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May 1990

SERI Solar Radiation Resource Assessment Project: FY 1989 Annual Progress Report

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PREFACE

This report summarizes the activities and accomplishments of SERI's Solar Radiation Resource Assessment Project during fiscal year 1989. This project is part of the Department of Energy's Resource Assessment Program.

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Solar Radiation Resource Assessment Project

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1.0 INTRODUCTION

The U. S. Department of Energy's (DOE) Resource Assessment Program develops a scientific understanding of and information about the availability and characteristics of renewable energy resources, such as solar energy, used by renewable energy technologies. The program is currently focused on solar radiation resource assessment for the United States. DOE's lead center for solar radiation resource assessment is the Solar Radiation Research and Metrology Branch (SRRMB)* in the Solar Electric Research Division at the Solar Energy Research Institute (SERI). Work is performed at SERI under the Solar Radiation Resource Assessment Project (SRRAP) in the SRRMB.

This annual report summarizes the activities and accomplishments of the SRRAP at SERI for the period 1 October 1988 through 30 September 1989, fiscal year (FY) 1989. The work was performed in accordance with the SRRAP Annual Operating Plan for FY 1989 [1]. Resources committed to SRRAP in FY 1989 supported 3.73 full-time equivalent (FTE) staff members, including part-time administrative support. Previous years' activities and historical information pertinent to the FY 1989 work are documented in the FY 1987 and FY 1988 annual reports [2,3].

Dr. Lloyd Herwig is the DOE Resource Assessment program manager. The SERI SRRAP leader is Dr. Carol Riordan in the SRRMB, managed by Roland Hulstrom. Questions and requests for information about the contents of this report and the SRRAP can be directed to C. Riordan, 303-231-1812.

1.1 Purpose and Scope of SRRAP

An understanding of the spatial and temporal variability of solar radiation at different locations is fundamental to the nation's efforts to develop and utilize incident solar radiation as a renewable energy resource. In addition to spatial and temporal characteristics, the spectral (color) content of solar radiation is important for the design and development of the spectrally selective solar conversion technologies, such as photovoltaics. A quantitative and scientific understanding of these solar radiation resource characteristics is attained through measurements, modeling, and analyses of the data. The purpose of the SRRAP is to help meet the needs of the public, government, industry, utilities, and researchers for these solar radiation data, models, and assessments, as required to develop, design, deploy, and operate solar conversion technologies and systems.

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*Formerly the Resource Assessment and Instrumentation Branch.

The scope of activities ranges from defining the natural characteristics and variability of solar radiation to assessing its availability. The SRRAP has concentrated on solar radiation characterization and resource assessment for the United States because funds do not allow for significant efforts to respond to a common need for better worldwide data. Although daylighting resource assessment has historically been the responsibility of the DOE Solar Buildings Program, the SRRAP and SRRMB have a strong interest in contributing our measurement and modeling expertise to this area. For example, in FY 1989 we submitted an initiative to DOE to participate in the International Daylighting Measurement Program and for SERI to serve as the lead center for the U.S.; however, no funds were obtained to initiate this activity at SERI.

1.2 Solar Radiation Resource Assessment Needs

Needs for solar radiation resource information are evaluated by direct interaction with DOE, industry, and utilities at special meetings and conferences. The SRRAP is also under the review and guidance of a Science and Technology Review Committee (STRC) with representatives from universities, government, and utilities to provide input regarding user needs. The SRRAP identifies many needs from various sources including the STRC and then determines common needs that can be addressed to reach a large number of users. The SRRAP has identified the following common needs.

- Maps and data of solar radiation availability and resource characteristics covering the U.S. for various types of solar collectors
- Long-term data bases that represent the natural spatial, temporal, and spectral variability of solar radiation required for solar energy system design and siting
- Representative solar radiation data that can be used for economic comparisons of solar energy systems
- Site-specific solar radiation estimation methods for site selection, design, and performance predictions
- Research-quality data bases to develop resource characterization methods
- Models or algorithms to convert solar radiation data from one component to another (for example, from total solar radiation on a horizontal surface [global-horizontal--the most common measurement] to solar radiation directly from the sun's disk [direct] and scattered radiation [diffuse] available to a collector surface of any orientation and configuration)

- Accurate solar radiation measurement instrumentation and methods to characterize the solar resource and evaluate system performance

- Worldwide solar radiation resource assessments to evaluate market potentials for U.S. industries and to design systems for foreign markets.

1.3 Multiyear Goals

SRRAP multiyear goals are developed with DOE based on the identified common needs, with the assumption that the level of project funding will remain the same or increase. The SRRAP has identified the following multiyear goals.

- To produce a 30-year (1961-1990) solar radiation data base for the U.S. that will replace the current 1952-1975 data base. An update is required to account for climate variations and changes. Also, known errors in the historical data base can be reduced using improved models and new data sets.

- To support the collection of high-quality solar radiation data for the U.S. through cooperative efforts with the National Oceanic and Atmospheric Administration (NOAA), which operates the national solar radiation network (SOLRAD); with selected Historically Black Colleges and Universities (HBCUs); and with others as resources permit. These data are needed to update the national data base at five-year intervals and to document long-term variability in the solar resources.

- To develop and implement methods that estimate site-specific solar radiation characteristics, in concert with the International Energy Agency (IEA) Subtask 9D which is addressing this topic. Interaction with IEA leverages the Resource Assessment Program funds and provides an avenue for obtaining results from other IEA subtasks pertinent to resource assessment.

- To produce a limited, research-quality spectral solar radiation data base and spectral simulation model(s) for various climate conditions, as needed for the development of spectrally selective solar energy conversion technologies (e.g., photovoltaics, biomass).

- To develop and disseminate products (e.g., a solar radiation atlas and typical day/year data sets) that will help to develop solar technologies and assist users in the design, sizing, and operation of solar power systems.

2.0 FY 1989 KEY ACTIVITIES

During FY 1989, the SRRAP defined and negotiated with DOE a set of FY 1989 key activities to help achieve the multiyear project goals. To provide effective research management and direction, the key activities were grouped technically under two research tasks. The following tasks, key activities, and allocation of the total budget (%) were developed.

1. Solar Radiation Data Bases and Models Task (70%)
   E. Maxwell, Task Leader

   Activities

   Solar Radiation Data Base (1961-1990) Development
   National Monitoring Networks
   HBCU Monitoring Network
   Site-Specific Solar Radiation Estimation Methods

2. Spectral Solar Radiation Data Bases and Models Task (30%)
   C. Riordan, Task Leader

   Activities

   Spectral Data Base
   Spectral Models

The SRRAP activities and accomplishments related to each of these tasks and activities are described in the following sections. The national solar radiation data base development is described in Section 3; cooperation with the national solar radiation measurement network is described in Section 4; the HBCU network activities are reviewed in Section 5; site-specific solar radiation estimation activities are covered in Section 6; and spectral solar radiation models and data base activities are discussed in Section 7.

3.0 NATIONAL SOLAR RADIATION DATA BASE DEVELOPMENT

The SRRAP has given top priority to the development of a national solar radiation data base, covering the period from 1961 through 1990, to replace the currently used 1952-1975 SOLMET/ERSATZ data base [4]. The 1961-1990 time frame was selected to coincide with the period to be used by NOAA to establish new long-term climatological means or norms for meteorological variables. The 1952-1975 SOLMET/ERSATZ data base was created by combining rehabilitated measured hourly global-horizontal solar radiation data for 26 SOLMET (SOLar METeorological) sites, modeled direct-normal values for these 26 sites, and modeled global-horizontal values for 222 ERSATZ (meaning synthetic) sites with meteorological data.

The new 1961-1990 data base, which will include measured data and estimated values, will improve the quality of the solar radiation data for the United States because of new, high-quality measured data and improved models. Good quality data are available for 1977-1985, and are expected to be available for 1988-1990. Measurements of both direct-normal and global-horizontal components were made at all sites, and nine stations also measured the diffuse component from 1977-1985. The data base will also be enhanced through the use of much improved models for estimating values for missing components and for estimating values for the ERSATZ stations using meteorological data. The improved models will effect improvements in the data base for the entire period from 1961-1990. Any climatological changes that have occurred since 1975 will be contained in the new data base.

The 1961-1990 data base development is a three-year effort that includes elements such as development of postmeasurement quality control procedures, models to convert global-horizontal measurements to direct-normal and diffuse components, and models to estimate solar radiation values using meteorological data. In FY 1989 we completed work on SERI QC, a software package for performing quality assessment of solar radiation data [5]. During FY 1990 a user's manual will be prepared, SERI QC will be tested and reviewed by outside organizations, and the final version will be distributed to NOAA, Sandia National Laboratories, and others. Requests for SERI QC have been received from Sweden, Norway, Korea, and several U.S. laboratories.

3.1 Conceptual Description of SERI QC

SERI QC assesses the quality of solar radiation data by comparing measured values with expected values. The natural variations of solar radiation with time of day, latitude, and season make it difficult and confusing to define or discuss the expected absolute values of these parameters in the context of quality control. Communications are further complicated by the variety of units used to express solar radiation values, including Langleys, Btu/ft^2, kWh/m^2, and mJ/m^2 for energy values and W/m^2 or kW/m^2 for irradiance values. Therefore, the QC algorithm and software deal with unitless values normalized with respect to extraterrestrial radiation (ETR).

These parameters are defined according to the expressions

$$Kn = I_n / I_o \quad (3\text{-}1)$$

$$Kt = I_t / (I_o \cos z) \quad (3\text{-}2)$$

$$Kd = I_d / (I_o \cos z) \quad (3\text{-}3)$$

where

I_o = extraterrestrial direct-normal irradiance

I_n = direct-normal irradiance at the earth's surface

I_t = total global-horizontal irradiance at the earth's surface

I_d = diffuse-horizontal irradiance at the earth's surface

$I_o \cos z$ = extraterrestrial irradiance on a surface parallel to the earth's surface

z = solar zenith angle

Kn = direct-beam transmittance

Kt = clearness index or effective global-horizontal transmittance

Kd = effective diffuse-horizontal transmittance.

The scatter plot of data shown in Figure 3-1 illustrates the advantages of working in K space when using an empirical approach to quality assessment of solar radiation data. This plot includes all of the hourly data collected at Tallahassee, Fla. from 1977 through 1980, for those hours when both global-horizontal and direct-normal data were collected and when the solar zenith angle was less than 80°. The three dashed lines shown on this figure establish the maximum expected values for Kt and Kn and the minimum expected value for Kt for the atmospheric conditions existing at Tallahassee, Fla. during these years. If we assume that these four years are representative of average conditions at Tallahassee, then the dashed lines provide quality assessment boundaries that can be used for any measurement of global-horizontal or direct-normal solar radiation at this location. This represents almost a 50% reduction in the area of acceptability as compared to ETR and zero. In K-space ETR equals 1.0.

When concurrent measurements are made of both global-horizontal and direct-normal solar radiation, the solid line encompassing the bulk of the measured values can be used to further

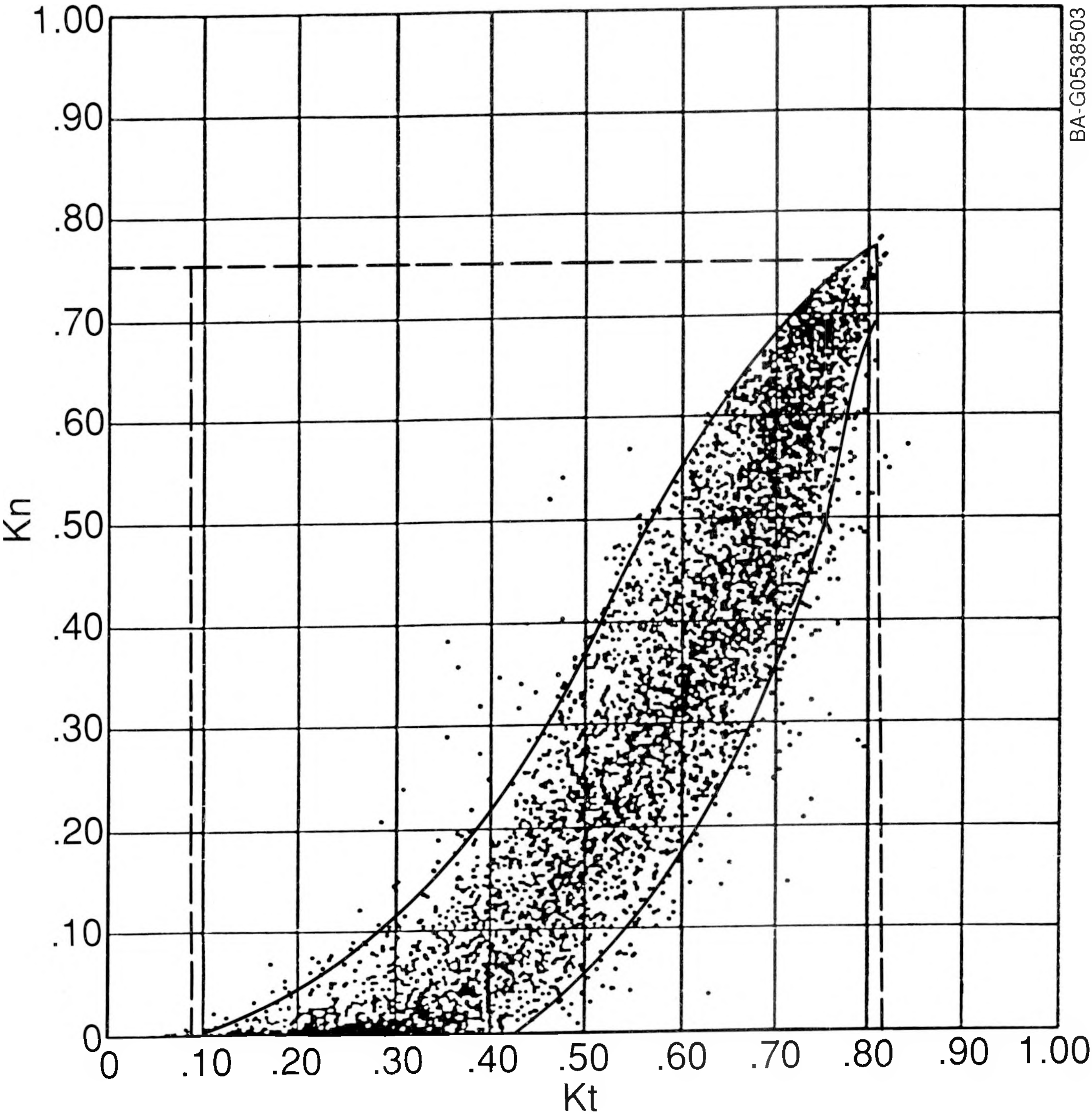


Figure 3-1. **Normalized Hourly Solar Irradiance Data for Tallahassee, Florida - 1977 to 1980**

reduce the range of expected values. The area of acceptability now is less than 14% of the total area between zero and ETR. When scatter plots such as this are made for each month of the year and for three air mass zones, the area of acceptability is further reduced.

If all three of the fundamental components of solar radiation have been measured, the expected K value of any one of the three can be computed from the other two using the relationship

$$Kt = Kn + Kd \tag{3-4}$$

It is possible, of course, that all three components could be in error by just the right amounts to still satisfy equation (3-4). However, the probability of this happening is quite low, since the sources of error for these three measurements are different and independent.

If we consider a point in three dimensional K-space to represent an accurate measurement of solar radiation, then using equation (3-4) to perform quality assessment is by far the best, because the region of acceptability can now be represented by a sphere, with a radius set to any range of acceptability desired.

3.1.1 Definition of Expected Ranges Used by SERI QC

The expected ranges of acceptable data are established for SERI QC according to the following definitions (see Figure 3-2).

One-Component

When only one of the three fundamental components has been measured for a given hour, acceptable data are expected to lie between empirical maximum and minimum values of Kt, Kn, or Kd, which are set for three air mass ranges for each station-month. The minimum value for Kn is always zero. The stippled area shown in Figure 3-2 encompasses the one-component region of expected values.

Two-Components

When both global horizontal and direct normal components are present, acceptable data are expected to lie within empirically determined boundaries such as shown in Figure 3-2. Boundaries are set for three air mass ranges for each station-month.

