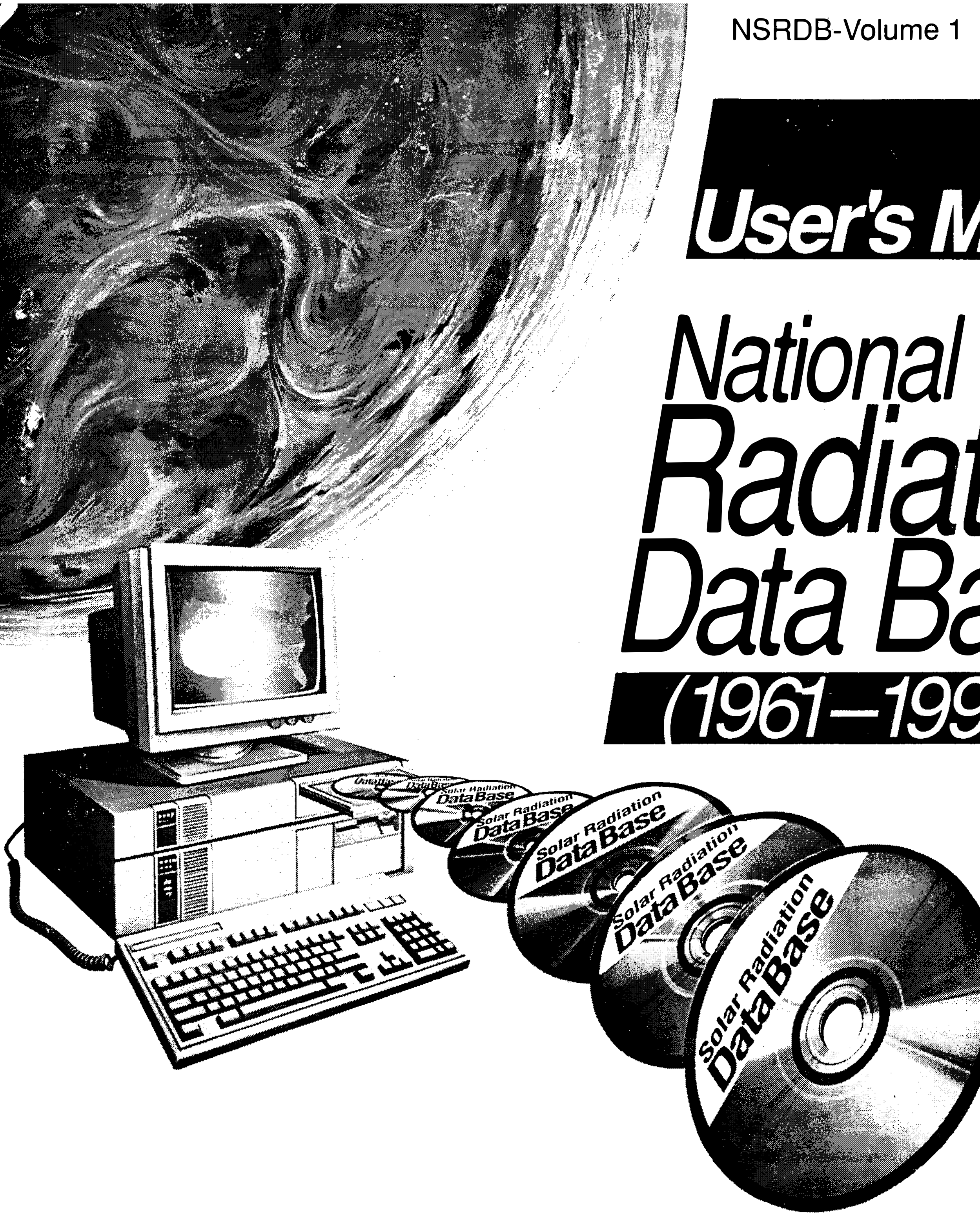
NSRDB-Volume 1

User's Manual

National Solar Radiation Data Base

(1961–1990)



NREL

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Errata

Appendix B: Pages B-5, B-9, & B-18

1) Change the WBAN number for Boulder, CO from 94918 to 94018.

2) Change the latitude for Stapleton Intl. Airport from N 34 46 to N 39 46.

3) Three stations deleted from the NSRDB (too much missing data) were not deleted from Appendix B. They are: Guantanamo Bay, Cuba; Brunswick, Maine; and Tatoosh Island, Washington.

Appendix C: Page C-3

The Quality Flags for GLOBAL for station 13722 RALEIGH, NC should read:

GLOBAL 0 130 0 0 0 737 133 0 0 0 0 0 0 559 401 41 0 0 0

Addendum

Section 10.6: Page 89

Add the following to the last paragraph of this section:

For example, direct normal values for Miami, Florida during July appear to be abnormally low during 1983 and 1984. The mean daily total for July 1984 is 1577 Wh/m^2; nearly three standard deviations (interannual) below the 30-year mean of 3701 Wh/m^2. Since the reported mean sky cover for July 1984 was identical to the 30-year mean, there does not appear to be any logical basis for such a low value. Nevertheless, the hourly data satisfied the quality assessment checks and an uncertainty flag of 2 was assigned to the monthly means.

NSRDB-Volume 1

September 1992

User's Manual

National Solar Radiation Data Base

(1961-1990)

Version 1.0

Hourly -- Synoptic & TD-3282
Daily Statistics
Hourly Statistics
Persistence
Quality Statistics

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Preface

The National Solar Radiation Data Base was produced by the National Renewable Energy Laboratory (NREL), formerly the Solar Energy Research Institute, under the Department of Energy's (DOE) Resource Assessment Program. All of the meteorological data were provided by the National Climatic Data Center (NCDC), a part of the National Oceanic and Atmospheric Administration (NOAA). The majority of the measured solar radiation data were collected by NOAA's National Weather Service (NWS) and supplied to NREL by NCDC. Solar radiation data were also obtained from the University of Oregon; WEST Associates (a consortium of southwestern utilities); the University of New York at Albany; Trinity University, Texas; Georgia Institute of Technology; Bethune-Cookman College, Florida; and Savannah State College, Georgia.

The data base production task was initiated in 1989 by Roland L. Hulstrom, who at the time was manager of the Solar Radiation Resource Assessment Project. The key task participants include Eugene L. Maxwell (Task Leader), Martin Rymes, Steve Wilcox, Daryl Myers, Thomas Stoffel, and Eric Hammond. Pamela Gray-Hann's painstaking preparation of the text and tables for this document is gratefully acknowledged. Many others, too numerous to list, also made valuable contributions. Program management support for the task, received from Lloyd Herwig and Michael Pulscak (DOE) and Carol Riordan and Dave Renné (NREL), is gratefully recognized. Also, the NREL task participants gratefully acknowledge the unfailing support and encouragement received from the management and staff at NCDC (especially Marc Plantico and Tom Ross).

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ACRONYMS AND NOMENCLATURE

ASME	American Society of Mechanical Engineers
CD-ROM	Compact Disk-Read Only Memory
CCF	Calibration Correction Factor
cfd	cumulative frequency distribution
CSN	Clear Solar Noon
DOE	Department of Energy
ERSATZ	meaning synthetic, or modeled
ETR	Extraterrestrial Radiation
HBCU	Historically Black Colleges and Universities
m/s	meters per second
mb	millibars
MB	Megabyte
METSTAT	METeorological-STATistical
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Data Base
NWS	National Weather Service
PSP	Precision Spectral Pyranometer (Eppley Laboratories)
QC	Quality Control
SEMRTS	Solar Energy Metorological Research and Training Site
SERI	Solar Energy Research Institute (now National Renewable Energy Laboratory - NREL)
SI	Standard International
SOLMET	SOLar METeorological
SOLRAD	SOLar RADiation (Network)
SRRL	Solar Radiation Research Laboratory
SYI	Standard Year Irradiance
SYNCAL	Synthetic Calibration
TD	Tape Deck
TMY	Typical Meteorological Year
TZ	Time Zone
UT	Universal Time
WBAN	Weather Bureau Army Navy
Wh/m^2	Watt-hours per square meter
WMO	World Meteorological Organization

How To Use This Manual

Welcome to the *new* National Solar Radiation Data Base. The National Solar Radiation Data Base (NSRDB) is the successor to the SOLMET/ERSATZ data base (SOLMET, Vol. 1 1978). This new data base covers a longer and more recent period (1961-1990) than the SOLMET/ERSATZ (1952-1975), uses improved measurements and an improved model for estimating solar radiation, and provides a variety of user-friendly products.

This manual provides guidance in using all data base products from the 1961-1990 NSRDB. It also acquaints you with the many features of the new data base, and provides information on how to order and use data base products. For these purposes, we have divided the manual into two main parts: Part 1, How to Use and Interpret Data Base Products; and Part 2, How the Data Base Was Produced.

Volume 2 - Final Technical Report of the data base documentation will become available in 1992. This document will describe the research and development performed in support of the data base production.

Part 1: How to Use and Interpret Data Base Products

Part 1 gives you a general overview of the NSRDB, summarizes the type of information contained in the data base, and gives information about the types of data base products you can order and the types of magnetic storage media on which these products are available. Part 1 also provides information necessary for viewing and extracting information from the magnetic media. The hourly data can be obtained in a synoptic format similar to the SOLMET and Typical Meteorological Year (TMY) formats that are familiar to many users. Hourly data are also available in the TD-3282 format. TD-3282 is the archive format used by the National Climatic Data Center (NCDC) and is similar to the TD-3280 format used for Surface Airways Hourly Data.

The statistical products prepared from the hourly data in the NSRDB also are described in Part 1. Daily statistical information is available for each month of each year and for the entire 30-year period of record (1961-1990). Hourly means and standard deviations are available for each month and year. Diurnal profiles of hourly energy can be developed from the means. The hourly data have also been binned to provide frequency distribution information.

Information on the persistence of solar radiation is provided for various levels of daily total solar radiation energy.

Extensive efforts have been made to flag the quality and uncertainty of all the hourly data in the NSRDB. Part 1 describes the format of these quality assessment flags, and provides the information necessary to interpret them. A summary of the quality statistics can be obtained as a separate product for each station.

Part 2: How the Data Base Was Produced

Part 2 begins with a brief history of solar radiation measurements in the United States, which form the basis of the NSRDB. This is followed by detailed information on how the NSRDB was produced, to help you better understand and interpret the information contained in the data base products. Part 2 contains information on the acquisition and derivation of meteorological data and describes the METSTAT (METeorological STATistical) model which was used to estimate solar radiation when measured data were not available. The upgrading of pre-1976 solar radiation data is discussed as is the calculation of uncertainty values used in the quality flags. Part 2 concludes with a discussion of the procedures used to control and monitor the production processes and to verify and validate the computer programs used to produce the NSRDB.

Several appendices are included in the back of this manual to give you additional information on using the data base. These appendices include a list of conversion factors, a detailed station listing, and a summary of the quality statistics for the data base.

PART 1: How to Use and Interpret Data Base Products

1.0 Background and Overview: The National Solar Radiation Data Base (Version 1.0)

Part 1 of this manual describes ways of acquiring and reading the information contained in the National Solar Radiation Data Base (NSRDB), Version 1.0. The foundation for the NSRDB is the hourly measured solar radiation data collected by the National Weather Service (NWS) over the past several decades. Although measured solar radiation data constitute less than 7% of the NSRDB, they provided the benchmark for model estimates of solar radiation. The METSTAT model used for producing approximately 93% of the solar radiation data in the NSRDB was developed by the National Renewable Energy Laboratory (NREL), using the relatively good quality solar radiation data collected by the NWS from 1977 through 1980.[1] These measured and modeled solar radiation data were combined with meteorological data (used by the solar energy industry to evaluate the performance of its systems) to form the NSRDB.

1.1 General Description

The NSRDB is a serially complete collection of hourly values of the three most common measurements of solar radiation (global horizontal, direct normal, and diffuse horizontal) over a period of time adequate to establish means and extremes, and at a sufficient number of locations to represent regional solar radiation climates. The solar radiation and meteorological elements contained in the data base are listed in Table 1-1.

National and international meteorological practices (WMO 1967) call for the use of a 30-year period of record to establish normals, means, and extremes for meteorological variables. Because the National Oceanic and Atmospheric Administration (NOAA) updates the normals, means, and extremes for the United States each decade, the period from January 1961 through December 1990 was used for the NSRDB.

Standard International (SI) units are used for all elements in the data base except atmospheric pressure. Atmospheric pressure is reported in millibars because these units are commonly used in computer models to estimate solar radiation and are consistent with standard NWS reporting practices. Appendix A contains factors to convert all elements to other commonly used units.

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[1] Because of the importance of these and other measured data, a brief history of solar radiation measurements in the United States is presented in Part 2.

Table 1-1. Solar Radiation and Meteorological Elements in the NSRDB

Global horizontal radiation in Wh/m^2	Atmospheric pressure in millibars
Direct normal radiation in Wh/m^2	Wind direction in increments of 10 degrees
Diffuse horizontal radiation in Wh/m^2	Wind speed in m/s
Extraterrestrial radiation (ETR) in Wh/m^2	Horizontal visibility in km
Direct normal ETR in Wh/m^2	Ceiling height in decameters
Total sky cover in tenths	Present weather
Opaque sky cover in tenths	Total precipitable water in mm
Dry-bulb temperature in °C	Aerosol optical depth
Dew-point temperature in °C	Snow depth in cm
Relative humidity in percent	Number of days since last snowfall

All data are referenced to local standard time. The solar radiation elements are the radiant energy integrated over the hour preceding the designated time. Meteorological elements are the values observed at the designated time.

When a station contains only modeled solar radiation data, it is referred to as a *Secondary* station. *Primary* stations contain measured solar radiation data for at least a portion of the 30-year record. The NSRDB contains a total of 56 Primary and 183 Secondary stations. Their locations are shown in Figure 1-1. Primary stations are listed in Table 1-2 and Secondary stations are in Table 1-3. The Weather Bureau Army Navy (WBAN) numbers used to identify the stations are given in these tables. Appendix B provides more comprehensive information about each of the stations incorporated into the data base.

1.2 Rationale for a New Data Base

The NSRDB replaces the SOLMET/ERSATZ data base (SOLMET Vol. 1 1978 and Vol. 2 1979), which we will refer to as the SOLMET data base. A number of investigators have examined data from the SOLMET data base as well as the models used in its preparation. Randall and Bird (1989) present a good summary of the results of these investigations. They found a great deal of variation in the apparent quality of the SOLMET data. For example, differences in the values for mean monthly global horizontal radiation from the SOLMET data base, which covers the period from 1952 to 1975, and monthly means from measurements taken from 1977 to 1980 were as great as 20%.

Differences between SOLMET and 1977 to 1980 values for mean monthly direct normal radiation were as great as 50%. This was probably due in part to the fact that the SOLMET data base contained only modeled estimates of direct normal radiation.

The large differences found between monthly mean values in the SOLMET data base and monthly mean values of data collected by NWS stations from 1977 to 1980 provided the primary motivation for upgrading the data base. The need to *update* the data base was apparent because the last data in the SOLMET data base were collected in 1975. Thus, the U.S. Department of Energy (DOE), in cooperation with the NCDC, undertook this effort to update the solar radiation data for the United States and to develop statistics consistent with standard climatic practices.

Table 1-2. Primary Stations (with measured solar radiation data for at least one year)

State	City	WBAN	State	City	WBAN
AL	Montgomery	13895	ID	Boise	24131
AK	Fairbanks	26411	IN	Indianapolis	93819
AZ	Phoenix	23183	KS	Dodge City	13985
AZ	Tucson[1]	23160			
			LA	Lake Charles	03937
CA	Daggett[1]	23161			
CA	Fresno	93193	ME	Caribou	14607
CA	Los Angeles	23174			
CA	San Diego[1]	23188	MA	Boston	14739
CA	Santa Maria	23273			
			MO	Columbia	03945
CO	Alamosa[1]	23061			
CO	Boulder/Denver	94018	MT	Great Falls	24143
CO	Grand Junction	23066			
			NE	Omaha	94918
FL	Daytona Beach[2]	12834			
FL	Miami	12839	NV	Ely	23154
FL	Tallahassee/ Apalachicola	93805	NV	Las Vegas	23169
			NM	Albuquerque	23050
GA	Atlanta[3]	13874			
GA	Savannah[4]	03822	NY	Albany[5]	14735
			NY	New York City	94728
HI	Honolulu	22521			

Table 1-2. Primary Stations (with measured solar radiation data for at least one year) (Concluded)

State	City	WBAN	State	City	WBAN
NC	Cape Hatteras	93729	TN	Nashville	13897
NC	Raleigh/Durham	13722			
			TX	Brownsville	12919
ND	Bismarck	24011	TX	El Paso	23044
			TX	Fort Worth	03927
OR	Burns[6]	94185	TX	Midland/Odessa	23023
OR	Eugene[6]	24221	TX	San Antonio[7]	12921
OR	Medford	24225			
OR	Portland[6]	24229	UT	Salt Lake City	24127
OR	Redmond/Bend[6]	24230			
			VT	Burlington	14742
PA	Pittsburgh	94823			
			VA	Sterling	93738
PI	Guam	41415			
			WA	Seattle/Tacoma	24233
PR	San Juan	11641			
			WI	Madison	14837
SC	Charleston	13880			
			WY	Lander	24021

Non-NOAA sources of solar radiation data:

[1] WEST Associates (consortium of Southwest utilities)
[2] Bethune-Cookman College
[3] Georgia Institute of Technology
[4] Savannah State College
[5] State University of New York at Albany
[6] University of Oregon
[7] Trinity University

Table 1-3. Secondary Stations (without measured solar radiation data)

State	City	WBAN	State	City	WBAN
AL	Birmingham	13876	AR	Fort Smith	13964
AL	Huntsville	03856	AR	Little Rock	13963
AL	Mobile	13894			
			CA	Arcata	24283
AK	Anchorage	26451	CA	Bakersfield	23155
AK	Annette	25308	CA	Long Beach	23129
AK	Barrow	27502	CA	Sacramento	23232
AK	Bethel	26615	CA	San Francisco	23234
AK	Bettles	26533			
AK	Big Delta	26415	CO	Colorado Springs	93037
AK	Cold Bay	25624	CO	Eagle	23063
AK	Gulkana	26425	CO	Pueblo	93058
AK	King Salmon	25503			
AK	Kodiak	25501	CT	Bridgeport	94702
AK	Kotzebue	26616	CT	Hartford	14740
AK	McGrath	26510			
AK	Nome	26617	DE	Wilmington	13781
AK	St Paul Is.	25713			
AK	Talkeetna	26528	FL	Jacksonville	13889
AK	Yakutat	25339	FL	Key West	12836
			FL	Tampa	12842
AZ	Flagstaff	03103	FL	West Palm Beach	12844
AZ	Prescott	23184			

Table 1-3. Secondary Stations (without measured solar radiation data) (Continued)

State	City	WBAN	State	City	WBAN
GA	Athens	13873	IA	Des Moines	14933
GA	Augusta	03820	IA	Mason City	14940
GA	Columbus	93842	IA	Sioux City	14943
GA	Macon	03813	IA	Waterloo	94910
HI	Hilo	21504	KS	Goodland	23065
HI	Kahului	22516	KS	Topeka	13996
HI	Lihue	22536	KS	Wichita	03928
ID	Pocatello	24156	KY	Covington	93814
			KY	Lexington	93820
IL	Chicago	94846	KY	Louisville	93821
IL	Moline	14923			
IL	Peoria	14842	LA	Baton Rouge	13970
IL	Rockford	94822	LA	New Orleans	12916
IL	Springfield	93822	LA	Shreveport	13957
IN	Evansville	93817	ME	Portland	14764
IN	Fort Wayne	14827			
IN	South Bend	14848	MD	Baltimore	93721
			MA	Worchester	94746

Table 1-3. Secondary Stations (without measured solar radiation data) (Continued)

State	City	WBAN	State	City	WBAN
MI	Alpena	94849	MT	Billings	24033
MI	Detroit	94847	MT	Cut Bank	24137
MI	Flint	14826	MT	Glasgow	94008
MI	Grand Rapids	94860			
MI	Houghton	94814	MT	Helena	24144
MI	Lansing	14836	MT	Kalispell	24146
MI	Muskegon	14840	MT	Lewistown	24036
MI	Sault Ste. Marie	14847	MT	Miles City	24037
MI	Traverse City	14850	MT	Missoula	24153
MN	Duluth	14913	NE	Grand Island	14935
MN	International Falls	14918	NE	Norfolk	14941
MN	Minneapolis/St. Paul	14922	NE	North Platte	24023
MN	Rochester	14925	NE	Scottsbluff	24028
MN	St. Cloud	14926			
			NV	Elko	24121
MS	Jackson	03940	NV	Reno	23185
MS	Meridian	13865	NV	Tonopah	23153
			NV	Winnemucca	24128
MO	Kansas City	03947			
MO	Springfield	13995	NH	Concord	14745
MO	St. Louis	13994			

Table 1-3. Secondary Stations (without measured solar radiation data) (Continued)

State	City	WBAN	State	City	WBAN
NJ	Atlantic City	93730	OK	Oklahoma City	13967
NJ	Newark	14734	OK	Tulsa	13968
NM	Tucumcari	23048	OR	Astoria	94224
			OR	North Bend	24284
NY	Binghamton	04725	OR	Pendleton	24155
NY	Buffalo	14733	OR	Salem	24232
NY	Massena	94725			
NY	Rochester	14768	PA	Allentown	14737
NY	Syracuse	14771	PA	Bradford	04751
			PA	Erie	14860
NC	Asheville	03812	PA	Harrisburg	14751
NC	Charlotte	13881	PA	Philadelphia	13739
NC	Greensboro	13723	PA	Wilkes-Barre	14777
NC	Wilmington	13748	PA	Williamsport	14778
ND	Fargo	14914	RI	Providence	14765
ND	Minot	24013			
			SC	Columbia	13883
OH	Akron/Canton	14895	SC	Greenville	03870
OH	Cleveland	14820			
OH	Columbus	14821	SD	Huron	14936
OH	Dayton	93815	SD	Pierre	24025
OH	Mansfield	14891	SD	Rapid City	24090
OH	Toledo	94830	SD	Sioux Falls	14944
OH	Youngstown	14852			

Table 1-3. Secondary Stations (without measured solar radiation data) (Concluded)

State	City	WBAN	State	City	WBAN
TN	Bristol	13877	WA	Olympia	24227
TN	Chattanooga	13882	WA	Quillayute	94240
TN	Knoxville	13891	WA	Spokane	24157
TN	Memphis	13893	WA	Yakima	24243
TX	Abilene	13962	WV	Charleston	13866
TX	Amarillo	23047	WV	Elkins	13729
TX	Austin	13958	WV	Huntington	03860
TX	Corpus Christi	12924			
TX	Houston	12960	WI	Eau Claire	14991
TX	Lubbock	23042	WI	Green Bay	14898
TX	Lufkin	93987	WI	La Crosse	14920
TX	Port Arthur	12917	WI	Milwaukee	14839
TX	San Angelo	23034			
TX	Victoria	12912	WY	Casper	24089
TX	Waco	13959	WY	Cheyenne	24018
TX	Wichita Falls	13966	WY	Rock Springs	24027
			WY	Sheridan	24029
UT	Cedar City	93129			
VA	Lynchburg	13733			
VA	Norfolk	13737			
VA	Richmond	13740			
VA	Roanoke	13741			

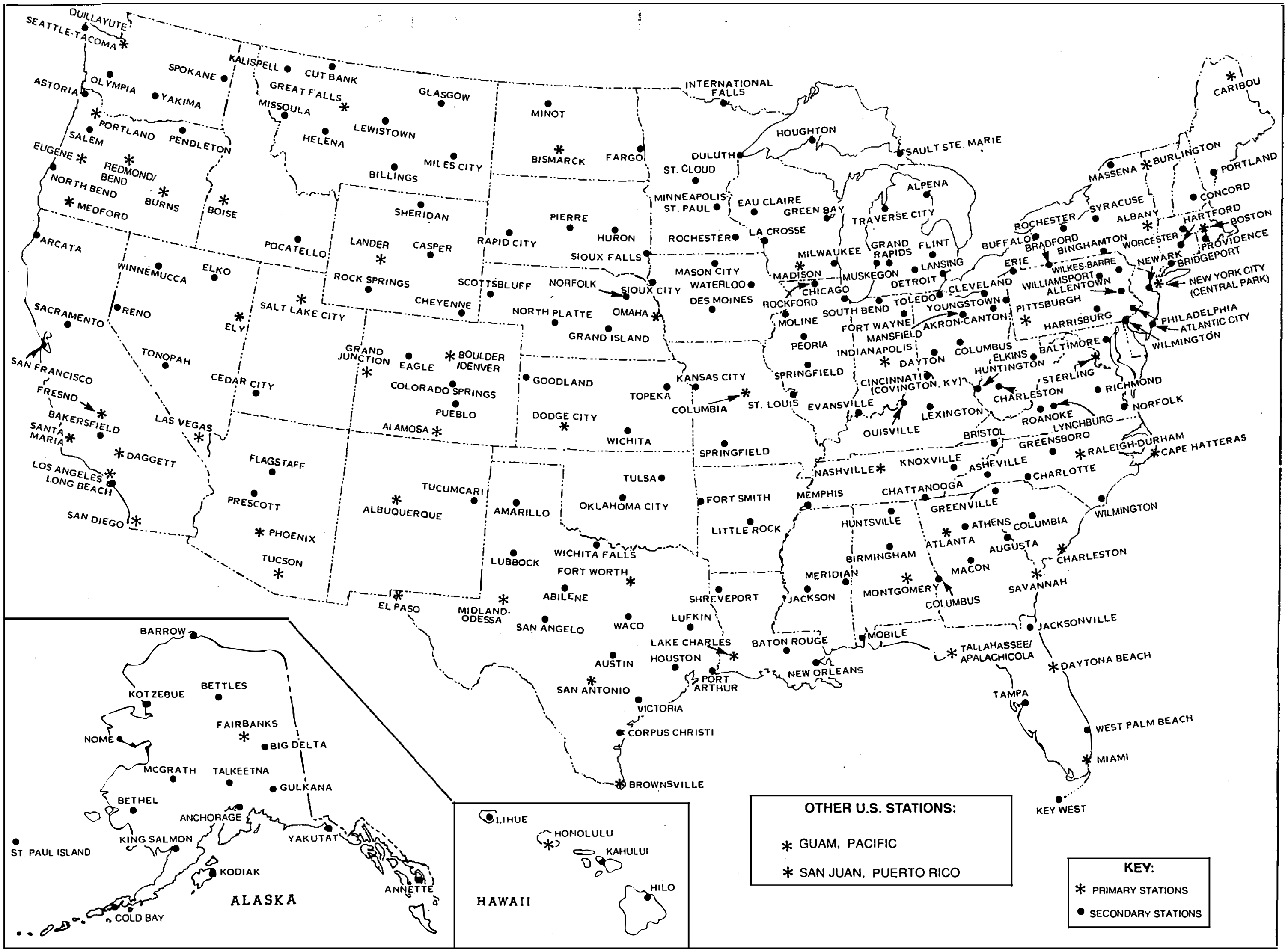

Figure 1-1. Map showing locations of all Primary and Secondary stations used in the NSRDB

2.0 Data Base Product Options

Current products available for Version 1.0 of the NSRDB are briefly described here. These products are intended to fit the applications of most data base users. Detailed descriptions of these products are provided in Section 3.0; information on how the products were developed is given in Part 2.

Product options include (1) serial hourly data in two formats, (2) hourly, daily, and quality statistics for solar radiation elements, (3) daily statistics for meteorological elements, and (4) persistence statistics for daily total solar radiation energy.

2.1 Hourly Data

The serially complete hourly data provided in the data base are available in NSRDB synoptic and TD-3282 formats. Each record in the NSRDB synoptic products contains hourly sequential data for five elements of solar radiation data (three surface and two extraterrestrial above the earth's atmosphere) and 15 elements of surface meteorological data. The synoptic format also contains quality flags (source and uncertainty) following each solar radiation element and separates each element by one space for greater readability when displayed line-by-line on your computer or terminal monitor. Flags for meteorological elements are not included in the synoptic format.

TD-3282 is NCDC's archive format featuring daily interleaving of each of the elements specified. Each logical record contains one station's hourly data values for a specific solar radiation or meteorological element for a period of one day. The next record contains hourly data for the same day for the next element; i.e., the elements are interleaved such that all of the elements for one day appear sequentially in a block of 6000 characters. The TD-3282 element file structure is designed to allow maximum flexibility in requesting data. You need order only those elements or groups of elements of particular interest to you. In other words, if you want only the three solar radiation elements, you do not have to purchase and store all of the meteorological elements included in the synoptic products.

More detailed information on the synoptic and TD-3282 formats can be found in Section 3.0.

2.2 Statistical Summaries

The NSRDB contains statistical summaries computed from the hourly data for the entire period of record for all stations. For the solar radiation data, these statistics include the average and standard deviation of the daily total solar energy (direct normal, diffuse horizontal, and global horizontal) for each station-year-month and each station-year. The 30-year averages and the standard deviations of monthly and annual means from 1961 through 1990 are also provided. For the meteorological elements, only monthly, annual, and 30-year averages were computed.

The hourly statistical products include monthly, annual, and 30-year averages and standard deviations for each hour of the day for global horizontal, direct normal, and diffuse horizontal solar radiation. The averages can be used to prepare average diurnal profiles of hourly solar energy. The hourly values have also been binned in twenty four 50-Wh/m^2 bins from 0 to 1200 Wh/m^2. The mean number of hourly values falling into each bin have been determined for each station-month for the 30-year period of record from 1961 to 1990. These statistics can be used to plot histograms and/or determine cumulative frequency distributions.

A solar radiation persistence product was created for each station-month by calculating the number of times the daily total solar radiation energy persisted above or below set thresholds for periods from 1 to 15 days. These calculations were performed for the entire 30-year period from 1961 to 1990.

Statistics on the quality of the solar radiation data were determined by calculating the percentage of the hourly values to which each source and uncertainty flag was assigned. These percentages were calculated for each station-year and for the 30-year period of record and are available as a separate product.

2.3 Media

NSRDB synoptic data are available on magnetic media (3.5-in. or 5.25-in. high-density diskettes and 9-track high-density magnetic tapes). Data for one year can be placed on one high-density (1.2 MB) diskette. All 30 years for three stations can be placed on one high-density magnetic tape. Approximately 80 tapes are required to hold the entire data base. Individual station-years or any combination of stations and years can be ordered from NCDC.

Data in TD-3282 format also are available on magnetic media (3.5-in. or 5.25-in. high-density diskettes or high-density magnetic tapes). Each 1.2-megabyte diskette can hold ten years of data for a single element. Two diskettes are needed for one year of data for all elements. All 30 years of data for two stations can be placed on one high-density magnetic tape.

Daily, hourly, persistence, and quality statistics are available on magnetic media (diskettes and tape), and printed hard copy:

- Daily statistics and persistence data for up to 15 stations can be placed on one diskette (3.5-in. or 5.25-in. double-sided, high-density) and the daily statistics for all 239 stations can be placed on a high-density magnetic tape. Data can be ordered for selected stations or all stations.

- Hourly statistics for two stations can be placed on each diskette and hourly statistics for all 239 stations can be placed on two magnetic tapes. Data can be ordered for selected stations or all stations.

- Quality statistics for all 239 stations are available on three diskettes or they can be ordered in printed form for individual stations.

- The daily, hourly, persistence, and quality statistics for individual stations can be placed on single diskettes.

When future NSRDB products are produced (e.g., CD-ROM products) they will be announced by NREL and NCDC.

2.4 Where to Order Data Base Products

All of the products from the NSRDB can be ordered from NCDC at the following address:

User Services
National Climatic Data Center
Federal Building
Asheville, NC 28801-2696
Phone - (704) 259-0682
Fax - (704) 259-0876

In addition to the products described in this manual, special products made to the user's specifications can be supplied at a cost that will be quoted by NCDC. NCDC will supply a cost sheet for standard products on request.

3.0 Reading and Understanding Data Base Products

In this section, we provide the information necessary for using the various products that have been developed from Version 1.0 of the NSRDB, including the solar radiation and meteorological elements and the quality flags assigned to these elements.

3.1 NSRDB Synoptic Format

A sample printout of data in the NSRDB synoptic format is shown in Figure 3-1. When data for multiple years are requested in a single file, the years will follow each other hour by hour with no end-of-file until the end of the last year. The first record in each file contains the WBAN number, city, state, time zone, latitude (degrees and minutes), longitude (degrees and minutes), and elevation (meters). Time zones are indicated in terms of the number of hours by which the local standard time lags or leads Universal Time (UT). For example, Mountain Standard Time at Albuquerque is designated as -7, to indicate a lag of 7 hours from UT (i.e., a UT of 1700 corresponds to a time of 1000 [10 AM] in Albuquerque). The field positions and definitions of these header elements are given in Table 3-1 along with the FORTRAN format required to read the header.

Following the header, there are 8,760 or 8,784 (for leap years) hourly data records in each station-year. Each of the elements found in each data record are defined in Table 3-2. The FORTRAN format for reading the data records is given at the bottom of Table 3-2.

