error:

$$\mathrm{SQRT}\ [B^2 + (2R)^2]\ .$$

To evaluate instrument-to-instrument differences or variability (also called between-instrument precision), simultaneous spectral solar radiation scans were made with each instrument in each configuration. The standard deviation of these measurements, multiplied by three, was converted to a percentage of the mean. This percentage indicates the expected instrument-to-instrument varibility, or precision, for this set of instruments. Figure 5-3 shows the results obtained for one of these comparisons using the integrating spheres. Similar results occur with the other configurations. The between-instrument precision above 0.4 µm is close to 5%.

Temperature control of the spectroradiometers with silicon detectors was important. Figure 5-4 shows the change in the response of the instruments, especially in the near-infrared, when operated at different control temperatures. Uncertainty of 1°C in the set point results in about a 2% uncertainty in the near-infrared measurements. On hot days, we found that the temperature

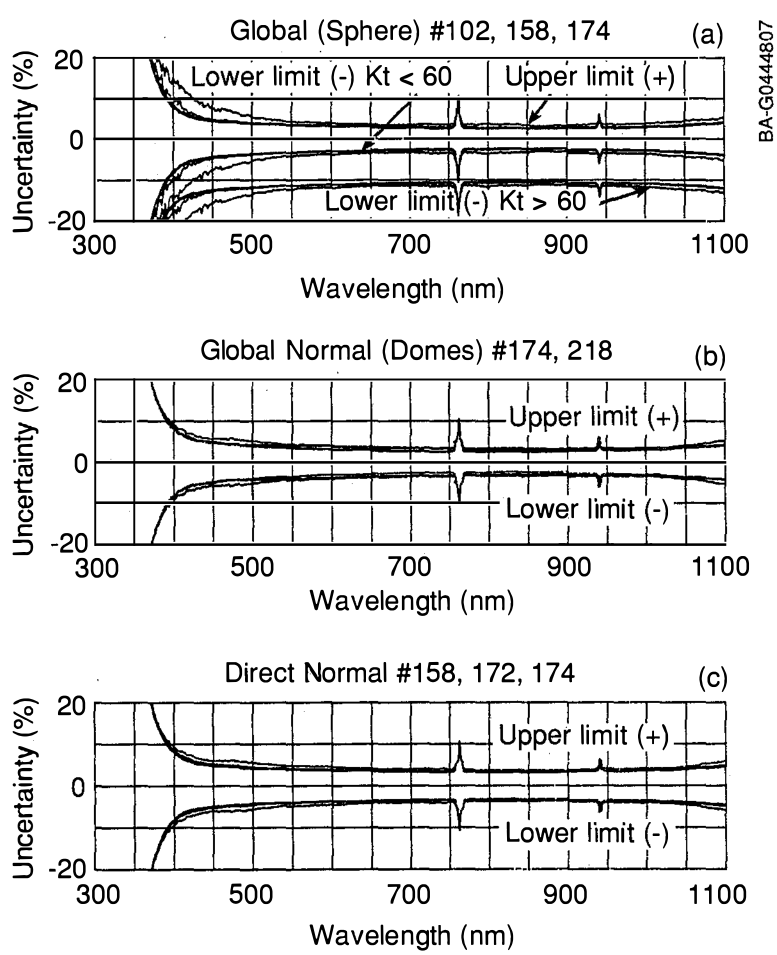


Figure 5-1. Estimated total spectral measurement uncertainty for global measurements with the integrating spheres on (a) units number 102, 158, and 174; (b) global-normal measurements with the Teflon dome receivers on units 174 and 218; and (c) direct-normal measurements with the view-limiting tubes on units 158, 172, and 174. The measurement uncertainty is symmetrical except in (a) where a -8% bias is included in the lower limit for global-horizontal and global-tilt cases due to nonuniform sphere response when a strong direct-beam component is present

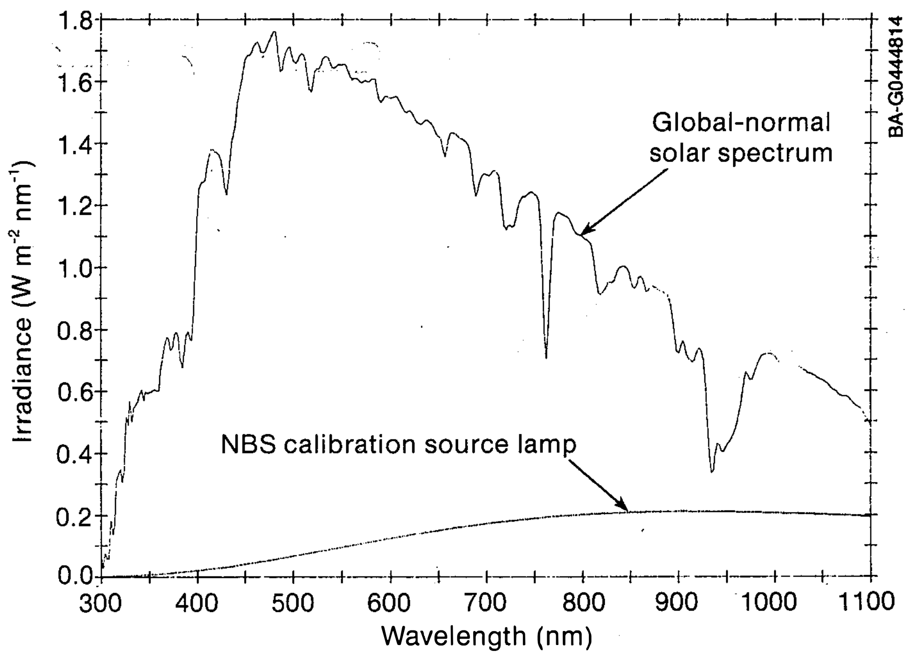


Figure 5-2. Comparison of the spectral intensity of an outdoor global-normal measurement and the NIST calibration lamp source. Low lamp values below 400 nm result in high measurement uncertainty