Three-Components

With all three components present, the expected value of any one component is determined from the equation Kt = Kn + Kd. The range of acceptability is based on an arbitrary error limit, shown as a circle around a data point on Figure 3-2.

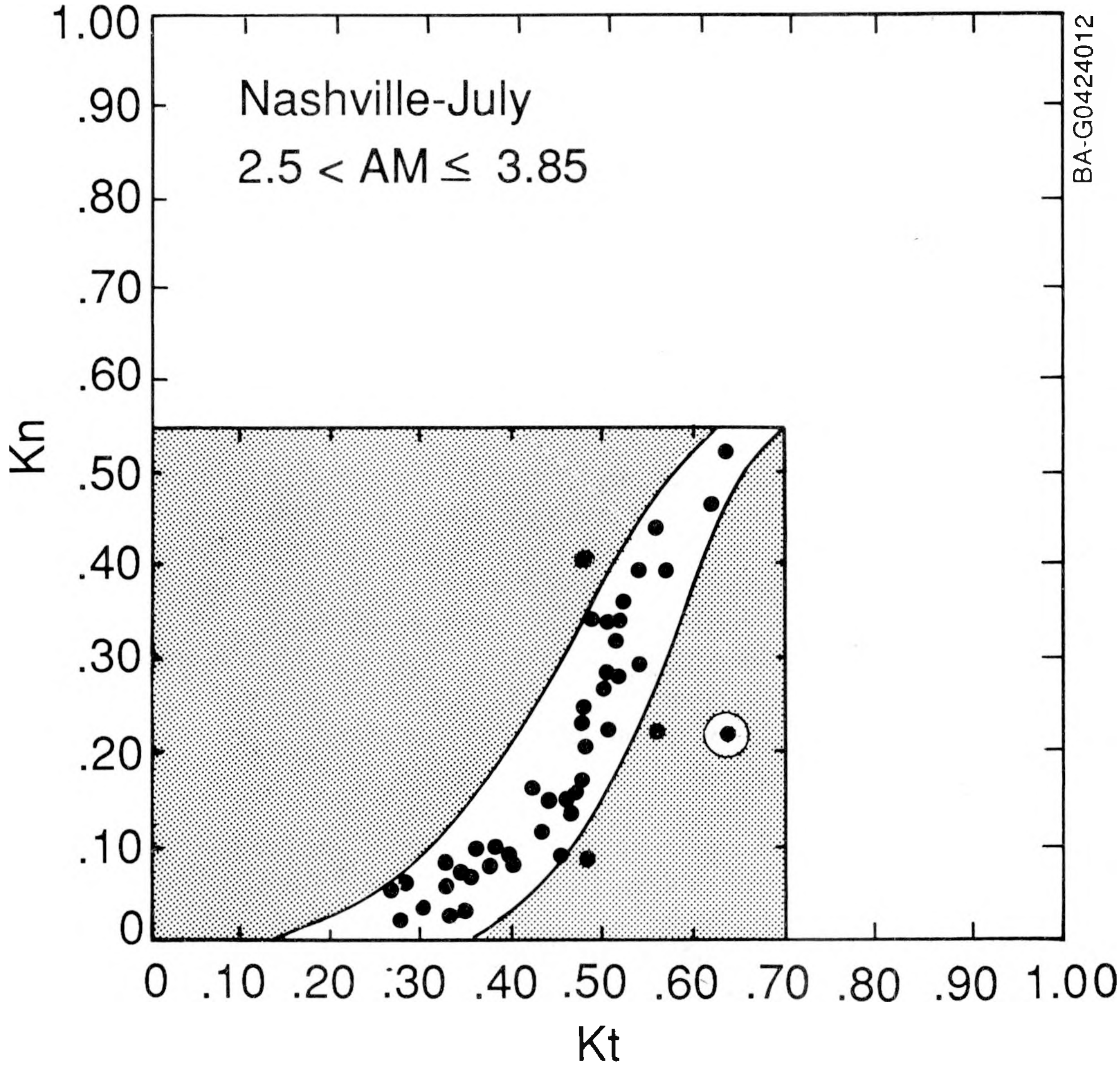


Figure 3-2. **Limits of Expected Values for Global (Kt) and Direct (Kn) Solar Irradiance for One, Two, and Three Component Data**

3.1.2 The Gompertz Function

Once the decision was made to employ empirical boundaries to define the limits of acceptable data, we were faced with the problem of defining those boundaries. It was recognized quite early that the boundaries varied as a function of climate and season as described above. It also was evident that quality control would be significantly compromised if the extreme left and right boundaries found for all station-month combinations were used for all stations. A search was then undertaken to find a function that would closely match the boundaries of actual data and that could be easily adapted to efficient software for performing the quality control function.

The function that was finally selected is a double exponential called the Gompertz equation [6], which for our purposes takes on the form

$$Kn = \alpha\beta^{\gamma\beta^{\delta Kt}} \tag{3-5}$$

The effect of each of the four parameters in this equation makes it ideal for establishing boundaries for solar radiation data plotted in Kt-Kn space. The Gompertz function takes on an S-shape similar to the boundaries on Figures 3-1 and 3-2 and is therefore well suited for forming boundaries around the solar radiation data. Furthermore, the individual effects of the four parameters provide the control needed to set the shape and position of the boundaries. The parameter, α, determines the asymptotic value for Kn, β positions the inflection point along the Kn axis, γ positions the inflection point along the Kt axis, and δ controls the slope of the curve at the inflection point. This function has proven to be invaluable for establishing quality control boundaries.

Data from a number of locations and months were used to select the boundary shapes that would most accurately represent the effects of the various climate and seasonal conditions found in the United States. The set of six shapes for the left boundary are shown in Figure 3-3. A similar but different set of five shapes developed to fit the right boundary are shown in Figure 3-4. These shapes have proven to be adequate for the range of climate and atmospheric conditions found in the United States.

In addition to varying the shapes of the boundaries, it was found that differences in air mass, elevation, and atmospheric variables result in a change in the position of boundaries along the Kt axis. Therefore, for each of the boundary shapes a family of curves spaced in increments of 0.025 along the Kt axis have been defined. This provides the ability to vary position along the Kt axis, without changing shape, to achieve the best match with the actual data.

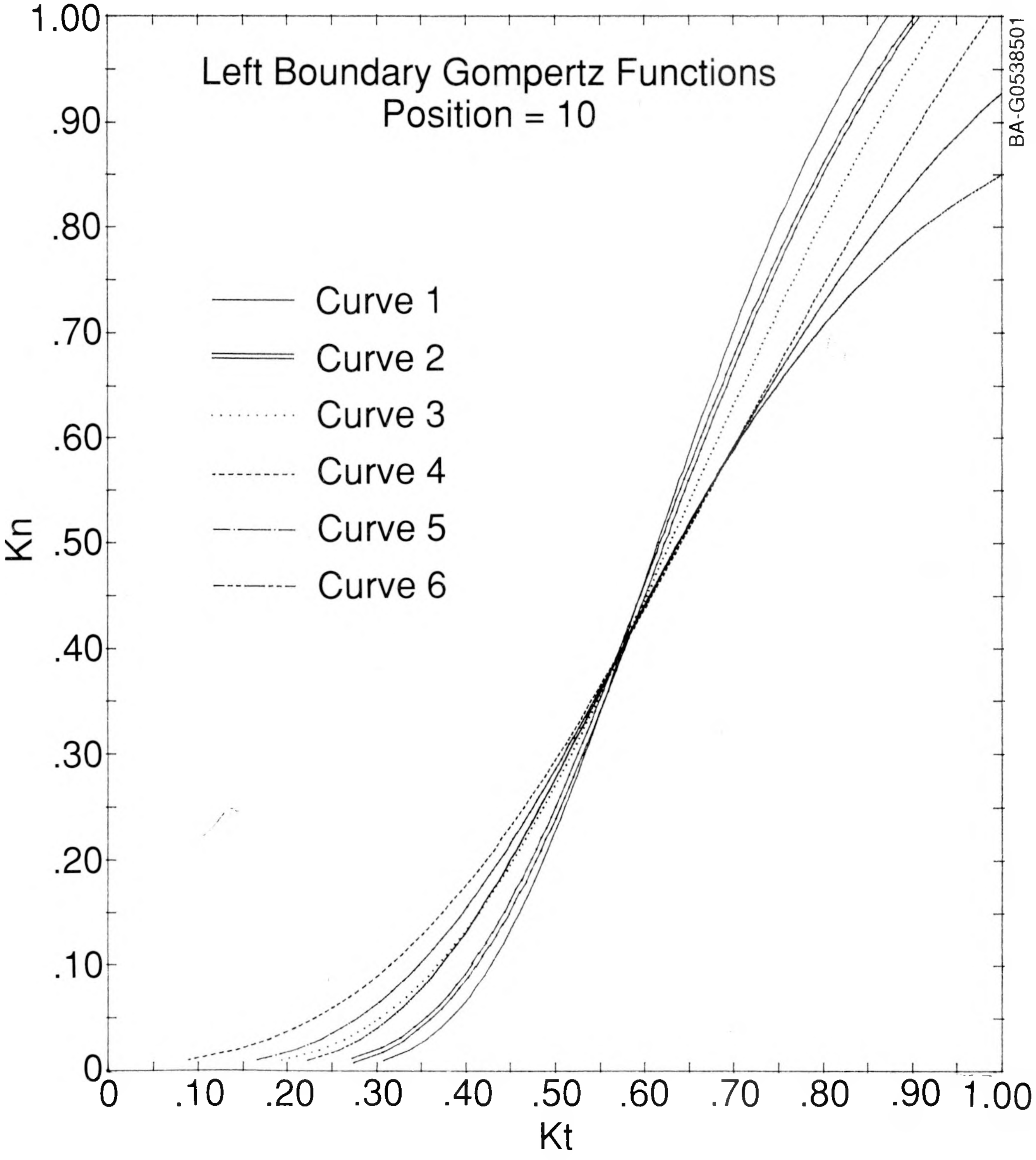


Figure 3-3. **Gompertz Shapes for the Left Boundary of Scatter Plots of Solar Irradiance Data in Kt-Kn Space**

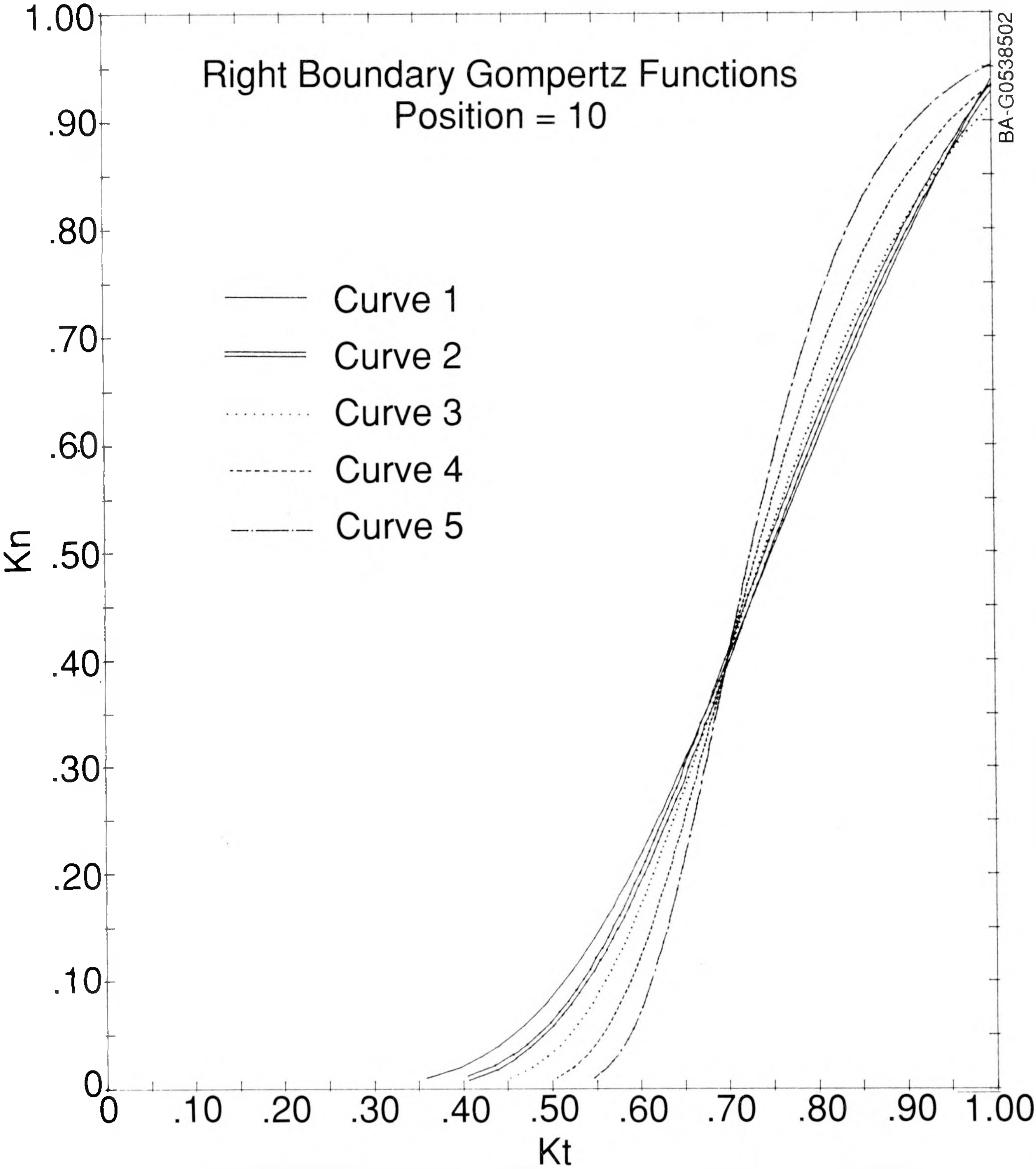


Figure 3-4. **Gompertz Shapes for the Right Boundary of Scatter Plots of Solar Irradiance Data in Kt-Kn Space**

3.2 Initial Model Development Efforts

About 300 station-months of measured data from the NOAA-National Weather Service (NWS) SOLRAD network were processed using SERI QC to produce high-quality measured data sets for model development. Models are being developed, evaluated, and upgraded to complete missing solar radiation components and missing hourly values, and to estimate values using meteorological data at locations where solar radiation is not measured. One example is the SERI DISC model, which estimates direct solar radiation using global-horizontal values [7].

Attention will also be given to modeling the statistical characteristics of measured data, such as their variance, skewness, and kurtosis, as well as mean values, to properly represent the expected distribution of the data. The statistical characteristics of measured data (global, direct, and diffuse) for four locations in the United States (Albuquerque, N. Mex.; Columbia, Mo.; Medford, Ore.; and Sterling, Va.) were compared with the statistical characteristics of modeled data for these locations. The models were the MAC, Joseffson, and Kasten2. The MAC and Joseffson models were judged by the IEA to be the best for calculating hourly and daily values of global solar radiation from cloud cover and other meteorological variables [8]. None of these models contains an explicit statistical term so none is capable of reproducing the statistical characteristics of measured data. Therefore, SRRAP is pursuing the development of a statistical model, which should be completed in FY 1990.

3.3 Processing NOAA Data from 1981-1985

Solar radiation data recorded at the NOAA-NWS SOLRAD network stations at one-minute intervals from 1981 through October 1985 are being processed into hourly values and combined with printed paper tape hourly data processed by the National Climatic Data Center (NCDC). A major effort was required in FY 1989 to sort out these data, which had been randomly transferred from cassettes to magnetic tape reels, with no examination or quality control due to lack of funds at NCDC. Recovery of these data required sophisticated programming and interpretation. The integration of these one-minute data into hourly values and comparisons with and addition of the NCDC hourly data will take place in early FY 1990. These data will be quality controlled and sent to NCDC for public distribution. They will eventually become part of the 1961-1990 data base.

3.4 Plans for Completing the Data Base

Our plans for FY 1990 include the following.

- The development and validation of models to be used to create the 1961-1990 data base will be completed. The procedures used to rehabilitate the historical data will also be reexamined and upgraded, if necessary.