3.2 TD-3282 Format

TD-3282 is a special version of the TD-3280 format designed for the NSRDB. TD-3280 is the archival format used by NCDC for Surface Airways Hourly data. These weather observations, made in support of aircraft operations, have been taken since the earliest days of commercial aviation. They include data from NWS and military stations.

In contrast to the synoptic formats, which contain all elements within each hourly data record, TD-3280 and TD-3282 could be described as element *interleaved* formats. Each record contains hourly data for one day and one element; all elements for each day are grouped together or interleaved. A TD-3282 station-year file contains all of the data for one station and one year. You also have the option of requesting the data for multiple years in a single file.

The record for each element begins with an identification (ID) portion, 30 characters in length, as shown in Figure 3-2. This is followed by the data portion of the record, which consists of the time, the sign of the data, the data value, and two flags, repeated as many times as necessary to contain one day of record. For TD-3282, all records for all elements contain 24 hourly values and are 322 characters in length (including a four character control word and the 30-character ID portion). The control word is used by the computer to determine record length. The data are blocked in lengths of 6,000 characters, each block containing data for all elements for one day.

The fields in the ID portion of the record are defined in Table 3-3. The data element type codes, data positions in the fields, and data definitions are given in Table 3-4. Flag 1 (FL1 in the data portion) is the data source flag and Flag 2 (FL2) is the data uncertainty flag, both of which are defined later in this section. Definitions of the TD-3282 units codes are given in Table 3-5.

One of the advantages of the TD-3282 format is the flexibility it offers in ordering data. You can order only those elements of value to your application. For example, if global horizontal solar radiation data for July 1988 at Denver, Colorado are all that is needed, then your order can be specifically limited to that data.

3.3 Statistical Summaries

The information needed to view and use the statistical products from the NSRDB is provided in this section.

3.3.1 Daily Statistics

Figure 3-3 is an example of the daily statistics as they will appear on a "wide-screen" display[2] or wide hardcopy print from the file. The header identifies the station by a five-digit WBAN number, city, and state. The header identifies the time zone (TZ) for the station by indicating the number of hours by which the local standard time lags (-) or leads (+) Universal Time (UT) (e.g., Eastern Standard Time is designated as -5). Latitude and longitude for the station are given in degrees and minutes, station elevation is in meters, and the mean atmospheric pressure is given in millibars.

The next line in each file identifies the year(s) for which the next section of data applies. In each file, the first group of data provides daily statistics for the 30 years from 1961 to 1990. Statistics for each year for the entire period of record follow. As an example, Figure 3-3 gives 30-year statistics for Albuquerque, New Mexico. January and annual statistics are also shown for 1961 and 1990. The FORTRAN formats for reading the header, year(s), and data records are given at the bottom of Figure 3-3.

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[2] If your monitor/software does not provide a "wide-screen" display, the statistics may wrap around on your screen or may be truncated.

The standard deviations of solar radiation elements (e.g., SDGLO) for individual years and for the period of record (61-90) are not the same. For individual years, the standard deviations provide a measure of daily variability. For the period of record, the standard deviations provide a measure of the interannual variability of monthly and annual averages.

The NSRDB mean values for meteorological elements may not be identical with the means published by NCDC in the Annual Summaries of Local Climatological Data. The small differences expected are the result of different computational methods and differences in methods used to replace missing data.

3.3.2 Hourly Means, Standard Deviations, and Distributions

The hourly statistics are presented in the form of means and standard deviations of the hourly values for each hour (from which diurnal profiles can be formed) and distributions generated by binning hourly values to determine the number of hours for which the radiation fell within twenty four 50-Wh/m^2 ranges (e.g., 0-50, 50-100, 100-150, ..., 1100-1150, 1150-1200). The bin data have been normalized to indicate the percentage (in tenths) of all daytime hours for which the radiation fell within each bin. Figure 3-4 provides an example of the hourly statistics as they will appear on a "wide-screen" display or a wide printout of the file. The header information is the same as that used for daily statistics except that the year(s) represented by each file has been added as the last field of the header.

Following the header, the next record identifies the solar radiation element (e.g., global horizontal radiation in Wh/m^2) and the statistic (e.g., means) for which the following data records apply. Each file contains data for all three solar radiation elements and each of the three statistics, as indicated in Figure 3-4.

The first two fields in each data record designate the month (13 indicates annual statistics) and the source and uncertainty flags that apply to each monthly profile and distribution.

The data fields for means and standard deviations contain these hourly statistics in Wh/m^2 for each of the 24 hours of the day. Values for hour 01 represent the mean or standard deviation of the total radiant energy measured from midnight (2400) to 1:00 AM (0100). The data fields for the distributions designate the percentage of hours, in tenths of one percent, for which the average radiation fell within the 50-Wh/m^2 bins described above.

The FORTRAN formats for reading the header, statistic identification, and data records are given at the bottom of Figure 3-4.

3.3.3 Daily Persistence Data

The persistence of weather events and the effect this has on the availability of solar radiation energy can affect many solar energy applications. In particular, the persistence of solar energy can affect energy storage requirements and the need for backup energy sources.

A persistence statistic calculated for the NSRDB is the number of sequential days (runs) in a month during which the daily total solar energy exceeded or fell below 12 energy thresholds (see Figure 3-5). The run lengths vary from 1 to 15+ days. The total number of runs over the entire 30-year period from 1961 to 1990 were determined for each month. The decision to compute persistence on a monthly basis resulted in the truncation of runs at the end of each month. Although this procedure caused some distortion of the statistics, it provided important information on seasonal changes in persistence.

An example of the persistence statistic is shown in Figure 3-5. The thresholds for diffuse horizontal radiation (0 to 5,000 Wh/m^2 in 11 steps) are one-half those used for global horizontal and direct normal radiation (0 to 10,000 Wh/m^2 in 11 steps). The header information gives the WBAN number, city, state, month, and the solar radiation element.

Each number in the matrices on the left side of Figure 3-5 gives the total number of times the daily total solar energy exceeded the threshold indicated for that row for no more or no less than the number of days indicated for that column. Each number in the matrices on the right gives the total number of times the daily total solar energy was less than the threshold indicated for that row for no more or no less than the number of days indicated for that column.

The numbers in these matrices can be used in a variety of ways. For example, the sum of all the numbers in the sector enclosed by the dotted line box on Figure 3-5 indicates that the daily total global horizontal energy fell below 6,000 Wh/m^2 for four or more days, 31 times from 1961 to 1990. These matrices can be sectored in any manner that produces information useful to specific applications.

The FORTRAN formats for reading the headers, number of days, thresholds, and numbers of events are given at the bottom of Figure 3-5.

3.4 Quality Flags

Quality flags are attached to each hourly solar radiation and meteorological element. These flags provide information on the source and uncertainty of a data element, allowing each user to evaluate its usefulness. The flags are further described in the following sections.

3.4.1 Quality Flags for Solar Radiation Elements

Two flags are used to define the quality of each solar radiation element. The first flag gives the user information about the source of each hourly value for each solar radiation element, including the methods and input data used to derive model estimates. Solar radiation source flags are defined in Table 3-6. The flags are ranked roughly from highest quality to lowest quality data. However, this ranking may not hold for an individual datum. For example, if the quality assessment of data from a station measuring all three elements of solar radiation (Source Flag A) shows a large probable error in the data, then a large uncertainty will be assigned to the hourly values for each element. This might be a larger uncertainty than that assigned to a modeled value with good quality input data.

The second flag designates the uncertainty attached to each hourly value. Uncertainty as used here provides an estimate of the interval around a measured or modeled value within which the true value will lie 95% of the time. The flags for each interval are defined in Table 3-7. In Version 1.0 of the NSRDB, no flags as low as 1 or as high as 9 were assigned. A special meaning defined in Section 8.3.2 is attached to the uncertainty of modeled data.

In general, the uncertainties assigned to measured solar radiation data show considerable variability because of instrument failures and human factors. The uncertainties assigned to modeled data will be higher, on average, than measured data, but will show lower variability for a given source category because the model is applied uniformly at all times. Only changes in the uncertainty of the input data will significantly affect the uncertainty of modeled data.

3.4.2 Quality Flags for Meteorological Elements

The flags which originally accompanied most of the NWS meteorological data have not been incorporated into the NSRDB. Instead, the source flags defined in Table 3-8 have been assigned.

The resources available for producing Version 1.0 of the NSRDB did not allow for a quantitative evaluation of the uncertainty of the meteorological elements. Rather, the relative uncertainties defined in Table 3-9 were assigned.

The source and uncertainty flags for meteorological elements are not included in the NSRDB synoptic product. They are included in the TD-3282 product.

3.4.3 Quality Flags Applied to Solar Radiation Statistical Products

The dominant source and uncertainty flags of the hourly data are assigned to each of the daily and hourly solar radiation statistics described previously. These flags provide a limited measure of the quality of the hourly data for each station-month and station-year. The quality statistics described in Section 3.4.4 provide a more comprehensive assessment of the quality of data available for each station in the data base.

3.4.4 Quality Statistics Product

An example of the quality statistics that are available for each station is given in Figure 3-6. The header for the quality statistics files contains the same information as does the header for daily statistics. Each record contains the percentages (in tenths of one percent) of the hourly values for each year to which the indicated source and uncertainty flags were assigned. The first record for each element is for the 30-year period from 1961 to 1990. FORTRAN formats for the header, element ID, and data records are given at the bottom of Figure 3-6.

If you have a choice of locations or years from which to select data, these quality statistics can be used to select the best quality data. Appendix C contains the quality statistics for 1961-1990 for each of the Primary stations.

Table 3-1. Header Elements in the NSRDB Synoptic Format (For first record of each file)

Field Position	Element	Definition
002 - 006	WBAN Number	Station's Weather Bureau Army Navy number. See Appendix B or Tables 1-2 and 1-3.
008 - 029	City	City where the station is located (maximum of 22 characters).
031 - 032	State	State where the station is located (abbreviated to two letters).
034 - 036	Time Zone	Time zone is the number of hours by which the local standard time lags or leads Universal Time. For example, Mountain Standard Time is designated -7 because it lags Universal Time by 7 hours.
039 - 044 039 040 - 041 043 - 044	Latitude	Latitude of the station. N = North of equator Degrees Minutes
047 - 053 047 048 - 050 052 - 053	Longitude	Longitude of the station. W = West, E = East Degrees Minutes
056 - 059	Elevation	Elevation of station in meters above sea level.
FORTRAN Format (1X,A5,1X,A22,1X,A2,1X,I3,2X,A1,I2,1X,I2,2X,A1,I3,1X,I2,2X,I4)		

Table 3-2. Data Elements in the NSRDB Synoptic Format (For all except the first record of each file)

Field Position	Element	Values	Definition
002 - 012	Local Standard Time		
002 - 003	Year	61 - 90	Year of observation
005 - 006	Month	1 - 12	Month of observation
008 - 009	Day	1 - 31	Day of month
011 - 012	Hour	1 - 24	Hour of day in local standard time
014 - 017	Extraterrestrial Horizontal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated.
019 - 022	Extraterrestrial Direct Normal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a surface normal to the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated.
024 - 030	Global Horizontal Radiation		Total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface during the 60 minutes preceding the hour indicated. 9999 = missing data.
024 - 027	Data Value	0 - 1415	
029	Flag for Data Source	A - H, ?	
030	Flag for Data Uncertainty	0 - 9	
032 - 038	Direct Normal Radiation		Amount of solar radiation in Wh/m^2 received within a 5.7° field of view centered on the sun, during the 60 minutes preceding the hour indicated. 9999 = missing data.
032 - 035	Data Value	0 - 1415	
037	Flag for Data Source	A - H, ?	
038	Flag for Data Uncertainty	0 - 9	
040 - 046	Diffuse Horizontal Radiation		Amount of solar radiation in Wh/m^2 received from the sky (excluding the solar disk) on a horizontal surface, during the 60 minutes preceding the hour indicated. 9999 = missing data.
040 - 043	Data Value	0 - 1415	
045	Flag for Data Source	A - H, ?	
046	Flag for Data Uncertainty	0 - 9	
048 - 049	Total Sky Cover	0 - 10	Amount of sky dome (in tenths) covered by clouds. 99 = missing data.
051 - 052	Opaque Sky Cover	0 - 10	Amount of sky dome (in tenths) covered by clouds that prevent observing the sky or higher cloud layers. 99 = missing data.
054 - 058	Dry Bulb Temperature	-70.0 to 60.0	Dry bulb temperature in °C. 9999. = missing data.

Table 3-2. Data Elements In the NSRDB Synoptic Format (Concluded)

Field Position	Element	Values	Definition
060 - 064	Dew Point Temperature	-70.0 to 60.0	Dew point temperature in °C. 9999. = missing data.
066 - 068	Relative Humidity	0 - 100	Relative humidity in percent. 999 = missing data.
070 - 073	Atmospheric Pressure	700 - 1100	Atmospheric pressure in millibars. 9999 = missing data.
075 - 077	Wind Direction	0 - 360	Wind direction in degrees. (N = 0 or 360, E = 90, S = 180, W = 270) 999 = missing data.
078 - 082	Wind Speed	0.0 - 99.0	Wind speed in m/s. 9999.= missing data.
083 - 088	Visibility	0.0 - 160.9	Horizontal visibility in kilometers. 777.7 = unlimited visibility. 99999.= missing data.
089 - 094	Ceiling Height	0 - 30450	Ceiling height in meters. 77777 = unlimited ceiling height. 88888 = cirroform. 999999 = missing data.
096 - 105	Present Weather	See Appendix D	Present weather conditions denoted by a ten digit number. See Appendix D for an explanation of weather elements and parameters.
106 - 109	Precipitable Water	0 - 100	Precipitable water in millimeters. 9999 = missing data.
110 - 115	Broadband Aerosol Optical Depth	0.0 - 0.900	Broadband aerosol optical depth (broadband turbidity) on the day indicated. 99999. = missing data.
116 - 119	Snow Depth	0 - 100	Snow depth in centimeters on the day indicated. 9999 = missing data.
120 - 122	Days Since Last Snowfall	0 - 88	Number of days since last snowfall. 88 = 88 or greater days. 999 = missing data.
FORTRAN Format (4(1X,I2),2(1X,I4),3(1X,I4,1X,A1,I1),2(1X,I2),2(1X,F5.1),1X,I3,1X,I4,1X,I3,F5.1,F6.1,I6,1X,10I1,I4, F6.3,I4,3I3)			

Notes: With the exception of solar radiation elements, broadband aerosol optical depths, snow depth, and days since last snowfall, all values were observed or measured at the hour indicated. Daily values of broadband aerosol optical depth were estimated as described in Section 5.2.3.

Table 3-3. TD-3282 Format

Field Position	Element	Values	Definition
			General - Each record consists of an identification portion (columns 001 - 030) and a data portion (columns 031 - 318) containing 24 hourly data values for one data element. The identification portion denotes the type of data element.
001 - 003	Record Type	HLY	All TD-3282 data are hourly values.
004 - 011	WBAN Number	See Tables 1-2 and 1-3 or Appendix B	The station's Weather Bureau Army Navy number. Five digit station numbers are right justified with three leading zeros.
012 - 015	Data Type Code	See Table 3-4	A four character code denoting a certain solar radiation or meteorological parameter.
016 - 017	Measurement Units Code	See Table 3-5	A two character code denoting the units of measurement for the data.
018 - 021	Year	1961-1990	Year of observation, 1961 - 1990.
022 - 023	Month	01 - 12	Month of observation
024	Source Code 1	1	Constant, column reserved for future applications
025	Source Code 2	1	Constant, column reserved for future applications
026 - 027	Day	01 - 31	Day of month
028 - 030	Number of Data Groups That Follow	024	All TD-3282 data have 24 data groups that follow the identification portion of the record. (One for each hour of the day.)
031 - 042	First Data Group		
031 - 034	Hour	0000-2300	Hour of the day in local standard time. 0000 = midnight
035	Data Sign	- or blank	Sign of the data. A minus sign is used for data below zero. A blank is used for data equal to or greater than zero.
036 - 040	Data Value	See Table 3-4	For solar radiation data, the value represents the amount of solar radiation in Wh/m^2 received during the preceding hour. For meteorological parameters, the value is based on the observation made at the hour.
041	Flag for Data Source	A - H, ?	Flag showing how data was measured or modeled.
042	Flag for Data Uncertainty	0 - 9	Flag showing estimate of the data uncertainty.
043 - 318	Remaining 23 Data Groups		Data groups in the same format as columns 031 - 042 are repeated 23 times to complete one day.

FORTRAN Format

```
( A3,A8,A4,A2,I4,I2,2A1,I2,I3,24(I4,I6,2A1) )
```

Table 3-4. TD-3282 Data Type Codes and Descriptions

Code	Position	Element	Values	Definitions
ETRH	0XXXX	Extraterrestrial Horizontal Radiation	0000 - 1415	Amount of solar radiation in Wh/m^2 received on a horizontal surface at the top of the atmosphere.
ETRN	0XXXX	Extraterrestrial Direct Normal Radiation	0000 - 1415	Amount of solar radiation in Wh/m^2 received on a surface normal to the sun at the top of the atmosphere.
GRAD	0XXXX	Global Horizontal Radiation	0000 - 1415	Total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface. 99999 = missing data.
DRAD	0XXXX	Direct Normal Radiation	0000 - 1415	Amount of solar radiation in Wh/m^2 received within a 5.7° field of view centered on the sun. 99999 = missing data.
SRAD	0XXXX	Diffuse Horizontal Radiation	0000 - 1415	Amount of solar radiation in Wh/m^2 received on a horizontal surface from the sky (excluding the solar disk). 99999 = missing data.
TSKC	0XXYY	Total Sky Cover = XX	00 - 10	Amount of sky dome (in tenths) covered by clouds. 999 = missing data.
		Opaque Sky Cover = YY	00 - 10	Amount of sky dome (in tenths) covered by clouds that prevent observing the sky or higher cloud layers. 99 = missing data.
TMPD	00XXX	Dry Bulb Temperature	000 to 600	Dry bulb temperature in °C and tenths. 600 = 60.0°C 99999 = missing data.
DPTP	00XXX	Dew Point Temperature	000 to 600	Dew point temperature in °C and tenths. 600 = 60.0°C 99999 = missing data.
RHUM	00XXX	Relative Humidity	000 - 100	Relative humidity in percent. 99999 = missing data.
PRES	0XXXX	Atmospheric Pressure	0700 - 1100	Atmospheric pressure in millibars. 99999 = missing data.

Table 3-4. TD-3282 Data Type Codes and Descriptions (Concluded)

Code	Position	Element	Values	Definitions
WIND	XXYYY	Wind Direction = XX	00 - 36	Wind direction in increments of 10 degrees. (N = 00 or 36) 99 = missing data.
		Wind Speed = YYY	000 - 990	Wind speed in m/s (in tenths). 000 - 990 = 0.0 - 99.0 m/s. 999 = missing data.
HZVS	0XXXX	Visibility	0000 - 1609	Horizontal visibility in hectometers. 0000 - 1609 = 0.0 - 160.9 km. 7777 = unlimited visibility. 99999 = missing data.
CLHT	0XXXX	Ceiling Height	0000 - 3045	Ceiling height in decameters. 7777 = unlimited ceiling height. 8888 = cirroform. 99999 = missing data.
PWX1	XXXXX	Present Weather for the First Five Weather Elements	See Appendix D	Present weather conditions for the first five weather elements. See Appendix D for an explanation of weather elements.
PWX2	XXXXX	Present Weather for the Second Five Weather Elements	See Appendix D	Present weather conditions for the last five weather elements. See Appendix D for an explanation of weather elements.
PH2O	00XXX	Precipitable Water	000 - 100	Precipitable water in millimeters. 99999 = missing data.
TURB	00XXX	Broadband Aerosol Optical Depth	000 - 900	Broadband aerosol optical depth (broadband turbidity) in thousandths. 000 - 900 = 0.0 - 0.900 99999 = missing data.
SNOW	XXXYY	Snow Depth = XXX	000 - 900	Snow depth in centimeters. 999 = missing data.
		Days Since Last Snowfall = YY	00 - 88	Number of days since last snowfall. 88 = 88 or greater days. 99 = missing data.

Table 3-5. TD-3282 Codes for Units of Measurement

Code	Description of Measurement Units
WM	Solar radiation in Wh/m^2
TC	Temperature in °C and tenths (i.e., 205 = 20.5°C)
P	Whole percent
MB	Atmospheric pressure in millibars
WD	Wind direction in tens of degrees (i.e., 18 = 180°)
WS	Wind speed in m/s and tenths (i.e., 107 = 10.7 m/s)
KM	Kilometers and tenths (i.e., 503 = 50.3 kilometers)
DM	Decameters (1 decameter = 10 meters)
CM	Centimeters
MM	Millimeters
NA	No units applicable (non-dimensional)

Table 3-6. Solar Radiation Source Flags

Flag	Definition
A	Post-1976 measured solar radiation data as received from NCDC or other sources
B	Same as 'A' except the global horizontal data underwent a calibration correction
C	Pre-1976 measured global horizontal data (direct and diffuse were not measured before 1976), adjusted from solar to local time, usually with a calibration correction
D	Data derived from the other two elements of solar radiation using the relation, Kt = Kn + Kd (see Part 2, Section 8.1 for more information)
E	Modeled solar radiation data using inputs of *observed* sky cover (cloud amount) and aerosol optical depths derived from direct normal data collected at the same location
F	Modeled solar radiation using *interpolated* sky cover and aerosol optical depths derived from direct normal data collected at the same location
G	Modeled solar radiation data using *observed* sky cover and aerosol optical depths *estimated* from geographical relationships
H	Modeled solar radiation data using *interpolated* sky cover and *estimated* aerosol optical depths
?	Source does not fit any of the above categories. Used for nighttime values, calculated extraterrestrial values, and missing data

Table 3-7. Solar Radiation Uncertainty Flags

Flag	Uncertainty Range (%)
1	0 - 2
2	2 - 4
3	4 - 6
4	6 - 9
5	9 - 13
6	13 - 18
7	18 - 25
8	25 - 35
9	35 - 50
0	Not applicable

Table 3-8. Meteorological Source Flags

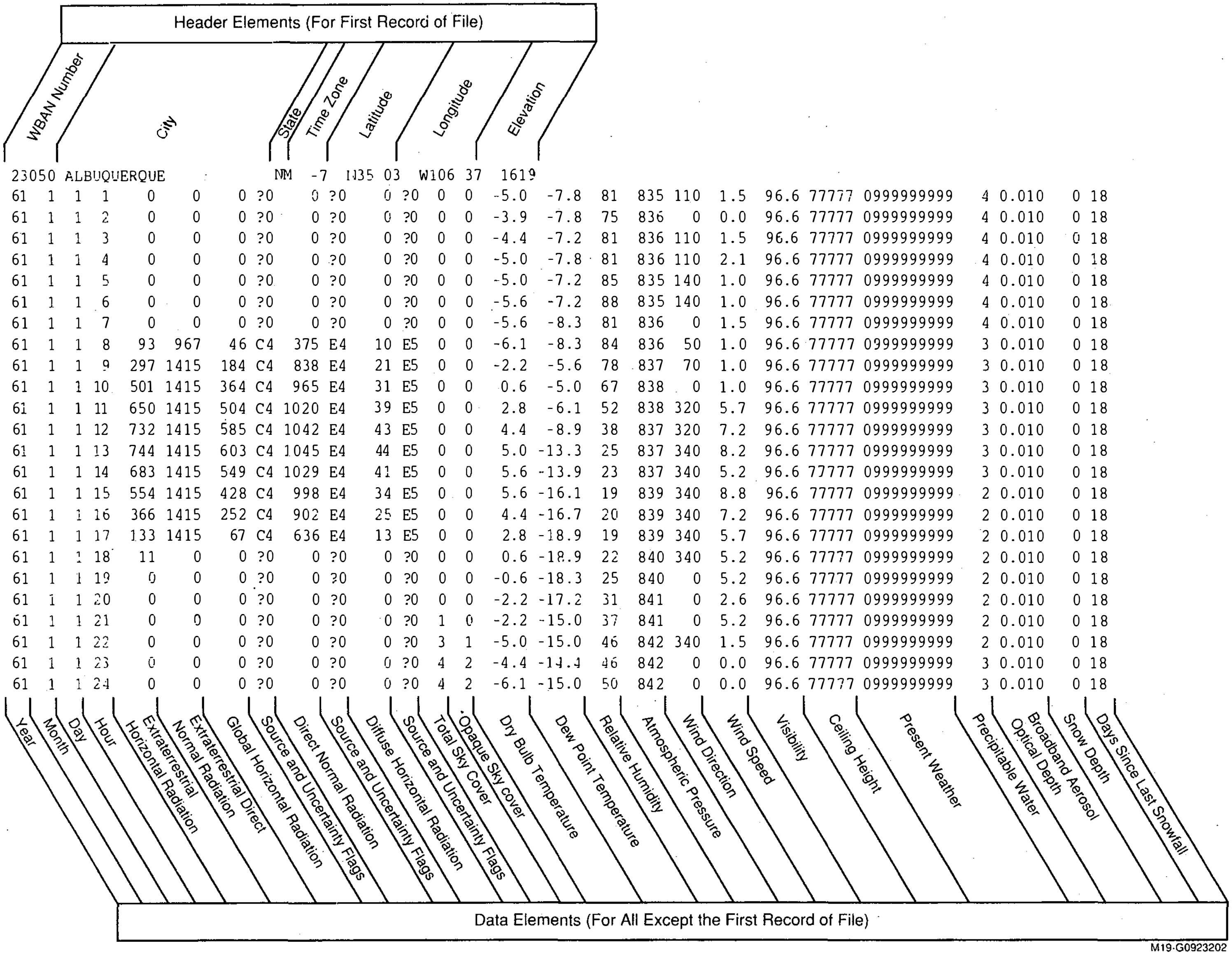
Flag	Definition
A	Data as received from NCDC, converted to SI units
B	Linearly interpolated to fill short data gaps
C	Non-linearly interpolated to fill data gaps from 6 to 47 hours in length
D	Long data gaps from 48 hours to one year filled from other years
E	Modeled or estimated, except: precipitable water, calculated from radiosonde data; and aerosol optical depth, calculated from direct normal data
F	Precipitable water, calculated from surface vapor pressure; aerosol optical depth, estimated from geographic correlations
?	Source does not fit any of the above. Used mostly for missing data

Notes: Flag B: For sky cover, temperature, and relative humidity, "short" is less than 6 hours. For precipitable water, "short" is less than 60 hours. Data gaps in other meteorological elements were not filled.

Long gaps in pressure data were filled with the climatological mean pressure for the station.

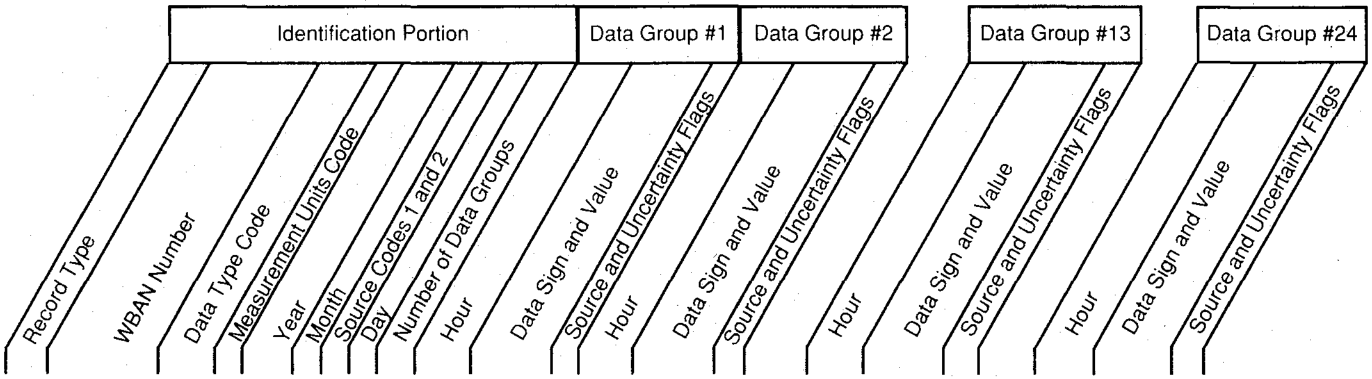
Table 3-9. Meteorological Uncertainty Flags

Flag	Definition
1	Not used
2	Not used
3	Not used
4	Not used
5	Not used
6	Not used
7	Uncertainty consistent with NWS practices and the instrument or observation used to obtain the data
8	Greater uncertainty than 7 because values were interpolated or estimated
9	Greater uncertainty than 8 or unknown
0	Not definable



```
23050 ALBUQUERQUE             NM   -7  N35 03  W106 37  1619
61  1  1  1    0    0    0 ?0    0 ?0    0 ?0  0  0  -5.0  -7.8  81  835 110  1.5  96.6 77777 0999999999   4 0.010   0 18
61  1  1  2    0    0    0 ?0    0 ?0    0 ?0  0  0  -3.9  -7.8  75  836   0  0.0  96.6 77777 0999999999   4 0.010   0 18
61  1  1  3    0    0    0 ?0    0 ?0    0 ?0  0  0  -4.4  -7.2  81  836 110  1.5  96.6 77777 0999999999   4 0.010   0 18
61  1  1  4    0    0    0 ?0    0 ?0    0 ?0  0  0  -5.0  -7.8  81  836 110  2.1  96.6 77777 0999999999   4 0.010   0 18
61  1  1  5    0    0    0 ?0    0 ?0    0 ?0  0  0  -5.0  -7.2  85  835 140  1.0  96.6 77777 0999999999   4 0.010   0 18
61  1  1  6    0    0    0 ?0    0 ?0    0 ?0  0  0  -5.6  -7.2  88  835 140  1.0  96.6 77777 0999999999   4 0.010   0 18
61  1  1  7    0    0    0 ?0    0 ?0    0 ?0  0  0  -5.6  -8.3  81  836   0  1.5  96.6 77777 0999999999   4 0.010   0 18
61  1  1  8   93  967   46 C4  375 E4   10 E5  0  0  -6.1  -8.3  84  836  50  1.0  96.6 77777 0999999999   3 0.010   0 18
61  1  1  9  297 1415  184 C4  838 E4   21 E5  0  0  -2.2  -5.6  78  837  70  1.0  96.6 77777 0999999999   3 0.010   0 18
61  1  1 10  501 1415  364 C4  965 E4   31 E5  0  0   0.6  -5.0  67  838   0  1.0  96.6 77777 0999999999   3 0.010   0 18
61  1  1 11  650 1415  504 C4 1020 E4   39 E5  0  0   2.8  -6.1  52  838 320  5.7  96.6 77777 0999999999   3 0.010   0 18
61  1  1 12  732 1415  585 C4 1042 E4   43 E5  0  0   4.4  -8.9  38  837 320  7.2  96.6 77777 0999999999   3 0.010   0 18
61  1  1 13  744 1415  603 C4 1045 E4   44 E5  0  0   5.0 -13.3  25  837 340  8.2  96.6 77777 0999999999   3 0.010   0 18
61  1  1 14  683 1415  549 C4 1029 E4   41 E5  0  0   5.6 -13.9  23  837 340  5.2  96.6 77777 0999999999   3 0.010   0 18
61  1  1 15  554 1415  428 C4  998 E4   34 E5  0  0   5.6 -16.1  19  839 340  8.8  96.6 77777 0999999999   2 0.010   0 18
61  1  1 16  366 1415  252 C4  902 E4   25 E5  0  0   4.4 -16.7  20  839 340  7.2  96.6 77777 0999999999   2 0.010   0 18
61  1  1 17  133 1415   67 C4  636 E4   13 E5  0  0   2.8 -18.9  19  839 340  5.7  96.6 77777 0999999999   2 0.010   0 18
61  1  1 18   11    0    0 ?0    0 ?0    0 ?0  0  0   0.6 -18.9  22  840 340  5.2  96.6 77777 0999999999   2 0.010   0 18
61  1  1 19    0    0    0 ?0    0 ?0    0 ?0  0  0  -0.6 -18.3  25  840   0  5.2  96.6 77777 0999999999   2 0.010   0 18
61  1  1 20    0    0    0 ?0    0 ?0    0 ?0  0  0  -2.2 -17.2  31  841   0  2.6  96.6 77777 0999999999   2 0.010   0 18
61  1  1 21    0    0    0 ?0    0 ?0    0 ?0  1  0  -2.2 -15.0  37  841   0  5.2  96.6 77777 0999999999   2 0.010   0 18
61  1  1 22    0    0    0 ?0    0 ?0    0 ?0  3  1  -5.0 -15.0  46  842 340  1.5  96.6 77777 0999999999   2 0.010   0 18
61  1  1 23    0    0    0 ?0    0 ?0    0 ?0  4  2  -4.4 -14.4  46  842   0  0.0  96.6 77777 0999999999   3 0.010   0 18
61  1  1 24    0    0    0 ?0    0 ?0    0 ?0  4  2  -6.1 -15.0  50  842   0  0.0  96.6 77777 0999999999   3 0.010   0 18
```