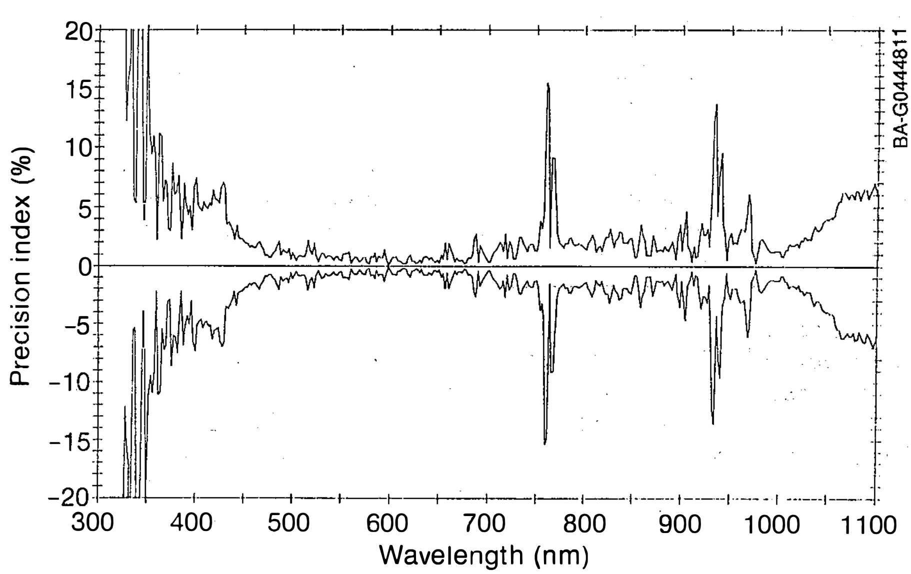


Figure 5-3. Between-instrument precision for global-normal spectral solar radiation measurements using the integrating spheres

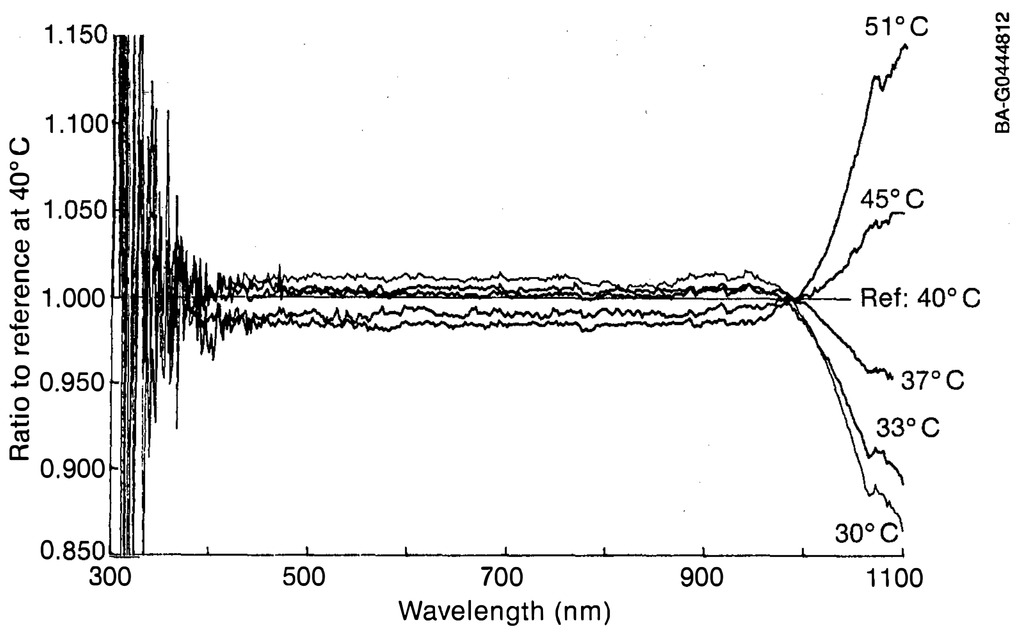


Figure 5-4. Ratio of the spectroradiometer detector response at different temperatures to the response at 40°C

of the detectors (controllers) sometimes exceeded the set point, and we experienced runaway temperatures. This resulted in amplifier millivolt drift errors and noise in some of the spectra. We achieved better temperature control by shielding the spectroradiometers with Mylar sheets supported by foam offsets to allow air flow.

Measurement uncertainty for the broadband and meteorological data is based on the calibration histories provided by the measurement sites and characteristics of the instruments. This information is given in Tables 5-1 through 5-3, and the values are included on the data-base tape.

In these tables, the measurement uncertainty for a 95% confidence interval was estimated by root-sum-squaring the estimated bias errors and by doubling the random errors, in the calibration process and measurements [15,16]. Radiometers used at PG&E in 1987 were post-calibrated at SERI, allowing estimates of the random calibration error component; the radiometers used in 1988 were calibrated elsewhere so nominal estimated errors were used in the uncertainty analysis. Instruments used at SERI were pre- and post-calibrated at SERI. Instruments used at FSEC were calibrated by FSEC, and nominal values for random and bias errors for these types of radiometers were used in the uncertainty analysis. Calibration information for the meteorological instruments is included in these tables, but no measurement uncertainty analysis was performed.

Table 5-1. FSEC Instrument Calibration History and Estimated Measurement Uncertainty

Channel #	Measurement	Beginning Time Stamp	Instrument	Calibration Date	Comments	Estimated Measurement Uncertainty (%)
1	Direct normal	862961507	Eppley NIP 14306E6	5-86	--	
	(thermopile)	863520931	Eppley NIP 23943E6	12-86	--	±2.9
		880120931	Eppley NIP 23943E6	12-87	1.32% change	
2	Global normal	862961507	Eppley PSP 24185F3	--	--	
			Eppley PSP 24185F3	11-86	1.67% change	±3.8
		872881032	Eppley PSP 18273F3	4-87	--	
		880120931	Eppley PSP 24185F3	12-87	--	
3	Global horizontal	862961507	Eppley PSP 14321F3	4-86	--	
	(thermopile)	870931631	Eppley PSP 14322F3	12-87	--	±3.8
		872881032	Eppley PSP 14318F3	4-87	--	
4	Global tilt	863291031	Eppley PSP 24183F3	11-86	--	
		872881032	Eppley PSP 14320F3	4-87	--	±3.8
		880120931	Eppley PSP 24183F3	12-87	--	
5	Direct normal	862961507	Matrix NIP3826	9-86	--	
	(silicon)	880120931	Matrix NIP3826	12-87	1.32% change	±2.9
6	Temperature	862961507	Weathermeasure 1420A 177	6-86 3-87 8-88	"small" changes; the calibration factor was changed in software	---
7	Pressure	862961507	Weathermeasure 1705 178	1-86 5-87 6-88	"small" changes; the calibration factor was changed in software	---
8	Relative humidity	862961507	Weathermeasure 1540 175	6-86	Calculated from dew point; compared every other week with another instrument	---
9	Wind speed	862961507	Weathermeasure 1222 1219	7-86 3-87 6-88	"small" changes; the calibration factor was changed in software	---