- The models and rehabilitation procedures will be validated and thoroughly tested by producing a data base for the period from 1961 to 1985 for those stations common to the SOLMET and SOLRAD networks. These stations have data from the historical period (1952-1975) and the 1977-1985 period when high-quality data were collected by the network. Therefore, they offer the best opportunity to validate the performance of the models and procedures to be used in producing the complete 1961-1990 data base. Values for all missing components and missing hours will be completed to produce a 25-year data base for 20 stations. These data will be transferred to NCDC for general distribution.

- Support for the collection of high-quality data by NOAA-NWS and other networks will be maintained to the extent that it is needed and budgets permit. This will include work with NWS to minimize the impact of its strategic modernization plan on the operation of the SOLRAD network.

Plans for FY 1991 include the following.

- Data for all 44 SOLMET and SOLRAD stations will be produced for the entire period from 1961-1990. This will provide the final checks for all the models and procedures to be used.

- The models and procedures will then be used to estimate solar radiation values using meteorological data for 200 to 250 ERSATZ sites where no solar radiation data have been or are being collected. These values will cover the 1961-1990 period.

- The two sets of data and estimated values described above will be combined and transferred to NCDC for general distribution. These data will be in the TD (Tape Deck)-3280 NCDC format and will contain quality control flags from the SERI QC processing. Consideration is also being given to transferring the entire data base to compact optical discs. This would greatly facilitate the distribution of the data and make it easier for users to access data for specific stations and times.

- The data from 1952 to 1961 will be rehabilitated using the new models and procedures; data will be added to the data base when time and budgets permit.

- SRRAP plans to continue providing support for the collection of high-quality solar radiation data for the foreseeable future.

Once the updated and upgraded data base is completed, the development of other data products such as solar radiation maps and atlases, interpolation/extrapolation methods for site-specific solar radiation estimates, and typical day/year data sets will be undertaken. Particular emphasis will be placed on developing methods to provide solar radiation estimates for any location in response to needs expressed by utilities, government agencies, researchers, and industry.

4.0 COOPERATION WITH THE NATIONAL SOLAR RADIATION MEASUREMENT NETWORK

NOAA operates the 31-station SOLRAD measurement network for the United States. Four NOAA organizations share responsibilities of SOLRAD operation. The overall direction of the network is under Dr. David Rodenhuis, Chief of the Climate Analysis Center (CAC). NWS is responsible for day-to-day operations at the stations and the daily transmission of data via the Automation of Field Operations and Services (AFOS) communication system. The data from the AFOS system are received daily at CAC where they are processed and made available for public dissemination via a telephone call-up system; the data are updated weekly. CAC sends the data to NCDC where they are quality assessed and archived.

Responsibility for the radiometric equipment at each station resides at the Solar Radiation Facility (SRF) in Boulder, Colo., which is part of the Environmental Research Laboratories (ERL). SRF provides annual calibrations of all network radiometers and is responsible for maintaining the National Radiometric Reference, with traceability to the World Radiometric Reference (WRR) in Davos, Switzerland. SRF is also responsible for installing and maintaining the new computer-controlled solar trackers recently purchased by NOAA.

The SRRAP needs high-quality solar radiation and meteorological data for the U.S. from this SOLRAD network. In FY 1989, work continued in cooperation with the elements of NOAA mentioned above in support of the SOLRAD network. Cooperation has been in the following areas:

- Radiometer calibrations
- Station operations
- Automatic solar trackers
- Data quality control.

4.1 Radiometer Calibrations

Since 1978, the traceability of all radiometer calibrations by SERI and NOAA to the international standard, WRR, has been maintained. The WRR was developed by the World Meteorological Organization (WMO) and is maintained at the World Radiation Center (WRC) in Davos, Switzerland. The WRR is defined by the collective measurements from six absolute cavity radiometers forming the working group. (In 1987, SERI contributed a well-characterized absolute cavity radiometer to the WRC as a new member of the working group.) Traceability of a laboratory reference standard radiometer, used for calibration transfer, is established and maintained by regular comparison with the WRC working group of cavity radiometers.

The three reference-standard absolute cavity radiometers owned by DOE/SERI and the three NOAA/SRF cavity radiometers are the basis for radiometer calibration traceability. These instruments are compared regularly at local, national, WMO regional, and WMO international intercomparisons.

In FY 1989, SRRAP participated in three absolute cavity intercomparisons. In October, absolute cavity radiometers from NOAA/SRF and the Centre de Developpement Des Energies Renouvelables (Morocco) were compared with the SERI instruments. We also participated in the WMO regional intercomparison held in Mexico during April (Figures 4-1 (a) and 4-1 (b)). In September, we compared instruments with NOAA at the NOAA/SRF in Boulder, Colo.

SRRAP also assisted NOAA/SRF with the recalibration of all radiometers used in the SOLRAD network. These instruments were calibrated in June and July and deployed in the network by September.

4.2 Station Operations

Proper training of the personnel responsible for the daily operation of a solar radiation monitoring station is essential for the collection of accurate and useful data from the SOLRAD network. At NOAA's invitation, we helped NWS develop a training manual for use by station personnel. A draft of the manual was delivered to NWS in January and will be completed by NWS next year.

4.3 Automatic Solar Trackers

From 1985 to 1987, we assisted NOAA in the selection and testing of a new automatic solar tracker for mounting a pyrheliometer and measuring the direct-normal component of solar radiation. In FY 1989, we provided limited funds for assisting with the installation of these trackers at the SOLRAD stations.

4.4 Data Quality Control

SRRAP's research and development of a new data quality control method for solar measurements [5] was directly applicable to the needs of NCDC for its routine data processing. We prepared the software and documentation for a preliminary version of SERI_QC for NCDC. An upgraded version of SERI_QC will be available in early 1990. NCDC will help us evaluate the new SERI_QC while using the software on data from the SOLRAD network.

Figures 4-1 (a) and 4-1 (b). International Cavity Radiometer Intercomparison

5.0 HBCU SOLAR RADIATION NETWORK

5.1 Overview

The HBCU network is one example of several regional networks operating in the U.S. [9-12]. These networks provide valuable data on a finer scale than the national SOLRAD network, and serve special regional needs. For example, a solar radiation monitoring program is operated by the Pacific Gas and Electric Company in California and provides resource assessment data for their service territory.

SRRAP established the six-station HBCU Solar Radiation Monitoring Network in FY 1985 in response to presidential and congressional mandates directing all federal agencies to implement programs that could strengthen the technical capability of the nation's HBCUs. Realizing that NOAA-NWS solar radiation measurement stations are sparse in the southeastern U.S., letters of interest were solicited from HBCUs in this area and six of them agreed to participate in the HBCU network. Routine network operations are performed at the stations, shown in Figure 5-1.

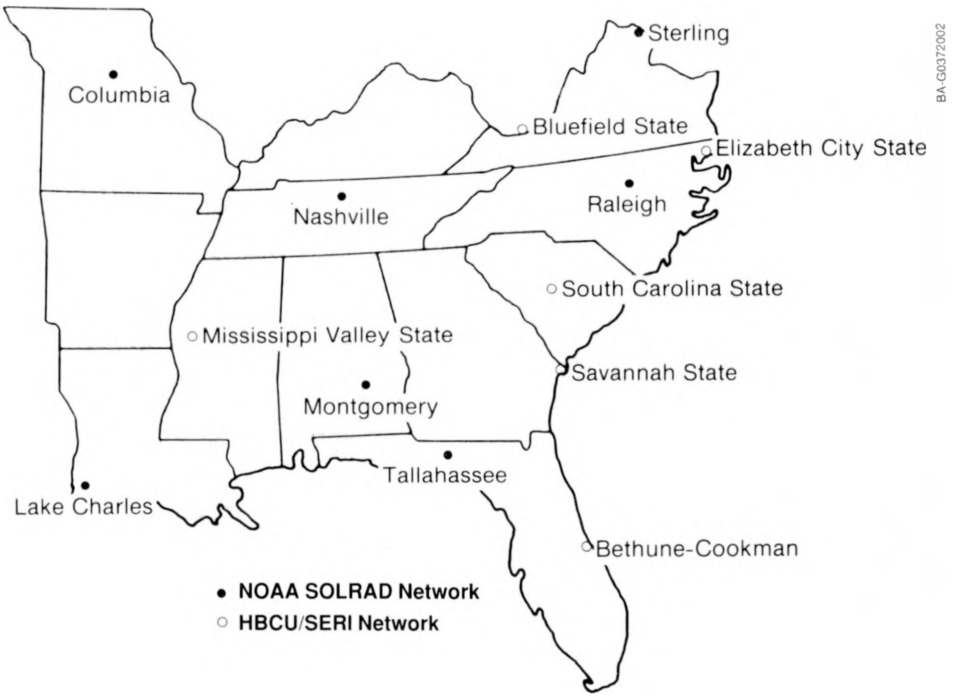


Figure 5-1. HBCU and NOAA/SOLRAD Stations in the Southeast U.S.

- Bethune-Cookman College; Daytona Beach, Fla.
- Bluefield State College; Bluefield, W. Va.
- Elizabeth City State University; Elizabeth City, N.C.
- Mississippi Valley State University; Itta Bena, Miss.
- South Carolina State College; Orangeburg, S.C.
- Savannah State College; Savannah, Ga.

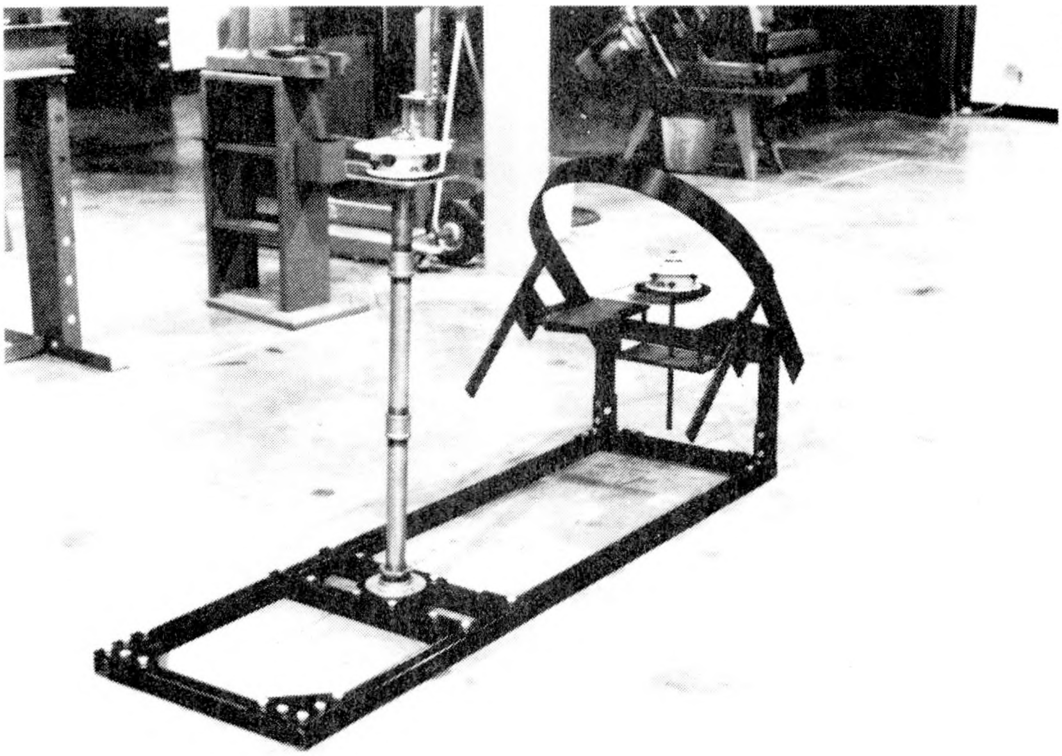
Each station is equipped with an Eppley Laboratory model PSP pyranometer for measuring global-horizontal solar irradiance, a shadow band stand with another pyranometer for measuring the diffuse-horizontal solar irradiance, and a Campbell Scientific model CR21L microprocessor-based data acquisition system for recording the data (see Figure 5-2(a) and (b)). The Bluefield State College station also has an Eppley Laboratory model NIP pyrheliometer mounted in a LI-COR model LI-200 automatic sun-following tracker for measuring the direct-normal solar irradiance (see Figure 5-3).

The data acquisition system records five-minute, hourly, and daily data on audiocassette tapes that are sent monthly to SERI for processing. Listings of the data are also produced at the station as an immediate display that may be used to check station operations. A maintenance inspection of the station equipment and a brief meteorological observation are made at least once a day, Monday through Friday.

5.2 Processing Data

Between January and March the SRRAP software used to process HBCU data was modified for improved processing and to reflect a more consistent report philosophy. Processing includes transfer of the raw data from the logging cassette to a personal computer in ASCII format. The raw data are archived on floppy disk, then transferred to a VAX computer.

On the VAX, the raw data are put in the SERI Standard Broadband Format (SBF) [13], which includes shadow band correction for diffuse data and quality control flags for all data. From the SBF files, monthly reports are generated for each instrument at each site, as well as the estimated direct radiation for the five sites without a pyrheliometer. The reports show hourly averages for each hour of the month, daily averages, and a monthly average (see Figure 5-4(a), (b), and (c)). From the monthly report, a time series plot is generated for each instrument showing the maximum, minimum, and average measurements for each hour of the day (Figure 5-5).



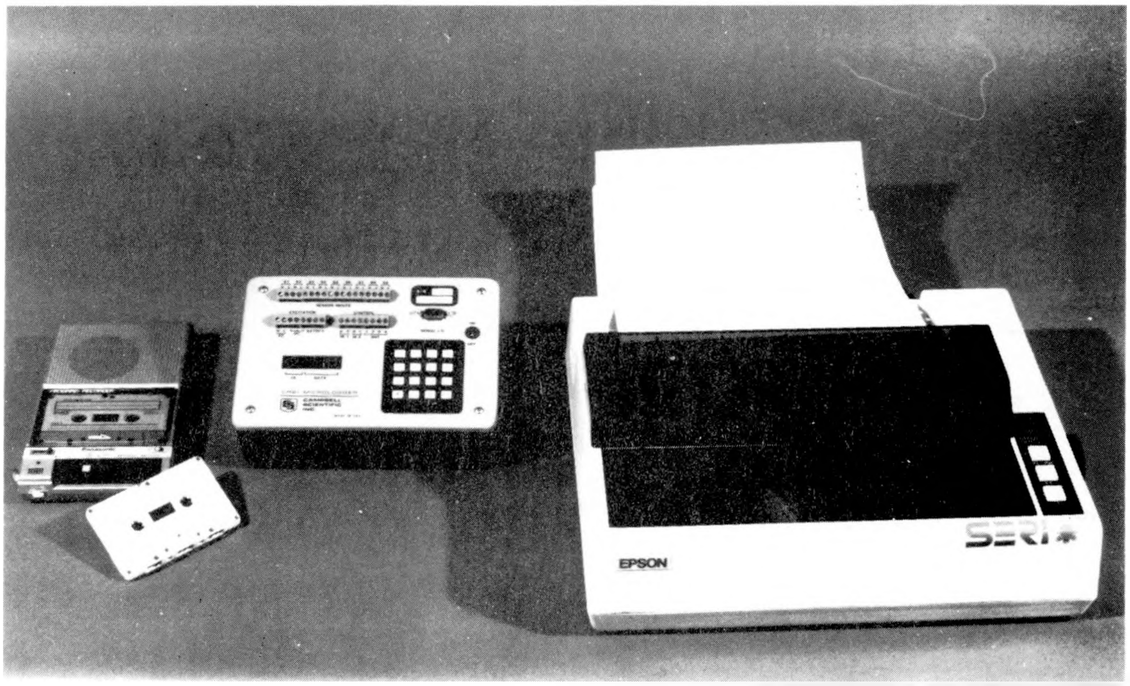


Figure 5-2. Radiometer Mounting Platform with Pyranometers in Place for Global and Diffuse Irradiance Measurements (a); HBCU Data Logging Equipment (b)

