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User's Manual for TMY2s

Typical Meteorological Years

Derived from the 1961-1990 National Solar Radiation Data Base

William Marion and Ken Urban

NREL

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Preface

This user's manual describes typical meteorological year (TMY) data sets derived from the 1961–1990 National Solar Radiation Data Base (NSRDB). Because they are based on more recent and accurate data and will make possible more accurate performance and economic analyses of energy systems, these data sets are recommended for use in place of earlier TMY data sets derived from the 1952–1975 SOLMET/ERSATZ data base.

To distinguish between the old and new TMY data sets, the new TMY data sets are referred to as TMY2s. TMY and TMY2 data sets cannot be used interchangeably because of differences in time (solar versus local), formats, elements, and units. Unless they are revised, computer programs designed for TMY data will not work with TMY2 data.

The TMY2s are data sets of hourly values of solar radiation and meteorological elements for a 1-year period. Their intended use is for computer simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different system types, configurations, and locations in the United States and its territories. Because they represent typical rather than extreme conditions, they are not suited for designing systems to meet the worst-case conditions occurring at a location.

The TMY2 data sets and this manual were produced by the National Renewable Energy Laboratory's (NREL's) Analytic Studies Division under the Resource Assessment Program, which is funded and monitored by the U.S. Department of Energy's Office of Solar Energy Conversion.

Approved for the
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Other individuals also reviewed NREL's plans to generate the TMY2 data sets and provided valuable recommendations. This feedback early in the project permitted efforts to be focused on maximizing the benefits of the TMY2s for users. We are thankful for the efforts of these individuals, whose names and affiliations are: Raymond Bahm (Raymond J. Bahm and Associates), William Beckman (University of Wisconsin), Larry Degelman (Texas A&M University), Nolan Doesken (Colorado State University), Randy Gee (Industrial Solar Technology Corporation), Chris Gueymard (Florida Solar Energy Center), Doug Hittle (Colorado State University), Michael Holtz (Architectural Energy Corporation), Michael Kennedy (Ecotope), Ed Kern (Ascension Technology, Inc.), Sandy Klein (University of Wisconsin), Jan Kreider (University of Colorado), Hans Lund (Technical University of Denmark), Ken May (Industrial Solar Technology Corporation), Dave Menicucci (Sandia National Laboratories), John Schaefer (Consultant), Arvid Skartveit (Geophysical Institute, Norway), Veronica Soebarto (Texas A&M University), Didier Thevenard (Watsun Simulation Laboratory), Mike Thomas (Sandia National Laboratories), and Frank Vignola (University of Oregon).

Contents

SECTION 1

Overview

This user's manual describes typical meteorological year (TMY) data sets derived from the 1961–1990 National Solar Radiation Data Base (NSRDB). Based on more recent and accurate data, these data sets are recommended for use in place of earlier TMY data sets (NCDC 1981) that were derived from the 1952–1975 SOLMET/ERSATZ data base (SOLMET—Vol. 1 1978 and SOLMET—Vol. 2 1979). To distinguish between the two TMY data sets, the new TMY data sets are referred to as TMY2s.

TMY and TMY2 data sets cannot be used interchangeably because of differences in time (solar versus local), formats, elements, and units. Unless they are revised, programs designed for TMY data will not work with TMY2 data.

Section 1 of the manual provides general information about the TMY2s and how they were developed; Section 2 lists the stations and provides station identifying information and classification; Section 3 details the contents of the TMY2 files and provides the location in the hourly records of data values and their source and uncertainty flags; Section 4 compares the TMY2s with 30-year data sets; Appendix A provides a description of the procedures used to develop the TMY2s; Appendix B provides a key for present weather elements; and Appendix C contains a table of unit conversion factors for converting SI data to other units.

Typical Meteorological Year—A Description

A TMY is a data set of hourly values of solar radiation and meteorological elements for a 1-year period. It consists of months selected from individual years and concatenated to form a complete year. The intended use is for computer simulations of solar energy conversion systems and building systems. Because of the selection criteria, TMYs are not appropriate for simulations of wind energy conversion systems.

A TMY provides a standard for hourly data for solar radiation and other meteorological elements that permit performance comparisons of system types and configurations for one or more locations. A TMY is not necessarily a good indicator of conditions over the next year, or even the next 5 years. Rather, it represents conditions judged to be typical over a long period of time, such as 30 years. Because they represent typical rather than extreme conditions, they are not suited for designing systems and their components to meet the worst-case conditions occurring at a location.

NSRDB—Source of Data for the TMY2s

The TMY2s were derived from the NSRDB, Version 1.1, which was completed in March 1994 by the National Renewable Energy Laboratory (NREL). The NSRDB contains hourly values of measured or modeled solar radiation and meteorological data for 239 stations for the 30-year period from 1961–1990. A complete description of the NSRDB and how it was produced is presented in its user's manual (NSRDB—Vol. 1 1992) and the final technical report (NSRDB—Vol. 2 1995). The original version of the NSRDB, Version 1.0, was completed in August 1992. Version 1.1 corrects two types of minor errors in Version 1.0 that affected about 10% of the stations (Rymes 1994).

There are two types of stations in the NSRDB: primary (denoted by asterisks in the station map in Figure 1-1) and secondary (denoted by dots in the station map in Figure 1-1). The 56 primary stations measured solar radiation for a part (from 1 to 27 years) of the 30-year period. The remaining 183 stations, designated as secondary stations, made no solar radiation measurements and therefore use modeled solar radiation data that are derived from meteorological data, such as cloud cover. Both primary and secondary stations are National Weather Service stations that collected meteorological data for the period 1961–1990.

Succeeding the older 1952–1975 SOLMET/ERSATZ data base, the NSRDB accounts for any recent climate changes and provides more accurate values of solar radiation for several reasons:

- Better model for estimating values (More than 90% of the solar radiation data in both data bases are modeled.)
- More measured data, some of which is direct normal radiation
- Improved instrument calibration methods
- Rigorous procedures for assessing quality of data.

A comparison of the old and new data bases provided an incentive for developing the TMY2s. On an annual basis, 40% of the NSRDB and SOLMET/ERSATZ stations are in disagreement for global horizontal radiation by more than 5%, with some stations showing disagreement of up to 18% (Marion and Myers 1992). For direct normal radiation, 60% of the NSRDB and SOLMET/ERSATZ stations are in disagreement by more than 5%, with some stations showing disagreement of up to 33%. Disagreement between the two data bases is even greater when compared on a monthly basis.

An analysis of cloud cover data indicated little or no change for the two periods; consequently, most of the disagreement for NSRDB and SOLMET/ERSATZ data is attributed to differences in reconstructing the instrument calibrations and differences in the solar radiation models (NSRDB—Vol. 2 1995).