Table 5-1. FSEC Instrument Calibration History and Estimated Measurement Uncertainty (Concluded)

Channel #	Measurement	Beginning Time Stamp	Instrument	Calibration Date	Comments	Estimated Measurement Uncertainty (%)
10	Albedo	863291031	Eppley PSP 16297F3	11-86	--	±3.8
		872881032	Eppley PSP 21065F3	4-87	--	
19	Global horizontal (silicon)	862961507	LI-COR Pyr. PY2276	7-86	--	±3.8
		871481431	LI-COR Pyr. PY2279	5-87	--	

SERI

Table 5-2. PG&E Instrument Calibration His ory and Estimated Measurement Uncertainty

Channel #	Measurement	Beginning Time Stamp	Instrument	Pre-Calibration	Post-Calibration	Comments	Estimated Measurement Uncertainty (%)
1	Direct normal (thermopile)	871100632	Eppley NIP 25508E6	1-86	8-88	0.3% change	±2.8
		880190752	Eppley NIP 25510E6	12-87	--	--	±3.6
2	Global normal	871100632	Eppley PSP 23202F3	1-86	8-88	1.7% change	±2.4
		880190752	Eppley PSP 23996F3	12-87	--	--	±4.7
3	Global horizontal (thermopile)	871100632	Eppley PSP 23995E3	10-84	8-88	3.2% change	±2.8
		880190752	Eppley PSP 25390F3	12-87	--	--	±4.7
4	Global tilt	871100632	Eppley PSP 25387F3	12-84	8-88	0.2% change	±3.8
		880190752	Eppley PSP 23201F3	12-87	--	--	±4.7
5	Direct normal* (silicon)	871100632	Matrix NIP 3818	5-86	7-88	2.7% change	±2.2
6	Temperature	871100632	Omega T-couple	--	--	--	--
7	Pressure	871100632	Yellow Springs 2014-22/31 -HA-1-WH 15593	3-84	--	--	--
8	Relative humidity	871100632	Hygro. 14276	2-85	--	--	--
9	Wind speed	871100632	Weathertronics 2301 184	9-82	--	--	--
		880400737	Weathertronics 2301 184	2-88	--	--	--
10	Albedo	871100632	Eppley PSP 21235F3	--	8-88	2.4% change	±2.6
19	Global horizontal (silicon)	871100632	LI-COR Pyr. PY5558	11-83	8-88	1.9% change	±2.6

*Beginning about 87211, the silicon NIP values appear consistently low; may be an alignment problem.

Table 5-3. SERI Instrument Calibration History and Estimated Measurement Uncertainty

Channel #	Measurement	Beginning Time Stamp	Instrument	Pre-Calibration	Post-Calibration	Comments	Estimated Measurement Uncertainty (%)
1	Direct normal (thermopile)	87328	Eppley NIP 17828E6	11-87	2-88	1.57% change	±3.3
2	Global normal		None	--	--	--	
3	Global horizontal (thermopile) at Welby	87328	Eppley PSP 17863F3	11-87	2-88	2.22% change	±3.7
	At SRRL	88057	Eppley PSP 20079F3	7-87	8-88	0.73% change	±2.3
4	Global tilt		None	--	--	--	--
5	Direct normal (silicon)		None	--	--	--	--
6	Temperature	87328	Taylor Pocket 21430-1	10-86	(Due 10-91)	--	±0.2 (deg)
7	Pressure		Calculated from elevation	--	--	--	
8	Relative humidity	87328	Dickson 86100-1	9-87	10-88	--	±2 (counts)
9	Wind speed		Observation	--	--	--	--
10	Albedo	--	None				
11-14		--	Sun photometer (relative comparisons only)		--	--	--
15	Cloud cover	--	Observed	--	--	--	--
19	Global Horizontal (silicon)	--	LI-COR Pyr. PY1245 (stability monitor only)	11-87	2-88	3.67% change	±2.9

We urge users of the data base to refer to the daily field notes for special circumstances recorded by the operator that may affect data uncertainty. These notes include references to the spectroradiometer temperature controller, solar-tracking accuracy, and weather conditions (such as rain). Included in the daily notes on the data-base tape are observations made in quality-control processing, as well as references to the existence and quality of photographs or slides.

Quantitative post-processing, quality-control information is also included on the data-base tape, and a complete description is given in the appendix of this report. Redundant measurements (such as before-scan and after-scan broadband solar radiation, direct-normal, and global-horizontal measurements with both thermopile and silicon detectors) and comparisons of integrated spectral solar radiation with broadband solar radiation were used in the quality-control procedures. Users are encouraged to perform their own quality-control processing on the data to meet their particular requirements.

6.0 FORMAT OF THE DATA TAPE

The measured data, field notes, quality-control information, and measurement uncertainty are stored on magnetic tape in 80-character lines with the filenames given in Table 6-1. The filenaming convention used for the measured data was

Filename	Content		
FLA8705.DAT	FSEC data	1987	May
PGE8801.DAT	PG&E data	1988	January
SER8711.DAT	SERI data	1987	November

Data were not acquired in all months, so the months may not be contiguous.

Quality-control information has the same filenaming convention, with ".QC" extension (for example, FLA8705.QC). Daily notes are contained in the files FSEC.NOTES, PGE.NOTES, and SERI.NOTES, respectively. The measurement uncertainty is in the ".UNCERT" files.