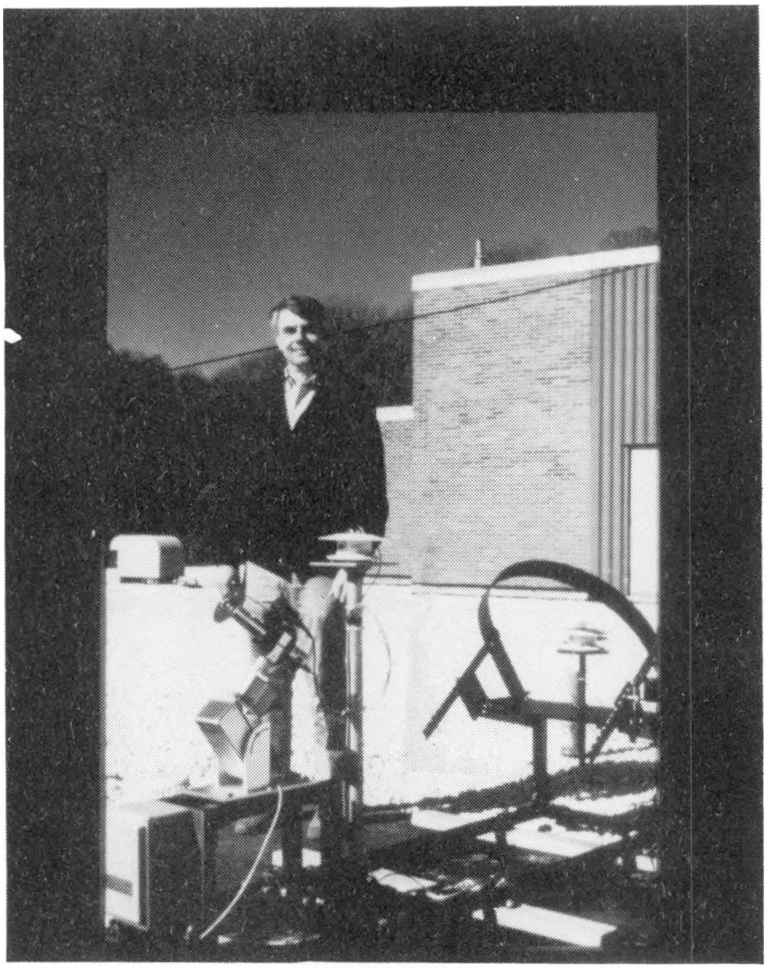


Figure 5-3. Dr. Lewis Foster is Standing Next to the HBCU Radiometer Platform. (Left to right: Eppley Model Normal Incidence Pyrheliometer [NIP] mounted on a LI-COR 2020 automatic sun tracker; Eppley Model Precision Spectral Pyranometer [PSP] measuring global solar radiation on a horizontal plane; and PSP under a shadow band measuring diffuse solar radiation on a horizontal plane.)

Monthly Summary Prepared By The Solar Energy Research Institute

STATION: MISSISSIPPI VALLEY STATE UNIVERSITY August 1989

33.50 N Latitude 90.33 W Longitude 52. Meters AMSL Time Zone -6.0

GLOBAL SOLAR RADIATION ON A HORIZONTAL SURFACE
HOURLY INTEGRATED AND DAILY TOTALS
WATT-HOURS PER SQUARE METER

DAY \ HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY
1	0	0	0	0	0	12	52	116	276	518	467	465	551	728	558	368	127	55	14	0	0	0	0	0	4306
2	0	0	0	0	0	14	43	117	230	480	776	747	840	797	791	540	371	196	31	0	0	0	0	0	5972
3	0	0	0	0	0	23	164	365	566	741	871	937	943	884	770	602	406	197	38	0	0	0	0	0	7505
4	0	0	0	0	0	22	164	371	572	751	876	940	884	866	784	615	418	211	40	0	0	0	0	0	7515
5	0	0	0	0	0	20	155	358	545	628	718	691	547	747	739	539	324	201	37	0	0	0	0	0	6248
6	0	0	0	0	0	21	159	327	552	697	791	942	939	875	757	631	247	73	18	0	0	0	0	0	7029
7	0	0	0	0	0	13	35	64	301	206	345	369	437	649	376	363	120	75	20	0	0	0	0	0	3372
8	0	0	0	0	0	21	165	379	592	782	887	969	986	890	712	604	362	199	31	0	0	0	0	0	7576
9	0	0	0	0	0	20	166	373	580	763	893	961	978	833	704	545	317	133	19	0	0	0	0	0	7287
10	0	0	0	0	0	15	134	326	522	693	826	742	737	806	518	509	294	184	21	0	0	0	0	0	6328
11	0	0	0	0	0	14	129	316	519	695	840	842	814	759	601	547	354	162	24	0	0	0	0	0	6615
12	0	0	0	0	0	13	121	307	503	685	817	893	853	822	682	511	301	158	20	0	0	0	0	0	6685
13	0	0	0	0	0	14	131	325	533	713	847	912	886	836	714	543	352	152	17	0	0	0	0	0	6976
14	0	0	0	0	0	12	129	332	525	695	828	900	909	864	782	592	220	54	15	0	0	0	0	0	6858
15	0	0	0	0	0	9	98	292	344	601	725	565	809	705	613	484	275	126	19	0	0	0	0	0	5663
16	0	0	0	0	0	4	44	92	203	410	452	439	566	405	286	427	315	135	13	0	0	0	0	0	3790
17	0	0	0	0	0	11	118	269	444	446	574	612	373	126	556	356	27	27	8	0	0	0	0	0	3948
18	0	0	0	0	0	11	133	239	363	673	655	718	786	767	662	512	321	135	13	0	0	0	0	0	5988
19	0	0	0	0	0	10	113	301	472	604	707	763	705	651	533	510	162	171	14	0	0	0	0	0	5716
20	0	0	0	0	0	11	108	257	458	680	839	813	854	584	752	504	363	152	17	0	0	0	0	0	6390
21	0	0	0	0	0	9	112	296	489	668	697	715	839	771	685	494	280	115	10	0	0	0	0	0	6179
22	0	0	0	0	0	11	132	332	524	499	862	861	833	794	595	547	344	144	12	0	0	0	0	0	6489
23	0	0	0	0	0	10	132	334	468	591	794	844	811	702	639	509	347	126	6	0	0	0	0	0	6313
24	0	0	0	0	0	5	108	188	372	417	413	637	512	378	405	209	52	19	3	0	0	0	0	0	3717
25	0	0	0	0	0	5	86	290	508	599	554	347	906	877	688	469	77	87	20	0	0	0	0	0	5511
26	0	0	0	0	0	9	119	307	509	534	639	695	757	819	694	482	101	16	12	0	0	0	0	0	5694
27	0	0	0	0	0	9	86	279	489	670	803	878	729	785	673	514	297	113	7	0	0	0	0	0	6332
28	0	0	0	0	0	7	99	276	479	659	777	880	772	719	519	469	279	102	5	0	0	0	0	0	6039
29	0	0	0	0	0	10	119	261	470	636	726	778	706	718	663	264	103	68	3	0	0	0	0	0	5525
30	0	0	0	0	0	5	78	220	479	672	654	879	847	662	361	390	253	95	9	0	0	0	0	0	5604
31	0	0	0	0	0	6	86	268	464	646	752	751	104	72	136	173	171	92	10	0	0	0	0	0	3730
AVG	0	0	0	0	0	12	113	277	463	615	723	758	749	706	611	478	257	122	17	0	0	0	0	0	5900
S D	0	0	0	0	0	5	37	83	102	125	149	174	197	203	159	113	111	56	10	0	0	0	0	0	1196
S/A	0	0	0	0	0	0.45	0.32	0.30	0.22	0.20	0.21	0.23	0.26	0.29	0.26	0.24	0.43	0.46	0.59	0	0	0	0	0	0.20
MIN	0	0	0	0	0	4	35	64	203	206	345	347	104	72	136	173	27	16	3	0	0	0	0	0	3372
MAX	0	0	0	0	0	23	166	379	592	782	893	969	986	890	791	631	418	211	40	0	0	0	0	0	7576

Daylight Data Recovery: 0% missing; 0% exceeded the 15% QC threshold -- total daylight 5-minute measurements, 4966.

NOTES:
"FAIL" = no 5-minute sample passed QC for the hour.
"N/A" = not applicable.
"M" = daily total missing one or more daylight hours; NOT used in monthly summary.
"?" = partial data: HOURLY, excludes more than 2 of the 12 five-minute values (missing or failed QC).
DAILY and MONTHLY, excludes more than 10% of the possible 5-minute values (missing or failed QC).
"HOUR" = ending hour local standard time.
"*" = this day has flagged data.
"MISS" = ALL 5-minute samples are missing for the hour; NOT used in further summaries.

Instrument: Eppley PSP
Calibration Constant: 8.252uV/Wm-2
Serial Number: 25951F3
Calibration Date: September, 1986

Figure 5-4(a). HBCU Report Example

Monthly Summary Prepared By The Solar Energy Research Institute

STATION: MISSISSIPPI VALLEY STATE UNIVERSITY August 1989

33.50 N Latitude 90.33 W Longitude 52. Meters AMSL Time Zone -6.0

DIFFUSE SOLAR RADIATION (SHADOW BAND) ON A HORIZONTAL SURFACE
HOURLY INTEGRATED AND DAILY TOTALS
WATT-HOURS PER SQUARE METER

DAY \ HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY
1	0	0	0	0	0	12	55	122	288	483	477	464	452	459	294	209	135	56	15	0	0	0	0	0	3521
2	0	0	0	0	0	13	45	123	232	371	368	344	239	248	196	112	103	87	27	0	0	0	0	0	2508
3	0	0	0	0	0	20	90	130	153	167	175	184	188	186	173	155	130	95	31	0	0	0	0	0	1876
4	0	0	0	0	0	18	68	89	93	92	95	102	134	114	94	79	68	56	22	0	0	0	0	0	1124
5	0	0	0	0	0	17	78	117	157	274	263	285	277	302	214	198	115	69	25	0	0	0	0	0	2390
6	0	0	0	0	0	16	70	125	143	251	212	187	215	166	183	208	155	76	19	0	0	0	0	0	2027
7*	0	0	0	0	0	13	36	68	264	216	361	387	442	508?	383	309	128	79	21	0	0	0	0	0	3215
8	0	0	0	0	0	16	67	93	108	140	156	157	148	178	242	173	140	91	25	0	0	0	0	0	1734
9	0	0	0	0	0	15	68	93	108	112	127	141	171	193	230	216	158	81	19	0	0	0	0	0	1730
10*	0	0	0	0	0	15	106	186	242	302	350	399?	418?	417?	320?	316?	232	162	21	0	0	0	0	0	3487-?
11	0	0	0	0	0	14	90	163	214	250	297	378	332	326	265	240	172	103	22	0	0	0	0	0	2868
12	0	0	0	0	0	13	91	177	247	290	319	335	371	334	288	232	162	96	19	0	0	0	0	0	2974
13	0	0	0	0	0	13	88	161	209	247	266	287	302	313	284	222	177	103	16	0	0	0	0	0	2690
14	0	0	0	0	0	12	91	166	223	267	308	319	295	276	299	268	158	56	15	0	0	0	0	0	2754
15*	0	0	0	0	0	9	98	244?	292	436?	487?	447	580?	518?	402	299	213	120	19	0	0	0	0	0	4165-?
16*	0	0	0	0	0	4	47	98	214	420	454	458	492	354	266	287?	212	120	13	0	0	0	0	0	3439
17*	0	0	0	0	0	12	120	206	353	441	497	373?	279	133	390	322	27	27	8	0	0	0	0	0	3188
18*	0	0	0	0	0	11	126	215	318	349?	440?	462?	406?	382?	309	251	174	92	13	0	0	0	0	0	3548-?
19*	0	0	0	0	0	10	87	177	290	374	441?	513	500?	433?	389	306?	165	138?	13	0	0	0	0	0	3837-?
20	0	0	0	0	0	10	82	148	202	230	292	352	359	333	280	246	195	101	16	0	0	0	0	0	2846
21*	0	0	0	0	0	9	90	181	249	295	372	422?	376?	335	299	264	186	86	10	0	0	0	0	0	3173
22*	0	0	0	0	0	9	61	94	136	255	328?	292	194	195	198	95	69	52	9	0	0	0	0	0	1987
23	0	0	0	0	0	9	59	83	117	188	197	232	247	214	155	124	79	47	5	0	0	0	0	0	1755
24*	0	0	0	0	0	5	76	191	308	365	343	330?	342	304	270	165	49	19	2	0	0	0	0	0	2766
25	0	0	0	0	0	5	62	140	242	276	316	252	331	321	242	169	81	90	22	0	0	0	0	0	2548
26	0	0	0	0	0	8	63	108	129	236	234	239	301	169	171	184	63	17	13	0	0	0	0	0	1936
27	0	0	0	0	0	8	70	144	161	171	182	198	229	199	171	149	109	60	7	0	0	0	0	0	1858
28*	0	0	0	0	0	7	80	166	220	254	287	344	364	377?	304	241	184	83	5	0	0	0	0	0	2915
29*	0	0	0	0	0	11	101	175	242	293	391?	359	302?	345	275	170	100	71	3	0	0	0	0	0	2838
30*	0	0	0	0	0	5	67	152	247	280	470?	372?	338	355	300	291?	175	83	9	0	0	0	0	0	3144-?
31	0	0	0	0	0	6	70	165	242	265	333	359	87	77	146	183	174	89	11	0	0	0	0	0	2206
AVG	0	0	0	0	0	11	77	145	214	277	317	322	313	292	259	216	138	81	15	0	0	0	0	0	2679
S D	0	0	0	0	0	4	21	43	68	95	110	105	115	114	77	67	53	32	7	0	0	0	0	0	723
S/A	0	0	0	0	0	0.37	0.27	0.30	0.32	0.34	0.35	0.32	0.37	0.39	0.30	0.31	0.38	0.40	0.49	0	0	0	0	0	0.27
MIN	0	0	0	0	0	4	36	68	93	92	95	102	87	77	94	79	27	17	2	0	0	0	0	0	1124
MAX	0	0	0	0	0	20	126	244	353	483	497	513	580	518	402	322	232	162	31	0	0	0	0	0	4165

Daylight Data Recovery: 0% missing; 3% exceeded the 15% QC threshold -- total daylight 5-minute measurements, 4966.

NOTES:
"FAIL" = no 5-minute sample passed QC for the hour.
"N/A" = not applicable.
"M" = daily total missing one or more daylight hours; NOT used in monthly summary.
"?" = partial data: HOURLY, excludes more than 2 of the 12 five-minute values (missing or failed QC). DAILY and MONTHLY, excludes more than 10% of the possible 5-minute values (missing or failed QC).
"HOUR" = ending hour local standard time.
"*" = this day has flagged data.
"MISS" = ALL 5-minute samples are missing for the hour; NOT used in further summaries.