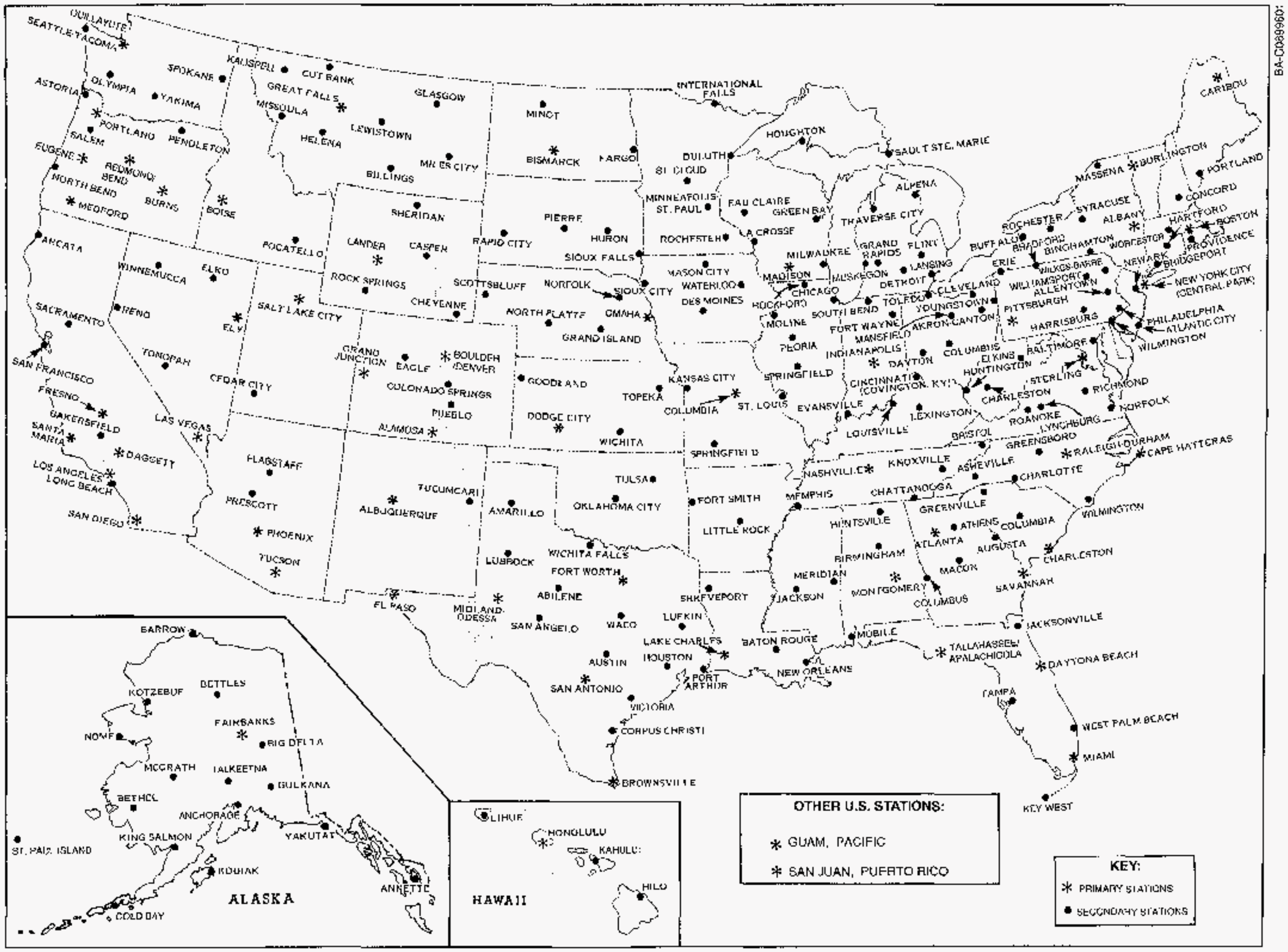

Figure 1-1. Map showing the 239 stations in the National Solar Radiation Data Base, whose data were used to derive the TMY2s

Because of differences in the data bases from which they were derived, the old TMYs and the new TMY2s will differ. For some stations, the differences may be minor, but other stations will have large differences.

Methodology

Except for a few changes to the weighting criteria, which accounts for the relative importance of the solar radiation and meteorological elements, the TMY2s were created using similar procedures that were developed by Sandia National Laboratories (Hall et al. 1978) to create the original TMYs from the 1952–1975 SOLMET/ERSATZ data. Studies by Freeman (1979), Siurna, D'Andrea, and Hollands (1984), and Menicucci and Fernandez (1988) have shown that this procedure gives reasonable results. Sandia's procedure has also been adopted by Siurna, D'Andrea, and Hollands (1984) for developing TMYs for Canada.

The Sandia method is an empirical approach that selects individual months from different years from the period of record. For example, in the case of the NSRDB that contains 30 years of data, all 30 Januarys are examined, and the one judged most typical is selected to be included in the TMY. The other months of the year are treated in a like manner, and then the 12 selected typical months are concatenated to form a complete year.

The 12 selected typical months for each station were chosen from statistics determined by using five elements: global horizontal radiation, direct normal radiation, dry bulb temperature, dew point temperature, and wind speed. These elements are considered the most important for simulation of solar energy conversion systems and building systems.

For other elements in the TMY2s, the selected months may or may not be typical. Cloud cover, which correlates well with solar radiation, is probably reasonably typical. Other elements, such as snow depth, are not related to the elements used for selection; consequently, their values may not be typical. Even though wind speed was used in the selection of the typical months, its relatively low weighting with respect to the other weighted elements prevents it from being sufficiently typical for simulation of wind energy conversion systems.

Appendix A contains a more detailed description of the procedures used to develop the TMY2s.

TMY2 Station Classification

The TMY2 station classification pertains to the amount of measured meteorological data available for a station to select typical months to form the typical meteorological year. Of a possible 30 candidate months, Class A stations had a minimum of 15 candidate months, without more than 2 consecutive hours of missing data, from which a typical month was selected. For Class B stations to achieve a minimum of 15 candidate months, data filling for periods of up to 47 hours were required. For some elements not required for the selection of the typical meteorological months, the data are unfilled in the TMY2 data files. The elements horizontal visibility, ceiling height, and present weather may be missing for up to 2 consecutive hours for Class A stations and for up to 47 hours for Class B stations. No data are missing for more than 47 hours, except for snow depth and days since last snowfall for Colorado Springs, Colorado.

Data Elements

Table 1-1 shows the data elements in the TMY2 data files. These are the same elements as for the 30-year NSRDB, except that illuminance and luminance elements were added to support building energy analysis. The table includes information by element and station classification to alert the user to the possibility of missing data. Definitions of the elements and their units are provided in Table 3-2 of Section 3.

Table 1-1. TMY2 Data Elements and Their Degree of Completeness

	Data Completeness	
Element	Class A	Class B
Extraterrestrial Horizontal Radiation	1	1
Extraterrestrial Direct Normal Radiation	1	1
Global Horizontal Radiation	1	1
Direct Normal Radiation	1	1
Diffuse Horizontal Radiation	1	1
Global Horizontal Illuminance	1	1
Direct Normal Illuminance	1	1
Diffuse Horizontal Illuminance	1	1
Zenith Luminance	1	1
Total Sky Cover	1	1
Opaque Sky Cover	1	1
Dry Bulb Temperature	1	1
Dew Point Temperature	1	1
Relative Humidity	1	1
Atmospheric Pressure	1	1
Wind Direction	1	1
Wind Speed	1	1
Horizontal Visibility	2	2, 3, 4
Ceiling Height	2	2, 3, 4
Present Weather	2	2, 3, 4
Precipitable Water	1	1
Broadband Aerosol Optical Depth	1	1
Snow Depth	1	5
Days Since Last Snowfall	1	5

Notes:
1. Serially complete, no missing data.
2. Data may be present only every third hour.
3. Nighttime data may be missing.
4. Data may be missing for up to 47 hours.
5. Serially complete, except for Colorado Springs, CO.

Where to Order

TMY2 data sets are available over Internet from NREL's Renewable Resource Data Center (RReDC). The Universal Resource Locator (URL) address of the RReDC is "http://rredc.nrel.gov." Users should have World Wide Web (WWW) browsing software, such as Mosaic or Netscape, to access the RReDC.

TMY2 data sets for all 239 stations may also be obtained on a CD-ROM. A "Readme" file, which describes the contents, is included on the CD-ROM. The CD-ROM may be ordered from:

NREL Document Distribution Service
1617 Cole Boulevard
Golden, Colorado 80401-3393
Phone: (303)275-4363
Fax: (303)275-4053
INTERNET: sally_evans@nrel.gov

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SOLMET, Vol. 2 (1979). *Final Report—Hourly Solar Radiation-Surface Meteorological Observations.* TD-9724. Asheville, NC: National Climatic Data Center.

SECTION 2

Stations

There are 239 TMY2 stations for the United States and its territories. These are the same stations as for the NSRDB, from which the TMY2 data sets were derived. The stations are National Weather Service stations that collected meteorological data for the period of 1961–1990. Table 2-1 lists the stations by state or territory and provides information describing the station location and the NSRDB and TMY2 classifications.

Compared to the SOLMET/ERSATZ TMYs, there is a net gain of five stations, and some of the station locations have changed. The TMY2 data sets include 37 new stations, but 32 previous SOLMET/ERSATZ TMY stations were not included because these stations were not included in the NSRDB.

Locations

The station locations are described in Table 2-1 by the city and state name, the station Weather Bureau Army Navy (WBAN) identification number, the latitude and longitude in degrees and minutes, and the elevation in meters.