The ".DAT" files contain two types of information: "D" for data, and "C" for instrument configuration. The first line of a data or configuration segment begins with a "D" or a "C", respectively, in the first column, followed by the site, year, day, and time stamp; the number of lines in the segment is in columns 76-80 so that the user can easily skip the desired number of lines. An example of the information in the configuration, or "C," segment is shown in Figure 6-1. It begins with a "C" followed by the site "FSEC," year "1987," day "122," and time "0830," latitude, longitude, and elevation. There are 19 channels for measurements, zero spectra in the "C" segment, and 40 lines in the segment. The configuration information appears whenever the instrument set-up or calibration was changed, or the data acquisition system was restarted. If the configuration was not changed at the beginning of the month, the configuration segment will be in the previous month's ".DAT" file.

An example of a "D" segment is shown in Figure 6-2. This segment contains the measured meteorological data, broadband and spectral solar radiation data, and ancillary data. The data contained in each line and column, and its format, are as follows:

POSITION OF VARIABLES IN THE "D" SEGMENTS (ALL LINES ARE 80 CHARACTERS)

Line/Column	Contents	Format
		a = character i = integer f = floating point
LINE 1:		
1:1	D (for data)	(a1)
3:15	Site, Year, Day Number, Time Stamp	(a13)
	3:6 FSEC, PG&E, or SERI	(a4)
	7:8 Year	(a2 or i2)
	9:11 Day Number	(a3 or i3)
	12:15 Standard Time	(a4 or i4)

Table 6-1. Names of Files on the Data Tape

Measured and Calculated Data

FSEC

FLA8610.DAT	FLA8706.DAT	FLA8712.DAT
FLA8610.QC	FLA8706.QA	FLA8712.QC
FLA8611.DAT	FLA8707.DAT	FLA8801.DAT
FLA8611.QC	FLA8707.QC	FLA8801.QC
FLA8612.DAT	FLA8708.DAT	FLA8802.DAT
FLA8612.QC	FLA8708.QC	FLA8802.QC
FLA8701.DAT	FLA8709.DAT	FLA8803.DAT
FLA8701.QC	FLA8709.QC	FLA8803.QC
FLA8704.DAT	FLA8710.DAT	FLA8804.DAT
FLA8704.QC	FLA8710.QC	FLA8804.QC
FLA8705.DAT	FLA8711.DAT	
FLA8705.QC	FLA8711.QC	

PG&E

PGE8704.DAT	PGE8708.DAT	PGE8801.DAT
PGE8704.QC	PGE8708.QC	PGE8801.QC
PGE8705.DAT	PGE8709.DAT	PGE8802.DAT
PGE8705.QC	PGE8709.QC	PGE8802.QC
PGE8706.DAT	PGE8711.DAT	PGE8803.DAT
PGE8706.QC	PGE8711.QC	PGE8803.QC
PGE8707.DAT		
PGE8707.QC		

SERI	Daily Notes
SER8711.DAT	FSEC.NOTES
SER8711.QC	PG&E.NOTES
	SERI.NOTES
SER8712.DAT	
SER8712.QC	
	Measurement Uncertainty
SER8801.DAT	
SER8801.QC	FSEC.UNCERT
	PG&E.UNCERT
SER8802.DAT	SERI.UNCERT
SER8802.QC	

1 2 3 4 5 6 7 8 9 10

C FSEC871220813 28.4000N 80.6000W 2M C=871220813 871220813+000000 19 0 40

BA-G044806

CHN NO	PARAMETER TYPE	INSTRUMENT MAKER	INSTRUMENT TYPE	INSTRUMENT SERIAL	CALIBRATION FACTOR	CALIBRATION DATE	OUTPUT UNITS	FOOT NOTES
1	Dir Norm	Eppley	NIP	23943E6	6.08	12-186	W/m^2	
2	Glo Norm	Eppley	PSP	24185F3	8.85	11-186	W/m^2	
3	Glo Horz	Eppley	PSP	14322F3	6.38	12-286	W/m^2	
4	Glo Tilt	Eppley	PSP	24183F3	8.99	11-186	W/m^2	
5	Dir N, Si	MATRIX	SI NIP	3826	31.80	9-186	W/m^2	
6	Amb. Temp	WTHRMEAS	PRT	177	1.00	3-187	Deg. C	
7	Surf Pres	WTHRMEAS	PIEZO	178	1.00	5-187	Millibar	
8	Rel. Hum.	WTHRMEAS	LiCl	175	1.00	6-186	Percent	
9	Wind Spd	WTHRMEAS	OPT.CHOP	1219	1.00	3-187	Meters/S	
10	% Albedo	Eppley	PSP	16297F3	10.09	11-186	Percent	
11	Phot 380	Unused	Unused	Unused	-99.00	-1-1-1	Counts	
12	Phot 500	Unused	Unused	Unused	-99.00	-1-1-1	Counts	
13	Phot 860	Unused	Unused	Unused	-99.00	-1-1-1	Counts	
14	Phot 942	Unused	Unused	Unused	-99.00	-1-1-1	Counts	
15	Opq Cloud	Unused	Unused	Unused	-99.00	-1-1-1	Tenths	
16	H2O, NWS	Unused	Unused	Unused	-99.00	-1-1-1	cm	
17	Spect #1	LI-COR	LI-1800	PRS-172	1.00	2-187	W/sq m/nm	1
18	Spect #2	LI-COR	LI-1800	PRS-102	1.00	2-187	W/sq m/nm	1
19	Glo H, Si	LI-COR	LI-200S	PY2276	8.45	7-186	W/m^2	2
-1	FIN							

FOOTNOTES:

1 - #17 = DN; #18 = GT.
2 - SERI loan unit
-1 - FIN

Figure 6-1. Example of the instrument configuration data on the data base tape. The numbers refer to:

1 "C" indicating configuration
2 FSEC 1987 Day 122 at 8:13 standard time
3 Latitude
4 Longitude
5 Elevation
6 Reference to configuration file that will be found in the data files
7 Starting data-acquisition time plus number of attempts to acquire spectra (which would extend the data acquisition time)
8 Number of data channels
9 Number of spectra (0 for configuration files; 1 or 2 for data files)
10 Number of lines in this segment

```
D FSEC871220813 28.4000N  80.6000W    2M C=871220813 871220814+000100  19 2  100
  See Q, N FSEC87122, U PRS-172 Col 2(+/-) U PRS-102 Col 2(-) Col 4(+)
  1  784.5  5  754.5  2  930.2 -1  -99.0  3  480.1 19  483.3  4  427.9 -1  -99.0
  1  785.0  5  755.7  2  930.4 -1  -99.0  3  481.1 19  485.3  4  430.1 -1  -99.0
  28.4 180.0
 10   95.4 15  -99.0  7 1017.8  6   20.7  8   75.8  9    1.5 -1  -99.0 -1  -99.0
 11  380.0  -99.0 Co 12  500.0  -99.0 Co 13  860.0  -99.0 Co 14  942.0  -99.0 Co
-1.60  715.8 57.85  67.1  58.3  86.9  19.9  1.87-9.00-9.00-9.00-9.00-9.0-9.0 3.1
17 401  300 1100 2.0 57.9  89.4  0.0 DNT18 401  300 1100 2.0 28.4 180.0 62.4 GTS
-1   0    0    0 0.0  0.0   0.0  0.0    -1   0    0    0 0.0  0.0   0.0  0.0
 1  300  0.000  0.035  0.004  0.021  0.025  0.014  0.041  0.021  0.057  0.038  &
 1  320  0.072  0.056  0.101  0.081  0.118  0.121  0.119  0.140  0.138  0.131  &
 1  340  0.149  0.161  0.162  0.155  0.160  0.163  0.185  0.195  0.198  0.199  &
 1  360  0.209  0.219  0.228  0.243  0.258  0.265  0.258  0.265  0.268  0.289  &
 1  380  0.280  0.279  0.267  0.273  0.301  0.308  0.317  0.326  0.349  0.402  &
 1  400  0.476  0.527  0.557  0.569  0.580  0.595  0.612  0.630  0.641  0.648  &
 1  420  0.652  0.654  0.658  0.649  0.636  0.632  0.646  0.678  0.718  0.746  &
 1  440  0.768  0.799  0.822  0.854  0.877  0.904  0.915  0.922  0.934  0.942  &
 1  460  0.960  0.964  0.970  0.973  0.969  0.974  0.990  0.999  1.017  1.028  &
 1  480  1.033  1.025  1.006  0.991  0.990  1.010  1.026  1.038  1.043  1.047  &
 1  500  1.038  1.034  1.038  1.051  1.058  1.058  1.051  1.035  1.017  1.007  &
 1  520  1.020  1.041  1.057  1.063  1.068  1.081  1.088  1.093  1.093  1.091  &
 1  540  1.089  1.084  1.088  1.095  1.097  1.095  1.098  1.102  1.094  1.087  &
 1  560  1.078  1.079  1.081  1.077  1.072  1.071  1.076  1.078  1.078  1.082  &
 1  580  1.090  1.098  1.101  1.088  1.074  1.062  1.061  1.067  1.074  1.080  &
 1  600  1.082  1.085  1.088  1.092  1.093  1.089  1.083  1.078  1.078  1.079  &
 1  620  1.082  1.083  1.076  1.065  1.059  1.056  1.061  1.073  1.080  1.085  &
 1  640  1.086  1.084  1.081  1.076  1.067  1.062  1.052  1.042  1.038  1.048  &
 1  660  1.070  1.086  1.094  1.097  1.096  1.096  1.092  1.093  1.091  1.089  &
 1  680  1.079  1.064  1.028  0.980  0.943  0.937  0.954  0.980  0.996  1.005  &
 1  700  1.008  1.009  1.013  1.019  1.025  1.022  1.003  0.973  0.924  0.874  &
 1  720  0.846  0.842  0.848  0.849  0.854  0.878  0.903  0.931  0.952  0.965  &
 1  740  0.969  0.977  0.983  0.989  0.988  0.982  0.976  0.950  0.881  0.767  &
 1  760  0.616  0.524  0.540  0.646  0.779  0.876  0.924  0.945  0.947  0.945  &
 1  780  0.942  0.942  0.937  0.926  0.916  0.907  0.899  0.894  0.891  0.890  &
 1  800  0.888  0.883  0.879  0.875  0.863  0.836  0.801  0.757  0.722  0.710  &
 1  820  0.710  0.719  0.733  0.741  0.749  0.757  0.763  0.777  0.797  0.810  &
 1  840  0.820  0.828  0.827  0.822  0.815  0.797  0.786  0.783  0.788  0.797  &
 1  860  0.804  0.800  0.788  0.780  0.775  0.780  0.787  0.786  0.785  0.781  &
 1  880  0.775  0.774  0.772  0.767  0.763  0.747  0.721  0.682  0.630  0.588  &
 1  900  0.571  0.573  0.589  0.584  0.568  0.549  0.534  0.533  0.538  0.556  &
 1  920  0.573  0.579  0.567  0.526  0.448  0.362  0.272  0.218  0.210  0.232  &
 1  940  0.254  0.262  0.257  0.253  0.257  0.266  0.275  0.285  0.299  0.317  &
 1  960  0.333  0.362  0.396  0.435  0.479  0.506  0.515  0.512  0.508  0.521  &
 1  980  0.537  0.560  0.584  0.597  0.609  0.617  0.618  0.623  0.621  0.619  &
 1 1000  0.618  0.607  0.605  0.602  0.601  0.605  0.604  0.604  0.604  0.601  &
 1 1020  0.601  0.595  0.595  0.593  0.589  0.590  0.584  0.582  0.580  0.575  &
 1 1040  0.576  0.571  0.571  0.567  0.560  0.560  0.558  0.552  0.545  0.540  &
 1 1060  0.536  0.532  0.529  0.525  0.519  0.515  0.512  0.511  0.509  0.508  &
 1 1080  0.506  0.502  0.492  0.483  0.483  0.483  0.469  0.452  0.447  0.431  &
 1 1100  0.411-99.000-99.000-99.000-99.000-99.000-99.000-99.000   -1   582.32  !
 2  300  0.006  0.001  0.004  0.013  0.019  0.023  0.041  0.055  0.064  0.088  &
 2  320  0.105  0.139  0.179  0.189  0.224  0.238  0.262  0.252  0.261  0.264  &
 2  340  0.287  0.292  0.266  0.288  0.298  0.286  0.300  0.300  0.291  0.285  &
 2  360  0.296  0.310  0.336  0.367  0.390  0.372  0.356  0.356  0.373  0.388  &
 .   .     .      .      .      .      .      .      .      .      .      .    .
 .   .     .      .      .      .      .      .      .      .      .      .    .
```