Instrument: Eppley PSP Serial Number: 25818F3
Calibration Constant: 9.526uV/Wm-2 Calibration Date: September, 1986

Figure 5-4(b). HBCU Report Example

SERI

Monthly Summary Prepared By The Solar Energy Research Institute

STATION: MISSISSIPPI VALLEY STATE UNIVERSITY — August 1989

33.50 N Latitude — 90.33 W Longitude — 52. Meters AMSL — Time Zone -6.0

ESTIMATED DIRECT NORMAL SOLAR RADIATION
HOURLY INTEGRATED AND DAILY TOTALS
WATT-HOURS PER SQUARE METER

DAY \ HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY
1	0	0	0	0	0	0	0	0	0	45	0	0	103	294	323	235	0	0	0	0	0	0	0	0	1000
2	0	0	0	0	0	3	0	0	0	139	457	422	626	600	730	634	538	363	11	0	0	0	0	0	4525
3	0	0	0	0	0	9	233	525	655	734	780	791	788	766	734	664	555	341	21	0	0	0	0	0	7597
4	0	0	0	0	0	14	303	634	762	844	877	882	784	826	849	798	707	523	56	0	0	0	0	0	8859
5	0	0	0	0	0	9	243	542	618	454	513	427	283	489	648	510	424	450	37	0	0	0	0	0	5647
6	0	0	0	0	0	15	278	457	653	574	652	796	759	781	710	634	189	0	0	0	0	0	0	0	6498
7*	0	0	0	0	0	0	0	0	59	0	0	0	0	156?	0	81	0	0	0	0	0	0	0	0	296
8	0	0	0	0	0	14	305	651	777	828	827	859	880	787	584	650	458	375	20	0	0	0	0	0	8016
9	0	0	0	0	0	18	309	640	761	842	868	868	850	709	590	499	331	185	0	0	0	0	0	0	7471
10*	0	0	0	0	0	0	89	321	451	507	FAIL	364?	335?	FAIL	247?	293?	131	78	0	0	0	0	0	0	2817-?M
11*	0	0	0	0	0	1	122	354	493	577	617	FAIL	508	481	420	469	381	211	5	0	0	0	0	0	4640-M
12*	0	0	0	0	0	0	93	301	416	515	566	594	FAIL	544	493	426	292	226	4	0	0	0	0	0	4471-M
13	0	0	0	0	0	1	132	381	528	607	662	666	619	585	541	493	371	182	3	0	0	0	0	0	5772
14	0	0	0	0	0	1	120	388	492	559	594	620	652	659	608	499	133	0	0	0	0	0	0	0	5326
15*	0	0	0	0	0	0	0	112?	85	216?	272?	126	244?	210?	266	286	133	20	0	0	0	0	0	0	1971-?
16*	0	0	0	0	0	0	0	0	0	0	0	0	79	57	26	217?	223	57	0	0	0	0	0	0	658
17*	0	0	0	0	0	0	0	150	150	7	89	257?	100	0	211	54	0	0	0	0	0	0	0	0	1018
18*	0	0	0	0	0	0	24	58	74	FAIL	247?	276?	407?	435?	450	410	322	136	0	0	0	0	0	0	2839-?M
19*	0	0	0	0	0	0	81	294	301	303	307?	270	220?	247?	184	322?	0	102?	1	0	0	0	0	0	2634-?
20*	0	0	0	0	0	0	81	262	424	595	632	498	FAIL	286	606	409	373	159	5	0	0	0	0	0	4329-M
21*	0	0	0	0	0	0	67	277	401	495	376	317?	FAIL	498	497	366	212	90	2	0	0	0	0	0	3599-?M
22*	0	0	0	0	0	0	224	578	648	324	618?	618	690	685	513	722	621	291	9	0	0	0	0	0	6542
23	0	0	0	0	0	0	229	611	589	537	694	665	611	559	629	619	611	249	4	0	0	0	0	0	6606
24*	0	0	0	0	0	0	101	0	109	69	81	335?	185	85	176	71	8	1	2	0	0	0	0	0	1223
25	0	0	0	0	0	0	75	368	448	433	278	104	626	642	584	487	0	0	0	0	0	0	0	0	4045
26	0	0	0	0	0	0	174	491	643	401	474	499	497	753	689	487	90	0	0	0	0	0	0	0	5197
27	0	0	0	0	0	0	53	333	555	671	729	747	546	680	664	601	444	168	1	0	0	0	0	0	6192
28*	0	0	0	0	0	0	60	275	440	546	576	590	447	398?	285	376	226	61	0	0	0	0	0	0	4279
29*	0	0	0	0	0	0	54	216	390	464	395?	462	445?	435	518	156	8	0	0	0	0	0	0	0	3543-?
30*	0	0	0	0	0	0	35	172	398	532	217?	FAIL	562	359	82	166?	190	36	0	0	0	0	0	0	2748-?M
31	0	0	0	0	0	0	50	261	381	519	495	435	19	0	0	0	0	8	0	0	0	0	0	0	2169
AVG	0	0	0	0	0	0	114	311	410	445	463	465	459	467	447	408	257	139	0	0	0	0	0	0	4462-?
S D	0	0	0	0	0	0	102	209	242	250	265	268	264	250	240	212	215	151	0	0	0	0	0	0	2582
S/A	0	0	0	0	0	0	0.89	0.67	0.59	0.56	0.57	0.58	0.57	0.54	0.54	0.52	0.84	1.08	0	0	0	0	0	0	0.58
MIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	296
MAX	0	0	0	0	0	0	309	651	777	844	877	882	880	826	849	798	707	523	0	0	0	0	0	0	8859

Daylight Data Recovery: 1% missing or failed of 425 daylight hours.

NOTES:
"FAIL" = failed QC; NOT used in further summaries.
"N/A" = not applicable.
"M" = daily total missing one or more daylight hours; NOT used in monthly summary.
"?" = partial data: HOURLY, estimate based on a partial global or diffuse value for the hour. DAILY and MONTHLY, excludes more than 10% of daylight hourly values (missing or failed QC).
"HOUR" = ending hour local standard time.
"*" = this day has flagged data.
"MISS" = one or both components missing for the hour; NOT used in further summaries.

ESTIMATED solar radiation component derived from the relation: Global = Diffuse + Direct * Cos (Zenith Angle) using available measurements of at least 2 of the components.

Figure 5-4(c). HBCU Report Example

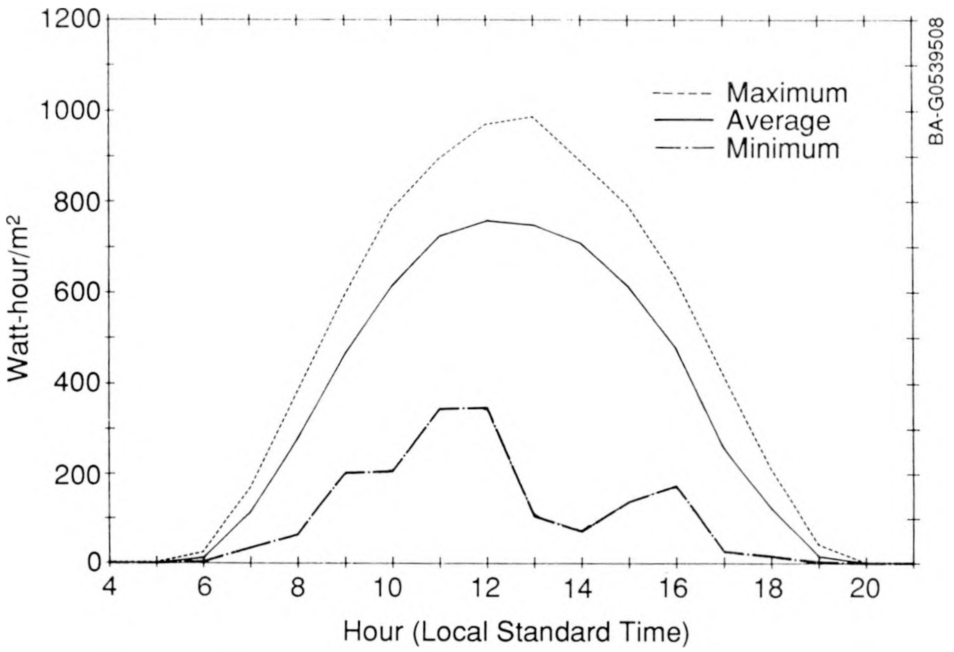


Figure 5-5. Report Time Series Plot. Mississippi Valley State University, August 1989, Global Solar Radiation on a Horizontal Surface (a)

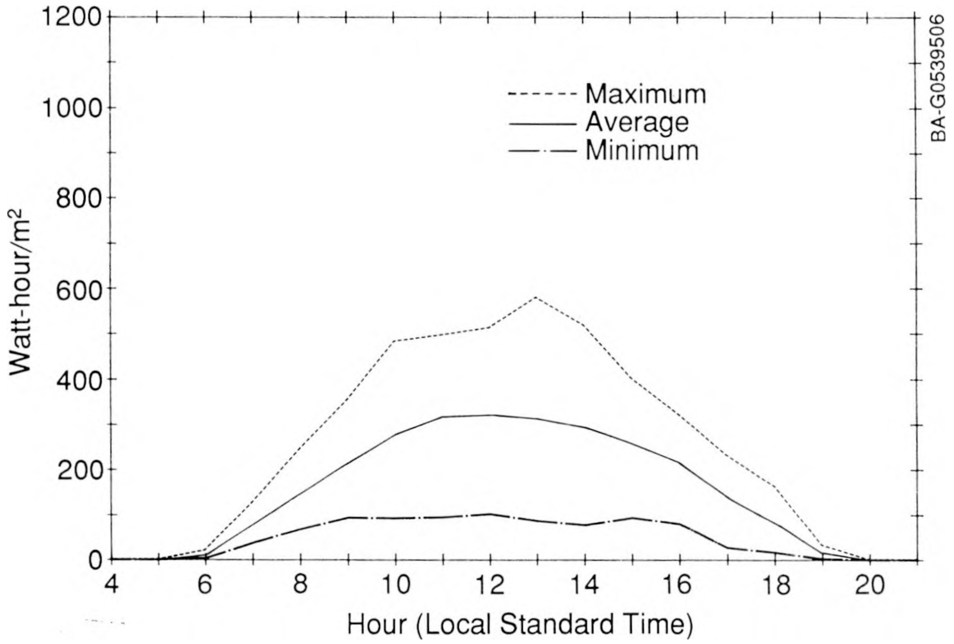


Figure 5-5. Report Time Series Plot. Mississippi Valley State University, August 1989, Diffuse Solar Radiation (Shadow Band) on a Horizontal Surface (b)

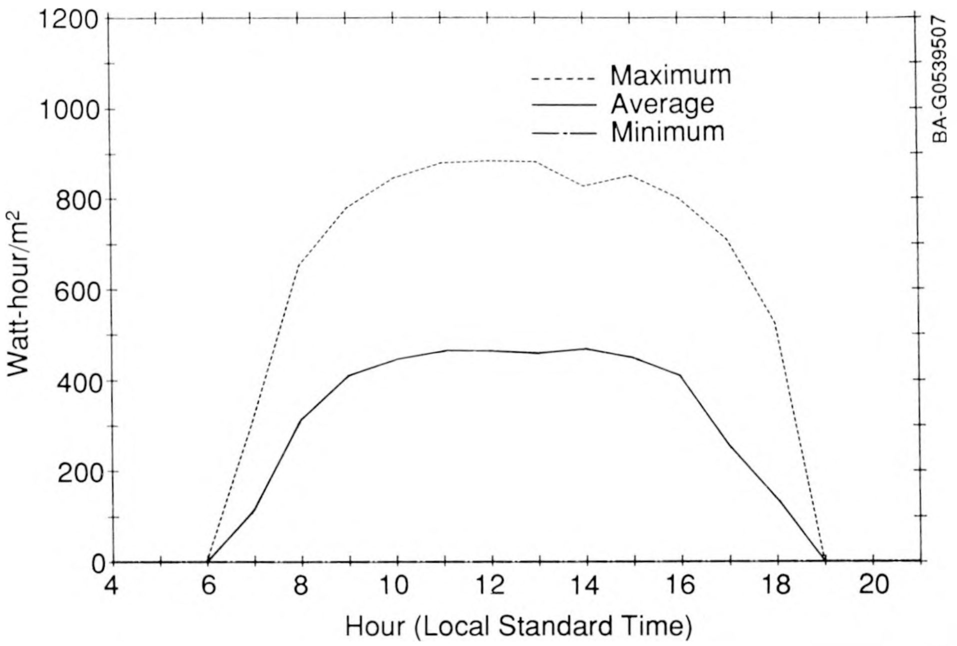


Figure 5-5. Report Time Series Plot. Mississippi Valley State University, August 1989, Estimated Direct-Normal Solar Radiation (c)

Since March the processing of HBCU data has been routine, with all reports and plots completed and returned to the sites within 30 days after the month being processed. Each site receives data from all sites in the network.

5.3 Equipment Recalibration

The radiometers at each station have been recalibrated outdoors at the SERI Solar Radiation Research Laboratory (SRRL) three times from 1985 to 1989, and are scheduled for recalibration on a 12- to 18-month cycle. The calibrations are traceable to the WRR via the absolute cavity radiometer used as part of the component summation technique [14,15]. The data loggers have been calibrated in the field using a single direct-current voltage reference. Replacement units are also recalibrated at SERI's metrology laboratory as needed.

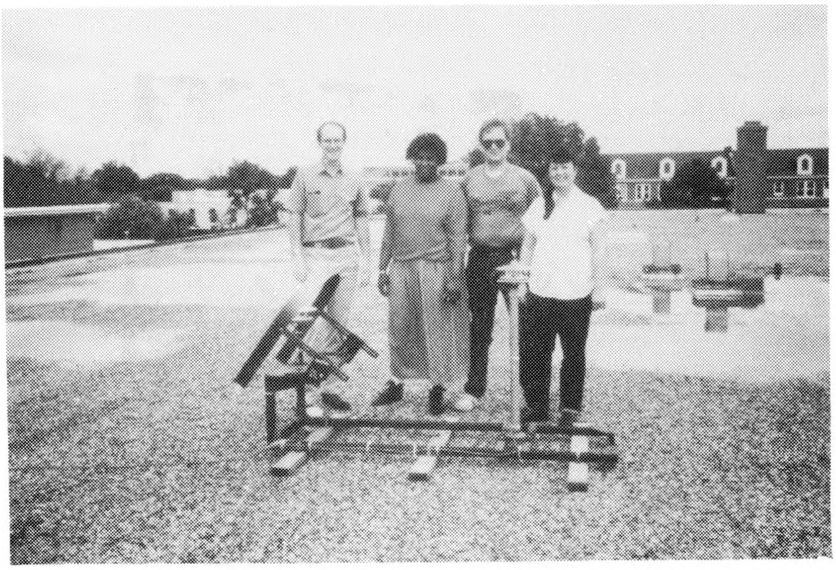
5.4 Site Visits

SRRAP's HBCU network coordinator, Tom Stoffel, visited four of the six sites in May: Elizabeth City State University, where he reinstalled equipment removed for building construction; South Carolina State College; Savannah State College; and Bethune-Cookman College. The equipment at each site was inspected (see field calibrations above) and a photographic record of the roof-top installation was made during the visits (Figure 5-6).

5.5 Newsletter

SRRAP produces the a monthly newsletter used to communicate between SERI and HBCU network stations and to promote interest in the network mission. Each newsletter contains short articles concerning, for example, upcoming events in the network, hints for operating the station, and comments on the analysis of processed data.

Most newsletters also include an in-depth report, several pages in length, on some aspect of solar measurement science. The reports are produced with the express goal of stimulating readers to incorporate the concepts in college curricula. These reports have included an on-going tutorial on solar concepts and terminology, a solar compass developed by one of the principal investigators, and an analysis of data taken by network stations in the path of Hurricane Hugo.



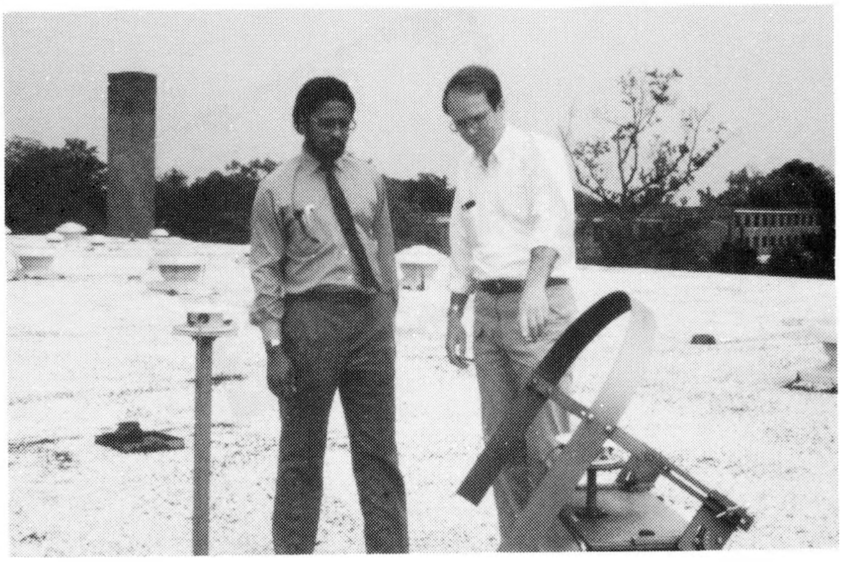


Figure 5-6. Tom Stoffel and Student Technicians, with Examples of Roof-top Instrument Installations at Elizabeth City State University (a); Tom Whitney, Principal Investigator, and Tom Stoffel with Roof-top Instruments at South Carolina State College (b)

6.0 SITE-SPECIFIC SOLAR RADIATION ESTIMATION

Because of the SRRAP emphasis on producing the 1961-1990 national solar radiation data base (section 3.0) and a limited budget, the activities on site-specific solar radiation estimation methods are limited to involvement in the IEA subtask that is addressing this topic. IEA Subtask 9D--Techniques for Supplementing Network Data for Solar Applications--is led by Dr. Antoine Zelenka, Swiss Meteorological Institute, Zurich. The other participating countries are West Germany, Sweden, Italy, and the United States.