Figure 3-1. Data for Albuquerque, New Mexico, in the NSRDB synoptic format



```
HLY00023050CLHTDM19610111010240000 99999?00100 07777A7 ... 1200 07777A7 ... 2300 07777A7
HLY00023050DPTPTC19610111010240000 99999?00100-00078A7 ... 1200-00089A7 ... 2300-00144A7
HLY00023050DRADWM19610111010240000 99999?00100 00000?0 ... 1200 01042E4 ... 2300 00000?0
HLY00023050ETRHWM19610111010240000 99999?00100 00000?0 ... 1200 00732?0 ... 2300 00000?0
HLY00023050ETRNWM19610111010240000 99999?00100 00000?0 ... 1200 01415?0 ... 2300 00000?0
HLY00023050GRADWM19610111010240000 99999?00100 00000?0 ... 1200 00585C4 ... 2300 00000?0
HLY00023050HZVSKM19610111010240000 99999?00100 00966A7 ... 1200 00966A7 ... 2300 00966A7
HLY00023050PH2OMM19610111010240000 99999?00100 00004F8 ... 1200 00003F8 ... 2300 00003F8
HLY00023050PRESMB19610111010240000 99999?00100 00835A7 ... 1200 00837A7 ... 2300 00842A7
HLY00023050PWX1NA19610111010240000 99999?00100 09999A7 ... 1200 09999A7 ... 2300 09999A7
HLY00023050PWX2NA19610111010240000 99999?00100 99999A7 ... 1200 99999A7 ... 2300 99999A7
HLY00023050RHUMP 19610111010240000 99999?00100 00081A7 ... 1200 00038A7 ... 2300 00046A7
HLY00023050SNOWCD19610111010240000 99999?00100 00018A7 ... 1200 00018A7 ... 2300 00018A7
HLY00023050SRADWM19610111010240000 99999?00100 00000?0 ... 1200 00043E5 ... 2300 00000?0
HLY00023050TMPDTC19610111010240000 99999?00100-00050A7 ... 1200 00044A7 ... 2300-00044A7
HLY00023050TSKCNA19610111010240000 99999?00100 00000A7 ... 1200 00000A7 ... 2300 00402A7
HLY00023050TURBNA19610111010240000 99999?00100 00010E7 ... 1200 00010E7 ... 2300 00010E7
HLY00023050WINDDM19610111010240000 99999?00100 11015A7 ... 1200 32072A7 ... 2300 00000A7
```

BA-G0955706

Figure 3-2. Data for Albuquerque, New Mexico in the TD-3282 Format.

```
 WBAN  CITY                  STATE  TZ   LAT     LONG     ELEV  PRES
 23050 ALBUQUERQUE            NM  -7  N35  3  W106 37  1619   838
 61-90
 MO AVGLO FL SDGLO AVDIR FL SDDIR AVDIF FL SDDIF AVETR AETRN  TOT  OPQ   H2O   TAU  MAX_T  MIN_T  AVG_T  AVGDT  RH  HTDD  CLDD AVWS
  1  3206 F4   249  5416 F4   899   980 F5   135  5187 14043  4.7  3.2  0.54  0.04   7.59  -4.82   0.96   3.60  56   539     0  3.6
  2  4164 F4   303  5897 F4   904  1276 F5   161  6568 15078  4.9  3.4  0.55  0.04  11.17  -2.14   4.18   6.73  50   400     0  3.9
  3  5389 F4   380  6323 F4   978  1707 F5   186  8396 16323  5.1  3.6  0.58  0.05  15.54   0.88   8.11  10.82  40   317     0  4.5
  4  6838 F4   287  7549 F4   728  1910 F5   196 10088 17530  4.4  3.1  0.68  0.06  20.78   5.05  13.05  15.48  33   161     3  4.9
  5  7703 F4   375  8141 F4   836  2051 F5   241 11162 18494  4.1  2.8  0.94  0.08  25.76  10.05  18.13  20.65  31    49    43  4.8
  6  8093 F4   330  8513 F4   782  2011 F5   279 11613 18958  3.4  2.5  1.35  0.09  31.43  15.44  23.64  25.62  30     2   162  4.5
  7  7541 F4   256  7284 F4   649  2211 F5   287 11375 18663  4.7  3.6  2.10  0.10  32.68  18.61  25.25  27.46  42     0   214  4.0
  8  6888 F4   293  6984 F4   683  2010 F5   233 10486 17758  4.5  3.5  2.12  0.09  30.87  17.54  23.76  25.90  47     0   168  3.8
  9  5865 F4   300  6765 F4   759  1653 F5   217  9014 16607  3.9  3.1  1.63  0.08  27.00  13.52  19.92  22.24  48    19    67  3.9
 10  4725 F4   319  6598 F4  1065  1226 F5   248  7231 15389  3.5  2.5  1.01  0.07  21.08   6.97  13.72  16.61  45   147     4  3.7
 11  3471 F4   249  5656 F4   902   996 F5   169  5581 14269  4.3  2.9  0.70  0.05  13.50   0.41   6.57   9.06  50   353     0  3.6
 12  2886 F4   233  5182 F4   945   874 F5   148  4764 13685  4.6  3.2  0.58  0.04   8.04  -4.09   1.54   4.22  57   521     0  3.6
 13  5569 F4   178  6694 F4   431  1577 F5   116  8463 16405  4.3  3.1  1.07  0.07  20.49   6.49  13.28  15.74  44  2508   661  4.1
 1961
  1  3417 C4   641  6407 E4  3033   836 E5   577  5187 14043  3.9  2.5  0.44  0.02   7.77  -5.45   0.45   3.10  53   554     0  2.6
  2  4461 C4   782  6813 E4  2792  1114 E5   619  6560 15073  4.2  3.0  0.54  0.03  11.37  -1.81   4.44   6.91  48   389     0  3.2
  3  5263 C4  1270  6049 E4  3382  1726 E5   808  8382 16313  5.6  4.3  0.63  0.04  14.83   1.88   8.14  10.33  42   316     0  4.3
  4  7160 C4  1612  8636 E4  3545  1553 E5   765 10077 17521  3.5  2.6  0.67  0.04  20.24   4.40  12.53  14.76  33   175     1  4.2
  5  7898 C4   771  8362 E4  2412  2084 E5   899 11156 18488  3.9  2.6  0.90  0.08  26.77  10.54  18.85  21.42  27    36    52  4.5
  6  8320 C4   662  8693 E4  1779  2015 E5   528 11613 18958  3.0  2.0  1.45  0.12  31.97  16.31  24.32  26.15  29     0   180  4.1
  7  7854 C4   699  7997 E4  1843  2083 E5   616 11380 18668  3.4  2.7  2.01  0.11  31.71  17.69  24.52  26.56  41     0   192  3.8
  8  6842 E4   953  6745 E4  2458  2154 E5   748 10495 17766  4.8  3.9  2.34  0.07  29.96  17.61  23.38  25.28  50     0   156  3.5
  9  6027 C4   861  7181 E4  2586  1639 E5   749  9027 16616  3.7  2.8  1.59  0.06  25.54  11.51  18.25  20.41  47    27    24  3.5
 10  5101 C4   904  7618 E4  2347  1065 E5   451  7244 15398  2.8  1.7  0.83  0.05  21.46   6.12  13.47  16.64  36   151     0  3.7
 11  3261 C4   780  4668 E4  2792  1216 E5   507  5592 14276  5.6  4.3  0.78  0.04   9.53  -0.26   4.30   5.96  58   421     0  3.5
 12  2904 C4   718  5297 E4  3075   871 E5   494  4766 13686  4.4  3.3  0.57  0.03   6.49  -4.00   0.77   3.02  59   544     0  3.4
 13  5714 C4  2066  7038 E4  2953  1532 E5   807  8465 16407  4.1  3.0  1.07  0.06  19.85   6.26  12.83  15.09  44  2613   605  3.7
 1962
  1  3145 C4   776  5180 E4  2990  1007 E5   489  5187 14043  5.2  3.9  0.52  0.03   5.69  -6.11  -0.72   1.79  60   591     0  3.3
  2  4197 C4   816  6286 E4  2754  1224 E5   602  6560 15073  4.1  3.2  0.64  0.03  12.64  -1.15   5.35   8.13  49   363     0  3.4
  3  5423 C4  1213  6501 E4  3328  1720 E5   797  8382 16313  4.8  3.6  0.42  0.05  12.72  -2.24   5.34   8.15  40   403     0  3.8
  .
  .
  .
  .
```

NOTES: 1) Bold face text is not part of the daily statistics file, but is included to identify header elements. The third record (line) in the file identifies the MOnth, quality FLag, and data elements (see definitions below).

AVGLO/DIR/DIF - Average daily total solar radiation for the GLObal horizontal, DIRect normal, and DIFfuse horizontal elements (Wh/m^2).
SDGLO/DIR/DIF - Standard deviation of daily total global, direct, and diffuse solar radiation (see note (2) below) (Wh/m^2.).
AVETR & AVTRN - Average daily total global horizontal (AVETR) and direct normal (AVTRN) extraterrestrial solar radiation (Wh/m^2).
TOT, OPQ, H2O, TAU - Average TOTal and OPaQue sky cover (tenths), precipitable water (cm), and aerosol optical depth (unitless).
MAX_T, MIN_T, AVG_T, AVGDT - Average maximum, minimum, 24-hour, and daylight temperatures (°C).
RH, HTDD, CLDD, AVWS - Average relative humidity (%), heating (HTDD) and cooling (CLDD) degree (°C) days, and wind speed (m/s).

2) The standard deviations of solar radiation elements (e.g., SDGLO) for individual years and for the period of record (61-90) are not the same. For individual years, the standard deviations provide a measure of daily variability. For the period of record, the standard deviations provide a measure of the interannual variability of monthly and annual averages.

HEADER FORMAT (1X, I5, 1X, A22, 1X, A2, I4, 2X, A1, I2, I3, 2X, A1, 2I3, 2I6)
YEAR(S) FORMAT (1X, A5)
DATAFORMAT (1X, I2, 3(I6, 1X, A1, I1, I6), 2I6, 2F5.1, 2F6.2, 4F7.2, I4, 2I6, F5.1)

Figure 3-3. Part of the Daily Statistics File for Albuquerque, New Mexico.

```
WBAN   CITY                    STATE  TZ     LAT      LONG  ELEV  PRES  YEAR(S)
 23050 ALBUQUERQUE                NM  -7  N35      W106 37  1619   838   1978
STATISTIC I.D.
GLOBAL MEANS
MO FL   01   02   03   04   05   06   07   08   09   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24
 1 E4    0    0    0    0    0    0    0   38  150  271  394  450  468  429  352  227   86   11    0    0    0    0    0    0
 2 A3    0    0    0    0    0    0    1   62  217  366  505  559  587  551  467  320  166   30    0    0    0    0    0    0
 3 A3    0    0    0    0    0    0   32  171  373  523  654  737  693  633  531  411  259   85    4    0    0    0    0    0
 4 A3    0    0    0    0    0   10  126  340  555  734  871  951  938  880  737  557  351  162   23    0    0    0    0    0
 5 A3    0    0    0    0    0   41  189  373  557  711  823  878  864  816  710  513  357  197   53    1    0    0    0    0
 6 A3    0    0    0    0    1   65  233  443  633  810  929  982  968  888  797  645  448  259   91    6    0    0    0    0
 7 A3    0    0    0    0    0   41  192  389  590  766  908  977 1009  946  803  547  360  219   69    4    0    0    0    0
 8 A3    0    0    0    0    0   13  135  336  549  697  862  906  898  887  706  505  327  158   36    0    0    0    0    0
 9 A3    0    0    0    0    0    2   73  248  434  609  734  803  818  732  620  449  264   95    5    0    0    0    0    0
10 A3    0    0    0    0    0    0   35  184  370  522  646  696  694  619  489  312  141   16    0    0    0    0    0    0
11 A3    0    0    0    0    0    0    5   81  208  298  415  458  430  402  292  167   41    1    0    0    0    0    0    0
12 A3    0    0    0    0    0    0    0   37  151  290  400  471  459  412  297  166   44    0    0    0    0    0    0    0
13 A3    0    0    0    0    0   14   86  226  400  551  679  740  736  683  567  402  237  103   24    1    0    0    0    0
GLOBAL STANDARD DEVIATIONS
 1 E4    0    0    0    0    0    0    0    8   45   93  135  130  139  124   99   66   32    7    0    0    0    0    0    0
 2 A3    0    0    0    0    0    0    2   33   88  136  181  194  204  176  146  113   62   17    0    0    0    0    0    0
 3 A3    0    0    0    0    0    0   21   76  105  161  195  199  241  241  223  160   87   34    3    0    0    0    0    0
 4 A3    0    0    0    0    0    7   40   70   99  132  109  112  124  118  166  131   97   43    9    0    0    0    0    0
 5 A3    0    0    0    0    0   21   79  147  205  255  285  305  296  275  242  227  161   78   24    1    0    0    0    0
 6 A3    0    0    0    0    1   15   48   62   99  114  140  160  173  198  189  153  105   68   31    3    0    0    0    0
 7 A3    0    0    0    0    0   12   42   72   96  103   77  118   75   86  146  215  185  110   36    3    0    0    0    0
 8 A3    0    0    0    0    0    7   31   58   42  110   68  133  194  110  188  185  142   83   23    1    0    0    0    0
 9 A3    0    0    0    0    0    2   27   66  121  167  181  185  189  192  167  142   97   46    5    0    0    0    0    0
10 A3    0    0    0    0    0    0   17   65  107  157  173  193  188  160  135  118   55   12    0    0    0    0    0    0
11 A3    0    0    0    0    0    0    4   43   93  150  174  186  188  161  134   85   23    1    0    0    0    0    0    0
12 A3    0    0    0    0    0    0    0   19   68  120  142  172  171  145  123   67   16    0    0    0    0    0    0    0
13 A3    0    0    0    0    0   23   89  158  202  241  256  268  275  259  246  212  167  104   35    2    0    0    0    0
GLOBAL DISTRIBUTIONS
 1 E4  188   74   74   94   85   76   82   76   35   74   62   50   21    9    0    0    0    0    0    0    0    0    0    0
 2 A3  152   84   62   71   65   56   84   40   56   31   50   40   71   65   25   43    6    0    0    0    0    0    0    0
 3 A3  150   75   73   35   35   45   70   50   43   60   28   55   28   58   25   30   55   45   40    0    0    0    0    0
 4 A3  145   24   52   60   33   17   31   40   52   10   31   40   60   31   17   43   88   31   55   83   55    2    0    0
 5 A3  111  118   40   36   67   53   11   11   29   62   24   13   22   73   31   13   29   65    9   71   62   47    0    0
 6 A3  134   84   42   17   46   44   42   10   33   52   38   17   17   52   44   10   56   38   31   84   65   46    0    0
 7 A3  146   65   41   41   45   22   26   26   45   19   39   19   43   26   39   43   22   52   58   80   92   13    0    0
 8 A3  145   48   57   52   34   18   29   54   20   36   32   66   11   25   59   50   34   52   63   88   25    0    0    0
 9 A3  135   94   52   39   32   69   42   20   25   39   62   32   34   39   49   44   62   64   64    2    0    0    0    0
10 A3  172   51   46   67   67    8   35   56   54   32   35   51   75   51   94   62   43    0    0    0    0    0    0    0
11 A3  204  136   83   50   91   77   47   32   74   44   38   59   41   24    0    0    0    0    0    0    0    0    0    0
12 A3  177  142   35   68   97   16   26  135   35   68  100  100    0    0    0    0    0    0    0    0    0    0    0    0
13 A3  152   81   54   50   56   41   42   43   41   43   43   43   35   39   34   29   35   32   29   39   29   11    0    0
```

Notes:

1) Boldface text is not part of the hourly statistic file, but is included to identify header and data information.

2) For the means and standard deviations, the numbers 1 to 24 represent the hours of the day. For the distributions, these numbers times 50 give the upper value of the bin range in Wh/m^2. The lower value of the range for each bin is 50 Wh/m^2 less.

3) Each hourly statistic file contains similar statistics for the direct normal and diffuse horizontal elements.

HEADER FORMAT (1X, I5, 1X, A22, 1X, A2, I4, 2X, A1, I2, I3, 2X, A1, 2I3, 2I6, I7)
STATISTIC I. D. FORMAT (A30)
DATA FORMAT (1X, I2, 1X, A1, I1, 24I5)

Figure 3-4. Part of the Hourly Statistics File for Albuquerque, New Mexico.

```
                          MONTHLY PERSISTENCE REPORT, WBAN # 23050, ALBUQUERQUE (NM),  MONTH  9, GLOBAL
   Number of runs of days solar energy EXCEEDED threshold                 Number of      of days solar energy LESS THAN threshold

 (Run length in DAYS)                                                    (Run length in DAYS)
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15+ Wh/m2      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15+
 -------------------------------------------------------------  -----   ------------------------------------------------------------
    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  10000      0   0   0   0   0   0   0   0   0   0   0   0   0   0  30
    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   9000      0   0   0   0   0   0   0   0   0   0   0   0   0   0  30
    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   8000      0   0   0   0   0   0   0   0   0   0   0   0   0   0  30
   29   9   4   0   2   0   0   1   0   0   0   0   0   0   0   7000      9   9   7   3   3   2   2   0   0   0   0   1   0   1  29
   56  38  22  21   8   7   4   3   3   0   0   3   0   0   2   6000     71  44  24   7   5   5   3   0   3   1   0   1   0   0   0
   14  17  14   9  11   7   6   9   2   3   3   2   4   5   9   5000     56  22  11   0   3   0   1   0   0   0   0   0   0   0   0
    4   4   6   7   3   2   7   3   2   3   4   1   4   1  23   4000     34  11   2   1   0   1   0   0   0   0   0   0   0   0   0
    3   0   1   5   1   1   3   3   1   1   2   0   1   0  29   3000     19   3   1   0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   1   0   0   0   1   1   0   0   0   0   0  30   2000      3   0   0   0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0   0   0  30   1000      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0   0   0  30    500      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0   0   0  30      0      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

                          MONTHLY PERSISTENCE REPORT, WBAN # 23050, ALBUQUERQUE (NM),  MONTH  9, DIRECT
   Number of runs of days solar energy EXCEEDED threshold                 Number of runs of days solar energy LESS THAN threshold

 (Run length in DAYS)                                                    (Run length in DAYS)
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15+ Wh/m2      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15+
 -------------------------------------------------------------  -----   ------------------------------------------------------------
   47  11   1   1   1   0   0   0   0   0   0   0   0   0   0  10000      9   5   7   8   8   5   5   3   1   4   1   4   0   5  19
   75  29  12   4   3   2   1   2   0   0   0   0   0   0   0   9000     35  19  22  15   9   4   8   5   5   3   5   2   0   2   6
   70  38  20  15   6   4   1   3   2   0   0   0   0   0   0   8000     56  30  29  12  12   6   4   3   3   2   1   1   0   1   3
   49  40  20  21  10   6   3   4   4   0   3   0   0   0   1   7000     63  38  23  13   9   3   2   1   2   1   0   0   2   0   0
   36  31  25  13  17  11   4   7   3   1   2   2   0   0   3   6000     66  38  19   7   4   0   2   0   2   1   0   1   0   0   0
   23  34  21   9  14  11   6   5   6   3   3   2   3   0   5   5000     72  32  13   3   3   2   1   0   0   0   0   0   0   0   0
   16  22  17  11  13   7   5   6   3   4   1   4   4   3   9   4000     66  26   8   0   2   1   1   0   0   0   0   0   0   0   0
   11   8  12   7   9   2   8   5   3   4   4   2   6   4  13   3000     50  16   5   3   0   1   0   0   0   0   0   0   0   0   0
    5   5   7   5   5   2   6   6   2   3   3   2   5   1  20   2000     35  12   3   1   0   1   0   0   0   0   0   0   0   0   0
    4   2   3   6   2   2   6   3   1   2   1   0   4   1  26   1000     27   8   1   0   1   0   0   0   0   0   0   0   0   0   0
    3   2   3   4   1   1   6   3   1   2   0   0   3   0  27    500     20   6   0   0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   1   0   0   0   0   0   0  30      0      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

                          MONTHLY PERSISTENCE REPORT, WBAN # 23050, ALBUQUERQUE (NM),  MONTH  9, DIFFUSE
   Number of runs of days solar energy EXCEEDED threshold                 Number of runs of days solar energy LESS THAN threshold

 (Run length in DAYS)                                                    (Run length in DAYS)
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15+ Wh/m2      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15+
 -------------------------------------------------------------  -----   ------------------------------------------------------------
    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   5000      0   0   0   0   0   0   0   0   0   0   0   0   0   0  30
    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   4500      0   0   0   0   0   0   0   0   0   0   0   0   0   0  30
    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   4000      0   0   0   0   0   0   0   0   0   0   0   0   0   0  30
    1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3500      1   0   0   0   0   0   0   0   0   0   0   0   0   0  30
   32   1   1   0   0   0   0   0   0   0   0   0   0   0   0   3000      3   4   7   2   4   2   0   1   1   2   3   1   3   2  27
   73  23   5   1   0   0   0   0   0   0   0   0   0   0   0   2500     21  23  14   9  10  10   1   4   6   2   2   1   6   3  12
   71  37  23   5   4   1   1   0   1   0   1   0   0   0   0   2000     41  33  15  18  16   5   8   6   2   4   1   3   0   1   3
   62  42  24  11  10   4   4   1   1   2   0   0   0   1   3   1500     56  41  25  17   9   5   2   4   1   0   1   0   0   0   1
   29  14  15  13  13   4   6   5   2   5   5   3   0   3   8   1000     69  20   8   6   4   1   1   2   0   0   0   0   0   0   0
    0   0   1   1   2   0   0   0   0   0   0   0   0   0  30    500      4   0   0   0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0   0   0  30    250      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
    0   0   0   0   0   0   0   0   0   0   0   0   0   0  30      0      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
```

HEADER FORMAT (A132) Note: For 8 lines before the data.

DATA FORMAT (1X, 15I4, I7, 2X, 15I4)

BA-G0955707

Figure 3-5. The Persistence Statistic File for Albuquerque, New Mexico for September. (The boxed data are discussed in Section 3.3.3.)

```
23050 ALBUQUERQUE              NM  -7  N35  3  W106 37  1619   838
GLOBAL HORIZONTAL
           ?    A    B    C    D    E    F    G    H        0    1    2    3    4    5    6    7    8    9
61-90      0  213   52  384    0  304   46    0    0        0    0    0   95  672  214   19    0    0    0
 1961      0    0    0  743    0  257    0    0    0        0    0    0    0  842  158    0    0    0    0
 1962      0    0    0  779    0  221    0    0    0        0    0    0    0  861  139    0    0    0    0
 1963      0    0    0  791    0  209    0    0    0        0    0    0    0  860  140    0    0    0    0
 1964      0    0    0  824    0  176    0    0    0        0    0    0    0  874  126    0    0    0    0
 1965      0    0    0  684    0  102  214    0    0        0    0    0    0  788  126   86    0    0    0
 1966      0    0    0  699    0   94  207    0    0        0    0    0    0  805  108   86    0    0    0
 1967      0    0    0  631    0  117  252    0    0        0    0    0    0  787  131   82    0    0    0
 1968      0    0    0  775    0   70  155    0    0        0    0    0    0  847   91   62    0    0    0
 1969      0    0    0  800    0   60  140    0    0        0    0    0    0  851   90   59    0    0    0
 1970      0    0    0  777    0   73  150    0    0        0    0    0    0  844   94   62    0    0    0
 1971      0    0    0  829    0   54  118    0    0        0    0    0    0  876   73   51    0    0    0
 1972      0    0    0  795    0   66  138    0    0        0    0    0    0  853   89   58    0    0    0
 1973      0    0    0  791    0  209    0    0    0        0    0    0    0  860  140    0    0    0    0
 1974      0    0    0  799    0  201    0    0    0        0    0    0    0  863  137    0    0    0    0
 1975      0    0    0  813    0  187    0    0    0        0    0    0    0  872  128    0    0    0    0
 1976      0    0    0    0    0 1000    0    0    0        0    0    0    0  530  470    0    0    0    0
 1977      0  832    0    0    0  168    0    0    0        0    0    0   82  801  116    0    0    0    0
 1978      0  918    0    0    0   82    0    0    0        0    0    0  641  313   46    0    0    0    0
 1979      0  965    0    0    1   34    0    0    0        0    0    0  634  340   26    0    0    0    0
 1980      0  931    0    0    1   68    0    0    0        0    0    0  554  383   63    0    0    0    0
 1981      0  580    0    0    0  420    0    0    0        0    0    0  382  298  320    0    0    0    0
 1982      0  563   42    0    0  395    0    0    0        0    0    0   70  599  330    1    0    0    0
 1983      0    0  871    0    0  129    0    0    0        0    0    0    0  618  375    7    0    0    0
 1984      0    0  492    0    0  508    0    0    0        0    0    0    0  481  516    3    0    0    0
 1985      0    0  150    0    0  850    0    0    0        0    0    0    0  424  558   18    0    0    0
 1986      0    0    0    0    0 1000    0    0    0        0    0    0    0  487  513    0    0    0    0
 1987      0    0    0    0    0  998    2    0    0        0    0    0    0  492  507    1    0    0    0
 1988      0  786    0    0    0  214    0    0    0        0    0    0    0  782  217    0    0    0    0
 1989      0   34    0    0    0  966    0    0    0        0    0    0   25  505  470    0    0    0    0
 1990      0  793    0    0    0  207    0    0    0        0    0    0  471  419  110    0    0    0    0
DIRECT NORMAL
61-90      0  233    0    0   12  577  178    0    0        0    0   61   86  773   26   54    0    0    0
 1961      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1962      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1963      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1964      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1965      0    0    0    0    0  331  669    0    0        0    0    0    0  775    0  225    0    0    0
 1966      0    0    0    0    0  331  669    0    0        0    0    0    0  782    0  218    0    0    0
 1967      0    0    0    0    0  331  669    0    0        0    0    0    0  800    0  200    0    0    0
 1968      0    0    0    0    0  330  670    0    0        0    0    0    0  808    0  192    0    0    0
 1969      0    0    0    0    0  331  669    0    0        0    0    0    0  798    0  202    0    0    0
 1970      0    0    0    0    0  331  669    0    0        0    0    0    0  799    0  201    0    0    0
 1971      0    0    0    0    0  331  669    0    0        0    0    0    0  826    0  174    0    0    0
 1972      0    0    0    0    0  332  668    0    0        0    0    0    0  800    0  200    0    0    0
 1973      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1974      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1975      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1976      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1977      0    0    0    0  245  755    0    0    0        0    0    0    0  755  232   13    0    0    0
 1978      0  864    0    0   49   87    0    0    0        0    0  458  211  280   51    0    0    0    0
 1979      0  904    0    0   53   43    0    0    0        0    0  476  224  244   55    0    0    0    0
 1980      0  909    0    0   22   70    0    0    0        0    0  475  195  306   23    1    0    0    0
 1981      0  577    0    0    4  420    0    0    0        0    0  351   55  503   91    0    0    0    0
 1982      0  605    0    0    0  395    0    0    0        0    0   64  198  679   58    0    0    0    0
 1983      0  871    0    0    0  129    0    0    0        0    0    0  492  460   48    0    0    0    0
 1984      0  489    0    0    0  511    0    0    0        0    0    0  229  719   52    0    0    0    0
 1985      0  151    0    0    0  849    0    0    0        0    0    0    0  849  146    4    0    0    0
 1986      0    0    0    0    0 1000    0    0    0        0    0    0    0 1000    0    0    0    0    0
 1987      0    0    0    0    0  998    2    0    0        0    0    0    0  999    0    1    0    0    0
 1988      0  786    0    0    0  214    0    0    0        0    0    0  332  638   29    0    0    0    0
 1989      0   34    0    0    0  966    0    0    0        0    0    0   25  975    0    0    0    0    0
 1990      0  791    0    0    0  209    0    0    0        0    0    0  604  390    6    0    0    0    0
DIFFUSE HORIZONTAL
61-90      0  108    0    0  137  577  178    0    0        0    0    0    0  129  801   69    1    0    0
 1961      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1962      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1963      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1964      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1965      0    0    0    0    0  331  669    0    0        0    0    0    0    0  775  225    0    0    0
 1966      0    0    0    0    0  331  669    0    0        0    0    0    0    0  782  218    0    0    0
 1967      0    0    0    0    0  331  669    0    0        0    0    0    0    0  800  200    0    0    0
 1968      0    0    0    0    0  330  670    0    0        0    0    0    0    0  808  192    0    0    0
 1969      0    0    0    0    0  331  669    0    0        0    0    0    0    0  798  202    0    0    0
 1970      0    0    0    0    0  331  669    0    0        0    0    0    0    0  799  201    0    0    0
 1971      0    0    0    0    0  331  669    0    0        0    0    0    0    0  826  174    0    0    0
 1972      0    0    0    0    0  332  668    0    0        0    0    0    0    0  800  200    0    0    0
 1973      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1974      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1975      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1976      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1977      0  245    0    0    0  755    0    0    0        0    0    0    0  186  814    0    0    0    0
 1978      0  824    0    0   89   87    0    0    0        0    0    0    0  709  290    1    0    0    0
 1979      0  767    0    0  190   43    0    0    0        0    0    0    0  742  256    1    0    0    0
 1980      0  719    0    0  211   70    0    0    0        0    0    0    0  680  320    1    0    0    0
 1981      0  560    0    0   20  420    0    0    0        0    0    0    0  408  576   16    0    0    0
 1982      0  124    0    0  481  395    0    0    0        0    0    0    0  198  770   32    1    0    0
 1983      0    0    0    0  871  129    0    0    0        0    0    0    0   60  863   71    6    0    0
 1984      0    0    0    0  488  512    0    0    0        0    0    0    0   54  804  139    3    0    0
 1985      0    0    0    0  150  850    0    0    0        0    0    0    0    0  850  139   10    0    0
 1986      0    0    0    0    0 1000    0    0    0        0    0    0    0    0 1000    0    0    0    0
 1987      0    0    0    0    0  998    2    0    0        0    0    0    0    0  999    1    0    0    0
 1988      0    0    0    0  786  214    0    0    0        0    0    0    0  279  678   43    0    0    0
 1989      0    0    0    0   34  966    0    0    0        0    0    0    0   25  975    0    0    0    0
 1990      0    0    0    0  791  209    0    0    0        0    0    0    0  544  450    6    0    0    0
```

BA-G0955708

Note: Boldface text is not part of the quality statistic file, but is included to identify the source and uncertainty flags to which each column applies. These flags are defined in Tables 3-6 and 3-7.

HEADER FORMAT (1X, I5, 1X, A22, 1X, A2, I4, 2X, A1, I2, I3, 2X, A1, 2I3, 2I6)
ELEMENT I. D. FORMAT (A30)
DATA FORMAT (1X, 10I5, 5X, 10I5)

Figure 3-6. The Quality Statistics File for Albuquerque, New Mexico.

PART 2: How the Data Base Was Produced

Familiarity with the history of solar radiation measurements in the United States and understanding the source data and the processes used to produce the NSRDB are not necessary for using the hourly data and statistics from the data base. Nevertheless, this information can lead to enhanced use of the data and will reduce the likelihood of misusing the data. You are encouraged, therefore, to become familiar with the subject matter of Part 2 and to refer to it as appropriate for your applications.

4.0 Brief History of Solar Radiation Measurements in the United States

4.1 NOAA'S Solar Radiation Network

From 1951 through 1975 there were about 60 stations in the National Weather Service (NWS) SOLRAD network.[3] Each of the stations measured global horizontal solar radiation. Some of these stations made continuous recordings on strip charts; other stations only recorded the daily total energy (insolation) received. Much of these data were digitized at the station, using instructions that changed over the years, and were forwarded to regional centers (later centralized at the National Climatic Data Center [NCDC]). There they were subjected to varying degrees of quality control. These historical solar radiation data contain errors resulting from a host of calibration and instrument problems. When these data were evaluated, only 26 stations, identified with a black dot on Figure 4-1, were deemed suitable for inclusion in a national data base.

During 1976, the network was essentially shut down while new equipment was purchased and installed. From 1977 through 1980, the NWS collected data at the 39 sites identified with a triangle on Figure 4-1. Almost all of these stations recorded both global horizontal and direct normal radiation, and nine of the stations also recorded diffuse horizontal radiation. None of the stations collected data for the entire 48 months, and data for some elements at some stations were collected for less than a year.

During the upgrade of the equipment at the NWS stations, the National Oceanic and Atmospheric Administration (NOAA) established a solar radiation facility at Boulder, Colorado, where all of the pyranometers and pyrheliometers were periodically recalibrated. During the four years from 1977 through 1980, the operation of the network was jointly funded by the Department of Energy (DOE) and NOAA. The quantity and quality of the data collected during these four years was impacted favorably by adequate funding, improved instrumentation, and improved instrument calibrations.

Beginning in 1981, funding was inadequate to fully support the operation of the network. From 1981 through October of 1985 the network gradually decayed, and none of the data were quality controlled and processed for archival and distribution. The data that had been recorded at the stations on cassette tapes were transferred to nine-track magnetic tapes, and copies were shipped to the Solar Energy Research Institute (SERI; now known as the National Renewable Energy Laboratory or NREL). During these years, neither NCDC nor SERI had the resources to process these data. By October 1985, equipment failures had

---

[3] Although the NWS network has carried different names during the past 40 years, for the sake of clarity and consistency we will refer to it as the National Weather Service Solar Radiation (SOLRAD) Network or NWS-SOLRAD Network, for all time periods.