BA-G044805

Figure 6-2. Examples of the data on the data-base tape

16:23	Latitude (deg)	(f8.4)
24:24	N (north)	(a1)
25:33	Longitude (deg)	(f9.4)
34:34	W (west)	(a1)
35:39	Elevation (m)	(i5)
40:40	M (m)	(a1)
41:52	Reference to Configuration Segment	(a12)
54:69	Starting year, day, time for the spectral scan(s), if any, and number of attempts to acquire the scan (which indicates possible time delay from the starting time)	
54:62	Year, Day Number, Time	(a9 or i9)
63:63	"+" for plus number of attempts to acquire a spectrum	(a1)
67:67	Number of attempts to acquire a spectrum	(i1)
70:73	Possible Number of Measurements (19)	(i4)
74:75	Number of Spectra in this Segment (0, 1, or 2)	(i2)
76:80	Number of Lines in Segment	(i5)
LINE 2:	Pointer to the quality-control, daily field notes, and measurement uncertainty information. Quality-control information is in the ".QC" file of the same month, with the same site, year, day, and time stamp. Daily field notes are in the ".NOTES" file for the same site, with the same site, year, and day stamp. Measurement uncertainty is in the files ".UNCERT" under the instrument serial number identified by PRS-xxx, and the columns in the uncertainty files for "+" and "-" uncertainty limits.	(a80)
LINE 3:	Broadband measurements before the spectral scan.	
1:3	Channel #1	(i3)
4:10	Direct Normal (thermopile) (W/m^2)	(f7.2)
11:13	Channel #5	(i3)
14:20	Direct Normal (silicon) (W/m^2)	(f7.2)
21:23	Channel #2	(i3)
24:30	Global Normal (W/m^2)	(f7.2)
31:40	Channel not used	
41:43	Channel #3	(i3)
44:50	Global Horizontal (thermopile) (W/m^2)	(f7.2)
51:53	Channel #19	(i3)
54:60	Global Horizontal (silicon) (W/m^2)	(f7.2)

61:63	Channel #4	(i3)
64:70	Global Tilt (W/m^2)...	(f7.2)
71:80	Channel not used	

LINE 4: Broadband measurements after the spectral scan; same format as before-scan (LINE 3).

LINE 5:

1:6	Tilt of the fixed-tilt instruments ... from the horizontal (deg)	(f6.1)
7:12	Azimuth of the fixed-tilt instruments (deg) (180 deg = south)	(f6.1)
13:80	Description of any special instrument (for example, diffuse-horizontal measurements at SERI)	(a88)

LINE 6:

1:3	Channel #10	(i3)
4:10	Albedo (W/m^2)...	(7.1)
11:13	Channel #15	(i3)
14:20	Cloud Cover (tenths)	(7.1)
21:23	Channel #7	(i3)
24:30	Surface Pressure (mb) Measured at FSEC and PG&E; calculated from elevation at SERI [11, p. 100]	(f7.1)
31:33	Channel #6	(i3)
34:40	Ambient Temperature (°C)	(f7.1)
41:43	Channel #8	(i3)
44:50	Relative Humidity (%)	(f7.1)
51:53	Channel #9	(i3)
54:60	Wind Speed (m/s)	(f7.1)
61:63	Additional channel described in line 5	(i3)
64:70	Value	(variable)
71:73	Additional channel described in line 5	(i3)
74:80	Value	(variable)

LINE 7: Sun Photometer readings (only recorded for SERI data; not used except for relative comparisons). ...

LINE 8:

1:5	Earth-Sun distance correction (% deviation from 1.0) ...	(f5.2)
6:12	Extraterrestrial Radiation (W/m^2)...	(f7.1)

13:18	Zenith Angle (deg)	(f6.2)
19:24	Kt (ratio calculated from thermopile instruments)	(f6.1)
25:30	Kn (ratio calculated from thermopile instruments)	(f6.1)
31:36	D/GH (ratio calculated from thermopile instruments)	(f6.1)
37:42	Albedo (%)	(f6.1)
43:48	Air Mass	(f6.2)
49:68	Reserved for Turbidity, if calculated	
69:72	Precipitable Water Vapor, if calculated from sun photometer	
73:76	Precipitable Water Vapor from the National Weather Service	(f4.1)
77:80	Precipitable Water Vapor Calculated from Relative Humidity	(f4.1)

LINE 9:

1:2	Channel #17	(i2)
3:6	Number of Wavelengths Recorded by Spectroradiometer #1	(i4)
7:11	Beginning Wavelength (nm)	(i5)
12:16	Ending Wavelength (nm)	(i5)
17:20	Wavelength Step Size (nm)	(f4.1)
21:25	Spectroradiometer #1 Tilt from the Horizontal (deg)	(f5.1)
26:31	Spectroradiometer #1 Azimuth (deg)	(f6.1)
32:36	Angle of Incidence of the Direct Beam on Spectroradiometer #1 (deg)	(f5.1)
38:39	Measurement Type (DN, GN, GH, GT, DF)	(a2)
40:40	Attachment (Teflon Dome D, Integrating Sphere S, View-limiting Tube T)	(a1)
41:42	Channel #18	(i2)
43:46	Number of Wavelengths Recorded by Spectroradiometer #2	(i4)

47:51	Beginning Wavelength (nm)	(i5)
52:56	Ending Wavelength (nm)	(i5)
57:60	Wavelength Step Size (nm)	(f4.1)
61:65	Spectroradiometer #1 Tilt from the Horizontal (deg)	(f5.1)
66:71	Spectroradiometer #2 Azimuth (deg)	(f6.1)
72:76	Angle of Incidence of the Direct Beam on Spectroradiometer #2 (deg)	(f5.1)
78:79	Measurement Type (DN, GN, GH, GT, DF)	(a2)
80:80	Attachment (Teflon Dome D, Integrating Sphere S, View-limiting Tube T)	(a1)

LINE 10: Saved for extra spectroradiometers if needed.

If no spectral data were recorded, the number of lines in the "D" segment is 10, the number of spectra is 0, and there is no corresponding quality-control information for this date/time in the ".QC" files. No quality control was performed because the atmosphere was unstable. If the number of spectra is 1, there are 60 lines in the "D" segment; if there are two spectra, the number of lines is 100.