NSRDB Classification

Stations are classified with respect to being NSRDB primary (P) or secondary (S) stations. The 56 primary stations measured solar radiation for a part (from 1 to 27 years) of the 30-year period of 1961–1990. The remaining 183 secondary stations made no solar radiation measurements and therefore use modeled solar radiation data that are derived from meteorological data such as cloud cover.

TMY2 Classification

This classification pertains to the amount of measured meteorological data available for a station to select typical months to form the typical meteorological year. Class A stations, of which there are 216, had a minimum of 15 candidate months without more than 2 consecutive hours of missing data. For the 23 Class B stations to achieve a minimum of 15 candidate months, data filling for periods of up to 47 hours were required. For some elements not required for the selection of the typical meteorological months, the data are unfilled in the TMY2 data files. The elements horizontal visibility, ceiling height, and present weather may be missing for up to 2 consecutive hours for Class A stations and for up to 47 hours for Class B stations. No data are missing for more than 47 hours, except for snow depth and days since last snowfall for Colorado Springs, Colorado.

Table 2-1. Station Locations and Classifications

State	City	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elev (m)	Classification NSRDB	Classification TMY2
Alabama									
	Birmingham	13876	N33	34	W 86	45	192	S	A
	Huntsville	03856	N34	39	W 86	46	190	S	A
	Mobile	13894	N30	41	W 88	15	67	S	A
	Montgomery	13895	N32	18	W 86	24	62	P	A
Alaska									
	Anchorage	26451	N61	10	W150	1	35	S	A
	Annette	25308	N55	2	W131	34	34	S	A
	Barrow	27502	N71	18	W156	47	4	S	A
	Bethel	26615	N60	47	W161	48	46	S	A
	Bettles	26533	N66	55	W151	31	205	S	B
	Big Delta	26415	N64	0	W145	44	388	S	B
	Cold Bay	25624	N55	12	W162	43	29	S	A
	Fairbanks	26411	N64	49	W147	52	138	P	A
	Gulkana	26425	N62	9	W145	27	481	S	B
	King Salmon	25503	N58	41	W156	39	15	S	A
	Kodiak	25501	N57	45	W152	20	34	S	A
	Kotzebue	26616	N66	52	W162	38	5	S	A
	McGrath	26510	N62	58	W155	37	103	S	A
	Nome	26617	N64	30	W165	26	7	S	A
	St. Paul Island	25713	N57	9	W170	13	7	S	A
	Talkeetna	26528	N62	18	W150	6	105	S	B
	Yakutat	25339	N59	31	W139	40	9	S	A
Arizona									
	Flagstaff	03103	N35	8	W111	40	2135	S	B
	Phoenix	23183	N33	26	W112	1	339	P	A
	Prescott	23184	N34	39	W112	26	1531	S	A
	Tucson	23160	N32	7	W110	56	779	P	A
Arkansas									
	Fort Smith	13964	N35	20	W 94	22	141	S	A
	Little Rock	13963	N34	44	W 92	14	81	S	A
California									
	Arcata	24283	N40	59	W124	6	69	S	A
	Bakersfield	23155	N35	25	W119	3	150	S	A
	Daggett	23161	N34	52	W116	47	588	P	A
	Fresno	93193	N36	46	W119	43	100	P	A
	Long Beach	23129	N33	49	W118	9	17	S	A
	Los Angeles	23174	N33	56	W118	24	32	P	A
	Sacramento	23232	N38	31	W121	30	8	S	A
	San Diego	23188	N32	44	W117	10	9	P	A
	San Francisco	23234	N37	37	W122	23	5	S	A
	Santa Maria	23273	N34	54	W120	27	72	P	B
Colorado									
	Alamosa	23061	N37	27	W105	52	2297	P	B
	Boulder	94018	N40	1	W105	15	1634	P	A
	Colorado Springs	93037	N38	49	W104	43	1881	S	B
	Eagle	23063	N39	39	W106	55	1985	S	A
	Grand Junction	23066	N39	7	W108	32	1475	P	A
	Pueblo	93058	N38	17	W104	31	1439	S	A

Table 2-1. Station Locations and Classifications (Continued)

State	City	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elev (m)	Classification NSRDB	Classification TMY2
Connecticut									
	Bridgeport	94702	N41	10	W 73	8	2	S	A
	Hartford	14740	N41	56	W 72	41	55	S	A
Delaware									
	Wilmington	13781	N39	40	W 75	36	24	S	A
Florida									
	Daytona Beach	12834	N29	11	W 81	3	12	P	A
	Jacksonville	13889	N30	30	W 81	42	9	S	A
	Key West	12836	N24	33	W 81	45	1	S	A
	Miami	12839	N25	48	W 80	16	2	P	A
	Tallahassee	93805	N30	23	W 84	22	21	P	A
	Tampa	12842	N27	58	W 82	32	3	S	A
	West Palm Beach	12844	N26	41	W 80	6	6	S	A
Georgia									
	Athens	13873	N33	57	W 83	19	244	S	A
	Atlanta	13874	N33	39	W 84	26	315	P	A
	Augusta	03820	N33	22	W 81	58	45	S	A
	Columbus	93842	N32	31	W 84	57	136	S	B
	Macon	03813	N32	42	W 83	39	110	S	A
	Savannah	03822	N32	8	W 81	12	16	P	A
Hawaii									
	Hilo	21504	N19	43	W155	4	11	S	A
	Honolulu	22521	N21	20	W157	55	5	P	A
	Kahului	22516	N20	54	W156	26	15	S	B
	Lihue	22536	N21	59	W159	21	45	S	A
Idaho									
	Boise	24131	N43	34	W116	13	874	P	A
	Pocatello	24156	N42	55	W112	36	1365	S	A
Illinois									
	Chicago	94846	N41	47	W 87	45	190	S	A
	Moline	14923	N41	27	W 90	31	181	S	A
	Peoria	14842	N40	40	W 89	41	199	S	A
	Rockford	94822	N42	12	W 89	6	221	S	A
	Springfield	93822	N39	50	W 89	40	187	S	A
Indiana									
	Evansville	93817	N38	3	W 87	32	118	S	A
	Fort Wayne	14827	N41	0	W 85	12	252	S	A
	Indianapolis	93819	N39	44	W 86	17	246	P	A
	South Bend	14848	N41	42	W 86	19	236	S	A
Iowa									
	Des Moines	14933	N41	32	W 93	39	294	S	A
	Mason City	14940	N43	9	W 93	20	373	S	A
	Sioux City	14943	N42	24	W 96	23	336	S	A
	Waterloo	94910	N42	33	W 92	24	265	S	A
Kansas									
	Dodge City	13985	N37	46	W 99	58	787	P	A
	Goodland	23065	N39	22	W101	42	1124	S	A
	Topeka	13996	N39	4	W 95	38	270	S	A
	Wichita	03928	N37	39	W 97	25	408	S	A

Table 2-1. Station Locations and Classifications (Continued)