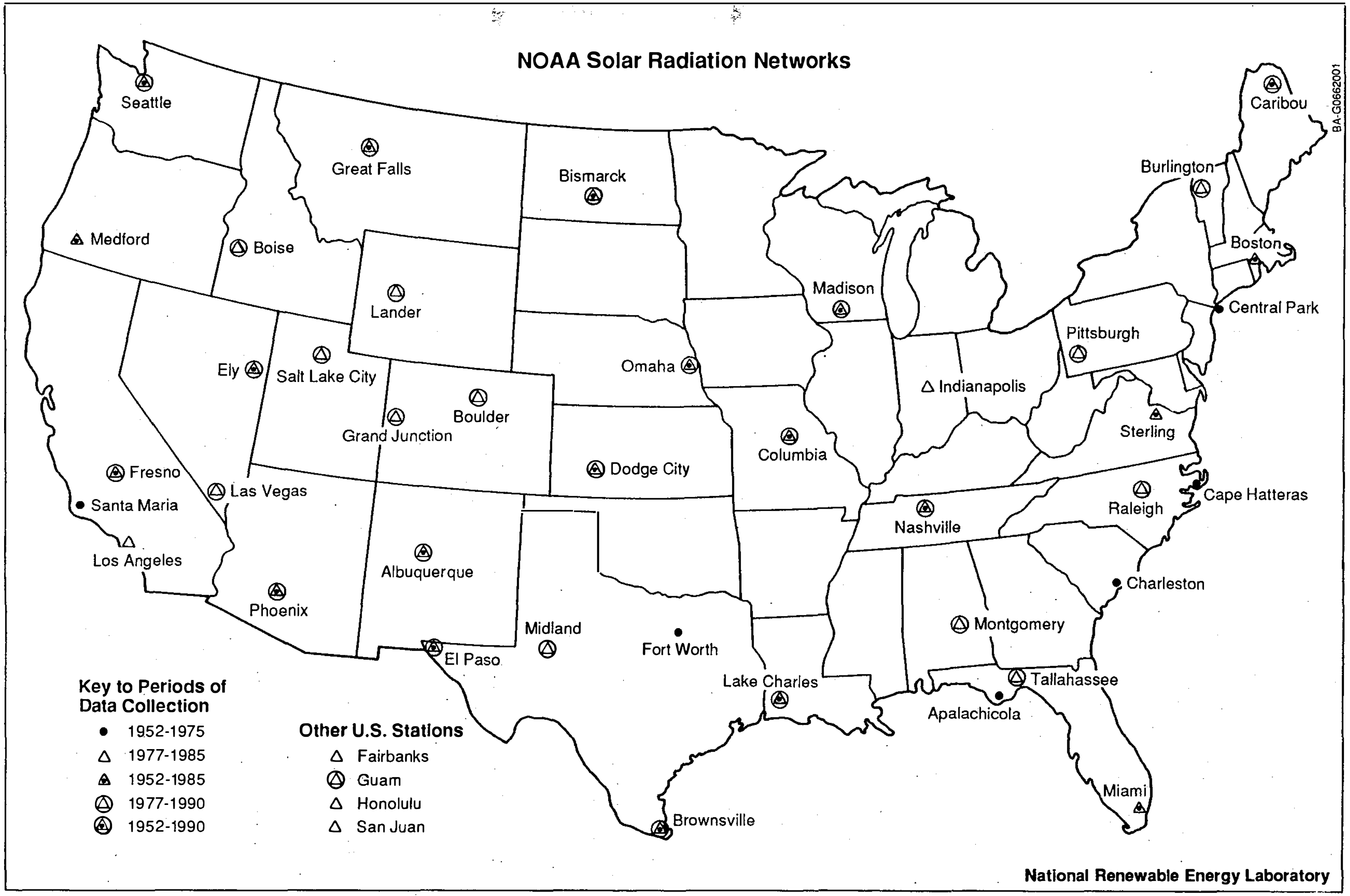


Figure 4-1. Station locations and periods of data collection for the NWS-SOLRAD Network

reduced the number of stations to fewer than 10, and NOAA made the decision to close the network to permit another upgrade of the equipment.

It should also be noted that from the spring of 1982 through 1985 no diffuse horizontal data were collected. The diffuse instruments, at the nine stations where they had been in use, were replaced with the Eppley Model 50 pyranometers used prior to 1976. This provided important comparative data, which clearly established the need for additional work to upgrade the pre-1976 global horizontal data. More information on these comparisons is given in Volume 2 - Final Technical Report of the NSRDB documentation.

Essentially no solar radiation data were collected by the National Weather Service from October 1985 through December 1987. During this period, an improved solar tracker was developed, and improved data recording equipment was installed at each station. Beginning in January 1988, the network resumed the collection of global horizontal and direct normal data at most of the 29 sites selected for the upgraded network. Because of a shortage of operational funds, two of the proposed stations for this reduced network, Sterling, Virginia, and Los Angeles, California, never achieved operational status, and some of the operating stations collected less than 50% of all possible hours of data.

As shown in Figure 4-1, 44 stations have participated in the NWS-SOLRAD Network from 1951 through 1990. However, only 16 of these stations have been active during the entire time that the network was in an operational status. Those 16 stations are identified by the circle enclosing the triangle that encloses the black dot. It is worth noting that during the entire period from 1977 through 1990, the solar radiation facility at Boulder, Colorado, continued to maintain calibrations of the pyranometers and pyrheliometers that were in use. Therefore, although the quantity of data varied greatly during these 14 years, the quality of the data that were collected remained relatively good.

Because of the increased interest in solar energy during the mid 1970s, a number of other organizations began collecting solar radiation data. These include data collected by universities and data collected by utilities. Some of these data have been included in the NSRDB.

4.2 The SOLMET/ERSATZ Data Base

The SOLMET/ERSATZ data base (SOLMET Vol. 1 1978 and Vol. 2 1979) for the United States was produced by NOAA and DOE during the latter half of the 1970s. SOLMET refers to the combination of <u>sol</u>ar radiation and <u>met</u>eorological data. This term is also used to identify the 26 stations that collected global horizontal data from 1951 through 1975. The term ERSATZ refers to the synthetic or modeled solar radiation data that were generated for 222 NWS stations not part of the SOLRAD network. The period of record for most stations in the SOLMET/ERSATZ data base is 23-1/2 years (July 1, 1952 through December 31, 1975).

The uncertainties surrounding the measurement of global horizontal radiation prior to 1976 required a major effort to upgrade the data. In addition to the problems already mentioned, the response characteristics of the Eppley Model 50 pyranometer, used for most stations and most years from 1951 through 1975, had to be addressed. These pyranometers were used without a temperature correction circuit, although their sensitivity was known to change on the average by 0.08% per degree Fahrenheit. Therefore, the sensitivity of these pyranometers could change by as much as 10% from summer to winter at mid-continent northern locations. A universal temperature correction was applied to these data, although it was known that the temperature sensitivity could vary considerably from instrument to instrument.

Furthermore, the response of these pyranometers was known to change as a function of exposure to solar radiation, by as much as 10% to 15% over a period of four to six years (Flowers and Starke 1966). In addition, the response of these instruments was sensitive to changes in the angle and direction of incidence of the solar radiation.

Nontemperature-related errors in the pre-1976 global horizontal data used in the SOLMET/ERSATZ data base were corrected using a technique known as the SYI/CSN procedure. Data for clear solar noons (CSN) were compared with standard year irradiance (SYI) values obtained from model calculations (SOLMET, Vol. 2 1979). In effect, a model was used to calculate global horizontal radiation values under clear sky conditions at solar noon for each of the 26 locations with measured data. These calculations made use of long-term monthly mean precipitable water and turbidity data. Every time a cloudless sky was observed at solar noon, the measured solar radiation was compared with the modeled standard year radiation value. The difference between the measured and modeled values as used to establish a synthetic calibration (correction) factor for the pyranometers. Linear interpolations were used to obtain correction factors for times between the occurrence of CSNs.

The corrected global horizontal data were used to develop clear sky and cloud regression equations for estimating global horizontal data from sunshine, opaque cloud, sky condition, and precipitation data. The coefficients for the regression equations were unique to each of the 26 SOLMET sites. These regression equations were used to fill-in missing data for the 26 SOLMET sites; they were also used to create global horizontal data for 222 ERSATZ sites. The climate at Central Park in New York City was considered to be unique to that location and was not used to estimate global horizontal radiation at any other location. Each of the other 25 SOLMET sites was used to create global horizontal data for a group of ERSATZ stations having similar climate conditions.

Unfortunately, the climates of some of the ERSATZ stations could not be well matched with any of the 25 SOLMET sites. For example, the regression equations for Dodge City, Kansas, were used to estimate solar radiation for Denver and Colorado Springs, Colorado. Dodge City is in the middle of the Great Plains whereas Denver and Colorado Springs are at the foot of the Rocky Mountains. Other questionable matches include Great Falls, Montana, at a latitude of 47.5°, as the reference station for Bettles, Alaska, at 67° north latitude. Also, Seattle is the reference station for both Barrow, Alaska, on the Arctic Ocean, and Redmond, Oregon, at an inland location at an elevation of 940 meters. Nevertheless, there were many good matches between the SOLMET reference stations and the ERSATZ stations.

Direct normal data for all stations were estimated using regression equations. Global horizontal and direct normal data for five stations (Albuquerque, New Mexico; Fort Hood, Texas; Livermore, California; Maynard, Massachusetts; and Raleigh, North Carolina) were used to develop regression equations to calculate direct normal values from global horizontal values (Randall and Whitson 1977). These few direct normal data were collected from 1974 to 1975, with the exception of Albuquerque (1961 to 1964). The regression equations were used to calculate all of the direct normal data for the 26 SOLMET stations for the entire period of record (16-1/2 to 24 years). Similar regression equations were used to calculate direct normal data for Typical Meteorological Year (TMY) data sets for the 222 ERSATZ stations (NCDC 1981).

This brief historical summary of solar radiation measurements and data base developments for the United States reveals shortcomings and limitations that must be considered when using data from the NSRDB. Although the NSRDB has benefitted from improved data and improved models, the uncertainties attached to much of the data are still unacceptably high. The user may want to use the source and uncertainty flags to screen data to be used for critical computations and decisions.

5.0 Sources of Solar Radiation and Meteorological Data

This section describes the sources of solar radiation and meteorological data that were used to produce the NSRDB. It also describes the methods used to derive some of the data that were used to estimate solar radiation at times and locations where it had not been measured.

5.1 Data Acquisition

NCDC provided all of the meteorological data for the entire period of record. NCDC also provided solar radiation data that had been collected by NWS. Solar radiation data were also acquired from WEST Associates (a consortium of Southwest utilities), the University of Oregon, three DOE SEMRTS (Solar Energy & Meteorological Research & Training Sites) and the NREL Historically Black College and University (HBCU) network in the Southeast. Although more solar radiation data are known to exist, and the period of solar data collection by the NWS extends back to 1950, budgets and time did not allow for its use in Version 1.0 of the NSRDB. Periodically, solar radiation data from other sources may be acquired and added to the data base, creating updated versions.

5.1.1 Meteorological Data - TD-3280

Most of the meteorological data required for the data base were available from the TD-3280 tape deck files at NCDC. TD-3280 files contain data from surface airways hourly observations. Copies of NCDC archive tapes were sent to NREL, where the variables of interest were extracted. The units were changed to Standard International units, and gaps in the data record were filled using methods noted in Section 5.2.1.

5.1.2 Precipitable Water

Development of the NSRDB benefitted from a recalculation of precipitable water as part of a DOE-funded climate-change project at Columbia University. The calculations were performed at NCDC, under a subcontract from Columbia University, for the period from 1948 to 1988. These data were made available to NREL, through NCDC, for more than 70 stations in the United States and Canada. Calculations for 1989 and 1990 and for stations not included in the Columbia University project were done by NCDC under a subcontract from NREL.

The data, as received from NCDC, provided precipitable water within five atmospheric pressure bands (1013-1000 mb, 1000-850 mb, 850-700 mb, 700-500 mb, and 500-300 mb). The values in the five layers were summed to obtain total precipitable water from the surface to 300 mb. The data indicate that no more than 1 mm of precipitable water is likely to exist above the 300-mb level.

Autocorrelation of the total precipitable water data yielded values between 0.9 and 0.6 for lags of 12 and 24 hours, respectively. Based on this, linear interpolation between soundings was used to obtain hourly values of precipitable water. These hourly values were input to the model used to estimate solar radiation.

5.1.3 Snow Depth - TD-3210

Snow depth data were used for estimating ground albedo. The high surface albedos resulting from snow cover increase diffuse radiation from the clouds and atmosphere. Under partly cloudy skies this can greatly increase diffuse radiation over the levels that exist when the ground is bare. Snow depth data were extracted by NREL from copies of TD-3210 archive tapes supplied by NCDC.

5.1.4 Ozone

Ozone data are not generally available for most locations for the entire period from 1961 to 1990. However, ozone has a relatively small effect on the transmittance of solar radiation between 0.3 µm and 3.0 µm. Thus, monthly mean values of ozone for geographic regions defined by state boundaries and latitude (Alaska, California, and Texas) were used as input to the solar radiation model described in Section 6.0. The monthly mean data were obtained from surface and satellite data (Morris and Barras 1977 and Schneider et al. 1991). These values were assumed to be the same for each year, and were incorporated into the model as a look-up table.

5.2 Derived Input Meteorological Data

In order to produce serially complete hourly values of solar radiation data, some meteorological data required as input to the solar radiation model had to be derived or created. Data were found to be missing for periods ranging from an hour to a year. The causes for missing data are many and include a NOAA cost-saving move in effect from 1965 to 1981, which called for digitizing only every third hourly observation. The NREL station selection criteria eliminated most stations with TD-3280 data gaps longer than one month, but some exceptions were found.

In addition to gaps in the data record, there were data elements that were not available at any time for some stations. For one element, aerosol optical depth, the available data were few in number and of uncertain quality. The manner in which each of these situations were handled is described in this section.

5.2.1 Filling Gaps in the Data Record

Short gaps in the data record, for those meteorological elements needed to perform model estimates of solar radiation, were filled by linear interpolation between data points on each side of the gap. Interpolated values were rounded to exhibit the same number of significant figures reported for the measured/observed data.

The definition of a short gap was a function of the known rate of change of the element. Sky cover, for example, was linearly interpolated over gaps as long as five hours. Based on an autocorrelation analysis that is described in Volume 2 of the NSRDB documentation, total precipitable water was linearly interpolated over gaps as long as 60 hours (five missed soundings). Interpolation between individual soundings was used to obtain hourly precipitable water data.

For longer gaps in radiosonde data, calculations of precipitable water were made using surface vapor pressure derived from surface temperature, relative humidity, and atmospheric pressure. When the surface data were also missing, *long gap* methods were applied to obtain the required data.

Long gaps in the TD-3280 meteorological data (sky cover, temperature, and relative humidity) were subdivided into two categories: 6 to 47-hour gaps and 48-hour to one-year gaps. For gaps 6 to 47 hours in length, data from adjacent time periods, for identical periods (e.g., beginning at 0600 and ending at 2300) were selected to fill the gap. These segments of data were adjusted to match the end-point values of the gap.

For gaps of 48 hours to one year, data from other years for the same time periods were selected to fill the gap. The selection was based on finding a year for which the data before and after the period of the gap had the best match with data before and after the actual gap. Best match was determined by characterizing three time slices for several days adjacent to the actual gap and comparing them to a corresponding period of time in candidate years. The larger the gap, the greater the number of days included in the characterization, up to four weeks.

No effort was made to fill gaps in the snow depth or present weather data. These discontinuous weather events did not lend themselves to any kind of interpolation or substitution methods. When missing, snow depth was set to zero.

5.2.2 Deriving Precipitable Water Data

There were times and many locations for which no precipitable water data were available from radiosonde soundings. From the work of Garrison and Adler (1990) and others, it was known that long-term monthly means of surface vapor pressure are well correlated with monthly means of total precipitable water.

Research conducted under this project showed similar correlations between hourly surface vapor pressure measurements and precipitable water calculated from individual radiosonde soundings. Therefore, surface temperature, relative humidity, and pressure data were used to derive hourly values of precipitable water for times and locations for which radiosonde data were not available.

5.2.3 Deriving Broadband Aerosol Optical Depth

Aerosol optical depth is, and will probably continue to be, the most difficult input parameter to obtain for models that estimate solar radiation at the earth's surface. Although aerosol optical depth measurements have been made at selected wavelengths using sunphotometers, these data are considered to have large uncertainties that become larger when extrapolated to broadband values for the entire solar spectrum (Hallaron 1982; Cachorro, de Frutos, and Casanova 1987; and Frohlich 1980). Furthermore, such data are only available for a limited number of locations for limited periods of time.

Given this situation, a decision was made to link broadband aerosol optical depth to the METSTAT model used to estimate solar radiation (METSTAT is described in Section 6.0). METSTAT algorithms were used to calculate direct normal transmittances for ozone absorption (T_O), Rayleigh scattering (T_R), absorption by uniformly mixed gases (T_{UM}), and water vapor absorption (T_W). These were combined to obtain a value for molecular transmittance, T_M,

$$T_M = T_O \, T_R \, T_{UM} \, T_W \tag{5-1}$$

Aerosol transmittance was then calculated as

$$T_A = I_N / I_O \, T_M \tag{5-2}$$

where

$_N$ = the measured direct normal radiation

I_O = the extraterrestrial direct normal radiation.

Finally, Beer's law[4] was used to compute broadband aerosol optical depth, τ_A,

$$\tau_A = - \ln T_A / m \tag{5-3}$$

where m is relative air mass.

This method produced broadband aerosol optical depths for locations and times for which measured direct normal data were already available. The calculated aerosol optical depths were then used to derive seasonal functions for estimating aerosol optical depths for any day of the year. A sine function was found to provide the best fit to the calculated values, as illustrated in Figure 5-1.

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[4] Beer's law in its simplest form expresses the transmittance (T) of solar radiation passing through a medium as $T = \exp(-\tau M)$, where τ is the optical depth of the medium, and m is the optical path length through the medium. The law applies rigorously only for monochromatic radiation.

Coefficients for the sine functions were then mapped to establish climatic/geographic relationships. These relationships were used to define seasonal functions for all Primary and Secondary stations. Volume 2 contains more information on this derivation of aerosol optical depths, including the national maps of the coefficients for the seasonal functions.

As shown in Figure 5-2, the calculated aerosol optical depths clearly revealed the atmospheric loading that resulted from the volcanic eruption of El Chichon between February 28 and March 4, 1982. Results from Lidar measurements of the effects of other volcanic eruptions (Mendonca, Hanson, and DeLuisi 1978) were used to determine the effects of other volcanic eruptions from 1961 through 1990. Although the effects of Mt. St. Helens were undoubtedly very large at locations in the path of its plume, they were short lived. No clear signature of Mt. St. Helens could be derived from the available direct normal data so the effects of this eruption could not be included.

The effects of volcanic eruptions were used to form a look-up table of daily optical depth increases. The combination of values derived from seasonal functions and values from the volcanic look-up table were used to estimate aerosol optical depth for each day from 1961 through 1990 for each of the stations. These values were input to the model used to estimate solar radiation when measured data were not available.

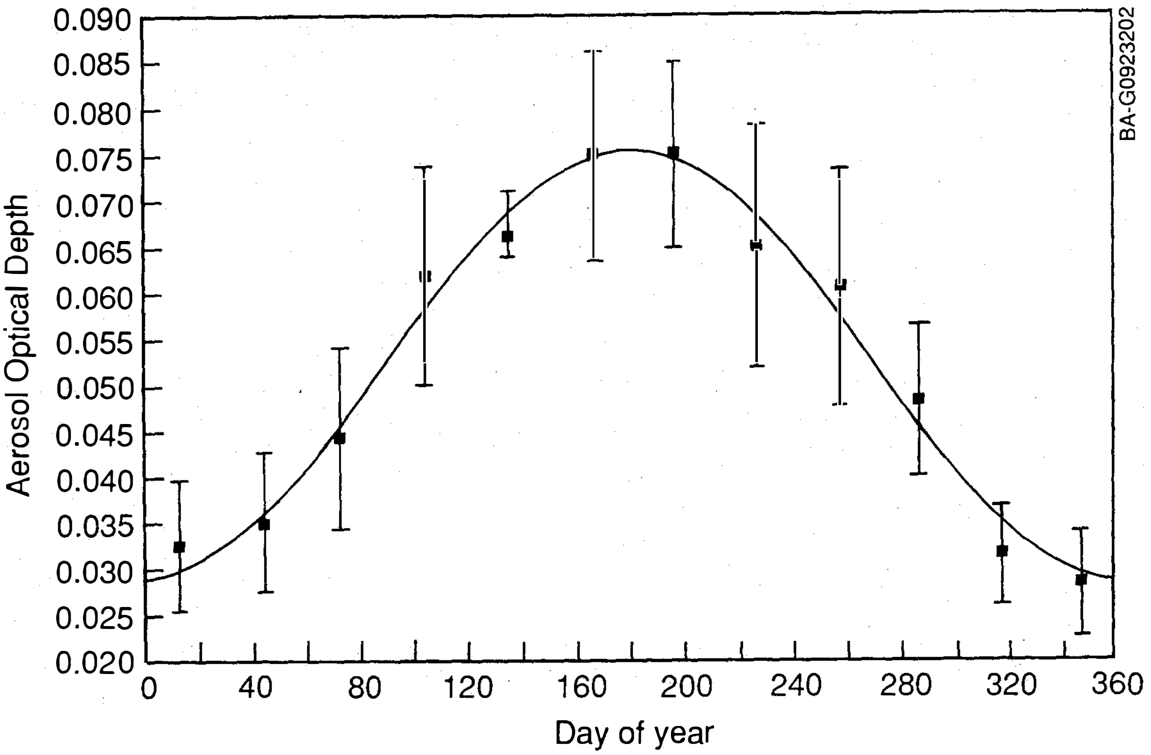

Figure 5-1. Monthly means and standard deviations of broadband aerosol optical depth for all years vs. day of the year for Albuquerque. A sine function is fitted to the data.

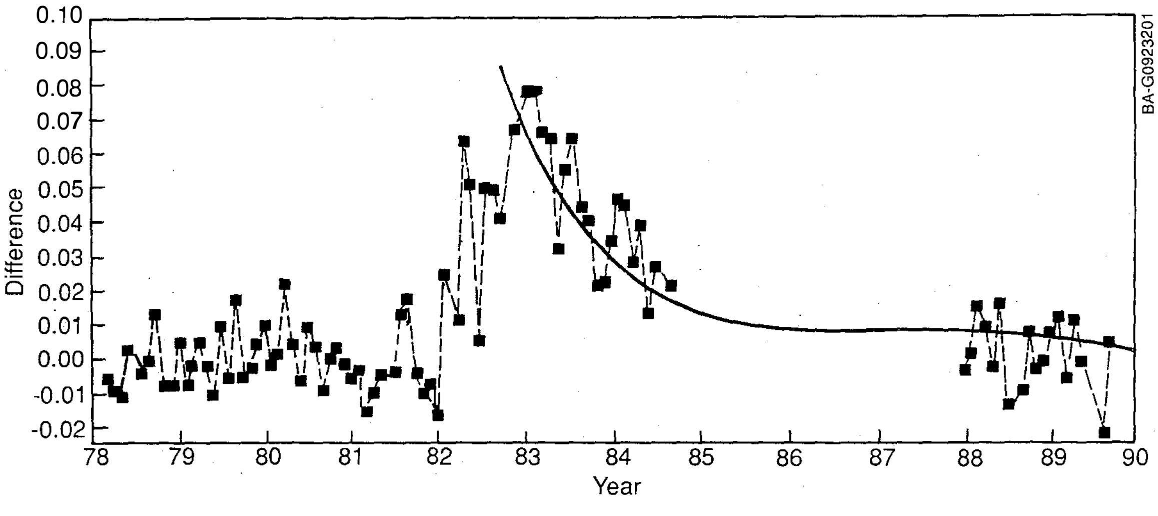

Figure 5-2. Monthly mean differences between calculated aerosol optical depth for individual days and daily values derived from the seasonal sine function for Albuquerque. The solid curve was obtained by smoothing Lidar measurements at Mauna Loa, Hawaii, and SAGE II satellite measurements and represents stratospheric aerosol optical depth.

6.0 Model Estimates of Solar Radiation

Under partly cloudy skies, because of the random and unknown *location* of the clouds, no model can accurately estimate the solar radiation incident on the earth's surface at any given time and location. Hence, the model used to estimate solar radiation when measured data were not available was designed specifically to reproduce the statistical and stochastic characteristics of multi year solar radiation data sets. This resulted in the sacrifice of accuracy for specific hours. Modeled values for individual hours (under partly cloudy skies), therefore, may differ greatly from measured values, had they been made.

It was anticipated that a multi year data base will most often be used to create design- and typical-year subsets; to establish normals, means, and extremes; and to select or evaluate sites for large solar energy systems. Given these uses, it is important that simulated data sets accurately represent the following statistical and stochastic characteristics of measured data.

Statistical

- Monthly moments (mean, variance, skewness, kurtosis)
- Monthly cumulative frequency distributions (cfds)

Stochastic

- Diurnal and seasonal patterns
- Hourly and daily autocorrelations
- Cross-correlations between elements (global horizontal, diffuse horizontal, direct normal)
- Persistence

A block diagram of the meteorological-statistical (METSTAT) solar radiation model developed for the NSRDB is shown in Figure 6-1. Several features of the model were critical to meeting data base objectives. Hourly calculations using hourly total and opaque cloud cover, hourly precipitable water vapor, daily aerosol optical depth, and daily albedo input data automatically produced representative diurnal and seasonal patterns, daily autocorrelations, and persistence. Placing the statistical algorithms between the input data and the deterministic algorithms led to proper cross-correlations between the direct normal, diffuse horizontal, and global horizontal components.

The deterministic algorithms were designed to meet the objective of creating data sets with accurate monthly means. The statistical algorithms randomly varied input parameters (cloud cover and aerosol optical depth) such that monthly data sets exhibit representative statistical characteristics. Daily rather than hourly variations of aerosol optical depth were applied to retain the smooth diurnal patterns that are observed under cloudless skies.

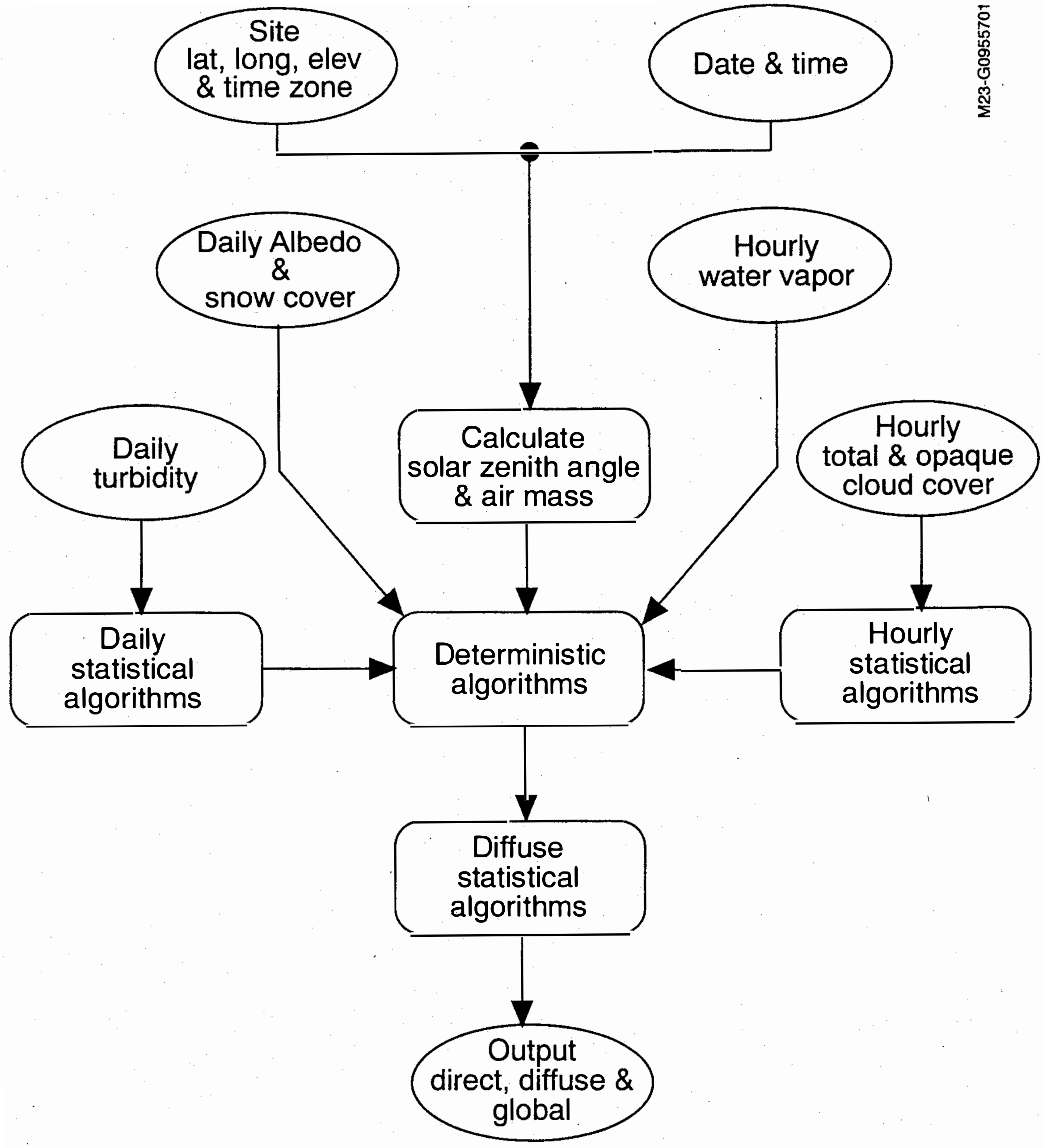

Figure 6-1. **Block diagram of the meteorological-statistical (METSTAT) model developed for estimating solar radiation from meteorological parameters**

Volume 2 of the data base documentation contains a full description of the development of the model. The mathematical details of the algorithms will also be found there, along with detailed evaluations of the model performance.

6.1 Direct Normal Algorithms

6.1.1 Cloudless Sky Transmittance

The cloudless sky direct normal transmittance algorithms are essentially those given by Bird and Hulstrom (1981) and Iqbal (1983) (Parameterization Model C). The only exceptions are the algorithm for water vapor absorption and the algorithm for the combined effect of aerosol absorption and scattering, which were somewhat modified. All of these algorithms are broadband (solar spectrum) parameterizations and include:

- Transmittance of ozone absorption (T_O)
- Transmittance of Rayleigh scattering (T_R)
- Transmittance of uniformly mixed gases, CO_2 and O_2 (T_{UM})
- Transmittance of water vapor absorption (T_W)
- Transmittance of aerosol absorption and scattering (T_A)
- Transmittance of aerosol absorption (T_{AA})
- Transmittance of aerosol scattering (T_{AS}).

6.1.2 Cloud Transmittance

The parametric cloud transmittance algorithms were developed using subsets of data assembled from NWS-SOLRAD network stations for the years from 1977 through 1980. The variables for data in the subsets were fixed within narrow ranges and came from across the United States for all months. This reduced the probability of developing algorithms that would exhibit regional or seasonal biases. The cloud effect algorithms included:

- Opaque sky cover transmittance (T_{OPQ})
- Translucent (total minus opaque) sky cover transmittance (T_{TRN}).

The total direct normal transmittance (T_N) is then given by

$$T_N = T_O\ T_R\ T_{UM}\ T_W\ T_A\ T_{OPQ}\ T_{TRN}. \qquad (6\text{-}1)$$

6.2 Diffuse Horizontal Algorithms

6.2.1 Atmospheric Scattering

The deterministic algorithms that estimate the diffusion of radiation by the atmosphere are:

- Rayleigh diffusion (KS_R)
- Aerosol diffusion (KS_A).

6.2.2 Scattering by Clouds

The deterministic algorithms that estimate the scattering of solar radiation by clouds are:

- Opaque cloud scattering (KS_{OPQ})
- Translucent (total minus opaque) cloud scattering (KS_{TRN}).

6.2.3 Multiple Surface-to-Atmosphere/Cloud Reflections

Some of the solar radiation incident on the earth's surface is scattered back toward the atmosphere. Some of this backscattered radiation is in turn scattered back to the surface by the atmosphere and/or clouds, and the process repeats itself. This multiple scattering process serves to increase the total diffuse radiation incident upon the surface. The intensity of these multiple surface-to-atmosphere/cloud reflections is a function of the albedo (solar spectrum reflectance) of the surface and the atmosphere and clouds.

This process is of greatest significance when there is snow on the ground under partly cloudy skies. The model algorithm calculates daily values of surface albedo from snow depth, a terrain factor, and the number of days since the last snow storm. These algorithms are based in part on the work of Baker, Skaggs, and Ruschy (1991) and Baker, Ruschy, and Wall (1990), who studied the reduction of albedo with time (days since last snowfall) and the effects of vegetative ground cover and snow depth.