IEA Task 9 (Solar Radiation and Pyranometry) activities are followed by attending and hosting meetings. The SERI-hosted April meeting of the Task 9 Expert's Meeting was attended by 20 scientists from nine countries. The DOE Solar Buildings International Review Meeting in Washington, D.C. was attended to present and discuss the status of SERI's involvement in IEA Task 9. The most recent meeting was held at the University of Genova, Italy, in November during which the status of all the Task 9 subtasks were updated.

During 1989, several countries developed data sets for testing spatial interpolation methods. West Germany, Sweden, Switzerland, and the United States assembled data sets of daily totals of global-horizontal irradiance for one year. The U.S. (SERI) provided three data sets: surface solar radiation measurements for the southwestern U.S., surface measurements for the Northwest (from the University of Oregon), and satellite estimates for the Northwest (from D. Tarpley, NOAA-National Environmental Satellite Data and Information Service). In addition, SERI has given funds to the State University of New York at Albany to provide surface measurements and satellite estimates for the northeastern United States. West Germany is in the process of adding satellite data to its surface measurements. The final data sets will be assembled and distributed to all participants by the IEA by March 31, 1990.

The evaluation of mathematical interpolation methods, such as weighted averaging, nearest neighbor, and Kriging, are being evaluated by all subtask participants. The Italian participants have the strongest capability in these methods. In addition, Sweden, West Germany, Switzerland, and the United States are investigating the use of satellite data to determine geographic variations of solar irradiance. This is particularly important to the United States since mathematical interpolation methods are not expected to work well with our sparse network of solar radiation stations (31 stations in the United States compared with a least 29 stations in West Germany and 41 stations in Switzerland).

The evaluation of the data sets is just beginning. V. D'Agostino (Italy) has been working primarily on the German data sets. G. Czeplak (Germany) experimented with a unique approach, using month and geographic position in a principal components analysis; initial results were inconclusive.

W. Josefsson (Sweden) reported on a very interesting effort being undertaken by the Nordic countries, the Netherlands, and Ireland working with the European Space Agency. A multivariate analysis of all channels of METEOSAT (satellite) data is used to estimate cloud type and amount for three layers on a mesobeta (22 x 22 km) grid. In the future, the estimates will be made on a mesogamma (5 x 5 km) grid. Josefsson intends to use these cloud data with a simplified model to estimate solar radiation over Sweden.

The work under IEA Subtask 9D will be completed by the spring of 1991 with reports to be completed by July 1991. The results should be quite comprehensive and useful to the solar community. The cost of our participation should be returned manyfold by keeping researchers up-to-date on methods that can be used to produce site-specific solar radiation estimates between sites in the new 1961-1990 data base.

7.0 SPECTRAL SOLAR RADIATION DATA BASES AND MODELS

Information about the spectral (color) distribution of solar radiation is important for the design, development, and performance studies of spectrally selective solar conversion technologies. An example of a spectrally selective technology is photovoltaics; i.e., each photovoltaic device has a particular spectral response. Another example is a window coating that is designed with particular spectral transmission characteristics to retain or block heat or light transfer. A third example is concentration of ultraviolet, direct-normal solar flux for detoxification of hazardous wastes, a new solar-heat technology application. Having data on the spectral distribution of solar radiation enables researchers to evaluate the spectral sensitivity of their solar conversion devices, to design devices to optimize performance for a range of spectral conditions, and to understand device performance.

The long-range goals of the SRRAP research on spectral solar radiation are to develop a research-quality data base of measured spectra and spectral simulation model(s) for the 290-3000 nm wavelength range for different climate conditions. These data and models are needed to characterize the natural, outdoor spectral variability of the solar radiation resource for use by all the various solar technologies that require spectral information.

7.1 Spectral Solar Radiation Data Base

Beginning in 1986, SRRAP obtained the cooperation of the Florida Solar Energy Center (FSEC) in Cape Canaveral, Fla., and the Pacific Gas and Electric Company (PG&E) in San Ramon, Calif., to measure spectral solar radiation and supporting meteorological data [16,17] for a range of climate conditions and collector configurations. Data were collected by FSEC, PG&E, and SRRAP through March 1988 and archived at SERI. More than 3000 spectral data sets for the 300-1100 nm wavelength range (wavelength limits of the instrumentation) were collected and processed through preliminary quality control procedures.

In FY 1989, the first phase of the spectral data base was completed. This included further quality control processing of the data, preparation of extensive spectral measurement uncertainty documentation [18,19], and preparation of a catalog and data base documentation [20].

The documentation was peer reviewed, and the final products will be printed in early FY 1990. The data base documentation contains extensive field notes, spectral and broadband solar radiation plots, formats, and quality-control information. Examples of the data in the data base, and its documentation are shown in Figures 7-1(a) and 7-1(b).

SRRAP's data that are included in the data base were collected in the Denver, Colo., area for research on the effects of urban air pollution on solar radiation resources. These data were analyzed in FY 1989 and documented in a SERI report [21]. The report was peer reviewed, and the final product will be printed in early FY 1990.

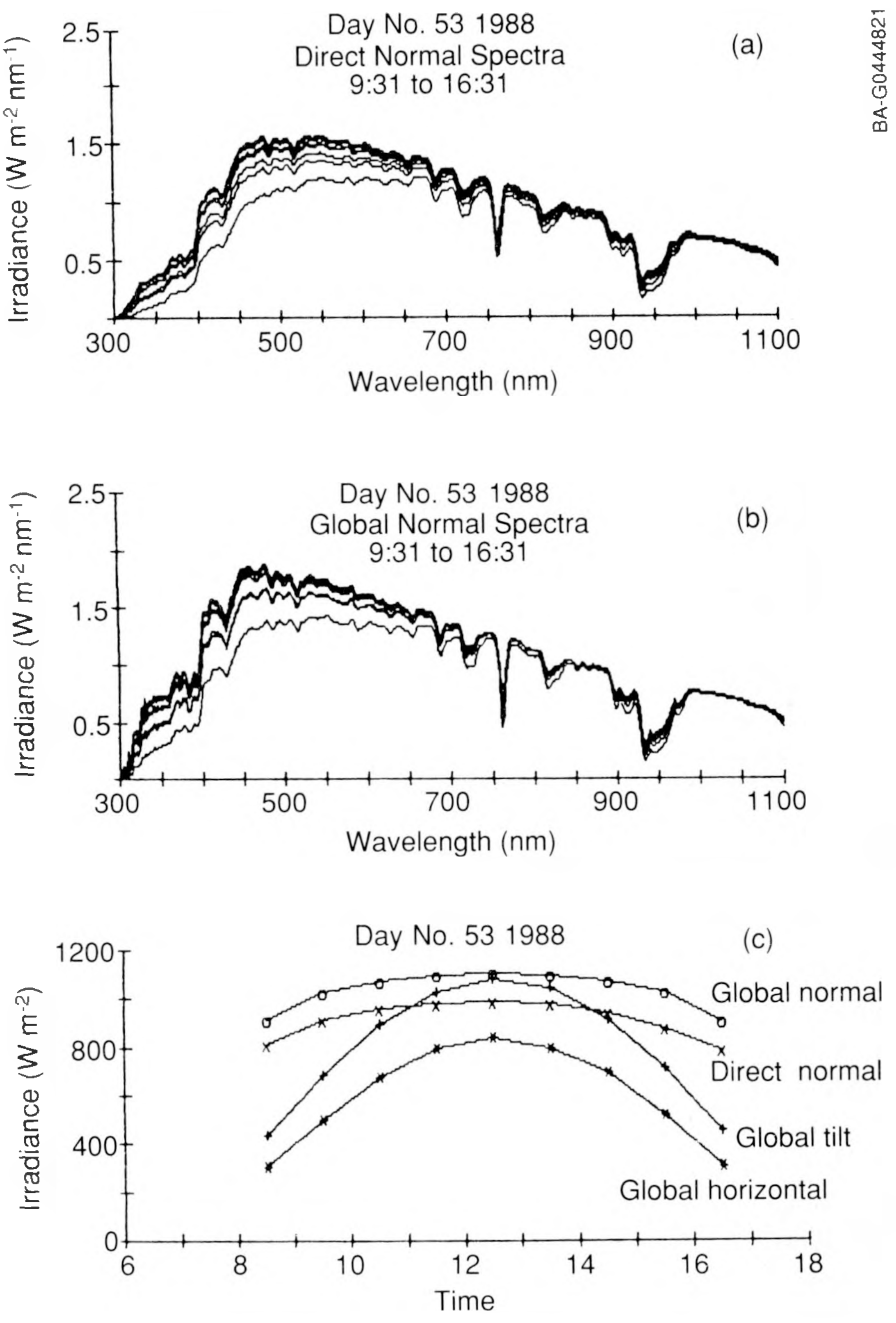


Figure 7-1(a). Spectral Data Base Documentation Example (Clear-Sky Conditions)

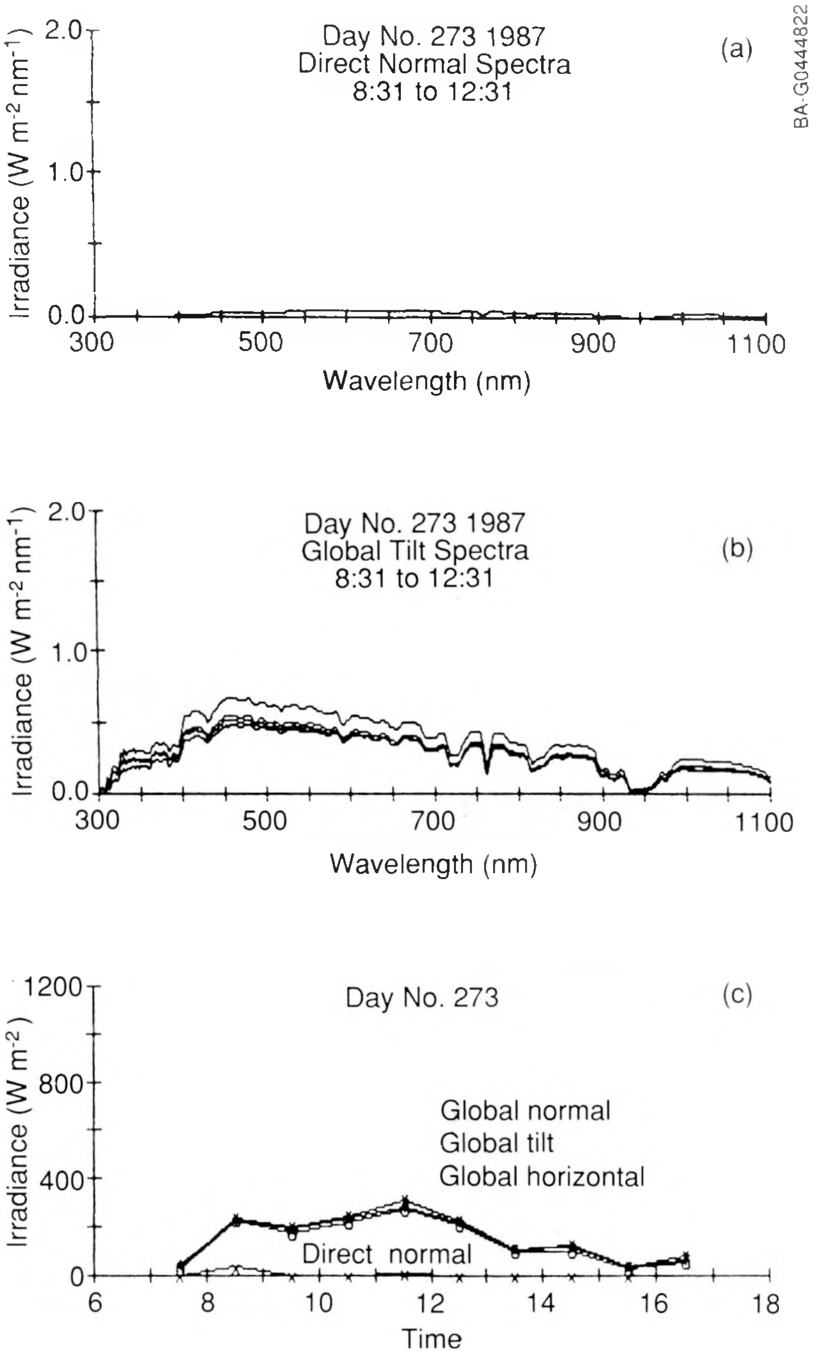


Figure 7-1(b). Spectral Data Base Documentation Example (Cloudy-Sky Conditions)

Expected spectral effects of air pollution included increased aerosol scattering, especially in the shorter (ultraviolet and visible) wavelengths, and increased absorption in the shorter wavelengths by nitrogen dioxide (peaking at about 400 nm), ozone (in the ozone-absorption bands), and black carbon particles. We observed an increase in the extinction and scattering in our measurements; the effects of nitrogen dioxide, ozone, and black carbon absorption could not be separated from scattering in the total extinction. Differences between the rural and urban global-horizontal broadband solar radiation values were generally within the measurement uncertainty, although one day showed 8%-10% lower values at the urban site with the sun at a low elevation. Differences between urban and rural direct-normal solar radiation due to urban air pollution were measurable, with reductions at the urban site of 2%-16%, depending mostly on sun angle.

7.2 Spectral Solar Radiation Models

Because outdoor spectral solar radiation measurements are rare (due to their complexity), spectral solar radiation simulation models are needed to calculate spectral distributions using meteorological data for a variety of climate conditions as input. The models can then be used to perform parametric studies of the sensitivity of spectrally selective solar conversion technologies to changes in meteorological conditions.

Our spectral solar radiation model, SPCTRAL2 [22], covering 300-4000 nm, was developed for cloudless-sky conditions. Our plan is to improve the model, as necessary, to accommodate other atmospheric conditions (such as cloudy and polluted skies) based on validation and verification of our model and others with measured data. Our intent is to develop hybrid models based on SPCTRAL2 and other models developed by laboratories such as the Air Force Geophysics Laboratory's (AFGL) LOWTRAN models [23-25].

Improvement of our spectral model is tied to two important considerations. One is a thorough measurement uncertainty analysis; i.e., it is essential to know spectral measurement uncertainty to determine if proposed model improvements are outside the measurement uncertainty limits. Secondly, the capability was needed to measure spectra beyond 1100 nm, which is the wavelength cutoff of several commercially available spectroradiometers (due to the silicon detector), to validate models past 1100 nm.

In FY 1989, very extensive spectral uncertainty estimation methods and analyses [18,19] were developed and exercised as part of the spectral data base documentation. An example of the spectral measurement uncertainty estimates is shown in Figure 7-2. These results set the limits of our verifiable model improvements. The results indicate a need to improve our ultraviolet (UV, below 400 nm) measurement capabilities for applications that require spectral UV data. UV applications include concentrated UV flux for detoxification of hazardous wastes, studies of UV degradation of materials, medical research, and climate change research.