State	City	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elev (m)	Classification NSRDB	Classification TMY2
Kentucky									
	Covington	93814	N39	4	W 84	40	271	S	A
	Lexington	93820	N38	2	W 84	36	301	S	A
	Louisville	93821	N38	11	W 85	44	149	S	A
Louisiana									
	Baton Rouge	13970	N30	32	W 91	9	23	S	A
	Lake Charles	03937	N30	7	W 93	13	3	P	A
	New Orleans	12916	N29	59	W 90	15	3	S	A
	Shreveport	13957	N32	28	W 93	49	79	S	A
Maine									
	Caribou	14607	N46	52	W 68	1	190	P	B
	Portland	14764	N43	39	W 70	19	19	S	A
Maryland									
	Baltimore	93721	N39	11	W 76	40	47	S	A
Massachusetts									
	Boston	14739	N42	22	W 71	2	5	P	A
	Worchester	94746	N42	16	W 71	52	301	S	B
Michigan									
	Alpena	94849	N45	4	W 83	34	210	S	A
	Detroit	94847	N42	25	W 83	1	191	S	A
	Flint	14826	N42	58	W 83	44	233	S	A
	Grand Rapids	94860	N42	53	W 85	31	245	S	A
	Houghton	94814	N47	10	W 88	30	329	S	A
	Lansing	14836	N42	47	W 84	36	256	S	A
	Muskegon	14840	N43	10	W 86	15	191	S	A
	Sault Ste. Marie	14847	N46	28	W 84	22	221	S	A
	Traverse City	14850	N44	44	W 85	35	192	S	A
Minnesota									
	Duluth	14913	N46	50	W 92	11	432	S	A
	International Falls	14918	N48	34	W 93	23	361	S	A
	Minneapolis	14922	N44	53	W 93	13	255	S	A
	Rochester	14925	N43	55	W 92	30	402	S	A
	Saint Cloud	14926	N45	33	W 94	4	313	S	B
Mississippi									
	Jackson	03940	N32	19	W 90	5	101	S	A
	Meridian	13865	N32	20	W 88	45	94	S	A
Missouri									
	Columbia	03945	N38	49	W 92	13	270	P	A
	Kansas City	03947	N39	18	W 94	43	315	S	A
	Springfield	13995	N37	14	W 93	23	387	S	A
	St. Louis	13994	N38	45	W 90	23	172	S	A
Montana									
	Billings	24033	N45	48	W108	32	1088	S	A
	Cut Bank	24137	N48	36	W112	22	1170	S	B
	Glasgow	94008	N48	13	W106	37	700	S	A
	Great Falls	24143	N47	29	W111	22	1116	P	A
	Helena	24144	N46	36	W112	0	1188	S	A
	Kalispell	24146	N48	18	W114	16	904	S	A
	Lewistown	24036	N47	3	W109	27	1264	S	A
	Miles City	24037	N46	26	W105	52	803	S	A

Table 2-1. Station Locations and Classifications (Continued)

State	City	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elev (m)	Classification NSRDB	Classification TMY2
Montana (continued)									
	Missoula	24153	N46	55	W114	5	972	S	A
Nebraska									
	Grand Island	14935	N40	58	W 98	19	566	S	A
	Norfolk	14941	N41	59	W 97	26	471	S	B
	North Platte	24023	N41	8	W100	41	849	S	A
	Omaha	94918	N41	22	W 96	31	404	P	A
	Scottsbluff	24028	N41	52	W103	36	1206	S	A
Nevada									
	Elko	24121	N40	50	W115	47	1547	S	A
	Ely	23154	N39	17	W114	51	1906	P	A
	Las Vegas	23169	N36	5	W115	10	664	P	A
	Reno	23185	N39	30	W119	47	1341	S	A
	Tonopah	23153	N38	4	W117	8	1653	S	A
	Winnemucca	24128	N40	54	W117	48	1323	S	A
New Hampshire									
	Concord	14745	N43	12	W 71	30	105	S	A
New Jersey									
	Atlantic City	93730	N39	27	W 74	34	20	S	A
	Newark	14734	N40	42	W 74	10	9	S	A
New Mexico									
	Albuquerque	23050	N35	3	W106	37	1619	P	A
	Tucumcari	23048	N35	11	W103	36	1231	S	B
New York									
	Albany	14735	N42	45	W 73	48	89	P	A
	Binghamton	04725	N42	13	W 75	59	499	S	A
	Buffalo	14733	N42	56	W 78	44	215	S	A
	Massena	94725	N44	56	W 74	51	63	S	A
	New York City	94728	N40	47	W 73	58	57	P	A
	Rochester	14768	N43	7	W 77	40	169	S	A
	Syracuse	14771	N43	7	W 76	7	124	S	A
North Carolina									
	Asheville	03812	N35	26	W 82	32	661	S	A
	Cape Hatteras	93729	N35	16	W 75	33	2	P	A
	Charlotte	13881	N35	13	W 80	56	234	S	A
	Greensboro	13723	N36	5	W 79	57	270	S	A
	Raleigh	13722	N35	52	W 78	47	134	P	A
	Wilmington	13748	N34	16	W 77	54	9	S	A
North Dakota									
	Bismarck	24011	N46	46	W100	45	502	P	A
	Fargo	14914	N46	54	W 96	48	274	S	A
	Minot	24013	N48	16	W101	17	522	S	A
Ohio									
	Akron	14895	N40	55	W 81	26	377	S	A
	Cleveland	14820	N41	24	W 81	51	245	S	A
	Columbus	14821	N40	0	W 82	53	254	S	A
	Dayton	93815	N39	54	W 84	13	306	S	A
	Mansfield	14891	N40	49	W 82	31	395	S	B
	Toledo	94830	N41	36	W 83	48	211	S	A
	Youngstown	14852	N41	16	W 80	40	361	S	A

Table 2-1. Station Locations and Classifications (Continued)

State	City	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elev (m)	Classification NSRDB	Classification TMY2
Oklahoma									
	Oklahoma City	13967	N35	24	W 97	36	397	S	A
	Tulsa	13968	N36	12	W 95	54	206	S	A
Oregon									
	Astoria	94224	N46	9	W123	53	7	S	A
	Burns	94185	N43	35	W119	3	1271	P	B
	Eugene	24221	N44	7	W123	13	109	P	A
	Medford	24225	N42	22	W122	52	396	P	A
	North Bend	24284	N43	25	W124	15	5	S	A
	Pendleton	24155	N45	41	W118	51	456	S	A
	Portland	24229	N45	36	W122	36	12	P	A
	Redmond	24230	N44	16	W121	9	940	P	A
	Salem	24232	N44	55	W123	1	61	S	A
Pacific Islands									
	Guam	41415	N13	33	E144	50	110	P	B
Pennsylvania									
	Allentown	14737	N40	39	W 75	26	117	S	A
	Bradford	04751	N41	48	W 78	38	600	S	A
	Erie	14860	N42	5	W 80	11	225	S	A
	Harrisburg	14751	N40	13	W 76	51	106	S	A
	Philadelphia	13739	N39	53	W 75	15	9	S	A
	Pittsburgh	94823	N40	30	W 80	13	373	P	A
	Wilkes-Barre	14777	N41	20	W 75	44	289	S	A
	Williamsport	14778	N41	16	W 77	3	243	S	A
Puerto Rico									
	San Juan	11641	N18	26	W 66	0	19	P	A
Rhode Island									
	Providence	14765	N41	44	W 71	26	19	S	A
South Carolina									
	Charleston	13880	N32	54	W 80	2	12	P	A
	Columbia	13883	N33	57	W 81	7	69	S	A
	Greenville	03870	N34	54	W 82	13	296	S	A
South Dakota									
	Huron	14936	N44	23	W 98	13	393	S	A
	Pierre	24025	N44	23	W100	17	526	S	A
	Rapid City	24090	N44	3	W103	4	966	S	A
	Sioux Falls	14944	N43	34	W 96	44	435	S	A
Tennessee									
	Bristol	13877	N36	29	W 82	24	459	S	A
	Chattanooga	13882	N35	2	W 85	12	210	S	A
	Knoxville	13891	N35	49	W 83	59	299	S	A
	Memphis	13893	N35	3	W 89	59	87	S	A
	Nashville	13897	N36	7	W 86	41	180	P	A
Texas									
	Abilene	13962	N32	26	W 99	41	534	S	A
	Amarillo	23047	N35	14	W101	42	1098	S	A
	Austin	13958	N30	18	W 97	42	189	S	A
	Brownsville	12919	N25	54	W 97	26	6	P	A
	Corpus Christi	12924	N27	46	W 97	30	13	S	A
	El Paso	23044	N31	48	W106	24	1194	P	A

Table 2-1. Station Locations and Classifications (Continued)