If the number of spectra is 1 or 2, the spectral data follow after the first 10 lines of the "D" segment. There are 10 spectral measurements per line, with the number in the left-most column indicating the first or second spectroradiometer (1 or 2), followed by the starting wavelength (in nanometers) and the 10 spectral measurements (in W/m^2-nm). The 10 measurements are at wavelength increments of 2 nm. There are 401 spectral measurements from 300 to 1100 nm in 2-nm steps, with 10 measurements per line for 40 lines, and one measurement in the 41st line. The last number in the 41st line is the spectral integral. If a second spectroradiometer was used, the next 41 lines follow the same format. Blank lines follow the spectral data to fill the "D" segment to 60 or 100 lines.

An example of a ".QC" file is shown in Figure 6-3. The first line of each segment begins with a "Q" followed by the site, year, day number, and time stamp, with the number of lines in the segment given in the last columns of the line. Following the identifier are messages about variables that were flagged by the automatic quality-control processing (see appendix), noted by an operator at the measurement site, or noted during inspection at SERI. The last line of the segment shows the QC code for variables such as DN (direct normal, thermopile detector), SN (direct normal, silicon detector), AL (albedo), and SP (spectrum), as described in the appendix. Three quality-control codes are used: 1 = good; 2 = suspect, see messages and daily notes; and 3 = poor or missing, see messages and daily notes. The broadband codes (DN, SN, GN, GH, SH, and GT) have two values; the first is the before-scan measurement and the second is the after-scan measurement.

```
Q FSEC871210731                                                                   4
Noise in GH spectrum in UV
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP2IN2

Q FSEC871210830                                                                   8
SN bef/SN aft =       1.055
SH bef/SH aft =       1.053
2nd Int/BB bef =      0.636
2nd Int/BB aft =      0.651
Noise in GH spectrum in UV
QCDN1DN1SN2SN2GN1GN1GH1GH1SH2SH2GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP2IN2

Q FSEC871211031                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871211131                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871211231                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871211331                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871211431                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871211554                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871211630                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871211731                                                                   5
GH bef/SH bef =       0.931
GH aft/SH aft =       0.933
QCDN1DN1SN1SN1GN1GN1GH2GH2SH2SH2GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1

Q FSEC871220731                                                                   3
QCDN1DN1SN1SN1GN1GN1GH1GH1SH1SH1GT1GT1AL1AP1PR1TC1RH1WV1WS1KT1KN1DG1SP1IN1SP1IN1
```

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Figure 6-3. Example of quality-control information on the data-base tape

Figure 6-4 shows an example of a segment of the daily notes from the FSEC.NOTES file. Each segment of the file begins with an "N" followed by the site, year, and day number stamp, with the number of lines in the segment given in the last columns of the line. The next line contains the site operator log sheet number, month, day, year, day number, spectroradiometer serial number(s), and measurement mode(s). The PG&E and SERI notes do not include the daily log sheet number. The first two lines are followed by field notes. Notes that were added after inspection at SERI are separated from the operator notes with "-------". The existence of slides or photographs is indicated as well as their quality, i.e., good (G), marginal (M), or poor (P). In the example in this figure, there were two log sheets for this day (number 116 and 117) because the measurement mode changed from global horizontal (GH) to global tilt (GT).

```
N FSEC87122                                                    22
116 05 02 87 122  172 DN 102 GH
Clear at 0730
GH for first two scans, then GT
Slides: 0632 G
        0733 G
        0833 G
        0933 M (dark)
        1033 P    "
        1133 P    "
        1233 P    "
        1333 P    "
        1433 M    "
        1533 G
        1633 G
        1733 G

117 05 02 87 122  172 DN 102 GT
GT starting at 0800
Clear at 0800
Slides: See above

N FSEC87123                                                    16
118 05 03 87 123  172 DN 102 GT
Clear at 0830
Slides: 0633 G
        0733 G
        0833 G
        0933 M (dark)
        1033 P    "
        1133 P    "
        1233 P    "
        1333 P    "
        1433 M    "
        1533 G
        1633 G
        1733 G
```

Figure 6-4. Examples of daily notes on the data-base tape

An example of a segment of the measurement uncertainty file "UNCERT.CAL" is shown in Figure 6-5. The first line begins with a "U" followed by the serial number of the spectroradiometer. The upper and lower measurement uncertainty limits are given in the columns following wavelength, with the appropriate measurement mode, dates, and description at the top of the column. The second line in each segment of the ".DAT" files is a pointer to the correct uncertainty information in "UNCERT.CAL". The broadband solar radiation and meteorological instrument measurement uncertainty follows each spectral measurement uncertainty segment in "UNCERT.CAL".

The format of this data base was established at SERI to accommodate expanded, multiyear, long-term data collection. Users can reformat the data to suit their particular needs. We recommend the following steps for accessing and documenting particular data sets:

1. Select and extract the desired spectral data from the ".DAT" files using information such as measurement mode, day number, time, air mass, or atmospheric conditions, depending on the desired attributes.

2. Extract and review the corresponding segments of the quality-control information from the ".QC" files.

3. Extract and review the corresponding field notes from the ".NOTES" files.

U PRS-102
LI-COR PRS-102

1	2	3	4	5
Wav	GHS GTS Kt>60 lower 2/87- 8/87	GHS GTS Kt>60 lower 8/87- 5/88	GHS GTS Kt>60 upper GNS upper lower +/- GHS GTS Kt<60 upper lower +/- 2/87- 8/87	GHS GTS Kt>60 upper GNS upper lower +/- GHS GTS Kt<60 upper lower +/- 8/87- 5-88
300	-100.0	-100.0	100.0	100.0
302	-100.0	-100.0	100.0	100.0
.	.	.	.	.
.	.	.	.	.
400	-23.3	-17.1	15.3	9.1
402	-22.0	-17.3	14.0	9.3
.	.	.	.	.
.	.	.	.	.
500	-13.4	-11.7	5.4	3.7
502	-13.3	-11.7	5.3	3.7
.	.	.	.	.
.	.	.	.	.
600	-11.8	-11.1	3.8	3.1
602	-11.9	-11.1	3.9	3.1
.	.	.	.	.
.	.	.	.	.
700	-11.5	-10.7	3.5	2.7
702	-11.3	-10.7	3.3	2.7
.	.	.	.	.
.	.	.	.	.
800	-11.6	-10.6	3.6	2.6
802	-11.7	-10.6	3.7	2.6
.	.	.	.	.
.	.	.	.	.
900	-11.2	-10.5	3.2	2.5
902	-11.4	-10.8	3.4	2.8
.	.	.	.	.
.	.	.	.	.
1000	-11.7	-10.8	3.7	2.8
1002	-11.8	-10.8	3.8	2.8
.	.	.	.	.
.	.	.	.	.
1100	-12.9	-12.2	4.9	4.2