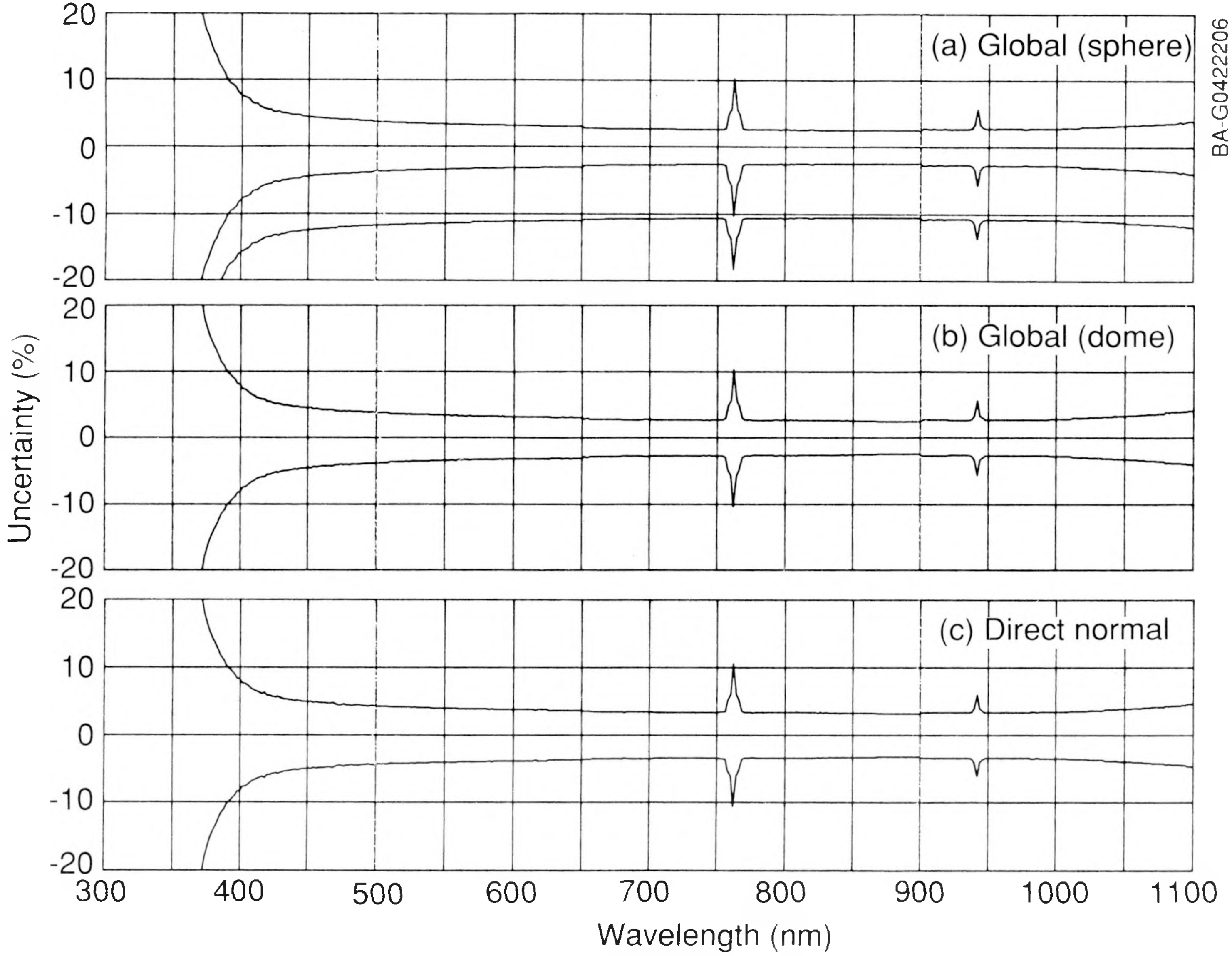


Figure 7-2. Spectral Measurement Uncertainty

Also in FY 1989, a spectroradiometer for measuring spectra from 290 to 3000 nm was purchased at SERI by the Photovoltaics Advanced Research and Development (PV AR&D) Project. The PV AR&D Project uses spectral solar radiation models and data bases (developed under the SRRAP for all technologies) for applications specific to PV; the two projects share equipment, such as spectroradiometers, for spectral measurements. The new spectroradiometer was designed for geophysical applications and requires software modifications to acquire irradiance data and hardware modifications to measure outdoor global and direct-normal irradiance. Progress was made toward the development of the spectroradiometer under the PV AR&D Project, but the instrument was not available for routine outdoor measurements under the SRRAP. When it is operational, it will be used to measure extended-wavelength spectra.

In June researchers attended AFGL's annual conference on atmospheric transmission models and obtained its latest code, LOWTRAN7. AFGL maintains an expert staff working on high-resolution spectral modeling, and our cooperative relationship allows us to leverage our resources using AFGL's results. Both LOWTRAN6 and LOWTRAN7 were installed on the VAX computer and comparisons were made with the current solar irradiance version of LOWTRAN5. There appear to be significant differences between the old and new codes, and these differences are being traced with AFGL before incorporating new features of LOWTRAN into the models library. The significance of these differences must be determined before producing extensive data sets using the models.

A cooperative relationship was established with staff members at the West German solar energy center in Stuttgart who are also developing and testing spectral solar radiation models. During FY 1989, arrangements were made for a scientist from West Germany to work at SERI from January through July 1990 and assist with the development of spectral irradiance models.

8.0 LABORATORIES

8.1 Solar Radiation Research Laboratory

SRRL is located on South Table Mountain in Golden, Colo., near the SERI offices. It serves as a facility for special experiments, instrument evaluation, and radiometer calibrations, and provides baseline solar radiation and meteorological monitoring for research. Two projects, SRRAP and the SERI PV AR&D Project, support SRRL and use its facilities and data. SRRL also serves outside requesters needing local solar radiation or meteorological data, such as the SERI high-flux solar facility under design and construction near SRRL.

Since 1979, the development and operation of SRRL have been focused on the following.

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

8.1.1 Research Data Base

The Baseline Monitoring System (BMS) collects observations of the 16 broadband (300-3000 nm) solar radiation and meteorological parameters listed in Table 8-1. The battery-powered data acquisition system is programmed to continuously monitor the 16 data channels, storing five-minute averages of all but the wind speed and wind direction data, which are instantaneous samples. Data are stored on audiocassette tape for 21 days. The tapes are read onto disk files and processed for quality control, reporting, and archival in SERI SBF [13]. Routine maintenance of the BMS is performed once each day. Records are made on a standard log form (Figure 8-1) of the condition of the equipment, adjustments to the system, and a simple weather observation. Figure 8-2 is a sample monthly report of two-axis global solar irradiance. Similar products are available for the remaining data channels.

Table 8-1. SRRL Baseline Monitoring System Data Channels

No.	Measurement Parameter	Instrument	Units
1	Global-Horizontal Irradiance (300-3000 nm)	PSP	W/m^2
2	Diffuse-Horizontal Irradiance (300-3000 nm)	PSP	W/m^2
3	Direct-Normal Irradiance (300-3000 nm)	NIP	W/m^2
4	Global Irradiance on 40° South-Facing Tilt (300-3000 nm)	PSP	W/m^2
5	Global-Normal Irradiance on Two-Axis Tracking Surface (300-3000 nm)	PSP	W/m^2
6	Global Irradiance on One-Axis Tracking Surface (Horizontal, North-South Axis) (300-3000 nm)	CM-11	W/m^2
7	Global-Horizontal Irradiance (780-3000 nm)	PSP	W/m^2
8	Direct-Normal Irradiance (780-3000 nm)	NIP	W/m^2
9	Total Ultraviolet Irradiance (295-385 nm)	TUVR	W/m^2
10	Ground-Reflected Irradiance (300-3000 nm)	PSP	W/m^2
11	Direct-Normal Irradiance (500 nm)	LCSP	counts
12	Wind Speed, 10 m above ground level	TGT	m/s
13	Wind Direction, 10 m above ground level	TGT	degrees
14	Dry Bulb Temperature	CSI	degrees C
15	Relative Humidity	CSI	percent
16	Barometric Pressure	YSI	millibar

Abbreviations:

CM-11 = Kipp & Zonen Pyranometer, Model CM-11
CSI = Campbell Scientific, Inc., Model 207 Temperature & RH Probe
LCSP = SERI-Designed Low-Cost Sun Photometer (T. Cannon)
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 Co.

SRRL MAINTENANCE & OPERATIONS LOG (Vol 23) Page 7

BA-G0539501

Observer: Tom Day: M T W T (F) (circle) Date: 6/16/89 DOY: 167 Time: 5:40 (MST)

Solar Declination (δ): 23.5

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

CR-21X Channel	Measured Parameter	Condition Code*	Reading		Condition Code*
1	GLOBAL HORIZONTAL WG7	✓	76 W/m2		
2	DIFFUSE (SB)	✓	44 W/m2	.....Shadow Band	✓
3	DIRECT NORMAL WG7	✓	130 W/m2	.....Sun-Follower III	A
4	GLOBAL 40-SOUTH	✓	39 W/m2		
5	2-AXIS GLOBAL	✓	143 W/m2	.....Eppley ST-3 #1	✓
6	1-AXIS GLOBAL	✓	91 W/m2	.....Eppley ST-3 #2	A
7	GLOBAL HORIZONTAL RG780	✓	17 W/m2		
8	DIRECT NORMAL RG780	✓	7.7 W/m2	.....Sun-Follower (See Above)	
9	TOTAL UV PHOTOMETER	✓	3.9 W/m2		
10	ALBEDO	✓	6.1 W/m2		
11	PHOTOMETER (500nm)	✓	0.02 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	✓	20.5 deg C		
15	RELATIVE HUMIDITY	✓	35.7 %	OK	
16	PRESSURE	✓	832.96 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 85 F Min 44 F RH 36 %

Cloud Cover: Total 6/10 Type(s) Ac Opaque 5/10 Types(s) Ac

⦶ Distribution: TWO DARK LAYERS TO EAST AND OVER 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 8-1. SRRL Maintenance and Operation Log Form

Monthly Summary Prepared By The Solar Energy Research Institute

STATION: SRRL 16-CHANNEL BASELINE MONITORING June 1989

39.74 N Latitude 105.18 W Longitude 1829. Meters AMSL Time Zone -7.0

GLOBAL SOLAR RADIATION ON A 2-AXIS TRACKING SURFACE
HOURLY INTEGRATED AND DAILY TOTALS
WATT-HOURS PER SQUARE METER

DAY \ HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY
1	0	0	0	0	26	387	866	990	966	671	613	891	823	124	468	437	361	264	308	7	0	0	0	0	8201
2	0	0	0	0	40	328	677	960	1035	977	600	393	664	405	393	1019	931	74	26	1	0	0	0	0	8525
3	0	0	0	0	0	8	40	149	632	740	797	210	201	172	24	10	7	24	18	0	0	0	0	0	3034
4	0	0	0	0	1	16	43	58	139	144	157	160	187	86	155	53	58	39	13	1	0	0	0	0	1309
5	0	0	0	0	69	617	882	987	1039	1063	1080	1084	952	1071	354	629	927	549	137	5	0	0	0	0	11443
6	0	0	0	0	23	152	832	876	881	1033	225	43	807	1105	227	205	124	77	72	5	0	0	0	0	6689
7	0	0	0	0	5	81	234	448	178	815	240	876	1201	1020	1021	1073	841	257	260	11	0	0	0	0	8561
8	0	0	0	0	10	236	222	911	906	1069	1133	334	371	64	79	655	238	540	184	6	0	0	0	0	6960
9	0	0	0	0	1	31	66	182	376	463	502	467	654	613	254	738	257	129	53	0	0	0	0	0	4787
10	0	0	0	0	44	577	871	953	1031	1006	777	175	219	477	669	276	174	194	90	8	0	0	0	0	7540
11	0	0	0	0	4	34	69	381	514	695	852	774	487	542	815	876	361	122	23	6	0	0	0	0	6555
12	0	0	0	0	44	192	713	881	605	482	942	913	157	130	25	65	53	72	8	0	0	0	0	0	5283
13	0	0	0	0	39	262	120	784	834	380	351	998	536	627	518	236	134	334	49	0	0	0	0	0	6203
14	0	0	0	0	1	8	26	37	109	282	477	963	803	664	858	776	923	503	60	3	0	0	0	0	6492
15	0	0	0	0	42	618	904	1005	1056	1069	1080	1075	1067	976	931	678	724	520	103	17	0	0	0	0	11865
16	0	0	0	0	80	408	141	666	834	1086	801	813	483	861	723	680	880	487	454	29	0	0	0	0	9426
17	0	0	0	0	1	336	960	1078	1107	1131	1137	1134	1128	1120	1105	1075	1017	903	631	42	0	0	0	0	13907
18	0	0	0	0	108	672	922	1028	1067	1089	1104	1101	1083	1098	1091	1065	1012	900	378	13	0	0	0	0	13730
19	0	0	0	0	108	560	853	987	1051	1076	1093	650	814	832	610	175	956	466	56	10	0	0	0	0	10297
20	0	0	0	0	23	262	376	377	466	930	1142	863	732	633	676	614	469	101	79	10	0	0	0	0	7754
21	0	0	0	0	6	278	151	595	498	553	382	204	166	96	120	80	32	13	7	1	0	0	0	0	3183
22	0	0	0	0	1	91	133	424	1094	1099	1111	1104	1161	807	1075	1079	757	304	28	2	0	0	0	0	10272
23	0	0	0	0	8	35	70	353	769	928	1030	1039	618	591	372	88	87	28	7	0	0	0	0	0	6021
24	0	0	0	0	23	518	838	967	1038	1057	1064	1061	905	815	751	780	667	143	202	5	0	0	0	0	10835
25	0	0	0	0	1	245	222	766	1018	1047	1051	967	633	545	253	463	128	111	20	4	0	0	0	0	7474
26	0	0	0	0	8	75	542	972	1032	1052	364	229	567	856	663	971	971	781	506	10	0	0	0	0	9601
27	0	0	0	0	79	645	915	1025	1073	1091	1099	1100	1110	1062	1064	564	114	549	114	16	0	0	0	0	11621
28	0	0	0	0	14	504	837	969	1035	1064	1077	763	603	259	211	417	275	578	195	23	0	0	0	0	8825
29	0	0	0	0	5	95	692	980	1037	1028	476	438	1046	884	75	639	988	590	550	33	0	0	0	0	9554
30	0	0	0	0	46	555	746	934	1059	1074	1081	1046	1043	967	1107	940	308	433	350	22	0	0	0	0	11713
AVG	0	0	0	0	29	294	499	724	816	873	795	729	707	650	556	579	493	336	166	10	0	0	0	0	8255
S D	0	0	0	0	32	225	360	331	312	282	333	360	326	350	369	353	376	266	181	11	0	0	0	0	3059
S/A	0	0	0	0	1.12	0.77	0.72	0.46	0.38	0.32	0.42	0.49	0.46	0.54	0.66	0.61	0.76	0.79	1.09	1.10	0	0	0	0	0.37
MIN	0	0	0	0	0	8	26	37	109	144	157	43	157	64	24	10	7	13	7	0	0	0	0	0	1309
MAX	0	0	0	0	108	672	960	1078	1107	1131	1142	1134	1201	1120	1107	1079	1017	903	631	42	0	0	0	0	13907

Daylight Data Recovery: < 1% missing; 0% exceeded the 15% QC threshold -- total daylight 5-minute measurements, 5351.

NOTES:
"FAIL" = no 5-minute sample passed QC for the hour.
"N/A" = not applicable.
"M" = daily total missing one or more daylight hours; NOT used in monthly summary.
"?" = partial data: HOURLY, excludes more than 2 of the 12 five-minute values (missing or failed QC). DAILY and MONTHLY, excludes more than 10% of the possible 5-minute values (missing or failed QC).
"HOUR" = ending hour local standard time.
"*" = this day has flagged data.
"MISS" = ALL 5-minute samples are missing for the hour; NOT used in further summaries.

Instrument: Eppley PSP
Calibration Constant: 7.695uV/Wm-2
Serial Number: 17860F3
Calibration Date: April, 1987

Figure 8-2. SRRL Sample Monthly Report

8.1.2 Radiometer Calibrations

A standard procedure for radiometer calibrations (RADCAL) during FY 1989 has been developed as more than 100 radiometers have been calibrated. The procedure is based on direct comparisons for pyrheliometers and the Component Summation Technique [14,15] for pyranometers.

Pyrheliometers are calibrated by comparing the voltage signal from the instrument under test with the direct-normal solar irradiance as measured with an electrically self-calibrating absolute cavity radiometer. Typically, the average of more than 500 such comparisons, made over at least two days, are used to determine the mean calibration factor (microvolts/watt/square meter).