State	City	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elev (m)	Classification NSRDB	Classification TMY2
Texas (continued)									
	Fort Worth	03927	N32	50	W 97	3	164	P	A
	Houston	12960	N29	59	W 95	22	33	S	A
	Lubbock	23042	N33	39	W101	49	988	S	A
	Lufkin	93987	N31	14	W 94	45	96	S	A
	Midland	23023	N31	56	W102	12	871	P	A
	Port Arthur	12917	N29	57	W 94	1	7	S	B
	San Angelo	23034	N31	22	W100	30	582	S	A
	San Antonio	12921	N29	32	W 98	28	242	P	A
	Victoria	12912	N28	51	W 96	55	32	S	A
	Waco	13959	N31	37	W 97	13	155	S	A
	Wichita Falls	13966	N33	58	W 98	29	314	S	A
Utah									
	Cedar City	93129	N37	42	W113	6	1712	S	A
	Salt Lake City	24127	N40	46	W111	58	1288	P	A
Vermont									
	Burlington	14742	N44	28	W 73	9	104	P	A
Virginia									
	Lynchburg	13733	N37	20	W 79	12	279	S	B
	Norfolk	13737	N36	54	W 76	12	9	S	A
	Richmond	13740	N37	30	W 77	20	50	S	A
	Roanoke	13741	N37	19	W 79	58	358	S	A
	Sterling	93738	N38	57	W 77	27	82	P	A
Washington									
	Olympia	24227	N46	58	W122	54	61	S	A
	Quillayute	94240	N47	57	W124	33	55	S	A
	Seattle	24233	N47	27	W122	18	122	P	A
	Spokane	24157	N47	38	W117	32	721	S	A
	Yakima	24243	N46	34	W120	32	325	S	A
West Virginia									
	Charleston	13866	N38	22	W 81	36	290	S	A
	Elkins	13729	N38	53	W 79	51	594	S	B
	Huntington	03860	N38	22	W 82	33	255	S	A
Wisconsin									
	Eau Claire	14991	N44	52	W 91	29	273	S	A
	Green Bay	14898	N44	29	W 88	8	214	S	A
	La Crosse	14920	N43	52	W 91	15	205	S	A
	Madison	14837	N43	8	W 89	20	262	P	A
	Milwaukee	14839	N42	57	W 87	54	211	S	A
Wyoming									
	Casper	24089	N42	55	W106	28	1612	S	A
	Cheyenne	24018	N41	9	W104	49	1872	S	A
	Lander	24021	N42	49	W108	44	1696	P	A
	Rock Springs	24027	N41	36	W109	4	2056	S	A
	Sheridan	24029	N44	46	W106	58	1209	S	B

SECTION 3

Data and Format

For each station, a TMY2 file contains 1 year of hourly solar radiation, illuminance, and meteorological data. The files consist of data for the typical calendar months during 1961–1990 that are concatenated to form the typical meteorological year for each station.

Each hourly record in the file contains values for solar radiation, illuminance, and meteorological elements. A two-character source and uncertainty flag is attached to each data value to indicate whether the data value was measured, modeled, or missing, and to provide an estimate of the uncertainty of the data value.

Users should be aware that the format of the TMY2 data files is different from the format used for the NSRDB and the original TMY data files.

File Convention

File naming convention uses the WBAN number as the file prefix, with the characters TM2 as the file extension. For example, 13876.TM2 is the TMY2 file name for Birmingham, Alabama. The TMY2 files contain computer readable ASCII characters and have a file size of 1.26 MB.

File Header

The first record of each file is the file header that describes the station. The file header contains the WBAN number, city, state, time zone, latitude, longitude, and elevation. The field positions and definitions of these header elements are given in Table 3-1, along with sample FORTRAN and C formats for reading the header. A sample of a file header and data for January 1 is shown in Figure 3-1.

Hourly Records

Following the file header, 8760 hourly data records provide 1 year of solar radiation, illuminance, and meteorological data, along with their source and uncertainty flags. Table 3-2 provides field positions, element definitions, and sample FORTRAN and C formats for reading the hourly records.

Each hourly record begins with the year (field positions 2-3) from which the typical month was chosen, followed by the month, day, and hour information in field positions 4-9. *The times are in local standard time (previous TMYs based on SOLMET/ERSATZ data are in solar time).*

```
14944 SIOUX_FALLS                SD  -6 N 43 34 W  96 44    435
850101010000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-211A7060A70975A7360A7052A70161A700945A70999099999004E7050F8000A700E7
850101020000000000000?00000?00000?00000?00000?00000?00000?010A710A7-144A7-206A7060A70975A7350A7077A70161A700914A70999099999004E7050F8000A700E7
850101030000000000000?00000?00000?00000?00000?00000?00000?010A710A7-144A7-200A7063A70975A7340A7062A70161A700732A70999099999004E7050F8000A700E7
850101040000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-206A7063A70976A7330A7072A70161A700640A70999099999004E7050F8000A700E7
850101050000000000000?00000?00000?00000?00000?00000?00000?010A710A7-156A7-217A7060A70976A7330A7067A70161A700640A70999099999003E7050F8000A700E7
850101060000000000000?00000?00000?00000?00000?00000?00000?010A710A7-167A7-222A7062A70976A7340A7067A70161A700640A70999099999003E7050F8000A700E7
850101070000000000000?00000?00000?00000?00000?00000?00000?004A704A7-183A7-233A7065A70977A7300A7052A70193A777777A70999999999003E7050F8000A700E7
850101080000000000000?00000?00000?00000?00000?00000?00000?002A702A7-194A7-244A7065A70978A7310A7036A70193A777777A70999999999003E7050F8000A700E7
85010109010212970037G50173G40024G50038I50071I40033I50043I604A700A7-200A7-256A7062A70978A7330A7046A70193A777777A70999999999003E7050F8000A700E7
85010110028714150157G50560G40043G50159I50444I40069I50079I600A700A7-189A7-256A7056A70979A7310A7067A70193A777777A70999999999003E7050F8000A700E7
85010111043614150276G40714G40056G50286I40642I40088I50111I500A700A7-172A7-250A7051A70979A7310A7062A70161A777777A70999999999003E7050F8000A700E7
85010112053014150357G40782G40064G50374I40735I40098I50131I500A700A7-167A7-244A7051A70978A7300A7062A70161A777777A70999999999003E7050F8000A700E7
85010113056214150387G40806G40067G50407I40767I40101I50139I500A700A7-156A7-244A7047A70978A7320A7067A70193A777777A70999999999003E7050F8000A700E7
85010114053014150359G40788G40064G50377I40742I40098I50131I500A700A7-144A7-239A7045A70978A7310A7062A70193A777777A70999999999003E7050F8000A700E7
85010115043614150277G40716G40056G50289I40645I40088I50111I500A700A7-139A7-239A7043A70978A7330A7052A70193A777777A70999999999003E7050F8000A700E7
85010116028614150157G50564G40043G50162I50450I40069I50080I600A700A7-139A7-233A7045A70978A7300A7052A70161A777777A70999999999003E7050F8000A700E7
85010117010412730038G50209G40021G50038I50104I40030I50038I600A700A7-150A7-233A7049A70978A7290A7041A70241A777777A70999999999003E7050F8000A700E7
850101180000000000000?00000?00000?00000?00000?00000?00000?000A700A7-167A7-233A7057A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
850101190000000000000?00000?00000?00000?00000?00000?00000?000A700A7-172A7-233A7059A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
850101200000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-233A7062A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
850101210000000000000?00000?00000?00000?00000?00000?00000?000A700A7-183A7-239A7062A70978A7260A7015A70241A777777A70999999999003E7050F8000A700E7
850101220000000000000?00000?00000?00000?00000?00000?00000?000A700A7-183A7-239A7062A70977A7220A7021A70241A777777A70999999999003E7050F8000A700E7
850101230000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7220A7015A70241A777777A70999999999003E7050F8000A700E7
850101240000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7240A7010A70241A777777A70999999999003E7050F8000A700E7

                                                                                                   1         1         1         1         1
         1         2         3         4         5         6         7         8         9         0         1         2         3         4
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
                                       (for field position identification only)
```

Figure 3-1. Sample file header and data in the TMY2 format for January 1

Table 3-1. Header Elements in the TMY2 Format (For First Record of Each File)

Field Position	Element	Definition
002 - 006	WBAN Number	Station's Weather Bureau Army Navy number (see Table 2-1)
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 is ahead of or behind Universal Time. For example, Mountain Standard Time is designated -7 because it is 7 hours behind Universal Time.
038 - 044	Latitude	Latitude of the station
038		N = North of equator
040 - 041		Degrees
043 - 044		Minutes
046 - 053	Longitude	Longitude of the station
046		W = West, E = East
048 - 050		Degrees
052 - 053		Minutes
056 - 059	Elevation	Elevation of station in meters above sea level

FORTRAN Sample Format:

```
( 1X,A5,1X,A22,1X,A2,1X,I3,1X,A1,1X,I2,1X,I2,1X,A1,1X,I3,1X,I2,2X,I4 )
```

C Sample Format:

```
( %s %s %s %d %s %d %d %s %d %d %d )
```

Table 3-2. Data Elements in the TMY2 Format (For All Except the First Record)