In the absence of snow cover, monthly values of surface albedo were estimated from satellite images, a general knowledge of ground cover, and the reflectance of cover types. Atmospheric albedo was based on aerosol effects, and the albedo of clouds was determined from the product of cloud cover and assigned reflectances for opaque and translucent clouds. More details on this algorithm will be found in Volume 2 of the data base documentation.

6.2.4 Precipitation Switch

The final factor affecting diffuse radiation is precipitation. The occurrence of rain is usually, although not always, accompanied by a darkening of the sky. Therefore, the precipitation switch reduces diffuse radiation when rain or hail has been recorded and when opaque sky cover exceeds 7 tenths.

A study of diffuse data yielded no evidence that precipitation in the form of snow significantly affected the diffuse radiation incident upon a horizontal surface. Hence, the precipitation switch does not respond to snowfall events.

6.3 Statistical Algorithms

6.3.1 Cloudless Sky Algorithms

Under cloudless skies, it was assumed that the hour-to-hour variations of solar radiation would depend primarily on the solar zenith angle. Hourly variations of water vapor and aerosol optical depth do occur, but the hourly changes are usually small. This results in the smooth diurnal variations of solar radiation that are commonly observed under clear skies.

The hourly variations of water vapor were obtained from linear interpolations between the twice daily radiosonde soundings or from hourly observations of surface vapor pressure. Therefore, it was not necessary to apply a statistical algorithm to water vapor.

From Valko (1980), it was noted that daily variations of aerosol optical depth exhibit a lognormal distribution around the monthly mean. This was verified from our calculations used to determine monthly means. Therefore, a lognormal distribution function was used to effect random variations of aerosol optical depth on a daily basis.

6.3.2 Random Effects of Cloud Cover

The random effects of cloud position, type, and size dominate the random variation of the direct normal component of solar radiation. The standard deviation of direct normal radiation for research data subsets with 4, 6, and 8 tenths opaque cloud cover was found to be two to four times greater than the standard deviation under cloudless or overcast skies. The position of the clouds with respect to the sun and the observer is probably the controlling factor. Therefore, these combined effects will be referred to as cloud position effects.

The cumulative frequency distributions (cfd's) of direct normal radiation for low aerosol optical depth and low water vapor conditions were used to derive the cfd's representing the random effect of opaque cloud position and are shown in Figure 6-2. A random number generator with a uniform distribution from 0 to 1 was used with tables of the cfd's to obtain values of effective opaque sky cover. This nonparametric method transforms uniformly distributed random numbers into random numbers having the distribution represented by the cfd (Yevjevich 1972, p. 249). These values were used to calculate opaque sky cover transmittance.

From Figure 6-2, it is noted that the cfd's for 0 and 10 tenths observed opaque sky cover allow for actual sky covers between 0 to 0.5 tenths and 9.5 to 10 tenths, respectively. Therefore, as the cfd's indicate, under reported cloudless skies, there is a small but finite probability that the sun will be occluded by a small cloud for a small part of the hour.

Likewise, under reported overcast skies, there is a small probability that the sun will shine through a small break in the clouds for a short time.

However, there are conditions under which the sky will be truly clear or overcast for several hours or days at a time. Under these conditions, the probability of a stray cloud or a break in the clouds becomes very small. Therefore, whenever unbroken sequences of cloudless or overcast hours occurred, the range of values from the random number generator were restricted. For instance, for the second cloudless or overcast hour, the random number generator was restricted to values from 0 to 0.9 or 0.1 to 1.0, respectively. For 3 sequential hours the values were restricted to 0 to 0.8 and 0.2 to 1.0, etc.; until for sequences of clear or overcast hours of 10 or more, the values were restricted to 0 to 0.1 and 0.9 to 10.0, respectively. This essentially eliminates the skewed portions of the cfd. This procedure ensured the generation of a smooth diurnal solar radiation pattern for truly cloudless and overcast days.

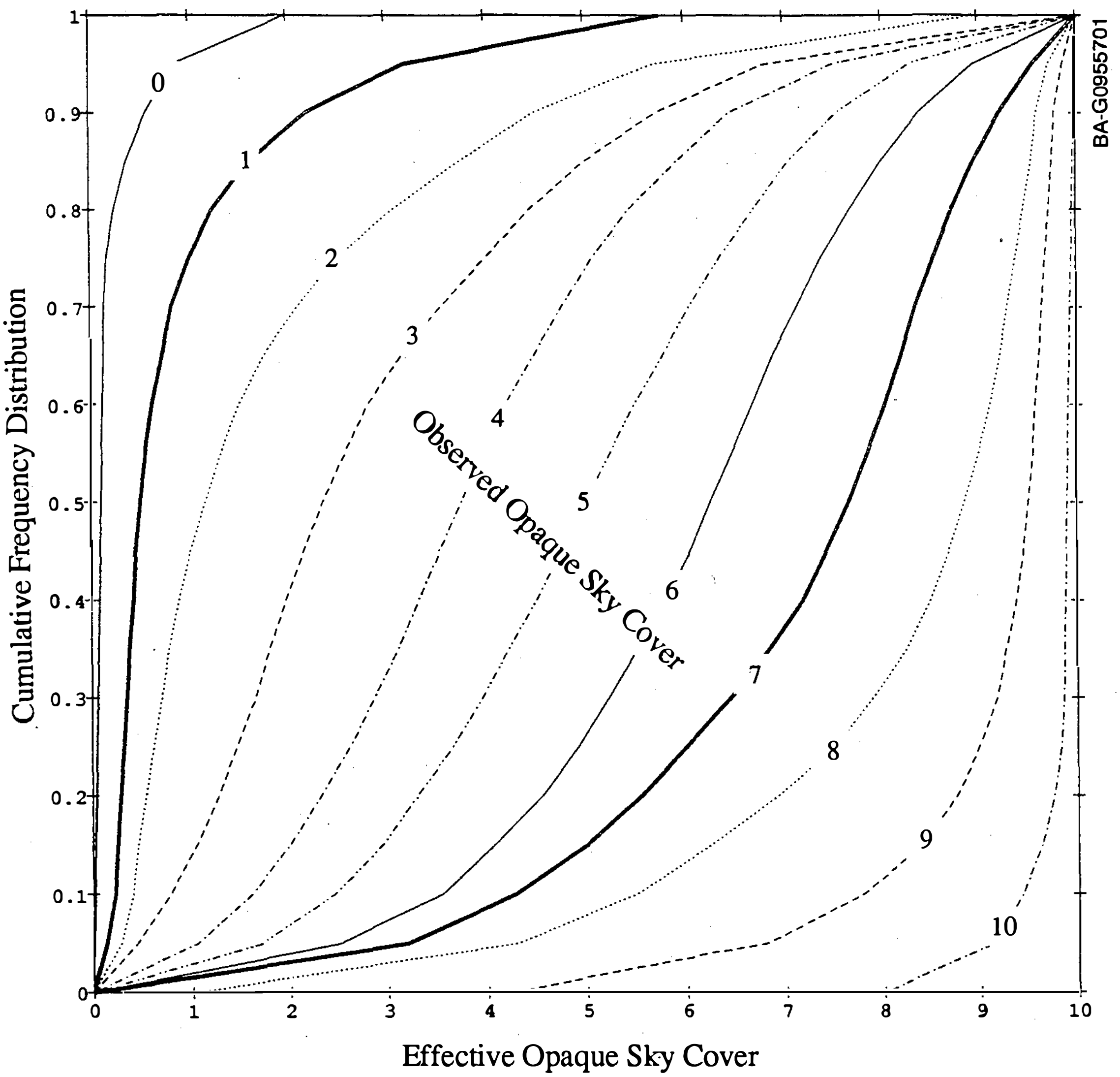

Figure 6-2. **Cumulative frequency distributions (cfd's) of effective opaque cloud cover for each of the 11 values of observed opaque cloud cover. (Derived from cfds for direct normal data for clear-dry atmospheres with no translucent clouds).**

7.0 Synthetic Calibration (SYNCAL) Procedures

As early as the 1960s, Flowers and Helfert (1966) recognized the need and the feasibility of compensating for certain solar radiometer response characteristics (temperature and zenith angle) to achieve much improved accuracy in the measurement of solar radiation. Nevertheless, even to this day (September 1992) the procedures they recommended are not usually followed, and single calibration factors are used to process all data.

A general temperature correction of the pre-1976 global horizontal data was effected during the production of the SOLMET/ERSATZ data base (SOLMET, Vol. 2 1979). These temperature-corrected data, found in field 109 of the SOLMET data tapes, are the pre-1976 data used for the production of the NSRDB. Furthermore, the pyranometers used for post-1976 measurements were constructed with a temperature correction circuit. Therefore, the SYNCAL procedures described in this section were designed only to correct for the angular response characteristics of pyranometers.

If pyranometer sensor surfaces were always perfectly planar and level, and if the globes surrounding the sensors were always perfectly formed, there would be no azimuth angle differences in pyranometer responses. However, because such imperfections are not infrequent, SYNCAL was designed to correct for azimuth angle response characteristics as well as zenith angle.

It was not possible to use field or laboratory procedures to determine the angular response characteristics of the pyranometers used prior to 1976 because most of these intruments had been lost or broken during shipments. Furthermore, the cost of fully characterizing all of the pyranometers used from 1961 to 1990 would have been prohibitive. Therefore, a synthetic calibration and characterization procedure, using comparisons between modeled and measured global horizontal data, was devised.

Initially, it was planned to use the synthetic calibration procedure only for global horizontal data collected before 1976, when instrument calibrations were almost universally suspect. However, the procedure was also used for post-1976 data, as another check on data quality. Although infrequent, a few apparent calibration problems were found after 1976 that required the use of a calibration correction factor.

Because the optimum or minimum uncertainty for global horizontal data had been determined to be ±5% (see Section 8.3.1), a general rule of thumb was adopted whereby apparent calibration errors less than this were ignored. This rule was invoked to avoid uncertain adjustments of measured data to achieve agreement with an imperfect model.

7.1 Developing the Calibration Correction Factors (CCFs)

The SYNCAL procedure used to derive calibration correction factors for global horizontal measurements involved several steps briefly described here.

STEP 1
The dates during which each pyranometer was in use at each station in the NWS-SOLRAD Network were determined from SOLMET, Vol. 2 (1979) and from handwritten station records obtained from NOAA's Solar Radiation Facility in Boulder, Colorado. For non-NOAA stations, it was initially assumed that the same pyranometer had been used during the entire period of record for the station. The following steps were then performed for each instrument that had been used at each station.

STEP 2
Total sky cover data were used to select those hours with no reported clouds. Because solar radiation data represent the integration of energy during the 60 minutes preceding the hour, only cloudless sky hours *preceded* by a cloudless sky hour were used to calculate calibration correction factors. Calculations also were limited to hours with zenith angles less than 80° at the midpoint of the hour. Both measurements and model estimates were considered to be too uncertain for larger zenith angles.

STEP 3
Using the hours selected from step 2, the ratio of modeled estimates to measured global horizontal radiation were used to obtain a calibration correction factor (CCF = Ig_{mod}/Ig_{meas}). The hourly CCFs were then used to calculate daily average CCFs that were used to generate time series plots of the correction factors for each instrument.

STEP 4
The time series plots of CCFs for each instrument were visually examined to look for discontinuities, such as those shown in Figure 7-1. The station records for Fresno, California, indicated that an instrument change had occurred on February 5, 1963. These results, however, indicate that the instruments were actually changed on about October 22, 1962 (the CCFs in 1963 agree with those after October 22 in 1962). Many instances of unrecorded instrument or calibration factor changes were found. These "apparent" instrument change dates were then used to initiate new calculations, then step 3 was repeated.

STEP 5
Once serial plots free of significant discontinuities were obtained, a linear least squares fit to the daily average CCFs for each instrument was obtained (see Figure 7-2). The slope of the line fit to the data was used to determine the average daily rate of change of the pyranometer sensitivity during the entire period of its use at that station. The daily rate of change was used to remove the drift from all of the hourly CCFs.

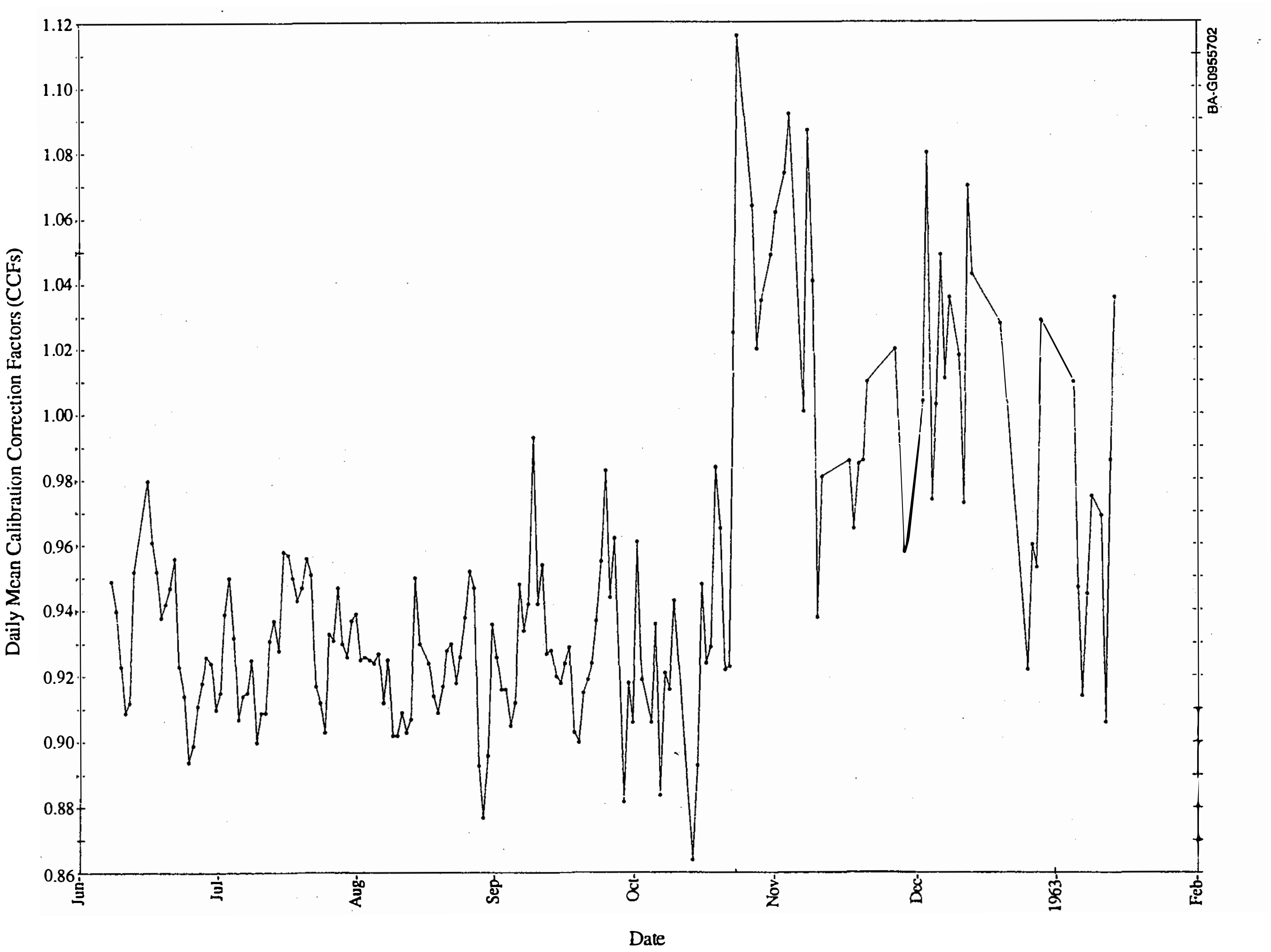

Figure 7-1. Serial plot of the mean daily Calibration Correction Factors (CCFs) for Fresno, Calif. from June 1962 to February 1963. An apparent instrument change occurred on about October 22, 1962. [Eppley Model 50 pyranometer, Serial No. 1798, Parsons Black sensor.]

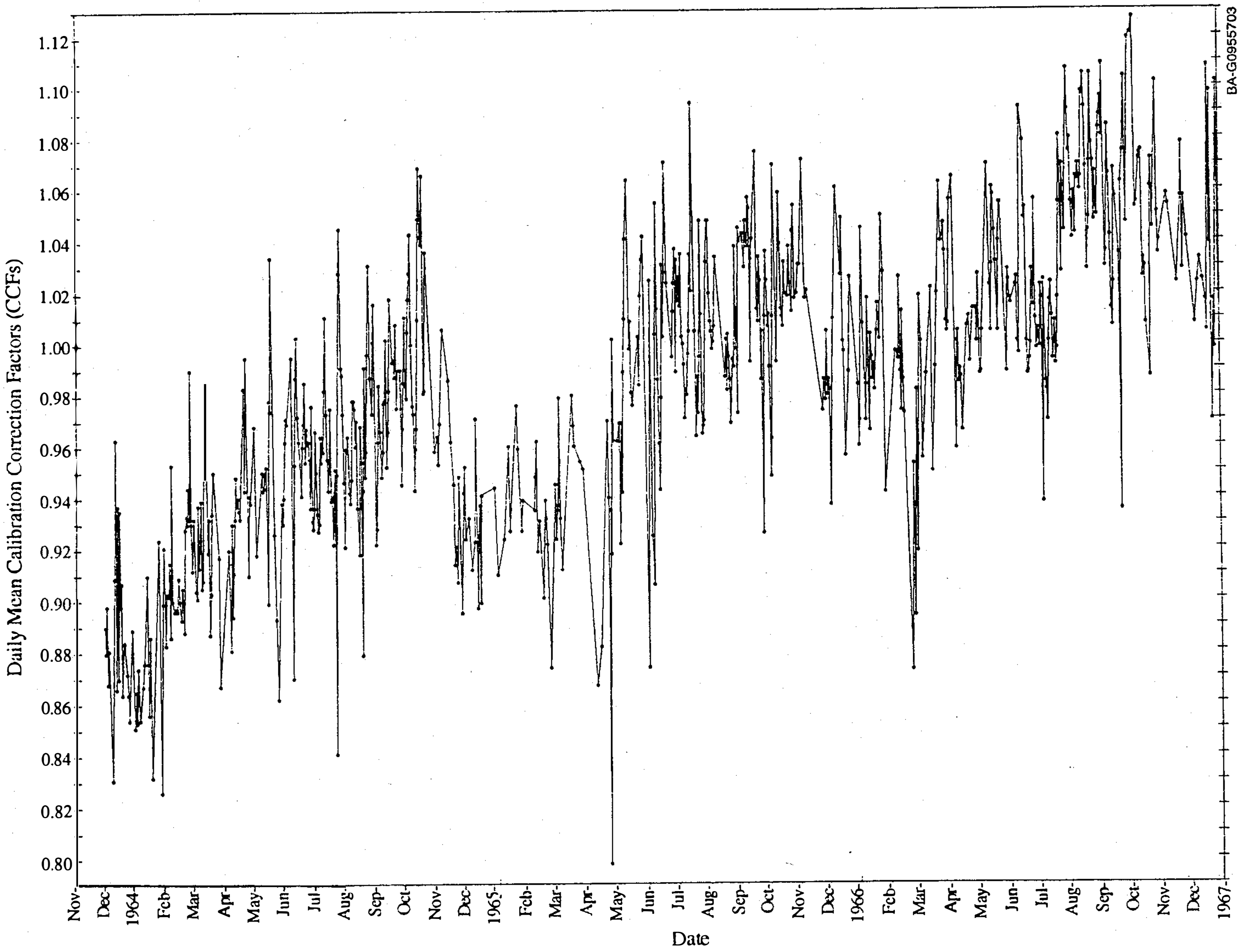

Figure 7-2. Serial plot of the mean daily Calibration Correction Factors (CCFs) for Santa Maria, Calif. from November 1963 to December, 1966. A significant (14.5%) reduction in sensitivity occurred over this time. [Eppley Model 50 pyranometer, Serial No. 3201, Parsons Black sensor.]

STEP 6

The drift-corrected hourly CCFs for each instrument were binned, i.e., placed in 10° by 20° zenith angle—zimuth angle cells. The number (count), mean, and standard deviation of the CCFs in each 10° by 20° cell was calculated and used to form matrices such as those shown in Figure 7-3 for Santa Maria, California (corresponds to the data in Figure 7-2).

STEP 7

The valid (not missing) CCFs for each 10° zenith angle range were averaged to obtain a vector of correction factors ($CCF_{vec)}$, indicating the variation of the pyranometer sensitivity with zenith angle. A weighted (according to the cosine of the zenith angle) average of the drift-corrected hourly CCFs was also calculated to obtain a calibration correction factor for use under isotropic (overcast) skies (CCF_{iso}). The CCF_{iso}, slope (M) of the daily average CCFs, and the CCF_{vec} were all displayed with the matrices of zenith-azimuth cell data as shown in Figure 7-3.

STEP 8

The information shown in Figure 7-3 was developed for each pyranometer used at each of the 56 Primary stations in the NSRDB. This information was examined to select from several options for effecting calibration corrections. The vector and the matrices were examined to determine if sufficient data of adequate quality had been found to accurately define the pyranometer angular response characteristics. For the example, shown in Figure 7-3, the count of hourly CCFs in each cell and the standard deviation of the values in each cell indicate that the response characteristics were well defined by a large data sample. For many instruments this was not the case. Either the period of use was too short or the weather was too cloudy to form an adequate set of data. In these instances, the CCF_{iso} was used to correct all data. For other instruments, the data set was adequate to define the zenith angle response (CCF_{vec}) but not the azimuth angle response. In a few rare instances, the data were not adequate to define even the CCF_{iso}, and no corrections were made.

Once the quality of the information had been determined, a decision was made regarding the need to perform a correction of the data. If the CCFs appeared to fall within or close to the optimum uncertainty established for global horizontal measurements (±5%) no corrections were made. If the angular response characteristics were determined to be acceptable, but the needed corrections exceeded the ±5% limit during any time that the instrument was in use, then the CCF_{iso}, adjusted for the daily drift of the instrument response, was imposed. In Figure 7-3, we note a large zenith angle change (10% from 15° to 75°) but very little azimuth variation in response and a large (14.5%) drift (see Figure 7-2) during the three years of use. Therefore, the CCF_{vec}, adjusted for daily drift was used to correct the data for these years. For some instruments, the matrix of correction factors (CCF_{mat}) was selected.

WBAN	Start Date	Stop Date			
23273	631127	670207	$CCF_{iso} = 0.926$	M = 0.128E-03	N = 689 of 1131 Days

					Zenith Angle						
		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	
		-99.000	0.948	0.942	0.938	0.933	0.920	0.891	0.850	-99.000	CCF_{vec}
Azimuth Angle	60-80	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	0.848	-99.000	
	80-100	-99.000	-99.000	-99.000	0.935	0.918	0.905	0.882	0.820	-99.000	
	100-120	-99.000	-99.000	0.939	0.938	0.929	0.918	0.895	0.876	-99.000	
	120-140	-99.000	-99.000	0.942	0.932	0.941	0.936	0.913	0.849	-99.000	
	140-160	-99.000	0.944	0.945	0.950	0.947	0.929	0.899	-99.000	-99.000	
	160-180	-99.000	-99.000	0.938	0.942	0.941	0.922	-99.000	-99.000	-99.000	MEANS
	180-200	-99.000	0.952	0.943	0.040	0.936	0.919	-99.000	-99.000	-99.000	
	200-220	-99.000	0.948	0.939	0.934	0.937	0.919	0.898	-99.000	-99.000	
	220-240	-99.000	-99.000	0.944	0.943	0.931	0.933	0.884	0.851	-99.000	
	240-260	-99.000	-99.000	0.943	0.931	0.938	0.922	0.928	0.870	-99.000	
	260-280	-99.000	-99.000	-99.000	0.939	0.914	0.894	0.891	0.839	-99.000	
	280-300	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	0.826	0.850	-99.000	
Azimuth Angle	60-80	0.	0.	0.	0.	0.	0.	0.	39.	0.	
	80-100	0.	0.	0.	32.	45.	28.	59.	29.	0.	
	100-120	0.	0.	103.	41.	31.	48.	46.	72.	0.	
	120-140	0.	0.	62.	62.	27.	64.	83.	112.	0.	
	140-160	0.	147.	33.	22.	73.	85.	129.	0.	0.	
	160-180	0.	0.	51.	60.	71.	95.	0.	0.	0.	NUMBER OF DAYS
	180-200	0.	39.	73.	65.	76.	96.	0.	0.	0.	
	200-220	0.	122.	6.	27.	76.	84.	132.	0.	0.	
	220-240	0.	0.	126.	70.	61.	70.	73.	90.	0.	
	240-260	0.	0.	98.	196.	56.	129.	72.	106.	0.	
	260-280	0.	0.	0.	26.	188.	131.	126.	71.	0.	
	280-300	0.	0.	0.	0.	0.	0.	11.	112.	0.	
Azimuth Angle	60-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.000	
	80-100	0.000	0.000	0.000	0.030	0.029	0.034	0.039	0.061	0.000	
	100-120	0.000	0.000	0.030	0.025	0.019	0.029	0.048	0.060	0.000	
	120-140	0.000	0.000	0.021	0.021	0.033	0.039	0.041	0.037	0.000	
	140-160	0.000	0.028	0.018	0.031	0.031	0.024	0.029	0.000	0.000	
	160-180	0.000	0.000	0.023	0.024	0.026	0.022	0.000	0.000	0.000	STANDARD DEVIATIONS
	180-200	0.000	0.026	0.021	0.022	0.026	0.021	0.000	0.000	0.000	
	200-220	0.000	0.026	0.017	0.020	0.025	0.024	0.029	0.000	0.000	
	220-240	0.000	0.000	0.021	0.021	0.020	0.032	0.031	0.047	0.000	
	240-260	0.000	0.000	0.025	0.023	0.025	0.029	0.044	0.061	0.000	
	260-280	0.000	0.000	0.000	0.030	0.028	0.038	0.038	0.056	0.000	
	280-300	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.049	0.000	

Figure 7-3. Isotropic, vector, and matrix calibration correction factors (CCFs) for the Eppley Model 50 pyranometer (Serial No. 3201) in use at Santa Maria, California, from November 27, 1963 to February 7, 1967.

7.2 Applying the Calibration Correction Factors

Some of the empty cells (-99.000) in the vectors and matrices were empty because the sun never occupies that region of the sky at that latitude. The cells for zenith angles from 80° to 90° were always empty because the algorithm excluded data in this range (step 2). Other cells might be empty just because no cloudless hours ever occurred when the sun was in that region. Therefore, in order to ensure the presence of a correction factor whenever needed, all of the cells in the vectors and matrices were filled through processes of extrapolation, interpolation, or weighted averaging of surrounding cells.

In order to simplify the computer application of the algorithm, an isotropic CCF_{iso}, daily drift (M), and CCF_{mat} were always employed. When no calibration correction was to be made, the CCF_{iso}, M, and all of the cells in CCF_{mat} were set to 1.0. When only the isotropic correction was to be made, all of the cells in CCF_{mat} were set to the CCF_{iso} value. When a zenith-angle correction was called for (with no azimuth angle correction), each column of the matrix, CCF_{mat}, was filled with the corresponding CCF_{vec} value. And, of course, when both zenith and azimuth angle corrections were to be made, the original CCF_{mat} was employed.

Following the required modification (if any) of the $CCF_{iso,}$ M, and CCF_{mat} correction factors, the calibration correction factor to be applied to each hourly datum (CCF_{app}) was determined from the equation

$$CCF_{app} = \{[CCF_{mat} (1 - (OPQ/10)] + CCF_{iso} (OPQ/10)\} + N_{days} M \qquad (7\text{-}1)$$

where

OPQ = the opaque sky cover for the hour

N_{days} = the number of days since the instrument had been placed in use.

Therefore, under skies free of opaque clouds (OPQ = 0), CCF_{app} was determined only by the values found in CCF_{mat}, adjusted for daily drift. Under overcast skies (OPQ = 10), only the CCF_{iso} value was applied. Under partly cloudy skies, a combination (weighted by opaque sky cover) of CCF_{mat} and CCF_{iso} values, plus drift, determined CCF_{app}.

In the presence of translucent clouds (e.g., cirrus), the correction would be in error because the translucent clouds could affect both the direct beam and diffuse sky radiation. No attempt was made to account for this because the effects were relatively small and of uncertain magnitude. The corrections made under partly cloudy skies should also be considered as estimates, because of the random effects that can be attributed to the position of the clouds in the sky.

7.3 Summary Comments

The synthetic calibration (SYNCAL) procedure developed for the NSRDB represents an improvement over the SYI/CSN procedure used for the SOLMET/ERSATZ data base. The improved features of SYNCAL are summarized below:

- An improved model (METSTAT) using improved input data (aerosol optical depth and precipitable water) was used to calculate global horizontal solar radiation under clear skies.
- All clear sky hours with zenith angles less than 80° were employed. This significantly increased the quantity of data involved in the calculations.
- The daily average CCFs were serially plotted for the entire period of record to detect any anomalies, drifts, or instrument changes and to avoid adding SYNCAL artifacts to the data.
- The drift corrected hourly CCFs were binned in 10° by 20° zenith-azimuth cells to allow full characterization of the pyranometers when adequate measured data were available.
- The use of average CCFs that define pyranometer response characteristics (based on the instrument's entire period of use), has served to avoid "corrections" that would eliminate or override the real effects of changes in atmospheric conditions (aerosol optical depth and precipitable water).

More information on the development, validation, and application of synthetic calibration factors will be found in Volume 2 of the data base documentation.

8.0 Data Base Quality

The quality of the solar radiation data in the NSRDB is indicated by two quality flags attached to each hourly value and each solar radiation statistic. The first of these flags, the source flag, identifies the source of the data and is described in Part 1- Section 3.0. The second flag, the uncertainty flag, provides a quantitative estimate (for the solar radiation elements) of the confidence you can have in the data. This section provides information on the methods employed to calculate uncertainties and should help you make good decisions regarding the use of the data.

8.1 Quality Assessment of Measured Solar Radiation Data

Because of the difficulties frequently encountered when measuring solar radiation and the resultant unknown quality of some solar radiation data (see Section 4.0), a major effort was undertaken to develop procedures and software for performing post-measurement quality assessment of these data. Such assessments were needed to ensure that the data selected for model development and other applications were of the highest quality available. The assessments also were needed to calculate the uncertainty of measured solar radiation data. A quality assessment software package (SERI QC) was developed to address these needs.

SERI QC is based on the establishment of boundaries or limits within which acceptable data are expected to lie. This is similar to previous quality assessment procedures that used extraterrestrial values for the upper limit and zero for the lower limit within which solar radiation data were expected to lie. SERI QC increased the sophistication of this approach by establishing much more restrictive boundaries specific to each station-month.

SERI QC operates in a unitless K-space, i.e., solar radiation normalized to extraterrestrial values. An example of the expected limits and boundaries established by SERI QC is given in Figure 8-1. The K-space variables that form the abscissa and ordinate in this figure are defined according to the expressions

$$Kn = I_n/I_o, \quad (8\text{-}1)$$

$$Kt = I_t/(I_o \cos z), \text{ and} \quad (8\text{-}2)$$

$$Kd = I_d/(I_o \cos z), \quad (8\text{-}3)$$

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
z = solar zenith angle.

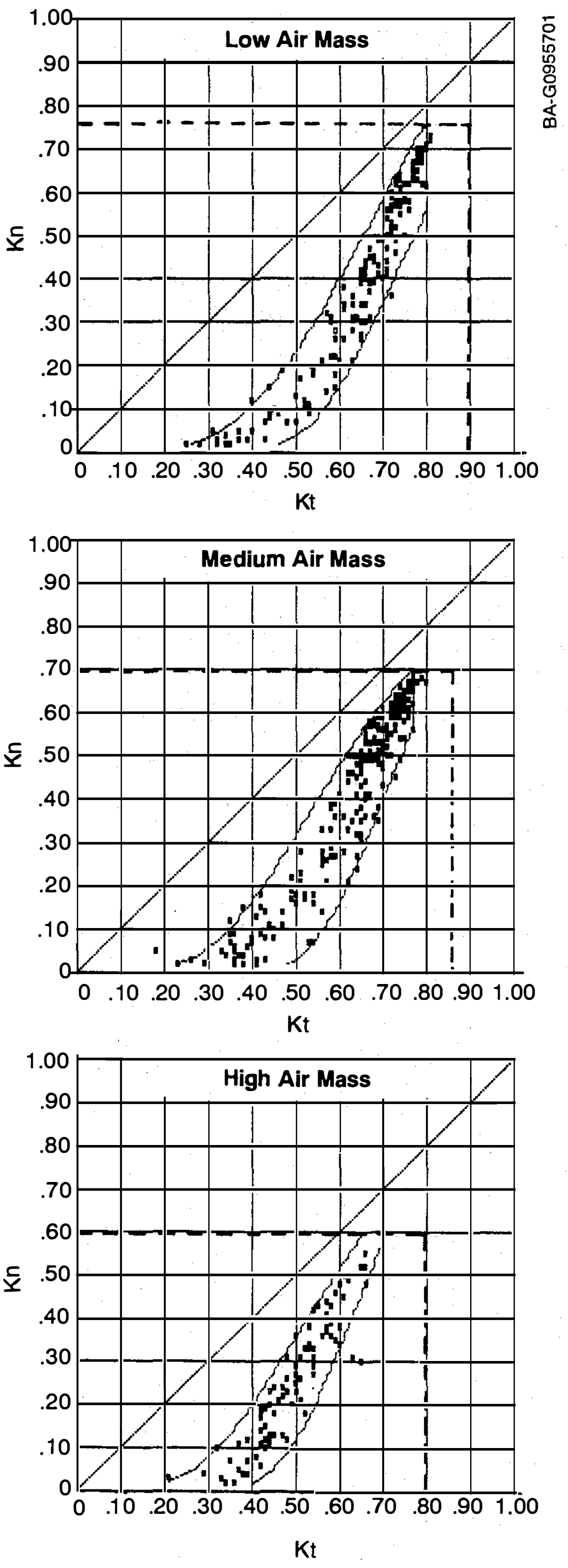

Figure 8-1. Scatter plot (in K-Space) of solar radiation data for Nashville, Tennessee, for April. The curved boundaries are used for quality assessment.