Pyranometers are calibrated by summing measurements of the direct-normal solar component as measured with an absolute cavity radiometer and the diffuse-horizontal (sky) solar irradiance as measured with a thermopile-based pyranometer. The reference solar irradiance is calculated from the sum of these two components, incorporating the effect of the solar zenith angle at the time of measurement. The reference irradiance is then compared with the voltage signal from each pyranometer under test to determine the calibration factor (microvolts/watt/square meter).

A procedure manual for collecting and analyzing RADCAL data was revised. The final reporting method was also improved to allow the instrument owner to more easily interpret the calibration process and results.

8.2 VAX/Geographic Information and Data Analysis System (GIDAS) Laboratory

The VAX/GIDAS laboratory is used for data processing and storage and scientific analysis. It is supported by multiple projects/programs in the SERI SRRMB, including the SRRAP. Operation and maintenance of the main processors and their peripherals are essential for reading large volumes of historical data from magnetic tape in the SRRAP tape vault, processing large volumes of solar radiation and ancillary data, and producing data products for the SRRAP.

The core of the VAX/GIDAS laboratory is the VAX network. This network contains three processors, each of which has a unique function.

1. The VAX 11/730, with 3-MB central memory and floating-point accelerator using the VMS operating system, is the host for the Earth Resources Data Analysis System (ERDAS) Geographic Information System and Image Analysis System (GIS/IAS) software. Thus, one of its primary functions is to process spatial data and produce maps. In support of this activity, its peripherals include the following.

   - The RA-81 disk drive provides space for the software, raw data, intermediate files, and finished maps

- The Gould FD-5000 image processor, with attached 512 x 512 pixel color monitor and joystick provides the hardware interface for overlaying, displaying, and manipulating images and GIS maps
- The COHU videodigitizer allows images to be captured in black-and-white or color and stored directly as raster data
- The CALCOMP 9100 digitizing tablet allows maps and other vector information to be encoded and stored on the system
- The Tektronix 4695 color ink-jet printer provides a means to print the final color maps and images
- The TU-81 tape drive allows data stored on the magnetic tape to be entered into the system
- The VT-220 operator's console is necessary to communicate with the VAX 11/730
- The LA-100 printer is used to obtain listings of data and software
- The VT-240 user console is used primarily to process data on magnetic tape
- The VT-241 user console is used to run the ERDAS software package.

Another important role of the VAX 11/730 system is preparation of solar radiation data. Most of the data are on 1/2-in. magnetic tape, and the VAX 11/730 is the only system capable of reading these tapes. The previously listed devices are used to read the tapes, store information on disk, and direct tape operations.

2. A MicroVAX II, with 16-MB central memory with the VMS operating system, is the primary platform for analyzing solar radiation information and for developing algorithms and models that characterize and predict the behavior and performance of solar radiation parameters. Peripherals include the following.

- The TK-70 tape cartridge loads the system software
- The Dilog SSSX videocassette drive is used to back-up the disk drives
- The RA-81 disk drive contains general user software

- The four Dilog disks contain task-specific data, specifically data useful for solar radiation model development, spectral solar radiation model and data base development, and solar instrument characterization and calibration

- The DELUA card and the DELNI allow users on the MicroVAX to access data on the VAX 11/730

- The Camintonn Turbolaser PS/Plus 3 printer is used to produce listings of data and software, plots, and tabular data reports

- The HP 7550a plotter is used to produce high-quality color plots

- The VT-220 system console is necessary to communicate with the MicroVAX II

- The VT-240 user terminals support graphics and allow staff members to analyze data and design software in support of their tasks

- The VT-330 terminal provides color displays and allows staff members to more easily discern subtleties that may not be apparent on the VT-240.

In addition, there is a spare port on the MicroVAX II which is generally attached to an IBM-type personal computer (PC). This allows use of PC-DOS software and data on PC-compatible media as well as the ability to exchange information with the MicroVAX II. A number of these PCs are used to download data from instruments or cassettes for transfer to the VAX and final processing.

3. A VAXstation 3100 with 8-MB central memory and VMS operating system allows very large software processes to run without affecting the performance of the MicroVAX II. Its peripherals include the following.

   - The 52-MB cache disk allows software and data to be copied from the MicroVAX II, speeding disk access

   - The Exabyte videocassette drive allows data to be stored and recalled, independent of global system backup procedures

   - The Ethernet attachment to the DELNI connects the VAXstation 3100 to the MicroVAX II. The VAXstation 3100 is not a stand-alone system and requires the MicroVAX II host.

In FY 1989, this laboratory supported all key activities described in previous sections. The following are examples of key applications.

- Read and process data from several hundred 9-track computer tapes containing historical solar radiation data for the U.S.
- Develop quality control procedures and create extensive data sets for model development described in Section 3
- Format, quality control, and archive data from the HBCU network
- Prepare solar radiation and satellite data sets for IEA
- Format, quality control, and archive more than 3000 spectral solar radiation data sets
- Exercise SERI's spectral irradiance models, and prepare plots and data documentation
- Process calibration data for more than 100 radiometers characterized at SRRL.

9.0 TECHNICAL INFORMATION TRANSFER

A very important and significant part of all SRRAP activities is technical information transfer. The SRRAP participants receive more than 20 requests per month for technical information, data, and models. If the information is readily available from NCDC, requesters are referred to the center. If the request can be filled without significantly affecting the research schedule, the information is provided. In other cases, recovery of costs may be requested or the request may be referred to the DOE program manager. Every attempt is made to respond to requests without compromising research directives from DOE.

The following are examples of some of the types of requests received during FY 1989.

- World maps of solar radiation for marketing brochures for Solar Signage
- Maps of direct-normal solar radiation for LUZ International
- Reference lists for solar radiation data for Chronar Corp.
- SRRL data for evapotranspiration rates for Rocky Flats facility in Colorado
- DISC and SPCTRAL2 models for several users such as the New Mexico Solar Energy Institute and Jet Propulsion Laboratory
- UV data references for TRW
- HBCU data for Pacific Northwest laboratories
- UV solar radiation data sources for the University of Chicago
- Solar radiation instrumentation advice for a utility in Wisconsin, and many others
- SERI standard broadband formats for IEA
- SRRL data summaries for Audi Corp.
- Radiometer calibration techniques for Augustyn + Company, California
- Tours of SRRL and resource assessment discussions with many U.S. and foreign visitors.

Interaction with other agencies and users at national conferences is critical to the relevance and application of our SRRAP products. In FY 1989, we attended the Annual Conference of the American Solar Energy Society and presented four papers [5,9,26,27], we attended AFGL's annual conference on atmospheric transmission codes and presented the status of spectral models and data bases at SERI, and we attended the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' winter and annual meetings. These meetings are in addition to the NOAA and IEA interactions described in Sections 4 and 6.

10.0 PROGRAM MANAGEMENT

Program management activities include interagency interactions; monthly, quarterly, semiannual, and annual reporting; review committee meetings; and special publications. The following are a few of the significant activities in FY 1989.

A brochure describing the history, goals, and accomplishments of the Resource Assessment Program and SRRAP was drafted with the help of SERI's technical communicators. The final document will be produced in early FY 1990 and will be distributed as a program overview.

Each year, SRRAP task leaders and Sandia National Laboratories - Albuquerque (SNLA) staff members meet to coordinate resource assessment needs. This meeting provides a very important interface between the resource assessment data and its use in system performance predictions at SNLA. The 1989 coordination meeting was held at SNLA in July.

The STRC met for one and one-half days in August to review the project priorities, technical content, and relevance of activities. The committee includes representatives of NOAA, the National Aeronautics and Space Administration, the Electric Power Research Institute, SNLA, FSEC, universities, and utilities. David Rodenhuis, chief of the NOAA CAC, is the chairman. The committee produced a very thorough report that was submitted to SERI management and the SRRAP participants as guidance for the project.

Specific recommendations by the STRC are summarized in the Appendix. These valuable suggestions from members of the user community will be considered in negotiations with DOE about key activities for each fiscal year. Key activities are specified in the SRRAP Annual Operating Plan. Each of the recommendations is discussed at SRRAP quarterly review meetings and will be discussed at the FY 1990 STRC meeting. We are unable to accommodate all of the recommendations because the limited resources must be focused on the highest priority activities, but action will be taken where possible. Suggestions for expanded activities will be pursued when funding levels are increased or high priority tasks are nearing completion.

11.0 ISSUES

As with many scientific programs, the need for solar radiation information, data, and measurement assistance exceed the resources (staff and budget) necessary to address these needs. Efforts must be focused on a few high-priority activities, such as development of the national 1961-1990 solar radiation data base. Specific needs that should be addressed if additional funds become available include the following.

- Assistance to the NOAA-NWS solar radiation measurement network (SOLRAD) to assure high-quality data collection at the existing sites, followed by expansion of the network for better spatial coverage in the U.S.

- Support for other solar radiation measurement networks (perhaps using high schools, colleges, and universities to serve a dual purpose of collecting data and supporting science education) and data collection, quality-control processing, instrument calibration, data archival, and dissemination at a central location to assure high-quality data for different climate regions in the U.S.

- An increased level of effort toward development of methods for site-specific solar radiation estimates so that requests for solar radiation information at any location can be accommodated as the need arises

- Participation in international solar radiation measurement programs (such as the International Daylighting Measurement Program) and standards activities

- Worldwide solar radiation data and resource assessments to support U.S. industry efforts to market solar energy technologies outside the U.S.

- More interaction with users and industry to deliver specific solar radiation information that will enhance the development of solar technologies; for example, specific programs with utilities to map solar radiation (and other renewable resources) in their service territories to encourage interest in renewables

- More subcontracts to universities and the private sector to obtain valuable resource assessment data and research interactions, and to take advantage of national scientific expertise to address resource assessment issues

- Improved solar radiation instrumentation and measurements to meet the growing need for ground reference measurements of solar radiation components that are important in evaluating global climate changes.

The intermittent character of solar radiation resources significantly affects the perceived risk of investing in solar energy conversion technologies. Better solar radiation resource data allows for better system design and performance predictions, which increase the dependability of the systems and reduce this perceived risk. Proper system sizing depends on accurate resource assessment and, therefore, directly affects system cost and long-term performance. The SRRAP seeks to anticipate the long-term solar radiation resource data needs in preparation for the successful design and deployment of solar technologies in the 1990s.

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APPENDIX
SUMMARY OF SPECIFIC STRC RECOMMENDATIONS

OVERALL

The STRC had a positive impression of the quality of the work and of changes made in the past year. Progress was made on the development of data sets and international participation has improved. The committee made a special note of the high quality of personnel involved and a good record of accomplishment in spite of limited resources.

The STRC generally agreed on priorities and identified some issues in need of immediate attention.

- Use outside expertise early in project planning

- Continue efforts of the past year to establish outside expertise especially in the areas of data quality control and model development.

Although not wishing to distract us from our focus and immediate tasks, the committee reminded participants to be aware of the growing interest in global climate change and to begin to prepare for this expanding interest by being sensitive to the needs of the user community for data sets and radiation models.

THE BROADBAND SOLAR RADIATION TASK

The STRC gave unqualified support to the aims of this task and endorsed the completion of the data as a high priority item. The committee made the following suggestions.

- Consider using hours of sunshine as an additional variable

- Learn from NOAA data rehabilitation efforts

- Include data prior to 1975 in the data base

- Make the digital data base a priority and maps (atlas) a summary

- Use innovative data transfer media for distribution.

Endorsement was given to past efforts to identify the user community and to expand contact with professional organizations.

Because of the importance of quality control, the committee recommended that this issue be summarized in the user's manual being prepared by NWS, in cooperation with SERI.

The STRC agreed on the following priority issues in need of immediate action.

- STRC endorses the use of a solar radiation model to prepare the data base. DISC model updates could be completed in the next six months, with outside help, and subsequent model development and testing can be completed as planned.

- Continue current quality control efforts. The committee expressed concern about incompatibility between SERI methods and international methods currently being developed. The committee recommendation was that SERI methods should be made compatible, or specific suggestions should be made to the chairman of the CIE Technical Committee drafting the CIE Guide to Recommended Practice of Daylighting and Solar Radiation Measurements.

THE SPECTRAL SOLAR RADIATION TASK

According to the STRC, the current work is properly directed, relevant, and important. Work on this task should continue at the current level of effort, but with increased emphasis on development of a global irradiance model as a companion to the direct-normal LOWTRAN-7 model. These two models should then be used to extend the measured spectra beyond 1100 nm. In addition, all spectra can be integrated to produce direct-normal and diffuse irradiances and illuminances, with the new data included in a new edition of the spectral handbook.

The committee recommended that SRRAP identify and quantify the impact of spectral variations on performance of all solar systems. Users and network operators need to know the impact of spectral observations.

The Spectral Solar Radiation Task should be expanded to encompass the UV portion of the spectrum, which would be a major and significant accomplishment for SERI. This expansion would also contribute measurably to the advancement of solar technology. Expansion and completion of this task may lead to a future growth area for environmental and climate issues. The committee reported that the atmospheric chemistry community needs this UV information quickly, and is a possible source of support.

NETWORKS

The STRC endorsed an enhanced effort by SERI to expand the sparse national network of solar radiation observations beyond the 30 stations of the NWS; they also recommended adding commercial subnetworks to the national data base. The committee recommended that SRRAP initiate data exchanges.

Most networks need some cooperative efforts to supplement substantial local funds. SERI could provide this cooperation, or "increment to success." The committee recommended that funds be identified or transferred for that purpose, as they have in the past.

An important task of the national solar radiation network is maintenance of the calibration effort. The committee recommended that SRRAP document their experience with calibrations for the user community and instrument manufacturers.

Satellite data are recognized by STRC as an important, comprehensive measurement platform to infer solar radiation data over a sparse measurement network. The committee recommended consideration of these techniques by SRRAP.

STRC recognizes that SRRAP staff have little time available to run workshops and train solar radiation users. Suggestions for training were:

- Presenting papers at conferences meets a training objective
- Further development of atlases and commentary provides a training tool
- SRRAP could improve its professional recognition by participating and/or directing future workshops, such as the IEA Workshop that SRRAP hosted in April.

INTERNATIONAL ACTIVITIES

SRRAP has been working toward a goal of increasing their participation in national and international workshops about solar radiation. STRC encouraged this effort to take advantage of available information and resources. This participation may permit SRRAP to give feedback to users and data collectors in the U.S. Timely status reports and copies of research results of international projects could be distributed to national network managers.

The International Daylight Measurement Program (IDMP) offers a unique opportunity to expand the U.S. SOLRAD network and to access world data. The committee recommended that SERI vigorously pursue funding for U.S. participation in the IDMP, and for its role as a central coordination organization.

CLIMATE ISSUES

In recent years there has been increasing concern for the environmental consequences of human-induced, inadvertent climate modification through the addition of particulates. The effects of increased haze and cloud cover could reduce solar radiation and substantially alter solar radiation statistics. The STRC reported a unique opportunity for SRRAP to acknowledge these possibilities and establish contacts with scientists studying effects of those changes, and to determine the value of improved historic and new solar radiation measurements.

As stated earlier, atmospheric chemistry studies require UV data that are not available. SRRAP's spectral studies and instrument development have begun the process of providing these unique data. SRRAP, in association with atmospheric modelers and chemists, could target those wavelengths of greatest interest.

Cloud cover and solar radiation are closely coupled. Changes in cloud cover predicted by cloud models will change the availability of daylight and increase air conditioning loads in some regions, which will affect electrical demands and fossil fuel usage. This feedback effect compounds climate change. The committee recommended that SRRAP be prepared with procedures to calculate effects of changes in cloud cover.

DATA BASE STRUCTURE AND THE ATLAS PROJECT

The STRC recognized that the atlas effort is valuable, and will be even more useful if it is expanded to include easy user access to supporting data in several layers of aggregation and model software. Many users need long period summaries of data by months, which could be produced in the form of station data in a regular grid across the U.S. as suggested by SRRAP. An expanded list of component data sets might include long period means and variability by year, month, and day; year-month data for stations; daily station data; noon data and variability; hourly data; or primary (1 to 15 minute) data samples. The committee recommended including models to calculate radiation components on vertical walls and sloped surfaces.

The data sets produced could be grouped on a CD-ROM or DAT tape, with some PC-access software.