Field Position	Element	Values	Definition
002 - 009	Local Standard Time		
002 - 003	Year	61 - 90	Year, 1961-1990
004 - 005	Month	1 - 12	Month
006 - 007	Day	1 - 31	Day of month
008 - 009	Hour	1 - 24	Hour of day in local standard time
010 - 013	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
014 - 017	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
018 - 023	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
018 - 021	Data Value	0 - 1200	
022	Flag for Data Source	A - H, ?	
023	Flag for Data Uncertainty	0 - 9	
024 - 029	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
024 - 027	Data Value	0 - 1100	
028	Flag for Data Source	A - H, ?	
029	Flag for Data Uncertainty	0 - 9	

Table 3-2. Data Elements in the TMY2 Format (Continued)

Field Position	Element	Values	Definition
030 - 035	Diffuse Horizontal Radiation		Amount of solar radiation in Wh/m^2
030 - 033	Data Value	0 - 700	received from the sky (excluding the
034	Flag for Data Source	A - H, ?	solar disk) on a horizontal surface
035	Flag for Data Uncertainty	0 - 9	during the 60 minutes preceding the hour indicated
036 - 041	Global Horiz. Illuminance		Average total amount of direct and
036 - 039	Data Value	0 - 1300	diffuse illuminance in hundreds of lux
040	Flag for Data Source	I, ?	received on a horizontal surface
041	Flag for Data Uncertainty	0 - 9	during the 60 minutes preceding the hour indicated. 0 to 1300 = 0 to 130,000 lux
042 - 047	Direct Normal Illuminance		Average amount of direct normal
042 - 045	Data Value	0 - 1100	illuminance in hundreds of lux
046	Flag for Data Source	I, ?	received within a 5.7° field of view
047	Flag for Data Uncertainty	0 - 9	centered on the sun during the 60 minutes preceding the hour indicated. 0 to 1100 = 0 to 110,000 lux
048 - 053	Diffuse Horiz. Illuminance		Average amount of illuminance in
048 - 051	Data Value	0 - 800	hundreds of lux received from the sky
052	Flag for Data Source	I, ?	(excluding the solar disk) on a
053	Flag for Data Uncertainty	0 - 9	horizontal surface during the 60 minutes preceding the hour indicated. 0 to 800 = 0 to 80,000 lux
054 - 059	Zenith Luminance		Average amount of luminance at the
054 - 057	Data Value	0 - 7000	sky's zenith in tens of Cd/m^2 during
058	Flag for Data Source	I, ?	the 60 minutes preceding the hour
059	Flag for Data Uncertainty	0 - 9	indicated. 0 to 7000 = 0 to 70,000 Cd/m^2
060 - 063	Total Sky Cover		Amount of sky dome in tenths
060 - 061	Data Value	0 - 10	covered by clouds or obscuring
062	Flag for Data Source	A - F	phenomena at the hour indicated
063	Flag for Data Uncertainty	0 - 9	
064 - 067	Opaque Sky Cover		Amount of sky dome in tenths
064 - 065	Data Value	0 - 10	covered by clouds or obscuring
066	Flag for Data Source	A - F	phenomena that prevent observing the
067	Flag for Data Uncertainty	0 - 9	sky or higher cloud layers at the hour indicated
068 - 073	Dry Bulb Temperature		Dry bulb temperature in tenths of °C
068 - 071	Data Value	-500 to 500	at the hour indicated.
072	Flag for Data Source	A - F	-500 to 500 = -50.0 to 50.0°C
073	Flag for Data Uncertainty	0 - 9	
074 - 079	Dew Point Temperature		Dew point temperature in tenths of
074 - 077	Data Value	-600 to 300	°C at the hour indicated.
078	Flag for Data Source	A - F	-600 to 300 = -60.0 to 30.0°C
079	Flag for Data Uncertainty	0 - 9	
080 - 084	Relative Humidity		Relative humidity in percent at the
080 - 082	Data Value	0 - 100	hour indicated
083	Flag for Data Source	A - F	
084	Flag for Data Uncertainty	0 - 9	

Table 3-2. Data Elements in the TMY2 Format (Continued)

Field Position	Element	Values	Definition
085 - 090	Atmospheric Pressure		Atmospheric pressure at station in
085 - 088	Data Value	700 - 1100	millibars at the hour indicated
089	Flag for Data Source	A - F	
090	Flag for Data Uncertainty	0 - 9	
091 - 095	Wind Direction		Wind direction in degrees at the hour
091 - 093	Data Value	0 - 360	indicated. (N = 0 or 360, E = 90,
094	Flag for Data Source	A - F	S = 180,W = 270). For calm winds,
095	Flag for Data Uncertainty	0 - 9	wind direction equals zero.
096 - 100	Wind Speed		Wind speed in tenths of meters per
096 - 98	Data Value	0 - 400	second at the hour indicated.
99	Flag for Data Source	A - F	0 to 400 = 0 to 40.0 m/s
100	Flag for Data Uncertainty	0 - 9	
101 - 106	Visibility		Horizontal visibility in tenths of
101 - 104	Data Value	0 - 1609	kilometers at the hour indicated.
105	Flag for Data Source	A - F, ?	7777 = unlimited visibility
106	Flag for Data Uncertainty	0 - 9	0 to 1609 = 0.0 to 160.9 km
			9999 = missing data
107 - 113	Ceiling Height		Ceiling height in meters at the hour
107 - 111	Data Value	0 - 30450	indicated.
112	Flag for Data Source	A - F, ?	77777 = unlimited ceiling height
113	Flag for Data Uncertainty	0 - 9	88888 = cirroform
			99999 = missing data
114 - 123	Present Weather	See Appendix B	Present weather conditions denoted by a 10-digit number. See Appendix B for key to present weather elements.
124 - 128	Precipitable Water		Precipitable water in millimeters at
124 - 126	Data Value	0 - 100	the hour indicated
127	Flag for Data Source	A - F	
128	Flag for Data Uncertainty	0 - 9	
129 - 133	Aerosol Optical Depth		Broadband aerosol optical depth
129 - 131	Data Value	0 - 240	(broad-band turbidity) in thousandths
132	Flag for Data Source	A - F	on the day indicated.
133	Flag for Data Uncertainty	0 - 9	0 to 240 = 0.0 to 0.240
134 - 138	Snow Depth		Snow depth in centimeters on the day
134 - 136	Data Value	0 - 150	indicated.
137	Flag for Data Source	A - F, ?	999 = missing data
138	Flag for Data Uncertainty	0 - 9	
139 - 142	Days Since Last Snowfall		Number of days since last snowfall.
139 - 140	Data Value	0 - 88	88 = 88 or greater days
141	Flag for Data Source	A - F, ?	99 = missing data
142	Flag for Data Uncertainty	0 - 9	

FORTRAN Sample Format:

```
(1X,4I2,2I4,7(I4,A1,I1),2(I2,A1,I1),2(I4,A1,I1),1(I3,A1,I1),
 1(I4,A1,I1),2(I3,A1,I1),1(I4,A1,I1),1(I5,A1,I1),10I1,3(I3,A1,I1),
 1(I2,A1,I1))
```

C Sample Format:

```
(%2d%2d%2d%2d%4d%4d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s
 %1d%4d%1s%1d%2d%1s%1d%2d%1s%1d%4d%1s%1d%4d%1s%1d%3d%1s%1d%4d%1s%1d%3d
 %1s%1d%3d%1s%1d%4d%1s%1d%5ld%1s%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%3d%1s
 %1d%3d%1s%1d%3d%1s%1d%2d%1s%1d)
```

Note: For ceiling height data, integer variable should accept data values as large as 99999.

For solar radiation and illuminance elements, the data values represent the energy received during the 60 minutes *preceding the hour indicated.* For meteorological elements (with a few exceptions), observations or measurements were made *at the hour indicated.* A few of the meteorological elements had observations, measurements, or estimates made at daily, instead of hourly, intervals. Consequently, the data values for broadband aerosol optical depth, snow depth, and days since last snowfall represent the values available for the day indicated.

Missing Data

Data for some stations, times, and elements are missing. The causes for missing data include such things as equipment problems, some stations not operating at night, and a NOAA cost-saving effort from 1965 to 1981 that digitized data for only every third hour.