Kn is the atmospheric transmission of the direct beam radiation from the solar disk, Kt is usually referred to as the clearness or cloudiness index, and Kd could be referred to as the effective diffuse transmittance. For the sake of simplicity, Kd, representing the diffuse component, is not displayed in Figure 8-1.

The hourly data values plotted in Figure 8-1 are the actual data collected by the NWS at Nashville, Tennessee, during April 1978 and April 1980 (no direct normal data were collected in April 1977 or 1979). The best quality data available from the NWS were collected during the four years from 1977 to 1980. Hence, data available from these four years were used to establish empirical limits and boundaries of acceptable data for NWS SOLRAD stations.

The heavy dashed lines represent the expected maximum global horizontal and direct normal values and the curved boundaries around the scatter plot of the data were empirically determined by these data. This was implemented by positioning a limited set of boundary shapes around the data. The position of the boundaries were adjusted in Kt increments of 0.025 such that up to 5% (approximately) of the data lay outside the boundaries. This criterion was based both on the assumption that some of the data were in error and a desire to limit the acceptance of erroneous data to small percentages.

The use of empirical boundaries established with data from 1977 to 1980 was justified by a number of factors including (1) the use of new instruments installed in 1977, which were well maintained during these four years; (2) the establishment of good calibration procedures maintained throughout this period; (3) the determination that boundary extremes could be reproduced using a solar radiation model; and (4) results that behaved according to expectations based on atmospheric processes and the climate characteristics at the stations involved (e.g., high diffuse values were observed during the winter with snow on the ground and scattered clouds).

Referring to Figure 8-1, Kt and Kn values of 1.0 are, by definition, global horizontal and direct normal extraterrestrial irradiance. Therefore, most previous quality control procedures would accept any data lying within the entire Kt-Kn space shown on this figure. When empirical maximum values for Kt and Kn are imposed, the area of acceptability is reduced to the area outlined by the heavy dashed lines. The maximum limits are based on the maximum values achieved by good quality data, as shown on the figure. Values approaching 0 are not found on these plots because data from times just after sunrise and just before sunset have been excluded from these plots. Zero values are observed, of course.

These maximum and minimum limits are employed when only one element of solar radiation has been measured. They significantly reduce the area of acceptability, provide a better assessment of data quality, and lead to the assignment of lower uncertainties.

When both global horizontal and direct normal measurements have been made, the area of acceptability can be further reduced to the region enclosed by the curved boundaries. This region encompasses about 95% of the data points and encloses less than 15% of the Kt-Kn space. When two component data fall within such boundaries, a further reduction in the assigned uncertainty can be made.

The three parts of Figure 8-1 show data, max-min limits, and boundaries for three different air mass or solar zenith angle ranges. Air mass is a unitless quantity that indicates the relative length of the path of the solar beam as it passes through the atmosphere. When the sun is directly overhead (zenith angle = 0°) the air mass is 1.0; at a zenith angle of 60° the air mass is 2.0; and when the sun is on the horizon (zenith angle = 90°) the air mass is 35.6. The air mass at 90° is not infinite because of the curvature of the earth.

SERI QC assigns limits and boundaries for three air mass ranges (low = 1.0 to 1.25; medium = 1.25 to 2.5; and high = 2.5 to 5.58). Changes in limits and boundary positions with smaller changes in air mass are not significant.

Finally, when all three of the solar radiation elements are available (global horizontal, direct normal, and diffuse horizontal) redundancy can be used to further reduce the uncertainty of the data. This is accomplished by calculating the global from the direct normal and diffuse, all in K-space,

$$Kt_c = Kn + Kd \tag{8-4}$$

and by comparing the calculated global (Kt_c) with the measured global (Kt). This comparison provides a direct indication of the accuracy of all three measurements. It is possible, of course, that offsetting measurement errors could partially invalidate this comparison. Nevertheless, when hourly values of global horizontal, direct normal, and diffuse horizontal agree within a specified error limit, the lowest possible uncertainty for solar radiation data can be assigned.

In addition to determining if the solar radiation data fall within expected boundaries, SERI QC calculates the distance (in K-space) by which data fall outside the boundaries. The flagging system used by SERI QC records these distances and indicates whether one-element, two-element or three-element data were involved and whether the data point was below or above expected boundaries. The SERI QC flags, therefore, permit the assignment of uncertainties that are dependent on the nature of the test performed (one, two, or three components) and the distance by which the data point exceeds expected limits. A more detailed description of SERI QC can be found in the *User's Manual for Quality Assessment of Solar Radiation Data* (NREL 1993).

8.2 Standard Methods for Calculating Uncertainties

The uncertainty flags assigned to NSRDB hourly values and statistics of solar radiation were derived using modifications of a standard method developed during the last 15 years by the standards and professional engineering communities. The objective of measurement uncertainty analysis is stated in the American Society of Mechanical Engineers (ASME) report (ASME 1985): "...to provide numerical estimates of an upper limit of precision error, bias error, and the combination of these into uncertainty." For the purposes of the NSRDB, uncertainty can be defined as *the interval about the reported solar radiation value that is expected to encompass the true value, 95% of the time.* For example, for all hours for which direct normal radiation is reported to be 1000 Wh/m^2 with an uncertainty of 10%, the user can expect that the true direct normal radiation was between 900 and 1100 Wh/m^2 95% of the time.

Each measurement process contains errors. Errors are the difference between a measured or reported value and the true value of the parameter in question. They are classified as: (1) systematic or bias (fixed offset) errors and (2) random (precision or repeatability) errors, which are assumed to follow the Gaussian (Normal) distribution. The calculation of uncertainties requires identification, classification (bias or random), and quantification of every significant source of error.

Quantification requires assignment of a numerical value to each of the identified and classified error sources. This step is usually based on empirical tests, measured data, instrument specifications, calibration results, etc. When data are not available, engineering judgment, experience, or previous knowledge must be used to estimate the magnitude of the error. The bias and random error magnitudes are then combined into total bias and random components of uncertainty, which are in turn used to compute the total uncertainty.

Random errors are the result of independent influences on the measurement process, which change with each measurement. They are recorded as an integral part of the data, varying with each individual measurement. Their magnitudes are estimated from the standard deviation(s) of repeated measurements. Because of their statistical nature, increasing the sample size (n) normally will result in a reduction in the magnitude of these errors.

Bias errors are those errors that are fixed and present for every measurement using specified procedures and instruments. For example, if an instrument has been miscalibrated, every measurement made with that instrument will exhibit the same error resulting from the miscalibration. The fact that calibration standards themselves contain bias errors that contribute to measurement errors is often overlooked.

Once all errors have been identified and quantified, they are combined to provide an estimate of uncertainty. The U_{95} method was used for combining solar radiation measurement errors. Using this method, the total bias error is determined by taking the square root of the sum of the squares (root-sum-square) of all bias errors. The root-sum-square (RSS) of all random error sources is used to obtain the total random error. The uncertainty of individual measurements or samples is determined from

$$U_{95} = [\Sigma(B_i)^2 + \Sigma(2\sigma_{Ri})^2]^{0.5} \qquad (8\text{-}5)$$

where B_i = the i^{th} bias error
σ_{Ri} = the standard deviation of the i^{th} random error.

It is well known that measurement accuracy can be improved by averaging a series of measurements. Therefore, the random component of uncertainty is reduced when the final value is derived from more than one measurement or sample (Barry 1978). Thus, the uncertainty of the monthly mean of daily measurements is calculated as

$$U_{95m} = [\Sigma_i(B_i)^2 + (\Sigma_i(2\sigma_{Ri})^2)/(30)^{0.5})]^{0.5} \qquad (8\text{-}6)$$

This assumes that the uncertainty of each daily measurement is the same. For annual means, the random component of error is divided by the square root of 365.

8.3 Calculating the Uncertainty of Solar Radiation Data

The solar radiation data in the NSRDB were obtained from a variety of sources that can be placed in one of the following three categories:

1. Actual measurements using solar radiometers
2. Corrected data based on actual measurements
3. Model estimates of solar radiation using meteorological data inputs.

The "true" solar radiation values to which assigned uncertainties are referenced are defined as follows:

- The true global horizontal radiation is the average total radiation incident upon a horizontal surface during the 60 minutes preceding the indicated hour.
- The true direct normal radiation is the average solar radiation falling within a 5.7° field of view centered on the sun during the 60 minutes preceding the indicated hour.
- The true diffuse horizontal radiation is the average diffuse radiation from the sky incident upon a horizontal surface during the 60 minutes preceding the indicated hour.

The standard methods for calculating uncertainty assume the use of a constantly controlled process whereby the instruments are maintained in the best working order possible. Measurements made in support of solar collector efficiency tests would likely meet this assumption. Although network operations for long-term monitoring of solar radiation may not satisfy this assumption (instruments are given only brief checks once each day), the calculation of uncertainties for solar radiation measurements began by assuming the maintenance of optimum conditions.

8.3.1 Optimum Uncertainties

The calculation of uncertainties for the many sources of solar radiation data acquired or estimated under a variety of circumstances was facilitated by defining "optimum" uncertainties for each of the sources. These "optimum" uncertainties are the uncertainties expected under optimum measurement or modeling conditions, using the instruments or models actually employed. For example, the optimum uncertainty for post-1976 measured global horizontal solar radiation is that uncertainty that would result if the instruments were properly calibrated and installed and used under the constant supervision of experts in the field of solar radiometry. Use of the term "optimum" in this context should not be interpreted in any other way.

Myers, Emery, and Stoffel (1989) and Wells (1992) identified the major sources of error associated with solar radiometers (pyranometers and pyrheliometers). The most significant measurement errors associated with the intrinsic characteristics of these instruments include:

- Deviations from cosine law response to incident radiation
- Ambient temperature effects on response to radiation
- Nonlinear response to incident radiation
- Nonuniform response across the solar spectrum
- Errors associated with the use of shadow bands for measuring diffuse radiation.

All of these sources of error have been exhibited in varying degrees by the various instruments employed from 1961 to 1990. All of them can be categorized as random errors because their effects on individual hourly values will be a function of more or less randomly varying measurement and atmospheric conditions.

In addition to the intrinsic sources of error, the following factors contribute to errors in the calibration of the radiometers:

- Uncertainty in the definition of the international scale of solar radiation
- Errors in the transfer of the World Radiometric Reference to the secondary reference instrument(s)
- Errors in the calibration of individual instruments.

Calibration errors are bias errors because the effect of miscalibration is the same for all measurements.

Data acquisition and data processing errors were also addressed. These errors include many small random sources that affect both calibrations and individual measurements.

The results of the work of Myers, Emery, and Stoffel (1989) and Wells (1992) yielded the following optimum uncertainties for the measurement of the three major elements of solar radiation using thermopile pyranometers and pyrheliometers.

- Global horizontal - ±5%
- Direct normal - ±3%
- Diffuse horizontal - ±7%

The reported uncertainties have been reduced to one significant figure because of the uncertainty associated with these calculations. This is not a reflection on the analytical procedures. Rather, it is a reflection on the lack of sufficient data on the characteristics of solar radiometers.

For application to the NSRDB, the concept of optimum uncertainties for reported values of solar radiation was extended to include each of the eight sources of solar radiation data, as indicated by the source flags. The meaning of the source flags is repeated here for easy reference.

A --- Post-1976 measured data

B --- Similar to A except the global horizontal data required a calibration correction

C --- Pre-1976 measured global horizontal data adjusted from solar to local time, with a calibration correction

D --- Data derived from the other two elements of solar radiation using the relation, Kt = Kn + Kd

E --- Modeled data using inputs of observed cloud cover and aerosol optical depths derived from direct normal data collected at the same site

F --- Modeled data using *interpolated* cloud cover and aerosol optical depths derived from direct normal data collected at the same site

G --- Modeled data using observed cloud cover and aerosol optical depths *estimated* from geographical relationships

H --- Modeled data using *interpolated* cloud cover and *estimated* aerosol optical depths

The optimum uncertainties that were assigned to data in each of these source categories follow (G = global horizontal; N = direct normal; D = diffuse horizontal). The changes noted for one source versus another are based on the consensus of experts in the field and represent engineering judgments.

Flag A G = ±5% N = ±3% D = ±7%

These uncertainties were established as described above.

Flag B G = ±7% N = ±3% D = ±7%

If post-1976 global horizontal data need synthetic calibration corrections, this indicates significant calibration error and/or serious angular response problems. Because calibration corrections cannot completely mitigate such problems, the uncertainty of the global element has been increased by 2%.

Flag C G = ±8% N = ±5% D = ±8%

Only pre-1976 global horizontal data have undergone a time shift from solar to local time and a synthetic calibration correction. The uncertainty of global data under optimum conditions was increased by an additional 1% to account for increased errors caused by the time shift.

Prior to 1976, the direct normal and diffuse elements were not measured. Hence, these elements will be model estimated when flag C is applied to the global element. The optimum uncertainties for modeled direct normal and diffuse horizontal elements, when accompanied by pre-1976 measured global horizontal values, were reduced by 1% from the optimum uncertainties of modeled data when all three elements are modeled (see below). This reduction in uncertainty results from the use of the METSTAT model in a procedure that limits the direct and diffuse values to those that result in agreement between measured and modeled global.

Flag D G = ±5% N = ±6% D = ±6%

The uncertainty of hourly values for elements calculated from the other two elements will be calculated from the root-sum-square (RSS) of the uncertainty of the two measured elements. It was not possible to define optimum uncertainties for hourly data created in this way. Hence, the optimum uncertainties given for this source flag were only used for assigning uncertainties to monthly and annual statistics.

Flags E to H G = ±7% N = ±6% D = ±9%

These optimum uncertainties are for modeled data based on daily turbidity values derived from direct normal data collected at the site in question. These values are the result of the RSS of optimum values for flag A and an assigned 5% uncertainty for model estimates.

8.3.2 Calculating the Uncertainty of Modeled Values

The use of a *statistical* model to estimate a majority of the data in the data base presented special problems relative to the assignment of uncertainties. Because of the random statistical variations incorporated into the model estimates, individual hourly values under partly cloudy skies could be greatly different from actual measurements, had they been made. For instance, under partly cloudy skies it is possible for the sun to be completely occluded during an entire hour. It is also possible for the sun to shine brightly for an entire hour. Under these conditions, the uncertainty of individual hourly estimates, relative to the true solar radiation, would be very large.

However, it had never been intended that the model estimates would reproduce actual measured data. Rather, the METSTAT model was designed to simulate the statistical and stochastic characteristics of monthly and annual data sets. Given this objective, the assignment of uncertainties with reference to the true solar radiation for specific hours would not provide the user with useful information. It was decided, therefore, that the uncertainty of individual hourly values estimated by METSTAT should be interpreted to mean that 95% of the time the *true* mean of measured hourly values *under fixed atmospheric conditions* lies within the range established by the estimated mean plus or minus the uncertainty. 95% of the time.

For example, if the average of 100 METSTAT estimates of global horizontal radiation at a specific time and place with fixed atmospheric conditions (e.g., total precipitable water = 2.2 cm, aerosol optical depth = 0.11, total sky cover = 5, and opaque sky cover = 2) equals 700 Wh/m^2, with an uncertainty of 8%, then 95% of the time the *true average global horizontal radiation* that would result from several measurements under these conditions should lie between 644 Wh/m^2 and 756 Wh/m^2.

8.4 The Total Uncertainty of Measured Solar Radiation Data

The optimum uncertainties defined above were assigned to data from the respective sources whenever the optimum conditions pertaining to these sources existed. Under less than optimum conditions, the uncertainties were increased as described in the following sections.

8.4.1 Total Uncertainty of Post-1976 Data (Sources A and B)

The total uncertainty of *post-1976* measured solar radiation data was calculated as the RSS of the optimum uncertainty and factors that increase the uncertainty

$$U_{tot} = (U2_{opt} + R^2_{type} + R^2_{flg} + R^2_{staq})^{0.5} \qquad (8\text{-}7)$$

where U_{opt} = the optimum uncertainty for source A or B
R_{type} = 0, 3, or 6 for three-, two- or one-element data, respectively
R_{flg} = INT ((Flg + 2)/4.0).
R_{staq} = $(\text{Staqlty})^{0.5}$

All factors are expressed in percents.

R_{type} increases the uncertainty of one- or two-element post-1976 data to account for the random errors of the quality assessment procedure. In other words, data falling within the expected max-min (one-element) or boundary (two-element) limits can be in error by a significant amount. The values of 3% and 6% are subjective estimates based on experience at NREL.

R_{flg} increases the uncertainty according to the magnitude by which SERI QC quality assessment limits and boundaries have been exceeded. This random error is given in percent of the extraterrestrial solar radiation.

R_{staq} increases the uncertainty to account for random errors associated with the quality of station operations. The station quality index (Staqlty) is based on the percent of hourly data for a month that have a SERI QC flag greater than 29, thereby indicating missing data or values outside limits or boundaries by an amount greater than 7% of the extraterrestrial value. The 7% threshold is consistent with optimum uncertainties for measured and modeled global horizontal data.

Missing data are considered valid indicators of station quality for the following reasons:

1. In general, if large amounts of data are missing, this indicates poor maintenance of equipment.

2. Missing data reduce the sample size available for setting the limits and boundaries used for quality assessment. This increases the uncertainty of the quality assessment results.

From the above, it is apparent that uncertainties greater than 50% could have been assigned. However, all post-1976 measured data with flags greater than 41 were replaced with modeled values. In reality therefore, no uncertainties greater than 35% will be found in the NSRDB.

8.4.2 Total Uncertainty of Pre-1976 Data (Source C)

The total uncertainty of *pre-1976* measured global horizontal data was always set equal to the optimum value (8%). Although the uncertainty of some of these data could exceed this value, there was no basis for making such a determination. Furthermore, all of these data were synthetically calibrated, and this value is consistent with that process and the accuracy of the METSTAT model for cloudless skies (used to determine calibration corrections).

8.4.3 Total Uncertainty of Calculated Data (Source D)

The total uncertainty of values calculated from the other two measured elements was determined from the RSS of the uncertainty of the two measured elements. For example, when the global horizontal element was calculated from measured direct normal and diffuse horizontal data, the uncertainty of the global (G) value was calculated from

$$UG_{tot} = (UN^2_{tot} \; + \; UD^2_{tot} \,)^{0.5} \qquad (8\text{-}8)$$

where the total uncertainty of the direct normal (N) and diffuse horizontal (D) elements had previously been determined from the procedures described above. Similar RSS equations were used to estimate uncertainty when direct normal or diffuse horizontal values were calculated from the other two elements.

8.4.4 Total Uncertainty of Modeled Data (Sources E-H)

The general or optimum uncertainties of METSTAT estimates of solar radiation were based on the optimum uncertainties of the measured data used during the development of the model and evaluations of the model performance under cloudless skies. These optimum modeled data uncertainties were increased according to the following algorithms.

$$UG_{ran} = (UG^2_{opt} \; + \; R^2_{cc} \; + \; R^2_z \,)^{0.5} \qquad (8\text{-}9)$$

$$UG_{tot} = (UG^2_{ran} \; + \; (B_{tau}\,/30.0)^2)^{0.5} \qquad (8\text{-}10)$$

$$UN_{ran} = (UN^2_{opt} \; + \; R^2_{cc} \,)^{0.5} \qquad (8\text{-}11)$$

$$UN_{tot} = (UN^2_{ran} \; + \; (B_{tau}\,/6.0)^2)^{0.5} \qquad (8\text{-}12)$$

$$UD_{ran} = (UD^2_{opt} \; + \; R^2_{cc} \,)^{0.5} \qquad (8\text{-}13)$$

$$UD_{tot} = (UD^2_{ran} \; + \; (B_{tau}\,/5.0)^2)^{0.5} \qquad (8\text{-}14)$$

where UG_{ran}, UN_{ran}, and UD_{ran} are the essentially random components of the uncertainties of the global, direct, and diffuse elements of solar radiation.

R_{cc} accounts for the random error introduced by errors that can be attributed to cloud cover estimates and/or the cloud cover algorithm. This term is largest when the cloud cover value has been interpolated and is a function of the cloud amount, being largest under partly cloudy skies.

R_z accounts for the increase in errors in the estimate of global horizontal values with large (>60°) zenith angles.

B_{tau} is the bias error in the estimate of aerosol optical depth (turbidity), which was assigned values as large as 50%. The effect of errors in aerosol optical depth on the global component is small because of the offsetting effects on the direct and diffuse components (due to the redistribution of direct radiation into diffuse radiation).

8.5 Calculating the Uncertainty of Monthly and Annual Statistics

When calculating the uncertainty of monthly and annual statistics, all random errors are decreased by the reciprocal of the square root of the sample size (n) (Barry 1978). Bias errors are not reduced, however, except in those instances for which biases become random. When calculating the uncertainty of 30-year statistics, it was assumed that all of the biases could be randomized, except for the modeling bias associated with errors in the estimate of aerosol optical depth.

After considerable evaluation and much discussion, it was decided that the uncertainties assigned to monthly and annual means should not be less than the optimum uncertainties assigned to the hourly values for each of the data sources (see Section 8.3.1), plus the effect of the modeling bias error attributed to errors in aerosol optical depth estimates. This determination was based on the following considerations:

- Calibration and other bias errors are the dominant sources of error for most solar radiation data, and these errors are not reduced by increases in sample size.

- The multiple problems associated with monitoring solar radiation in the United States, in particular the discontinuous operation of measurement stations, have resulted in small quantities of measured data not necessarily representative of climatological means.

- Because the METSTAT model was based on limited quantities of measured data, the uncertainty of model estimates could not be less than the uncertainty of the measured data.

Therefore, the total uncertainty of the monthly mean for each element was calculated as

$$U_{tot} = \{[1/n\ \Sigma U_{ran}/5.5]^2 + [P_{mod}(B_{tau}/x]^2\}^{0.5} \qquad (8\text{-}15)$$

where P_{mod} = the proportion of the monthly data coming from a model source
x = 30, 6, or 5 for the global, direct, and diffuse elements, respectively

and the other parameters are as defined previously. The first term in equation (8-15) was not allowed to become less than U_{opt}.

For annual and 30-year monthly and annual means, the first term in equation (8-15) was always smaller than U_{opt}. Therefore, the total uncertainty of these statistics were calculated as

$$U_{tot} = \{U^2_{opt} + [P_{mod}(B_{tau}/x)]^2\}^{0.5} \qquad (8\text{-}16)$$

The uncertainties calculated for monthly and annual means of daily totals were also assigned to the distributions of hourly means and the cumulative frequency distributions of hourly values. Although this does not constitute a rigorous analysis of the uncertainty of these statistics, it is consistent with the state of the art of solar radiation measurements; i.e., the information available will not support a more rigorous analysis.

The user should recognize that the uncertainties assigned to the monthly and annual statistics are probably conservative for those stations that were well operated and for which a large quantity of good quality data had been collected. This is consistent with the philosophy of uncertainty analyses, which prefers to err on the high side, not the low.

8.6 Using the Solar Radiation Quality Flags

The source and uncertainty flags assigned to the solar radiation data can be used for a number of purposes. For example, the flags could be used to aid in the selection of station-months to form typical- and design-year data subsets. Individual users can use the quality flags to set their own limits of acceptability for whatever application they have in mind. For example, the user may want to only use those data containing at least one measured component and may also want to set some maximum uncertainty limit as a data screen. Regardless of the specifics of the application, users can use these flags to set confidence limits for their designs or performance evaluations.

8.7 The Uncertainty of Meteorological Data

Information was not readily available for the calculation of the uncertainty of meteorological data. The subjective uncertainty statements made in Table 3-9 should be considered in the light of the following information.

All surface airways hourly observational data were subjected to some form of quality control. During the earlier years, this was almost entirely a manual effort. As more sophisticated techniques of processing were introduced, the quality control procedures became more automated. Observations are checked for conformance to established observing and coding practices, for internal consistency, for serial, or for time-oriented consistency, and against defined limits for each meteorological element.

Snow depths are measured at several locations near the NWS facility and are averaged to obtain the reported depth. In the absence of wind, these data should be of reasonably good quality. At windy sites, where drifting of the snow occurs, the uncertainty of the reported value may be greater than under calm conditions. However, since the snow depth data were used only to establish an estimate of surface albedo, no further analysis of the quality of this data was undertaken.

The quality of precipitable water data obtained from surface measurements and adjacent sites was assessed by comparing these estimates with radiosonde data for several years of data. These analyses showed that the standard error between the estimated values and the radiosonde values was always less than 1 cm, and at most locations and for most seasons the standard error was found to be less than 0.5 cm. The impact of these errors on the model estimates of solar radiation were incorporated into the calculation of uncertainties for the solar radiation data.

All aerosol optical depth values used in the NSRDB were calculated according to the procedures outlined in Section 6.2.3 Since very few accurate measurements of aerosol optical depth exist, calculated values were used throughout. These estimates of aerosol optical depth are no better than the quality of the direct normal radiation data that were used in their calculation. For times and locations for which direct normal data were not available, uncertainties from 10% to 50% were assigned to the estimates of aerosol optical depth.

The quality flags for meteorological elements are available only in the TD-3282 format. They were not incorporated into the NSRDB synoptic format.

9.0 The Production Process

NREL has maintained a detailed record of the processes used in producing the data base. This record will be documented in a permanent archive of the entire data base production. Here we only mention those aspects of production that affected the quality of the products.

9.1 Verification and Validation

Approximately half of the data base software development time was devoted to software testing. We used two fundamental concepts while testing: verification and validation. Verification determined if the software meets specifications; validation determined if specifications were correct. For the most part, validation was performed during the R & D part of the project and is reported in Volume 2 of the data base documentation.

Our software testing strategy employed conventional techniques, such as functional testing and logic analysis. Much of the initial processing in the data base production involved relatively simple data transfer or units conversion. These processes also involved decoding data from the source format and encoding for our data structures. Because of the complexity of some source data formats, automation of testing was difficult.

During functional testing, verification of the process was accomplished by comparing the output with that predicted from the input. The completeness of the verification, however, hinged on the proper selection of input. Our test data sets were usually divided into two categories:

1. Synthetic input data that included a wide range of valid and invalid values, particularly values near boundaries between the valid and invalid.
2. Subsets of real data. These subsets were chosen to test the processing at critical boundaries, such as month or year boundaries, and site or file changes.

Most of the initial inspection of input and output values was done by hand from printouts of test files. However, when problems were found and changes to the software were made, we verified the change by creating a new file of output values from the same input values, followed by an automated file comparison. This comparison (the "DIFFERENCE" command in VAX/VMS) outputs only the differences between the two files. This helped us verify not only that the desired change was made, but that no unwanted side effects occurred.

9.2 Production Control and Monitoring

To produce a data base of 30 gigabytes, involving numerous processes and a variety of input data sources, some method was needed to track the production progress. We tracked progress through four tracking mechanisms: (1) Project Status Log, (2) Production Status (ProStat) Data Base, (3) File Status Log, (4) Process ID File.

Figure 9-1 gives an overview of these process and control mechanisms. The value of these process control procedures lies primarily in the detailed permanent record they provide of the data base production procedures and processes. Should questions arise regarding any of the data in the data base, these files will allow an exact determination of the processes used to arrive at specific data for any location and time. Furthermore, this information will be invaluable as a starting point for future upgrades of the data base.

9.2.1 The Project Status Log

This log aided the production team in tracking the data as they were processed. The values in this log indicated the number of hours that each element existed in any number of predefined production states. The states of production, for example, might represent that the datum was missing or had been interpolated.

The state of each element was stored in the same record as the data, and the Project Status Log was automatically updated by library routines that were invoked each time data were written to a data base file. Knowing that the production states followed a clear path from beginning to end, this log allowed the production team to verify that all data had been moved from state to state as expected.

9.2.2 The Production Status (ProStat) Data Base

This data base, which was formed from the Project Status Log, held information about the status of each site/year/element that helped project leaders make management decisions. Several status codes were devised to indicate the progress of production. A code was assigned only if all hours for that site/year/variable met the criteria for that code. This data base reduced the probability of overlooking a few hours of data that could not be processed using normal procedures.

9.2.3 The File Status Log

This log aided the production team in keeping track of which processes had been applied to which files and where the files were located. Media transfer software supervised the movement of data between on-line disk to laser disk or tape and recorded the movement in the File Status Log via temporary File Status Update files. The File Status Log held the date on which each file was most recently modified and the file's current location, i.e., a tape or disk number.

9.2.4 Process ID File

A critical part of production control was the Process ID File. This file held an enumerated list of all processes authorized by the production team. The library routine that wrote to a binary file required that the calling program have a process authorization number; thus, a binary file could be written only if that authorization number resided in the Process ID File. Each time a binary file was modified by a process, the process ID number was written to a File Status Update file for that site-year. The File Status Log was updated from these update files nightly. Note that even if a process was changed, such as for a bug fix or enhancement, it was considered a new process with a new process ID and description in the process ID file.

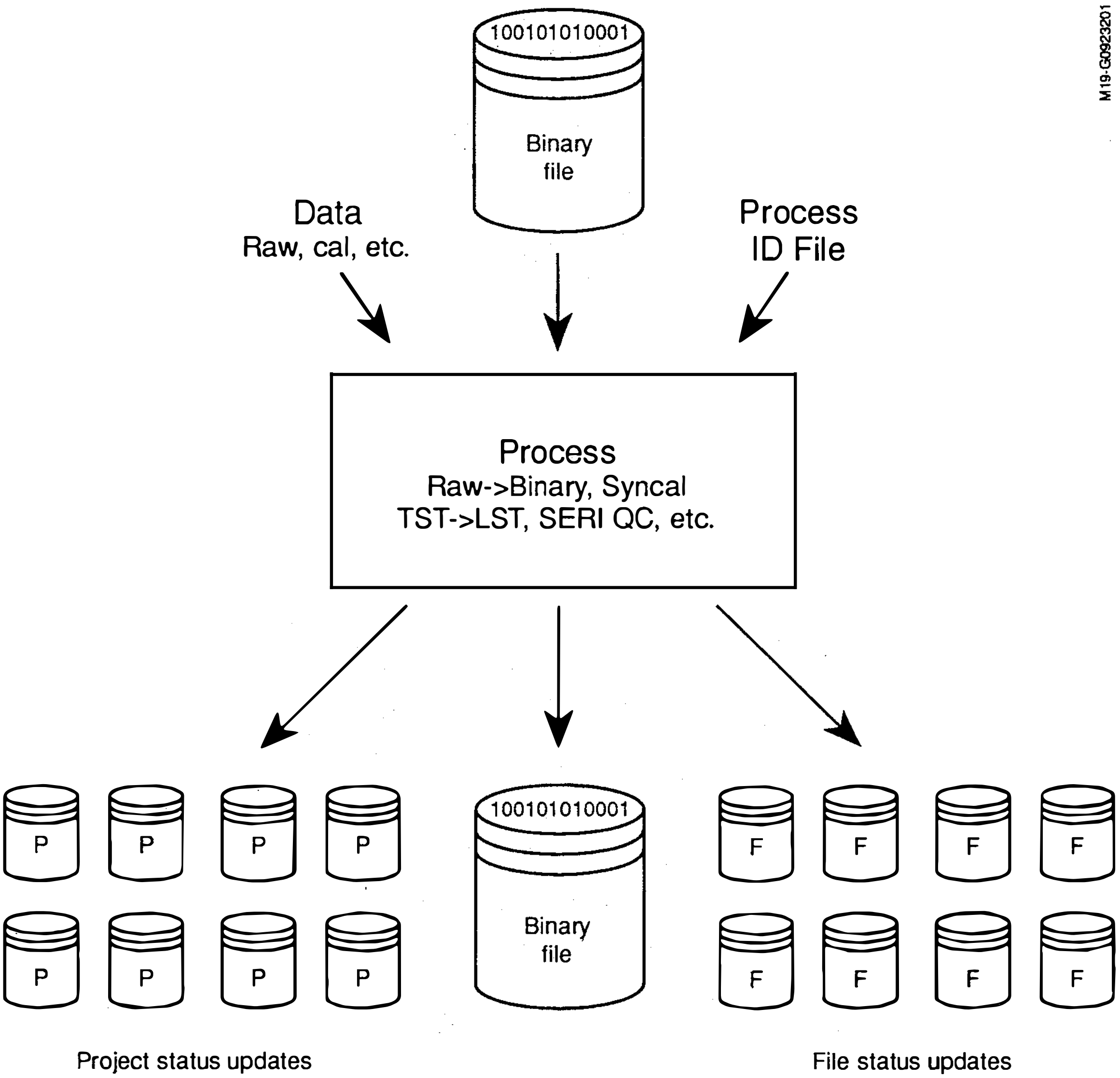

Figure 9-1. Overview of the data base production process.