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Figure 6-5. Examples of spectral measurement uncertainty on the data-base tape. A value of ±100 indicates greater than 100% measurement uncertainty

4. Extract the measurement uncertainty information from the ".UNCERT" files and quote measurement uncertainty for all data used.

5. Examine the daily broadband and spectral solar radiation data graphs in the catalog (Volume II of this report [18]), if available. These graphs provide information on atmospheric conditions during the day. For example, Figure 4-3 shows daily broadband and spectral plots for partly cloudy conditions when solar radiation is changing rapidly throughout the day. The sun is obscured when the direct-normal values drop to zero and the global values approach each other. Figure 4-1 shows a clear day.

No data should be used without consulting the quality-control information, daily notes, and measurement uncertainty.

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APPENDIX

QUALITY-CONTROL PROCESSING

Limited quality-control processing was applied to the data base as described below. The results are in the ".QC" files on the data-base tape by site, year, and month. For example:

FLA8705.QC is FSEC, 1987, May
PGE8801.QC is PG&E, 1988, January
SER8711.QC is SERI, 1987, November.

These files correspond to the ".DAT" files for the same site, year, and month. Each data segment that includes a spectrum was processed through this quality-control procedure. If the atmospheric conditions were unstable, and a spectrum was not acquired, the broadband and meteorological data were included on the data-base tape, but no quality-control processing was applied.

An example of a segment of a ".QC" file is shown in Figure 6-3. The first line begins with a "Q" followed by the site, year, day, and time stamp. The last columns give the number of lines in the segment so the user can skip to the next segment. Following the first line are messages that were printed whenever the quality-control processing flagged a suspect or poor value.

Following the messages in an 80-character QC line listing the variables that were examined are one of three quality-control codes: 1, good; 2, marginal or suspect; and 3, missing or poor. The QC line was prepared using an automatic (computerized) check of the variables, and manual editing to include information from correspondence, log sheets, and visual inspection. Additional messages were added above the QC line if appropriate.

The two-character descriptors in the QC line are:

DN	Direct-normal (thermopile) solar radiation, before the spectral scan
DN	Direct-normal (thermopile) solar radiation, after the spectral scan
SN	Direct-normal (silicon), before
SN	Direct-normal (silicon), after
GN	Global-normal, before
GN	Global-normal, after
GH	Global-horizontal (thermopile), before
GH	Global-horizontal (thermopile), after
SH	Global-horizontal (silicon), before
SH	Global-horizontal (silicon), after
GT	Global-tilt, before
GT	Global-tilt, after
AL	Albedo (W/m^2)
AP	Albedo (%)
PR	Surface Pressure
TC	Temperature (°C)
RH	Relative Humidity
WV	Water Vapor (calculated from relative humidity)
WS	Wind Speed
KT	K_t
KN	K_n

DG D/GH
SP First Spectrum
IT Integral of the First Spectrum
SP Second Spectrum
IT Integral of the Second Spectrum

The automatic tests that were performed to determine the QC code following each variable were:

(a) Check for missing or negative values for the broadband, solar radiation, meteorological, or atmospheric data, or the spectral integrals:

<0 = Code 2
Missing (-9 or -99) = Code 3

(b) Check for atmospheric or broadband instrument instability using the difference and ratio of the before- and after-scan values and redundant measurements, if neither values are negative or missing:

DN before/DN after	if the absolute difference
SN before/SN after	is >10 W/m (e.g.,
DN before/SN before	5% of 200 W/m^2)
DN before/SN after	and
GH before/GH after	
SH before/SH after	the ratio is <0.95 or >1.05, each of the
GH before/SH before	two variables = Code 2
GH after/SH after	or
GN before/GN after	the ratio is <0.90 or >1.10, each of the
GT before/GT after	two variables = Code 3

(c) Check for DN > GN, or GN > ETR (extraterrestrial solar radiation) using ratios of the variables:

DN before/GN before	>0.95, each variable = Code 2
DN after/GN after	>1.0, each variable = Code 3
GN before/ETR	
GN after/ETR	

(d) Check for values of K_t, K_n, and D/GH that are too high:

KT (involves GH before and after and KT)
KN (involves DN before and after and KN)
DG (involves DN and GH, before and after, and DG)
>0.95, each variable = Code 2
>1.0, each variable = Code 3

(e) Check the spectral integrals for unusual ratios to the corresponding broadband solar radiation value.

IT/(Broadband value before and after)

For direct spectra: <0.6 or >0.85, IT = Code 2
For global spectra: <0.7 or >0.95, IT = Code 2

For direct and global spectra: <0.5 or >1.0, IT = Code 3

We suggest that users of the data base develop a computer program to access fields in the QC line and to print the messages. This limited quality control will not flag all possible errors and additional tests should be applied depending on the users' requirements and applications.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

The Solar Energy Research Institute (SERI), Electric Power Research Institute, Florida Solar Energy Center, and Pacific Gas and Electric Company cooperated to produce a spectral solar radiation data base representing a range of atmospheric conditions. These data will help to characterize the natural variability in the spectral (color) content of outdoor solar radiation so that the sensitivity of spectrally selective solar devices (such as photovoltaics) to these variations can be studied quantitatively. Volume I of this report documents the history, approach, content and format of the data base; Volume II contains graphs and field notes for each of the spectral data sets. The data reside on magnetic tape at SERI.

17. Document Analysis

a. Descriptors
Spectral solar radiation ; broadband solar radiation ; meteorological data ; spectroradiometers ;

b. Identifiers/Open-Ended Terms

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