Although both the NSRDB and the TMY2 data sets used methods to fill data where possible, some elements, because of their discontinuous nature, did not lend themselves to interpolation or other data-filling methods. Consequently, data in the TMY2 data files may be missing for horizontal visibility, ceiling height, and present weather for up to 2 consecutive hours for Class A stations and for up to 47 hours for Class B stations. For Colorado Springs, Colorado, snow depth and days since last snowfall may also be missing. No data are missing for more than 47 hours, except for snow depth and days since last snowfall for Colorado Springs, Colorado. As indicated in Table 3-2, missing data values are represented by 9's and the appropriate source and uncertainty flags.

Source and Uncertainty Flags

With the exception of extraterrestrial horizontal and extraterrestrial direct radiation, the two field positions immediately following the data value provide source and uncertainty flags both to indicate whether the data were measured, modeled, or missing, and to provide an estimate of the uncertainty of the data. Source and uncertainty flags for extraterrestrial horizontal and extraterrestrial direct radiation are not provided because these elements were calculated using equations considered to give exact values.

For the most part, the source and uncertainty flags in the TMY2 data files are the same as the ones in NSRDB, from which the TMY2 files were derived. However, differences do exist for data that were missing in the NSRDB, but then filled while developing the TMY2 data sets. Uncertainty values apply to the data with respect to when the data were measured, and not as to how "typical" a particular hour is for a future month and day. More information on data filling and the assignment of source and uncertainty flags is found in Appendix A.

Tables 3-3 through 3-6 define the source and uncertainty flags for the solar radiation, illuminance, and meteorological elements.

Table 3-3. Solar Radiation and Illuminance 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 relationship, global = diffuse + direct × cosine(zenith)
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 data 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
I	Modeled illuminance or luminance data derived from measured or modeled solar radiation data
?	Source does not fit any of the above categories. Used for nighttime values and missing data

Table 3-4. Solar Radiation and Illuminance Uncertainty Flags

Flag	Uncertainty Range (%)
1	Not used
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 3-5. Meteorological Source Flags

Flag	Definition
A	Data as received from NCDC, converted to SI units
B	Linearly interpolated
C	Non-linearly interpolated to fill data gaps from 6 to 47 hours in length
D	Not used
E	Modeled or estimated, except: precipitable water, calculated from radiosonde data; dew point temperature calculated from dry bulb temperature and relative humidity; and relative humidity calculated from dry bulb temperature and dew point temperature
F	Precipitable water, calculated from surface vapor pressure; aerosol optical depth, estimated from geographic correlation
?	Source does not fit any of the above. Used mostly for missing data

Table 3-6. Meteorological Uncertainty Flags

Flag	Definition
1 - 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

SECTION 4

Comparison with Long-Term Data Sets

The TMY2 data were compared with 30-year data sets to show differences between TMY2 data and long-term data for the same stations. Comparisons were made on a monthly and annual basis for global horizontal, direct normal, and south-facing latitude tilt radiation; and for heating and cooling degree days. These comparisons give general insight into how well, with respect to long-term conditions, the TMY2s portray the solar resource and the dry bulb temperature environment for simulations of solar energy conversion systems and building systems. On an annual basis, the TMY2s compare closely to the 30-year data sets. The monthly comparisons are less favorable than the annual comparisons.

Solar Radiation Comparisons

Monthly and annual solar radiation for the TMY2 data sets were compared with previously determined (Marion and Wilcox 1994) monthly and annual averages for the 1961–1990 NSRDB, from which the TMY2 data sets were derived. These comparisons were made for global horizontal, direct normal, and a fixed surface facing south with a tilt angle from horizontal equal to the station's latitude.

Results of these comparisons are shown in Figures 4-1 through 4-6. TMY2 values for all stations are plotted against their respective 30-year average from the 1961–1990 NSRDB. As indicated by the scatter of the data and the statistical information at the top of the figures, agreement is better on an annual basis than on a monthly basis. This is a consequence of cancellation of some of the monthly differences when the monthly values are summed for the annual value. The statistical information presented is the mean difference between the TMY2 value and the 1961–1990 average and the standard deviation of the differences.

Table 4-1 provides 95% confidence intervals, determined as twice the standard deviation of the differences between TMY2 and NSRDB values, for TMY2 monthly and annual solar radiation. The confidence intervals are given in units of kWh/m^2/day. Differences between TMY2 and NSRDB 30-year values should be within the confidence interval 95% of the time.

Table 4-1. 95% Confidence Intervals for Monthly and Annual Solar Radiation

	Confidence Interval (±kWh/m^2/day)	
Element	Monthly	Annual
Global Horizontal	0.20	0.06
Direct Normal	0.50	0.16
Latitude Tilt	0.29	0.09

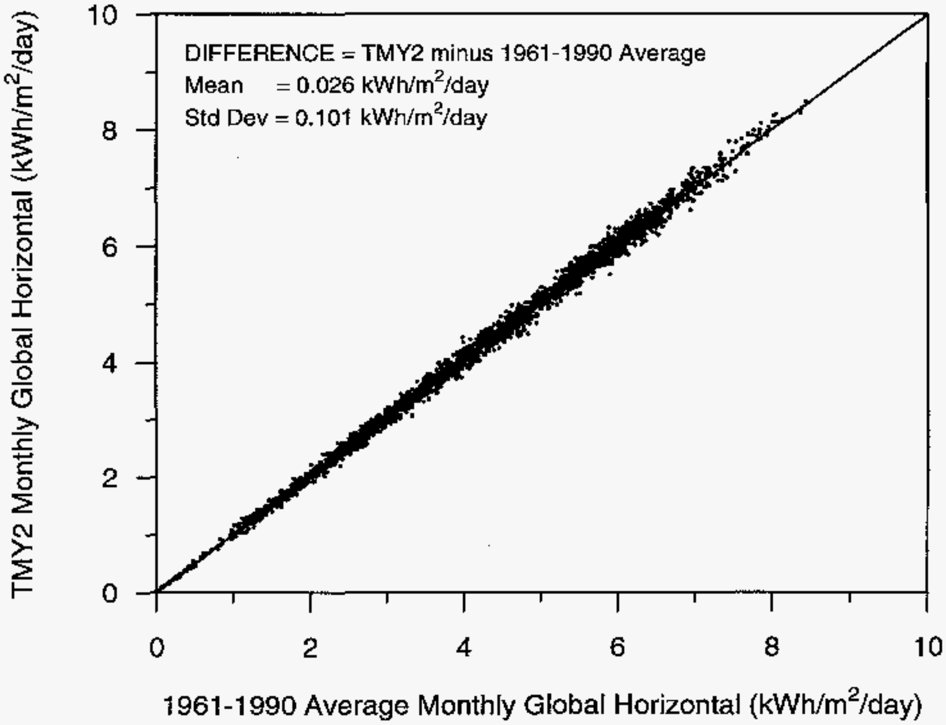

Figure 4-1. Comparison of monthly averages of global horizontal solar radiation when calculated using NSRDB and TMY2 data

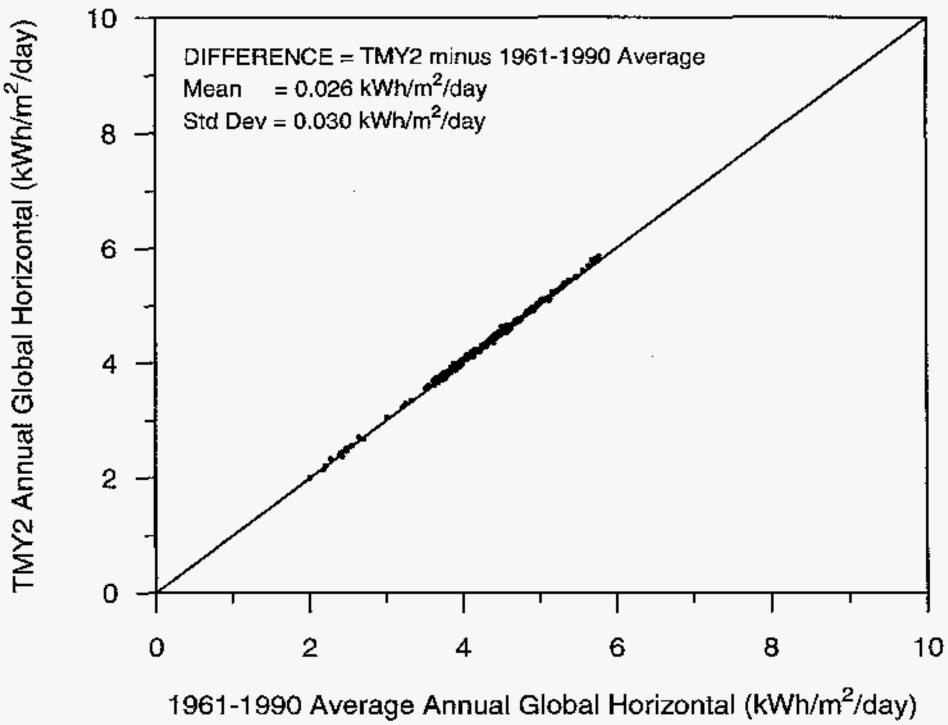

Figure 4-2. Comparison of annual averages of global horizontal solar radiation when calculated using NSRDB and TMY2 data