10.0 Known Imperfections within the NSRDB

The procedures and processes described in the previous sections produced a data base with known quality characteristics, representing significant improvements over the SOLMET/ERSATZ data base. Nevertheless, as might be expected in a project of this magnitude, there are known imperfections. It is likely that there also are unknown imperfections that the data base users will find during the coming years. Those problems of which we are aware at this time are noted in this section.

10.1 Bad Meteorological Data

NCDC's quality control procedures detect and flag data that fail internal consistency checks or exceed preselected climatological limits. When bad data are detected, edited values that pass all quality checks are often inserted immediately after the bad data. Sometimes, however, edited data are not inserted. During the data base production, the last value in the TD-3280 and TD-3210 files for a given hour and element were always used. Therefore, whenever an edited value was available it was used. However, when bad data were not followed by an edited value, the bad data were used.

Although the same interpolation procedures used to replace missing data could have been used to replace bad data, they were not. When this oversight was discovered, it was too late to effect a correction with the time and resources remaining.

Only two instances have been discovered when this problem affected the estimation of solar radiation data, but it is likely that others exist. Abnormally large snow depths, 300 to 900 inches, were found during one month and one year for Kansas City, Missouri, and San Antonio, Texas. These two problems were corrected, of course, but they led to the realization that similar problems of lesser magnitude could go undetected. Although bad meteorological data may be infrequent and may be insignificant in most instances, exceptions undoubtedly exist.

10.2 Using Data from Other Years to Replace Missing Meteorological Data

Special means were employed to maintain serially complete files of solar radiation data when long segments (more than 47 hours) of missing meteorological data were found. The majority of these situations occurred at stations that were not operated during the evening or on weekends, but in some instances a station would be shut down for several weeks or even longer. When these situations occurred, the gaps in the data were filled with data from other years, for the same days of the year. This procedure is described in Section 5.2.1.

Only those elements required to provide input to the METSTAT model were replaced. These elements include total and opaque sky cover, dry bulb temperature, relative humidity, and atmospheric pressure (the last three were used to estimate precipitable water). Because all of the data replacement processes were done one element at a time, it is possible that different elements may have been selected from different years. Therefore, it is possible that this replacement process produced some inconsistencies among the meteorological elements. The impact on model estimates of solar radiation, however, should be minor, because total and opaque sky cover were always checked for consistency, and errors in precipitable water have a relatively small effect on solar radiation estimates.

To mitigate this problem, the station notes in Appendix B contain footnotes that identify the stations for which this replacement method was invoked. Furthermore, any extended periods of time (greater than 10 days in a row) that were replaced in this way have been identified by the beginning and ending dates of the replacement period. NREL intends to investigate the impact of this replacement method in more detail and will notify users of their findings.

10.3 Present Weather Data

For some stations and years, the first field position in the present weather data was inadvertently set to 0 for all hours. The possible presence of a 9 in this position, indicating missing data or no observations made, was lost. Therefore, it is possible that reportable weather events did occur, although the data indicate otherwise.

This did not affect the model estimates of solar radiation because no attempt was made to replace missing present weather data. Interpolation cannot be used to estimate the occurrence of discontinuous events such as rainfall. This problem should be of concern primarily to those using present weather for other applications.

10.4 Incomplete Replacement of Missing Meteorological Data

Some NWS stations limit their operations to daylight hours and, in some instances, to only part of the day. When data for hours at the beginning and ending of the sun-up period were missing for these stations, the meteorological elements needed for model estimates of solar radiation were filled-in through an extrapolation process, but only to sunrise and/or sunset. No reasonable method of filling in nighttime data could be devised. Therefore, users who are concerned with nighttime conditions will have to avoid these stations or devise their own replacement scheme.

We should also note that no replacement of missing data was attempted for discontinuous elements or elements not required for model estimates of solar radiation. This includes dew-point temperature, wind direction and speed, horizontal visibility, ceiling height, present weather, snow depth, and number of days since last snowfall.

10.5 Lack of Aerosol Optical Depth Data

As described in Section 5.2.3, aerosol optical depths were estimated from direct normal solar radiation measurements. Direct normal data were especially sparse for three regions: (1) most of Alaska; (2) all island locations such as Hawaii, Guam, and Puerto Rico; and (3) the industrial heartland of the United States from Chicago to New York City.

In the states of Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York, direct normal data during the period from 1961 to 1990 were available, at NREL and NCDC, only for Pittsburgh, Pennsylvania and Albany, New York. Furthermore, the data from Pittsburgh were sparse and of questionable quality.

Therefore, the model estimates of direct normal and diffuse horizontal solar radiation for these regions must be considered as suspect, perhaps even more suspect than is indicated by the assigned uncertainty values. Fortunately, errors in aerosol optical depth have a relatively small effect on global horizontal values.

10.6 NWS Solar Radiation Measurements from 1981 to 1985

From January 1981 through October 1985, the data collected by NOAA-NWS was not processed or quality controlled. Although NREL attempted to effect a quality assessment of this data during the data base production, it is known that some defects are difficult to detect. One problem of particular concern are errors in time. Large errors in time, resulting in shifts of daytime data to nighttime hours, were easy to detect. However, we know that smaller shifts in time, of one or two hours or even partial hours, could go undetected by our quality assessment software.

NREL's quality assessment software detected measured data with gross errors for all years.
data from NWS stations for

For example, direct normal values for Miami, Florida during July appear to be abnormally low during 1983 and 1984. The mean daily total for July 1984 is 1577 Wh/m^2; nearly three standard deviations (interannual) below the 30-year mean of 3701 Wh/m^2. Since the reported mean sky cover for July 1984 was identical to the 30-year mean, there does not appear to be any logical basis for such a low value. Nevertheless, the hourly data satisfied the quality assessment checks and an uncertainty flag of 2 was assigned to the monthly means.

From an examination of the quality flags for some of the 26 SOLMET stations, the user will find modeled global horizontal data during periods of time when measured data may have been expected. This is particularly true for stations in the western United States from about 1968 to 1975. Although the serial plots of 15-day averages (solar noon values) found in SOLMET Vol. 2 (1979) indicate that data were available, the extraction of hourly values from the strip chart records was sometimes not completed. The station notes in SOLMET Vol. 1 (1978) identify the periods of time when the global horizontal data were modeled. The global horizontal data in the SOLMET/ERSATZ data base for these stations and years were modeled.

During the production of the NSRDB, the SOLMET modeled data were replaced with estimates using the METSTAT model. More specifically, whenever temperature corrected global horizontal data were not found in field 109 of the SOLMET/ERSATZ data records, the value was estimated with the METSTAT model.

10.8 Undetected Problems

We and other NSRDB users may discover other problems. As we learn of these, we will have addendum sheets inserted into this manual to alert users to these problems. Therefore, we encourage NSRDB users to notify NREL or NCDC of any problems or questionable data that are discovered. This will also give us the opportunity to correct these shortcomings in future upgrades of the data base.

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Appendix A

Units Conversion Factors

Appendix A contains a table of units conversion factors to assist users in the conversion of SI data base units to other units of their choice.

Table A-1. Conversion Factors

To Convert From	Into	Multiply By
watt-hours per square meter	joules per square meter	3600.0
watt-hours per square meter	Btu's per square foot	0.3172
watt-hours per square meter	Langleys	0.0860
watt-hours per square meter	calories per square centimeter	0.0860
degree Centigrade	degree Fahrenheit	C° x 1.8 + 32
millibars	pascals	100.0
millibars	atmospheres	0.0009869
millibars	pounds per square inch	0.0145
degrees (angle)	radians	0.017453
meters per second	miles per hour	2.237
meters per second	kilometers per hour	3.6
meters per second	knots	1.944
meters	inches	39.37
meters	feet	3.281
meters	yards	1.094
meters	miles (statute)	0.0006214

Appendix B

Station Notes

Appendix B contains ancillary information for each of the 239 stations in the NSRDB. The station WBAN number, latitude, longitude, elevation (meters), time zone, and the periods of time during which solar radiation data were being collected are all included. Information specific to subsets of stations is provided in footnotes.

Stations for which solar radiation data were collected at a location different from the meteorological instruments are identified. Stations which were moved during the 30-year period of record are also noted.

Appendix B

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
AL Birmingham	13876	N 33 34	W 86 45	192	-6	
AL Huntsville	03856	N 34 39	W 86 46	190	-6	
AL Mobile	13894	N 30 40	W 88 15	67	-6	
AL Montgomery	13895	N 32 17	W 86 24	62	-6	2,5
Global	770109-850728 880331-901231					1
Direct	780120-850728 880331-901231					1
AK Anchorage	26451	N 61 10	W 150 1	35	-10	2
AK Annette	25308	N 55 1	W 131 34	34	-9	2
AK Barrow	27502	N 71 18	W 156 46	4	-10	2,6
	✓ Long term fill from other years used for period from 890321 to 890331. (see Section 10.2)					
AK Bethel	26615	N 60 46	W 161 48	46	-11	5
AK Bettles	26533	N 66 55	W 151 31	205	-10	6
	✓ Long term fill from other years used for period from 890118 to 890130. (see Section 10.2)					
AK Big Delta	26415	N 64 0	W 145 43	388	-10	7
AK Cold Bay	25624	N 55 12	W 162 43	29	-11	
AK Fairbanks	26411	N 64 49	W 147 52	138	-10	2,6
Global	770401-801231					1
AK Gulkana	26425	N 62 9	W 145 26	481	-10	7
	Long term fill from other years used for periods: 730930 to 731201, 760416 to 760428, 761203 to 761229, and 870731 to 870901. (see Section 10.2)					
AK King Salmon	25503	N 58 40	W 156 38	15	-10	
AK Kodiak	25501	N 57 45	W 152 19	34	-10	2,6
	Long term fill from other years used for period from 721130 to 730101. (see Section 10.2) clouds					

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
AK Kotzebue	26616	N 66 52	W 162 37	5	-11	2,6
	Long term fill from other years used for period from 890117 to 890127. (see Section 10.2)					
AK McGrath	26510	N 62 58	W 155 37	103	-10	2,6
	Long term fill from other years used for period from 890115 to 890125. (see Section 10.2)					
AK Nome	26617	N 64 30	W 165 25	7	-11	2,6
	Long term fill from other years used for period from 880901 to 880930. (see Section 10.2)					
AK St Paul Is.	25713	N 57 9	W 170 13	7	-11	
AK Talkeetna	26528	N 62 17	W 150 6	105	-10	6
AK Yakutat	25339	N 59 31	W 139 40	9	-9	2,5
AZ Flagstaff	03103	N 35 7	W 111 40	2135	-7	
AZ Phoenix	23183	N 33 25	W 112 1	339	-7	
Global	520701-751231 770102-850722 880101-901210					
Direct	780509-850722 880101-901229					
AZ Prescott	23184	N 34 39	W 112 25	1531	-7	
AZ Tucson	23160	N 32 7	W 110 55	779	-7	
Global	780101-801231					
Direct	780101-800902					
	Solar radiation data from WEST Associates at Lat N 32 20, Long W 110 54.					
AR Fort Smith	13964	N 35 19	W 94 22	141	-6	
AR Little Rock	13963	N 34 43	W 92 13	81	-6	2,5
CA Arcata	24283	N 40 58	W 124 5	69	-8	6
	Long term fill from other years used for period from 860531 to 860630. (see Section 10.2)					

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
CA Bakersfield	23155	N 35 25	W 119 3	150	-8	
CA Daggett	23161	N 34 52	W 116 46	588	-8	6
Global	760101-801231					1
Direct	760101-801231					1
	Solar radiation data from WEST Associates at Barstow, CA, Lat N 34 53, Long W 117 00. Long term fill from other years used for period from 840930 to 841101 and 850930 to 851031. (see Section 10.2)					
CA Fresno	93193	N 36 46	W 119 43	100	-8	
Global	520701-751231 770118-840928 880511-901231					1
Direct	780721-840928 880511-901231					1
CA Long Beach	23129	N 33 49	W 118 9	17	-8	
Global	810823-841120					1
Direct	810823-841120					1
CA Los Angeles	23174	N 33 55	W 118 24	32	-8	
Global	780615-801231					1
Direct	780615-801231					1
Diffuse	790901-801231					1
	Solar radiation data were obtained by combining data from the NWS station with data from WEST Associates at Lat N 34 04, Long W 118 14. NWS data were used whenever it was available.					
CA Sacramento	23232	N 38 31	W 121 30	8	-8	
CA San Diego	23188	N 32 43	W 117 10	9	-8	2
Global	791017-801231					1
Direct	791017-801231					1
	Solar radiation data from WEST Associates at Lat N 32 43, Long W 117 10.					
CA San Francisco	23234	N 37 37	W 122 22	5	-8	

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
CA Santa Maria	23273	N 34 54	W 120 26	72	-8	
Global	520701-541031 541101-690331					
CO Alamosa	23061	N 37 27	W 105 52	2297	-7	6
Global	780101-801231					1
Direct	780101-801231					1
	Solar radiation data from WEST Associates at Lat N 37 29, Long W 105 52. Long term fill from other years used for period from 650831 to 651001. (see Section 10.2)					
CO Boulder	94019 ~~94918~~	N 40 01	W 105 15	1625	-7	2
Global	770101-851017 880101-900331					1
Direct	780301-851017 880101-900331					1
Diffuse	770803-820429					1
N39 46	Meteorological data from Stapleton Intl. Airport, Denver, CO, Lat ~~N 34 46~~, Long W 104 52.					
CO Colorado Springs	93037	N 38 49	W 104 43	1881	-7	
CO Eagle	23063	N 39 39	W 106 55	1985	-7	3,7
	Long term fill from other years used for periods: 870215 to 870301 and 890331 to 900101. (see Section 10.2)					
CO Grand Junction	23066	N 39 7	W 108 31	1475	-7	2
Global	770407-850712 880404-890929 900823-900831					1
Direct	780701-850712 880404-890929 900801-900831					1
CO Pueblo	93058	N 38 16	W 104 31	1439	-7	
CT Bridgeport	94702	N 41 10	W 73 7	2	-5	5
CT Hartford	14740	N 41 55	W 72 40	55	-5	
~~CU Guantanamo Bay~~	~~11706~~	~~N 19 53~~	~~W 75 9~~	~~16~~	~~-5~~	
DE Wilmington	13781	N 39 40	W 75 35	24	-5	

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
FL Daytona Beach	12834	N 29 10	W 81 3	12	-5	
Global	850802-901231					1
Diffuse	850802-901231					1
	Solar radiation data from Bethune-Cookman College at Lat N 29 11, Long W 81 01.					
FL Jacksonville	13889	N 30 30	W 81 41	9	-5	2
FL Key West	12836	N 24 32	W 81 45	1	-5	6
	Long term fill from other years used for period from 810514 to 810531. (see Section 10.2)					
FL Miami	12839	N 25 47	W 80 16	2	-5	2
Global	520701-751231 770104-851031					1
Direct	780411-851031					1
FL Tallahassee	93805	N 30 22	W 84 22	21	-5	2
Global	520701-751231 770106-801231 880101-901231					1
Direct	780205-801231 880101-901231					1
Diffuse	771026-801231					1
	Solar radiation and meteorological data for Apalachicola and Tallahassee were combined. Apalachicola's data and location (Lat N 29 43, Long W 85 01) were used from 610101 to 751231 and Tallahassee's data and location were used from 760101 to 901231.					
FL Tampa	12842	N 27 58	W 82 31	3	-5	2,5
FL West Palm Beach	12844	N 26 40	W 80 5	6	-5	2
GA Athens	13873	N 33 57	W 83 19	244	-5	
GA Atlanta	13874	N 33 39	W 84 25	315	-5	2
Global	800701-810630					1
Direct	800701-810630					1
	Solar radiation data from the Georgia Institute of Technology at Lat N 33 46, Long W 84 24.					
GA Augusta	03820	N 33 22	W 81 58	45	-5	

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
GA Columbus	93842	N 32 31	W 84 56	136	-5	
GA Macon	03813	N 32 42	W 83 39	110	-5	
GA Savannah	03822	N 32 7	W 81 11	16	-5	
Global	850829-901231					1
Diffuse	850829-901231					1
	Solar radiation data from Savannah State College at Lat N 32 02, Long W 81 04.					
HI Hilo	1504	N 19 43	W 155 4	11	-10	
HI Honolulu	22521	N 21 19	W 157 55	5	-11	
Global	780701-801231					1
Direct	790731-800531					1
HI Kahului	22516	N 20 53	W 156 25	15	-10	
HI Lihue	22536	N 21 58	W 159 21	45	-11	
ID Boise	24131	N 43 34	W 116 13	874	-7	
Global	770112-801231 880101-901231					
Direct	780321-801231 880101-901231					
ID Pocatello	24156	N 42 55	W 112 35	1365	-7	
IL Chicago	94846	N 41 46	W 87 45	190	-6	
IL Moline	14923	N 41 27	W 90 31	181	-6	
IL Peoria	14842	N 40 40	W 89 40	199	-6	2
IL Rockford	94822	N 42 12	W 89 5	221	-6	5
IL Springfield	93822	N 39 49	W 89 40	187	-6	5
IN Evansville	93817	N 38 2	W 87 31	118	-6	
IN Fort Wayne	14827	N 41 0	W 85 11	252	-5	

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
IN Indianapolis	93819	N 39 43	W 86 16	246	-5	6
Global	770814-801231					1
Direct	800801-800831					1
	Long term fill from other years used for period from 651231 to 660131. (see Section 10.2)					
IN South Bend	14848	N 41 42	W 86 19	236	-5	
IA Des Moines	14933	N 41 31	W 93 39	294	-6	
IA Mason City	14940	N 43 9	W 93 19	373	-6	6
IA Sioux City	14943	N 42 24	W 96 22	336	-6	2
IA Waterloo	94910	N 42 32	W 92 24	265	-6	6
	Long term fill from other years used for period from 811220 to 811231. (see Section 10.2)					
KS Dodge City	13985	N 37 46	W 99 58	787	-6	2,5
Global	520701-751231 770101-801231 880331-90101					1
Direct	780719-801231 880331-901014					1
KS Goodland	23065	N 39 22	W 101 41	1124	-7	
KS Topeka	13996	N 39 4	W 95 37	270	-6	2
KS Wichita	03928	N 37 39	W 97 25	408	-6	
KY Covington (Cin	93814	N 39 4	W 84 40	271	-5	
KY Lexington	93820	N 38 1	W 84 35	301	-5	
KY Louisville	93821	N 38 10	W 85 43	149	-5	5
LA Baton Rouge	13970	N 30 31	W 91 9	23	-6	
LA Lake Charles	03937	N 30 7	W 93 13	3	-6	2
Global	520701-751231 770107-801231 880101-901231					1
Direct	790513-801231 880101-901228					1
LA New Orleans	12916	N 29 58	W 90 15	3	-6	
LA Shreveport	13957	N 32 28	W 93 49	79	-6	2

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
~~ME Brunswick~~	~~14611~~	~~N 43 52~~	~~W 69 55~~	~~22~~	~~-5~~	9
ME Caribou	14607	N 46 52	W 68 1	190	-5	2
Global	520701-751231 770901-850926 880102-901225					1
Direct	780301-850926 880102-901225					1
ME Portland	14764	N 43 39	W 70 19	19	-5	2
MD Baltimore	93721	N 39 10	W 76 40	47	-5	
MA Boston	14739	N 42 22	W 71 1	5	-5	
Global	520701-681130					1
MA Worchester	94746	N 42 16	W 71 52	301	-5	
MI Alpena	94849	N 45 4	W 83 34	210	-5	5
MI Detroit	94847	N 42 25	W 83 1	191	-5	
MI Flint	14826	N 42 58	W 83 43	233	-5	2
MI Grand Rapids	94860	N 42 52	W 85 31	245	-5	
MI Houghton	94814	N 47 10	W 88 30	329	-5	
MI Lansing	14836	N 42 46	W 84 35	256	-5	
MI Muskegon	14840	N 43 10	W 86 15	191	-5	
MI Sault Ste. Marie	14847	N 46 28	W 84 22	221	-5	2
MI Traverse City	14850	N 44 43	W 85 34	192	-5	6
MN Duluth	14913	N 46 49	W 92 10	432	-6	
MN Int'l Falls	14918	N 48 34	W 93 22	361	-6	2
MN Minneapolis/St. Paul	14922	N 44 52	W 93 13	255	-6	2

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
MN Rochester	14925	N 43 55	W 92 30	402	-6	
MN Saint Cloud	14926	N 45 32	W 94 4	313	-6	2
MS Jackson	03940	N 32 19	W 90 4	101	-6	2
MS Meridian	13865	N 32 19	W 88 45	94	-6	
MO Columbia	03945	N 38 49	W 92 13	270	-6	2
Global	520701-700123 700124-751231 880526-901231					1
Direct	880526-901231					1
MO Kansas City	03947	N 39 17	W 94 43	315	-6	6
	Long term fill from other years used for period from 720930 to 721231. (see Section 10.2)					
MO Springfield	13995	N 37 13	W 93 22	387	-6	
MO St. Louis	13994	N 38 45	W 90 22	172	-6	
MT Billings	24033	N 45 47	W 108 31	1088	-7	
MT Cut Bank	24137	N 48 35	W 112 22	1170	-7	3,7
	Long term fill from other years used for periods: 841003 to 841101, 860531 to 860701, 870215 to 870301, and 890228 to 900101. (see Section 10.2)					
MT Glasgow	94008	N 48 13	W 106 37	700	-7	2
MT Great Falls	24143	N 47 28	W 111 22	1116	-7	2
Global	520701-751231 770101-850819 880105-901231					1
Direct	781201-850819 880105-901231					1
MT Helena	24144	N 46 35	W 112 0	1188	-7	
MT Kalispell	24146	N 48 17	W 114 16	904	-7	
MT Lewistown	24036	N 47 2	W 109 26	1264	-8	7
MT Miles City	24037	N 46 25	W 105 52	803	-7	4
MT Missoula	24153	N 46 55	W 114 4	972	-7	

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
NE Grand Island	14935	N 40 58	W 98 19	566	-6	
NE Norfolk	14941	N 41 58	W 97 25	471	-6	
NE North Platte	24023	N 41 7	W 100 40	849	-6	2
NE Omaha	94918	N 41 22	W 96 31	404	-6	2,5
Global	570601-751231 770117-850919 880101-901231					1
Direct	781116-850919 880101-901231					1
NE Scottsbluff	24028	N 41 52	W 103 35	1206	-7	
NV Elko	24121	N 40 49	W 115 46	1547	-8	6
	Long term fill from other years used for period from 641109 to 641231. (see Section 10.2)					
NV Ely	23154	N 39 16	W 114 50	1906	-8	2
Global	511201-751231 770304-841017 880309-90123					1
Direct	780223-841017 880309-901231					1
Diffuse	770531-820331					1
NV Las Vegas	23169	N 36 4	W 115 10	664	-8	2
Global	770201-850707 880101-901231					1
Direct	780213-850707 880101-901231					1
NV Reno	23185	N 39 30	W 119 46	1341	-8	
NV Tonopah	23153	N 38 4	W 117 7	1653	-8	6
	Long term fill from other years used for period from 841211 to 850101. (see Section 10.2)					
NV Winnemucca	24128	N 40 54	W 117 48	1323	-8	2
NH Concord	14745	N 43 12	W 71 30	105	-5	
NJ Atlantic City	93730	N 39 27	W 74 34	20	-5	
NJ Newark	14734	N 40 42	W 74 10	9	-5	5

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
NM Albuquerque	23050	N 35 2	W 106 37	1619	-7	2
Global	520701-751231 770101-851031 880101-901231					1
Direct	780201-851031 880101-901231					1
Diffuse	770915-820504					1
NM Tucumcari	23048	N 35 10	W 103 35	1231	-7	3,6
	Long term fill from other years used for period from 8910301 to 900101. (see Section 10.2)					
NY Albany	14735	N 42 45	W 73 48	89	-5	2
Global	790101-820331					1
Direct	790101-820331					1
Diffuse	790101-820331					1
	Solar radiation data from the State University of New York at Lat N 42 42, Long W 73 50.					
NY Binghamton	04725	N 42 13	W 75 58	499	-5	
NY Buffalo	14733	N 42 55	W 78 43	215	-5	2,5
NY Massena	94725	N 44 55	W 74 50	63	-5	6
	Long term fill from other years used for period from 721204 to 721215. (see Section 10.2)					
NY New York City	94728	N 40 46	W 73 58	57	-5	
Global	520701-751231					1
	Solar radiation data from Central Park at location noted; meteorological data from La Guardia Airport at Lat N 40 46, Long W 73 54.					
NY Rochester	14768	N 43 7	W 77 40	169	-5	
NY Syracuse	14771	N 43 7	W 76 7	124	-5	5
NC Asheville	03812	N 35 25	W 82 31	661	-5	6
	Long term fill from other years used for period from 891025 to 891231. (see Section 10.2)					
NC Cape Hatteras	93729	N 35 16	W 75 33	2	-5	
Global	520701-751231					1

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
NC Charlotte	13881	N 35 13	W 80 55	234	-5	
NC Greensboro	13723	N 36 4	W 79 56	270	-5	5
NC Raleigh/Durham	13722	N 35 52	W 78 46	134	-5	
Global	770701-801231 880101-901229					1
Direct	781106-801130 880101-901230					1
NC Wilmington	13748	N 34 16	W 77 54	9	-5	
ND Bismarck	24011	N 46 46	W 100 45	502	-6	2,5
Global	520701-751231 770101-801231 880101-901016					1
Direct	780601-801231 880101-901016					1
Diffuse	770901-801231					1
ND Fargo	14914	N 46 54	W 96 48	274	-6	
ND Minot	24013	N 48 16	W 101 16	522	-6	3,6
	Long term fill from other years used for period from ~~900~~627 to 90~~11~~30. (see Section 10.2) 10/28/89 - 12/31/89					
OH Akron/Canton	14895	N 40 55	W 81 25	377	-5	
OH Cleveland	14820	N 41 24	W 81 50	245	-5	5
OH Columbus	14821	N 40 0	W 82 52	254	-5	
OH Dayton	93815	N 39 54	W 84 13	306	-5	2
OH Mansfield	14891	N 40 49	W 82 31	395	-5	
OH Toledo	94830	N 41 35	W 83 48	211	-5	
OH Youngstown	14852	N 41 16	W 80 40	361	-5	
OK Oklahoma City	13967	N 35 24	W 97 35	397	-6	
OK Tulsa	13968	N 36 12	W 95 54	206	-6	5
OR Astoria	94224	N 46 9	W 123 52	7	-8	

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
OR Burns	94185	N 43 34	W 119 3	1271	-8	3,7
Global	790401-901231					1
Direct	790401-901231					1
	Solar radiation data from the University of Oregon; collected at Lat N 43 51, Long W 119 01.					
OR Eugene	24221	N 44 7	W 123 13	109	-8	
Global	750401-901231					1
Direct	771201-901231					1
	Solar radiation data from the University of Oregon; collected at Lat N 44 03, Long W 123 04.					
OR Medford	24225	N 42 22	W 122 52	396	-8	2,5
Global	511201-751231 770103-841231					1
Direct	780301-841231					1
OR North Bend	24284	N 43 25	W 124 15	5	-8	7
	Long term fill from other years used for period from 900627 to 901130. (see Section 10.2)					
OR Pendleton	24155	N 45 40	W 118 50	456	-8	2
OR Portland	24229	N 45 35	W 122 35	12	-8	2
Global	800801-850930					1
Direct	800801-850930					1
	Solar radiation data from the University of Oregon; collected at Lat N 45 27, Long W 122 38.					
OR Redmond	24230	N 44 16	W 121 9	940	-8	7
Global	800101-841231					1
	Solar radiation data from the University of Oregon; collected at Bend, OR, Lat N 44 04, Long W 121 17.					
OR Salem	24232	N 44 55	W 123 1	61	-8	2

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
PI Guam	41415	N 13 33	W-144 49	110	10	
Global	780701-840831 880101-901231					1
Direct	781107-840831 880101-901231					1
PA Allentown	14737	N 40 39	W 75 25	117	-5	
PA Bradford	04751	N 41 47	W 78 37	600	-5	6
	Long term fill from other years used for period from 791028 to 791115 and 800830 to 801009. (see Section 10.2)					
PA Erie	14860	N 42 4	W 80 10	225	-5	
PA Harrisburg	14751	N 40 13	W 76 50	106	-5	7
	Long term fill from other years used for periods: 810305 to 810331 and 840515 to 841106. (see Section 10.2) 8/31/79 – 10/1/80					
PA Philadelphia	13739	N 39 52	W 75 15	9	-5	
PA Pittsburgh	94823	N 40 30	W 80 13	373	-5	2,6
Global	770901-801231 880131-901220					1
Direct	771202-801231 880131-901220					1
	Long term fill from other years used for period from 790208 to 790220. (see Section 10.2)					
PA Wilkes-Barre/S	14777	N 41 19	W 75 43	289	-5	
PA Williamsport	14778	N 41 16	W 77 3	243	-5	6
✓	Long term fill from other years used for period from 820728 to 820810. (see Section 10.2)					
PR San Juan	11641	N 18 25	W 66 0	19	-4	5
Global	790109-7912311					1
Direct	790118-800930					1
RI Providence	14765	N 41 43	W 71 25	19	-5	5
SC Charleston	13880	N 32 54	W 80 1	12	-5	2,5
Global	520701-751231					1
SC Columbia	13883	N 33 57	W 81 7	69	-5	
SC Greenville	03870	N 34 54	W 82 13	296	-5	

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
SD Huron	14936	N 44 22	W 98 13	393	-6	
SD Pierre	24025	N 44 22	W 100 16	526	-6	5
SD Rapid City	24090	N 44 2	W 103 4	966	-7	2
SD Sioux Falls	14944	N 43 34	W 96 43	435	-6	
TN Bristol	13877	N 36 28	W 82 24	459	-5	
TN Chattanooga	13882	N 35 1	W 85 11	210	-5	
TN Knoxville	13891	N 35 49	W 83 58	299	-5	
TN Memphis	13893	N 35 2	W 89 58	87	-6	
TN Nashville	13897	N 36 7	W 86 40	180	-6	2
Global	520701-751231 880101-901231					1
Direct	880101-901231					1
TX Abliene	13962	N 32 25	W 99 40	534	-6	
TX Amarillo	23047	N 35 13	W 101 41	1098	-6	
TX Austin	13958	N 30 17	W 97 41	189	-6	
TX Brownsville	12919	N 25 53	W 97 25	6	-6	2
Global	520701-751231 770105-850331 880103-901231					1
Direct	770609-850331 880103-901231					1
Diffuse	770616-820411					1
TX Corpus Christi	12924	N 27 46	W 97 30	13	-6	2
TX El Paso	23044	N 31 47	W 106 24	1194	-7	2
Global	520701-751231 770117-801231 880101-90123					1
Direct	780414-801231 880101-901231					1
TX Fort Worth	03927	N 32 49	W 97 3	164	-6	2
Global	520701-740731					1
TX Houston	12960	N 29 58	W 95 22	33	-6	7
	Long term fill from other years used for period from 690531 to 7001201. (see Section 10.2)					

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
TX Lubbock	23042	N 33 39	W 101 49	988	-6	
TX Lufkin	93987	N 31 13	W 94 45	96	-6	6
	Long term fill from other years used for period from 890930 to 891201. (see Section 10.2)					
TX Midland/Odessa	23023	N 31 55	W 102 11	871	-6	2,5
Global	770101-801231 880101-901230					1
Direct	780301-801231 880101-901230					1
TX Port Arthur	12917	N 29 57	W 94 1	7	-6	
TX San Angelo	23034	N 31 22	W 100 30	582	-6	
TX San Antonio	12921	N 29 31	W 98 28	242	-6	5
Global	810401-820331					1
Direct	810401-820331					1
	Solar radiation data from Trinity University; collected at Lat N 29 15 Long W 98 30.					
TX Victoria	12912	N 28 51	W 96 55	32	-6	2,7
TX Waco	13959	N 31 37	W 97 13	155	-6	
TX Wichita Falls	13966	N 33 58	W 98 28	314	-6	
UT Cedar City	93129	N 37 42	W 113 5	1712	-7	
UT Salt Lake City	24127	N 40 46	W 111 58	1288	-7	2
Global	770103-850719 880101-901231					1
Direct	781101-850719 880101-901231					1
VT Burlington	14742	N 44 28	W 73 9	104	-5	5
Global	770103-850109 880101-901231					1
Direct	780301-850109 880101-901231					1

Appendix B (Continued)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
VA Lynchburg	13733	N 37 19	W 79 11	279	-5	
VA Norfolk	13737	N 36 54	W 76 11	9	-5	
VA Richmond	13740	N 37 30	W 77 19	50	-5	
VA Roanoke	13741	N 37 19	W 79 58	358	-5	
VA Sterling	93738	N 38 57	W 77 26	82	-5	2
Global	530801--751231 770112-841231 880101-880128					1
Direct	790101-841231 880101-880105					1
Diffuse	780706-820516					1
WA Olympia	24227	N 46 58	W 122 54	61	-8	
WA Quillayute	94240	N 47 57	W 124 33	55	-8	
WA Seattle/Tacoma	24233	N 47 27	W 122 18	122	-8	2
Global	511201-751231 770511-850925 880101-901231					1
Direct	780516-850925 880101-901231					1
Diffuse	770511-820510					1
WA Spokane	24157	N 47 37	W 117 31	721	-8	2
~~WA Tatoosh Island~~	~~24240~~	~~N 48 22~~	~~W 124 43~~	~~33~~	~~-8~~	
WA Yakima	24243	N 46 34	W 120 31	325	-8	2
WV Charleston	13866	N 38 22	W 81 35	290	-5	
WV Elkins	13729	N 38 52	W 79 50	594	-5	
WV Huntington	03860	N 38 22	W 82 33	255	-5	7
	Long term fill from other years used for period from 610103 to 611201. (see Section 10.2)					
WI Eau Claire	14991	N 44 52	W 91 28	273	-6	
WI Green Bay	14898	N 44 28	W 88 7	214	-6	2
WI La Crosse	14920	N 43 52	W 91 15	205	-6	5

Appendix B (Concluded)

Sites	WBAN	Lat	Long	Elev/ Meters	TZ	Footnotes
WI Madison	14837	N 43 7	W 89 19	262	-6	5
Global	520701-751231 770112-851031 880101-901231					1
Direct	770930-851031 880101-901231					1
WI Milwaukee	14839	N 42 57	W 87 54	211	-6	
WY Casper	24089	N 42 55	W 106 28	1612	-7	
WY Cheyenne	24018	N 41 9	W 104 49	1872	-7	
WY Lander	24021	N 42 49	W 108 43	1696	-7	2,5
Global	770101-850924 880114-901231					1
Direct	780601-850924 880114-901231					1
WY Rock Springs	24027	N 41 35	W-109 4	2056	-7	5
WY Sheridan	24029	N 44 46	W-106 58	1209	-7	

Footnotes:

1. Indicates periods when solar radiation was being measured.
2. Precipitable water values were obtained from radiosonde data for one or more years.
3. The period of record for this station is less than 30 years (1961-1988).
4. The period of record for this station is less than 30 years (1961-1989).
5. In order to maintain a serially complete record of solar radiation, one or more of the meteorological elements required as input to the METSTAT model (cloud cover and precipitable water (derived from temperature, relative humidity and pressure)) were obtained from other years for 1 to 10 days using the procedure described in Section 5.2.1.
6. Same as 5 except 11 to 100 days of data were obtained in this manner.
7. Same as 5 except 101 to 400 days of data were obtained in this manner.

Appendix C

30-Year Summary of Quality Flags

Appendix C provides a 30-year summary of hourly solar radiation quality flags for each of the 56 Primary stations and for a representative sample of Secondary stations. These summaries can be used to identify stations with the most measured data and to determine the percentages of the data that fall into the various uncertainty ranges. Tables 3-6 and 3-7 are duplicated here as Tables C-3 and C-4 for ready identification of the source and uncertainty flags.

Because Secondary stations have no measured data, the source and uncertainty flags for all 183 stations are quite similar. Therefore, summary quality statistics are included for only five Secondary stations. The stations selected are quite representative of all 183 stations. It is likely that the large uncertainties for solar radiation data for Wilkes-Barre, Penn. are due at least in part to the large uncertainty for aerosol optical depths (50%) for this region. On the other hand, the low uncertainty for aerosol optical depths (10%) for the central valley of California is likely related to the small uncertainties for the solar radiation data for Bakersfield, Calif. Many factors, of course, contribute to the uncertainties for these and all other stations.

Stations appear in the order of their WBAN numbers. Table 1-2 in Part 1 can be used to find the WBAN numbers of individual Primary stations.

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
03822 SAVANNAH, GA																			
GLOBAL	0	0	166	0	0	546	288	0	0	0	0	0	0	511	390	99	0	0	0
DIRECT	0	0	0	0	153	559	288	0	0	0	0	0	0	749	116	135	0	0	0
DIFFUSE	0	153	0	0	0	559	288	0	0	0	0	0	0	114	787	99	0	0	0
03927 FORT WORTH, TX																			
GLOBAL	0	0	0	338	0	0	0	485	177	0	0	0	0	670	283	47	0	0	0
DIRECT	0	0	0	0	0	0	0	666	334	0	0	0	0	736	171	93	0	0	0
DIFFUSE	0	0	0	0	0	0	0	666	334	0	0	0	0	0	907	93	0	0	0
03937 LAKE CHARLES, LA																			
GLOBAL	0	124	0	332	0	448	96	0	0	0	0	0	4	706	262	29	0	0	0
DIRECT	0	57	0	0	0	701	242	0	0	0	0	0	34	877	3	86	0	0	0
DIFFUSE	0	0	0	0	57	701	242	0	0	0	0	0	0	28	882	89	0	0	0
03945 COLUMBIA, MO																			
GLOBAL	0	120	14	352	0	470	45	0	0	0	0	0	28	715	248	10	0	0	0
DIRECT	0	87	0	0	0	779	134	0	0	0	0	0	55	905	4	36	0	0	0
DIFFUSE	0	0	0	0	87	779	134	0	0	0	0	0	0	48	911	41	0	0	0
11641 SAN JUAN, PR																			
GLOBAL	0	25	0	0	0	0	0	677	298	0	0	0	0	332	482	186	0	0	0
DIRECT	0	30	0	0	0	0	0	672	298	0	0	0	11	416	387	186	0	0	0
DIFFUSE	0	0	0	0	16	0	0	686	298	0	0	0	0	11	802	187	0	0	0
12834 DAYTONA BEACH, FL																			
GLOBAL	0	135	0	0	0	499	366	0	0	0	0	0	21	474	350	155	0	0	0
DIRECT	0	0	0	0	135	499	366	0	0	0	0	0	0	710	117	173	0	0	0
DIFFUSE	0	135	0	0	0	499	366	0	0	0	0	0	0	92	752	156	0	0	0
12839 MIAMI, FL																			
GLOBAL	0	173	0	326	0	451	50	0	0	0	0	0	21	600	353	27	0	0	0
DIRECT	0	144	0	0	0	746	109	0	0	0	0	0	47	870	25	58	0	0	0
DIFFUSE	0	0	0	0	144	747	109	0	0	0	0	0	0	44	872	82	2	0	0

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations (Continued)

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
12919 BROWNSVILLE, TX																			
GLOBAL	0	212	0	336	1	343	108	0	0	0	0	0	58	649	249	44	0	0	0
DIRECT	0	178	0	0	23	531	269	0	0	0	0	40	51	761	35	112	0	0	0
DIFFUSE	0	99	0	0	01	531	269	0	0	0	0	0	0	104	769	126	1	0	0
12921 SAN ANTONIO, TX																			
GLOBAL	0	0	31		0	647	322	0	0	0	0	0	0	490	402	108	0	0	0
DIRECT	0	28	0	0	650	322	0	0	0	0	0	0	21	871	0	108	0	0	0
DIFFUSE	0	0	0	0	28	650	322	0	0	0	0	0	0	8	883	108	0	0	0
13722 RALEIGH, NC																			
GLOBAL	0	130	0	737	133	0	0	0	0	0	0	559	401	41	0	0	0	0	0
DIRECT	0	81	0	0	0	785	133	0	0	0	0	0	27	925	8	41	0	0	0
DIFFUSE	0	0	0	0	81	786	133	0	0	0	0	0	0	21	930	48	1	0	0
13874 ATLANTA, GA																			
GLOBAL	0	21	8	0	0	960	11	0	0	0	0	0	0	536	461	3	0	0	0
DIRECT	0	29	0	0	0	960	11	0	0	0	0	0	18	978	1	3	0	0	0
DIFFUSE	0	0	0	0	29	960	11	0	0	0	0	0	0	11	985	4	0	0	0
13880 CHARLESTON, SC																			
GLOBAL	0	0	0	362	0	0	0	554	84	0	0	0	0	669	304	27	0	0	0
DIRECT	0	0	0	0	0	0	0	822	178	0	0	0	0	698	242	60	0	0	0
DIFFUSE	0	0	0	0	0	0	0	822	178	0	0	0	0	0	940	60	0	0	0
13895 MONTGOMERY, AL																			
GLOBAL	0	202	0	0	0	687	111	0	0	0	0	0	5	557	399	38	0	0	0
DIRECT	0	172	0	0	0	717	111	0	0	0	0	0	78	860	25	37	0	0	0
DIFFUSE	0	0	0	0	172	717	111	0	0	0	0	0	0	73	864	60	3	0	0
13897 NASHVILLE, TN																			
GLOBAL	0	165	0	340	0	461	34	0	0	0	0	0	61	700	231	8	0	0	0
DIRECT	0	143	0	0	0	745	111	0	0	0	0	0	98	862	5	35	0	0	0
DIFFUSE	0	0	0	0	143	745	111	0	0	0	0	0	0	91	868	40	0	0	0
13985 DODGE CITY, KS																			
GLOBAL	0	130	38	338	0	447	47	0	0	0	0	0	3	716	267	15	0	0	0
DIRECT	0	110	0	0	0	734	156	0	0	0	0	0	50	897	6	48	0	0	0
DIFFUSE	0	0	0	0	110	734	156	0	0	0	0	0	0	32	909	58	0	0	0

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations (Continued)

(Values are in percent (tenths) of all daylight hours.)

		Source Flags								Uncertainty Flags									
	?		B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
14607 CARIBOU, ME																			
GLOBAL	0	241	0	246	0	341	172	0	0	0	0	0	12	674	270	44	0	0	0
DIRECT	0	232	0	0	0	492	276	0	0	0	0	0	91	803	32	74	0	0	0
DIFFUSE	0	0	0	0	231	493	276	0	0	0	0	0	0	83	809	106	1	0	0
14735 ALBANY, NY																			
GLOBAL	0	0	93	0	0	745	163	0	0	0	0	0	0	508	442	50	0	0	0
DIRECT	0	92	0	0	0	745	163	0	0	0	0	38	23	887	1	50	0	0	0
DIFFUSE	0	91	0	0	1	745	163	0	0	0	0	0	0	62	888	50	0	0	0
14739 BOSTON, MA																			
GLOBAL	0	0	0	163	0	0	0	798	39	0	0	0	0	601	390	9	0	0	0
DIRECT	0	0	0	0	0	0	0	910	90	0	0	0	0	776	200	24	0	0	0
DIFFUSE	0	0	0	0	0	0	0	910	90	0	0	0	0	0	976	24	0	0	0
14742 BURLINGTON, VT																			
GLOBAL	0	168	0	0	0	674	158	0	0	0	0	0	0	528	426	47	0	0	0
DIRECT	0	148	0	0	0	695	158	0	0	0	0	0	42	885	28	46	0	0	0
DIFFUSE	0	0	0	0	142	701	158	0	0	0	0	0	0	38	890	71	1	0	0
14837 MADISON, WI																			
GLOBAL	0	254	0	290	0	389	67	0	0	0	0	0	0	672	307	20	0	0	0
DIRECT	0	211	0	0	0	609	180	0	0	0	0	0	26	871	53	49	0	0	
DIFFUSE	0	0	0	0	210	610	180	0	0	0	0	0	0	20	871	106	3	0	0
22521 HONOLULU, HI																			
GLOBAL	0	19	0	0	0	0	0	687	294	0	0	0	0	339	483	177	0	0	0
DIRECT	0	0	0	0	0	0	0	706	294	0	0	0	0	438	385	177	0	0	0
DIFFUSE	0	0	0	0	0	0	0	706	294	0	0	0	0	0	823	177	0	0	0
23023 MIDLAND, TX																			
GLOBAL	0	0	102	0	0	717	181	0	0	0	0	0	0	537	412	51	0	0	0
DIRECT	0	83	0	0	0	735	181	0	0	0	0	0	48	897	3	51	0	0	0
DIFFUSE	0	0	0	0	83	736	181	0	0	0	0	0	0	19	922	59	0	0	0
23044 EL PASO, TX																			
GLOBAL	0	200	0	419	0	352	30	0	0	0	0	0	24	760	203	13	0	0	0
DIRECT	0	164	0	0	0	678	158	0	0	0	0	0	97	851	7	44	0	0	0
DIFFUSE	0	0	0	0	164	678	158	0	0	0	0	0	0	88	860	52	1	0	0

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations (Continued)

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
23050 ALBUQUERQUE, NM																			
GLOBAL	0	213	52	384	0	304	46	0	0	0	0	0	95	672	214	19	0	0	0
DIRECT	0	233	0	0	12	577	178	0	0	0	0	61	86	773	26	54	0	0	0
DIFFUSE	0	108	0	0	137	577	178	0	0	0	0	0	0	129	801	69	1	0	0
23061 ALAMOSA, CO																			
GLOBAL	0	63	0	0	0	547	390	0	0	0	0	0	21	478	361	140	0	0	0
DIRECT	0	62	0	0	0	547	391	0	0	0	0	0	44	815	1	140	0	0	0
DIFFUSE	0	0	0	0	62	547	391	0	0	0	0	0	0	44	815	141	0	0	0
23066 GRAND JUNCTION, CO																			
GLOBAL	0	112	30	0	0	594	264	0	0	0	0	0	3	496	408	92	0	0	0
DIRECT	0	108	0	0	0	628	264	0	0	0	0	0	33	851	30	86	0	0	0
DIFFUSE	0	0	0	0	104	632	264	0	0	0	0	0	0	27	853	117	3	0	0
23154 ELY, NV																			
GLOBAL	0	193	0	143	1	432	231	0	0	0	0	0	26	571	320	83	0	0	0
DIRECT	0	157	0	0	23	547	273	0	0	0	0	16	46	794	48	95	0	0	0
DIFFUSE	0	60	0	0	117	550	273	0	0	0	0	0	0	72	810	117	1	0	0
23160 TUCSON, AZ																			
GLOBAL	0	0	74	0	0	618	308	0	0	0	0	0	0	557	376	67	0	0	0
DIRECT	0	58	0	0	0	623	319	0	0	0	0	0	42	887	1	69	0	0	0
DIFFUSE	0	0	0	0	57	623	319	0	0	0	0	0	0	34	894	72	0	0	0
23161 DAGGETT, CA																			
GLOBAL	0	164	0	0	0	572	264	0	0	0	0	0	124	513	300	63	0	0	0
DIRECT	0	162	0	0	0	573	265	0	0	0	0	0	125	810	1	63	0	0	0
DIFFUSE	0	0	0	0	162	573	265	0	0	0	0	0	0	125	811	64	0	0	0
23169 LAS VEGAS, NV																			
GLOBAL	0	0	286	0	0	449	264	0	0	0	0	0	0	523	412	65	0	0	0
DIRECT	0	257	0	0	0	478	264	0	0	0	0	0	121	788	31	61	0	0	0
DIFFUSE	0	0	0	0	256	480	264	0	0	0	0	0	0	40	843	115	3	0	0
23174 LOS ANGELES, CA																			
GLOBA	0	63	17	0	0	919	0	0	0	0	0	0	25	583	392	0	0	0	0
DIRECT	0	77	0	0	1	921	0	0	0	0	0	13	42	942	3	0	0	0	0
DIFFUSE	0	40	0	0	38	921	0	0	0	0	0	0	0	51	946	2	0	0	0

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations (Continued)

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
23183 PHOENIX, AZ																			
GLOBAL	0	62	250	188	0	372	129	0	0	0	0	0	0	656	313	31	0	0	0
DIRECT	0	278	0	0	0	544	178	0	0	0	0	0	153	793	15	40	0	0	0
DIFFUSE	0	0	0	0	276	546	178	0	0	0	0	0	0	41	894	64	1	0	0
23188 SAN DIEGO, CA																			
GLOBAL	0	32	0	0	0	647	321	0	0	0	0	0	17	553	340	90	0	0	0
DIRECT	0	29	0	0	0	648	323	0	0	0	0	0	21	888	1	90	0	0	0
DIFFUSE	0	0	0	0	29	648	323	0	0	0	0	0	0	21	888	91	0	0	0
23273 SANTA MARIA, CA																			
GLOBAL	0	0	0	134	0	0	0	509	357	0	0	0	0	631	285	84	0	0	0
DIRECT	0	0	0	0	0	0	0	607	393	0	0	0	0	814	94	92	0	0	0
DIFFUSE	0	0	0	0	0	0	0	607	393	0	0	0	0	0	908	92	0	0	0
24011 BISMARCK, ND																			
GLOBAL	0	122	55	356	0	436	31	0	0	0	0	0	55	644	290	11	0	0	0
DIRECT	0	133	0	0	27	731	109	0	0	0	0	46	22	856	40	37	0	0	0
DIFFUSE	0	104	0	0	55	732	109	0	0	0	0	0	0	75	866	57	2	0	0
24021 LANDER, WY																			
GLOBAL	0	193	76	0	0	468	263	0	0	0	0	0	12	467	410	111	0	0	0
DIRECT	0	236	0	0	0	501	263	0	0	0	0	0	73	787	31	110	0	0	0
DIFFUSE	0	0	0	0	235	502	263	0	0	0	0	0	0	47	796	155	1	0	0
24127 SALT LAKE CITY, UT																			
GLOBAL	0	279	0	0	0	721	0	0	0	0	0	0	2	571	425	2	0	0	0
DIRECT	0	243	0	0	0	757	0	0	0	0	0	0	90	880	29	1	0	0	0
DIFFUSE	0	0	0	0	242	758	0	0	0	0	0	0	0	73	892	32	2	0	0
24131 BOISE, ID																			
GLOBAL	0	190	0	0	0	652	157	0	0	0	0	0	20	578	361	41	0	0	0
DIRECT	0	170	0	0	0	673	157	0	0	0	0	0	110	846	3	41	0	0	0
DIFFUSE	0	0	0	0	169	673	157	0	0	0	0	0	0	102	853	44	0	0	0
24143 GREAT FALLS, MT																			
GLOBAL	0	115	115	157	0	390	223	0	0	0	0	0	0	520	393	87	0	0	0
DIRECT	0	186	0	0	0	550	264	0	0	0	0	0	64	803	32	100	0	0	0
DIFFUSE	0	0	0	0	185	551	264	0	0	0	0	0	0	38	825	135	2	0	0

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations (Continued)

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
24221 EUGENE, OR																			
GLOBAL	0	464	0	0	0	288	248	0	0	0	0	0	215	527	201	56	0	0	0
DIRECT	0	419	0	0	0	304	277	0	0	0	0	0	307	626	2	65	0	0	0
DIFFUSE	0	0	0	0	417	305	278	0	0	0	0	0	0	305	628	67	0	0	0
24225 MEDFORD, OR																			
GLOBAL	0	0	195	173	0	504	128	0	0	0	0	0	0	620	353	27	0	0	0
DIRECT	0	166	0	0	0	677	157	0	0	0	0	0	82	873	14	31	0	0	0
DIFFUSE	0	0	0	0	166	677	157	0	0	0	0	0	0	27	918	54	1	0	0
24229 PORTLAND, OR																			
GLOBAL	0	145	0	0	0	683	172	0	0	0	0	0	40	559	366	35	0	0	0
DIRECT	0	129	0	0	0	699	172	0	0	0	0	0	79	883	3	35	0	0	0
DIFFUSE	0	0	0	0	128	700	172	0	0	0	0	0	0	78	883	38	0	0	0
24230 REDMOND, OR																			
GLOBAL	0	0	92	0	0	0	0	560	348	0	0	0	0	422	467	111	0	0	0
DIRECT	0	0	0	0	0	0	0	633	367	0	0	0	0	691	191	117	0	0	0
DIFFUSE	0	0	0	0	0	0	0	633	367	0	0	0	0	0	883	117	0	0	0
24233 SEATTLE, WA																			
GLOBAL	0	200	52	146	0	535	68	0	0	0	0	0	16	603	363	18	0	0	0
DIRECT	0	196	0	0	44	692	68	0	0	0	0	11	54	843	69	23	0	0	0
DIFFUSE	0	69	0	0	171	693	68	0	0	0	0	0	0	67	876	55	2	0	0
26411 FAIRBANKS, AK																			
GLOBAL	0	0	44	0	0	0	0	780	176	0	0	0	0	315	617	68	0	0	0
DIRECT	0	0	0	0	0	0	0	824	176	0	0	0	0	692	240	68	0	0	0
DIFFUSE	0	0	0	0	0	0	0	824	176	0	0	0	0	0	932	68	0	0	0
41415 GUAM, PI																			
GLOBAL	0	153	0	0	0	485	362	0	0	0	0	0	20	384	393	203	0	0	0
DIRECT	0	155	0	0	0	484	360	0	0	0	0	0	60	448	291	201	0	0	0
DIFFUSE	0	0	0	0	150	486	364	0	0	0	0	0	0	57	712	229	2	0	0
93193 FRESNO, CA																			
GLOBAL	0	79	146	189	0	370	216	0	0	0	0	0	15	643	301	41	0	0	0
DIRECT	0	188	0	0	0	544	267	0	0	0	0	0	79	857	16	48	0	0	0
DIFFUSE	0	0	0	0	188	545	267	0	0	0	0	0	0	35	884	80	1	0	0

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations (Continued)

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
93729 CAPE HATTERAS, NC																			
GLOBAL	0	0	0	348	0	0	0	448	204	0	0	0	0	673	264	63	0	0	0
DIRECT	0	0	0	0	0	0	0	631	369	0	0	0	0	716	170	115	0	0	0
DIFFUSE	0	0	0	0	0	0	0	631	369	0	0	0	0	0	885	115	0	0	0
93738 STERLING, VA																			
GLOBAL	0	148	0	330	0	450	72	0	0	0	0	0	65	656	260	19	0	0	0
DIRECT	0	135	0	0	2	706	156	0	0	0	0	60	24	856	9	51	0	0	0
DIFFUSE	0	87	0	0	50	706	156	0	0	0	0	0	0	78	864	57	0	0	0
93805 TALLAHASSEE, FL																			
GLOBAL	0	150	0	0	0	585	265	0	0	0	0	0	39	473	382	106	0	0	0
DIRECT	0	116	0	0	12	606	265	0	0	0	0	34	32	811	16	107	0	0	0
DIFFUSE	0	66	0	0	63	607	265	0	0	0	0	0	0	66	823	111	0	0	0
93819 INDIANAPOLIS, IN																			
GLOBAL	0	53	0	0	0	0	0	790	158	0	0	0	0	527	425	48	0	0	0
DIRECT	0	0	0	0	0	0	0	842	158	0	0	0	0	747	204	48	0	0	0
DIFFUSE	0	0	0	0	0	0	0	842	158	0	0	0	0	0	952	48	0	0	0
94018 BOULDER, CO																			
GLOBAL	0	294	0	0	1	565	140	0	0	0	0	0	124	482	342	53	0	0	0
DIRECT	0	252	0	0	24	584	140	0	0	0	0	45	127	741	33	54	0	0	0
DIFFUSE	0	105	0	0	172	584	140	0	0	0	0	0	0	190	749	61	0	0	0
94185 BURNS, OR																			
94728 NEW YORK CITY, NY																			
GLOBAL	0	0	0	242	0	612	146	0	0	0	0	0	0	611	349	40	0	0	0
DIRECT	0	0	0	0	0	720	280	0	0	0	0	0	0	0	907	93	0	0	0
DIFFUSE	0	0	0	0	0	720	280	0	0	0	0	0	0	0	0	907	93	0	0
94823 PITTSBURGH, PA																			
GLOBAL	0	16	69	0	0	803	112	0	0	0	0	0	0	487	478	35	0	0	0
DIRECT	0	66	0	0	0	822	112	0	0	0	0	0	10	925	31	34	0	0	0
DIFFUSE	0	0	0	0	53	836	112	0	0	0	0	0	0	0	943	56	1	0	0

Table C-1. 30-Year Summary of Quality Flags Assigned to Primary Stations (Concluded)

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
94918 OMAHA, NE																			
GLOBAL	0	230	0	333	0	381	57	0	0	0	0	0	1	706	276	17	0	0	0
DIRECT	0	191	0	0	0	652	157	0	0	0	0	0	48	872	35	45	0	0	0
DIFFUSE	0	0	0	0	190	653	157	0	0	0	0	0	0	40	876	82	2	0	0

Table C-2. 30-Year Summary of Quality Flags Assigned to Selected Secondary Stations

(Values are in percent (tenths) of all daylight hours.)

	Source Flags									Uncertainty Flags									
	?	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9
23155 BAKERSFIELD, CA																			
GLOBAL	0	0	0	0	0	0	0	644	356	0	0	0	0	577	356	67	0	0	0
DIRECT	0	0	0	0	0	0	0	644	356	0	0	0	0	933	0	67	0	0	0
DIFFUSE	0	0	0	0	0	0	0	644	356	0	0	0	0	0	933	67	0	0	0
22516 KAHULUI, HI																			
GLOBAL	0	0	0	0	0	0	0	624	376	0	0	0	0	423	396	181	0	0	0
DIRECT	0	0	0	0	0	0	0	624	376	0	0	0	0	164	655	181	0	0	0
DIFFUSE	0	0	0	0	0	0	0	624	376	0	0	0	0	0	559	441	0	0	0
14840 MUSKEGON, MI																			
GLOBAL	0	0	0	0	0	0	0	739	261	0	0	0	0	551	391	58	0	0	0
DIRECT	0	0	0	0	0	0	0	739	261	0	0	0	0	809	133	58	0	0	0
DIFFUSE	0	0	0	0	0	0	0	739	261	0	0	0	0	0	942	58	0	0	0
14820 CLEVELAND, OH																			
GLOBAL	0	0	0	0	0	0	0	910	90	0	0	0	0	524	451	26	0	0	0
DIRECT	0	0	0	0	0	0	0	910	90	0	0	0	0	499	475	26	0	0	0
DIFFUSE	0	0	0	0	0	0	0	910	90	0	0	0	0	0	765	235	0	0	0
14777 WILKES-BARRE, PA																			
GLOBAL	0	0	0	0	0	0	0	731	269	0	0	0	0	531	396	72	0	0	0
DIRECT	0	0	0	0	0	0	0	731	269	0	0	0	0	0	928	72	0	0	0
DIFFUSE	0	0	0	0	0	0	0	731	269	0	0	0	0	0	0	928	72	0	0

Table C-3. Solar Radiation Source Flags

Flag	Definition
A	Post-1976 measured solar radiation data as received from NCDC or other sources
B	Same as 'A' except the global horizontal data underwent a calibration correction
C	Pre-1976 measured global horizontal data (direct and diffuse were not measured before 1976), adjusted from solar to local time, usually with a calibration correction
D	Data derived from the other two elements of solar radiation using the relation, Kt = Kn + Kd (see Part 2, Section 8.1 for more information)
E	Modeled solar radiation data using inputs of *observed* sky cover (cloud amount) and aerosol optical depths derived from direct normal data collected at the same location
F	Modeled solar radiation using *interpolated* sky cover and aerosol optical depths derived from direct normal data collected at the same location
G	Modeled solar radiation data using *observed* sky cover and aerosol optical depths *estimated* from geographical relationships
H	Modeled solar radiation data using *interpolated* sky cover and *estimated* aerosol optical depths
?	Source does not fit any of the above categories. Used for nighttime values, calculated extraterrestrial values, and missing data

Table C-4. Solar Radiation Uncertainty Flags

Flag	Definition
1	0 - 2
2	2 - 4
3	4 - 6
4	6 - 9
5	9 - 13
6	13 - 18
7	18 - 25
8	25 - 35
9	35 - 50
0	Not applicable

Appendix D

Key to the Present Weather Elements

Appendix D provides the key for the present weather elements included in the TD-3282 and NSRDB synoptic formats.

Table D-1. Present Weather Elements in the NSRDB and TD-3282 Format

NSRDB Column	TD-3282		Element	Values	Remarks
	Code	Position			
096	PWX1	XXXXX	Observation Indicator	0 or 9	0 = Weather observation made. 9 = Weather observation not made, or missing.
097	PWX1	XXXXX	Occurrence of Thunderstorm, Tornado, or Squall	0 - 2, 4, 6 - 9	0 = Thunderstorm - lightning and thunder. Wind gusts less than 25.7 m/s, and hail, if any, less than 1.9 cm diameter. 1 = Heavy or severe thunderstorm - frequent intense lightning and thunder. Wind gusts greater than 25.7 m/s and hail, if any, 1.9 cm or greater diameter. 2 = Report of tornado or waterspout. 4 = Moderate squall - sudden increase of wind speed by at least 8.2 m/s, reaching 11.3 m/s or more and lasting for at least one minute. 6 = Water spout (beginning January 1984) 7 = Funnel cloud (beginning January 1984) 8 = Tornado (beginning January 1984) 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9.
098	PWX1	XXXXX	Occurrence of Rain, Rain Showers, or Freezing Rain	0 - 9	0 = Light rain 1 = Moderate rain 2 = Heavy rain 3 = Light rain showers 4 = Moderate rain showers 5 = Heavy rain showers 6 = Light freezing rain 7 = Moderate freezing rain 8 = Heavy freezing rain 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9. Notes Light = up to 0.25 cm per hour Moderate = 0.28 to 0.76 cm per hour Heavy = greater than 0.76 cm per hour
099	PWX1	XXXXX	Occurrence of Rain Squalls, Drizzle, or Freezing Drizzle	0, 1, 3 - 9	0 = Light rain squalls 1 = Moderate rain squalls 3 = Light drizzle 4 = Moderate drizzle 5 = Heavy drizzle 6 = Light freezing drizzle 7 = Moderate freezing drizzle 8 = Heavy freezing drizzle 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9. (See next page for notes)

Table D-1. Present Weather Elements in the NSRDB and TD-3282 Format (Continued)

NSRDB Column	TD-3282		Element	Values	Remarks
	Code	Position			
			Occurrence of Rain Squalls, Drizzle, or Freezing Drizzle (continued)		Notes When drizzle or freezing drizzle occurs with other weather phenomena: Light = up to 0.025 cm per hour Moderate = 0.025 to 0.051 cm per hour Heavy = greater than 0.051 cm per hour When drizzle or freezing drizzle occurs alone: Light = visibility 1 km or greater Moderate = visibility between 0.5 and 1 km Heavy = visibility 0.5 km or less
100	PWX1	XXXX$\underline{X}$	Occurrence of Snow, Snow Pellets, or Ice Crystals	0 - 9	0 = Light snow 1 = Moderate snow 2 = Heavy snow 3 = Light snow pellets 4 = Moderate snow pellets 5 = Heavy snow pellets 6 = Light ice crystals 7 = Moderate ice crystals 8 = Heavy ice crystals 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9. Notes Beginning in April 1963, any occurrence of ice crystals is recorded as a 7.
101	PWX2	$\underline{X}$XXXX	Occurrence of Snow Showers, or Snow Squalls	0 - 5, 9	0 = Light snow showers 1 = Moderate snow showers 2 = Heavy snow showers 3 = Light snow squall 4 = Moderate snow squall 5 = Heavy snow squall 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9.
102	PWX2	X$\underline{X}$XXX	Occurrence of Sleet, Sleet Showers, or Hail	0 - 2, 4, 9	0 = Light ice pellet showers 1 = Moderate ice pellet showers 2 = Heavy ice pellet showers 4 = Hail 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9. Notes Prior to April 1970, ice pellets were coded as sleet. Beginning in April 1970, sleet and small hail were redefined as ice pellets and are coded as 0, 1, or 2.

Table D-1. Present Weather Elements in the NSRDB and TD-3282 Format (Concluded)

NSRDB Column	TD-3282		Element	Values	Remarks
	Code	Position			
103	PWX2	XXXXX	Occurrence of Fog, Blowing Dust, or Blowing Sand	0 - 9	0 = Fog 1 = Ice fog 2 = Ground fog 3 = Blowing dust 4 = Blowing sand 5 = Heavy fog 6 = Glaze (beginning 1984) 7 = Heavy ice fog (beginning 1984) 8 = Heavy ground fog (beginning 1984) 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9. Notes These values recorded only when visibility is less than 11 km.
104	PWX2	XXXXX	Occurrence of Smoke, Haze, Smoke and Haze, Blowing Snow, Blowing Spray, or Dust	0 - 7, 9	0 = Smoke 1 = Haze 2 = Smoke and haze 3 = Dust 4 = Blowing snow 5 = Blowing spray 6 = Dust storm (beginning 1984) 7 = Volcanic ash 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9. Notes These values recorded only when visibility is less than 11 km.
105	PWX2	XXXXX	Occurrence of Ice Pellets	0 - 2, 9	0 = Light ice pellets 1 = Moderate ice pellets 2 = Heavy ice pellets 9 = None if Observation Indicator element equals 0, else unknown or missing if Observation Indicator element equals 9.

USCOMM-NOAA-ASHEVILLE,NC. 10/92/750

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Operated for the
U.S. Department of Energy
by the Midwest Research Institute
Under Contract No. DE-AC02-83CH10093

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