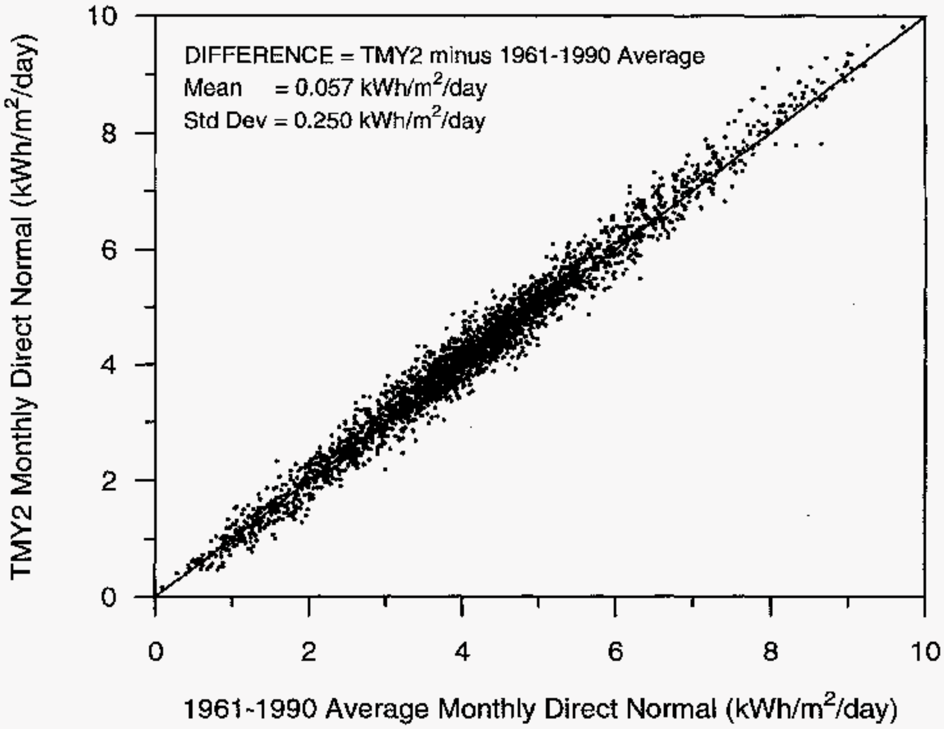

Figure 4-3. Comparison of monthly averages of direct normal solar radiation when calculated using NSRDB and TMY2 data

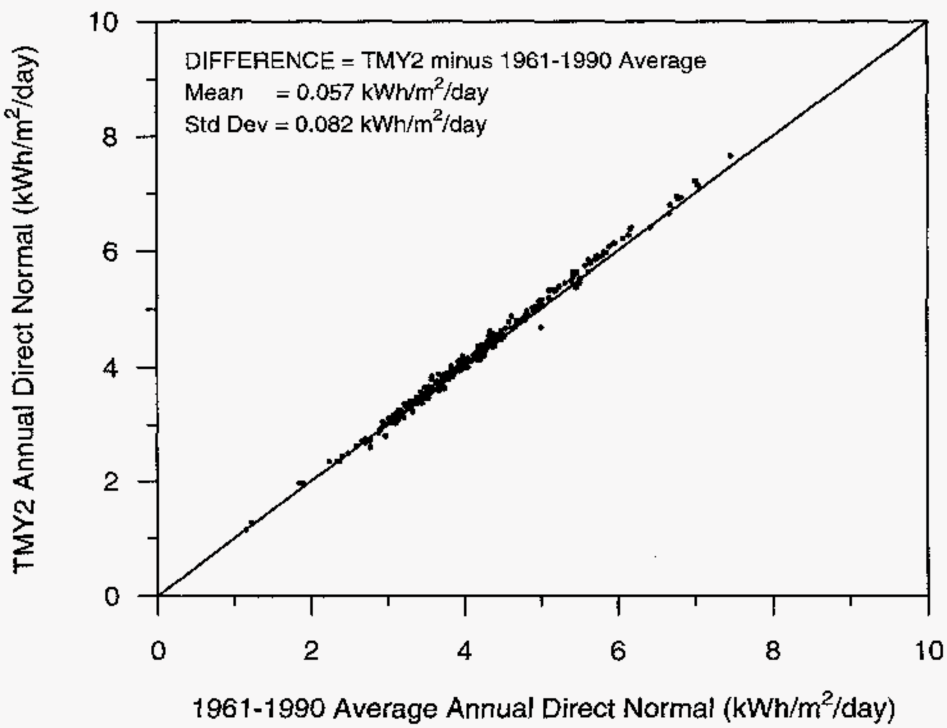

Figure 4-4. Comparison of annual averages of direct normal solar radiation when calculated using NSRDB and TMY2 data

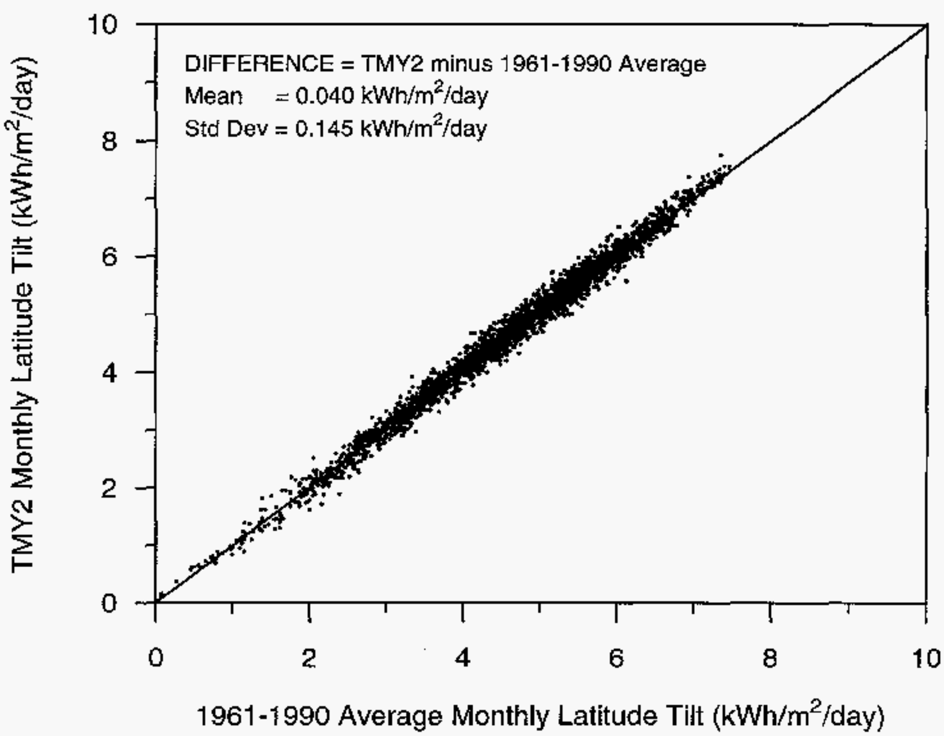

Figure 4-5. **Comparison of monthly averages of latitude tilt solar radiation when calculated using NSRDB and TMY2 data**

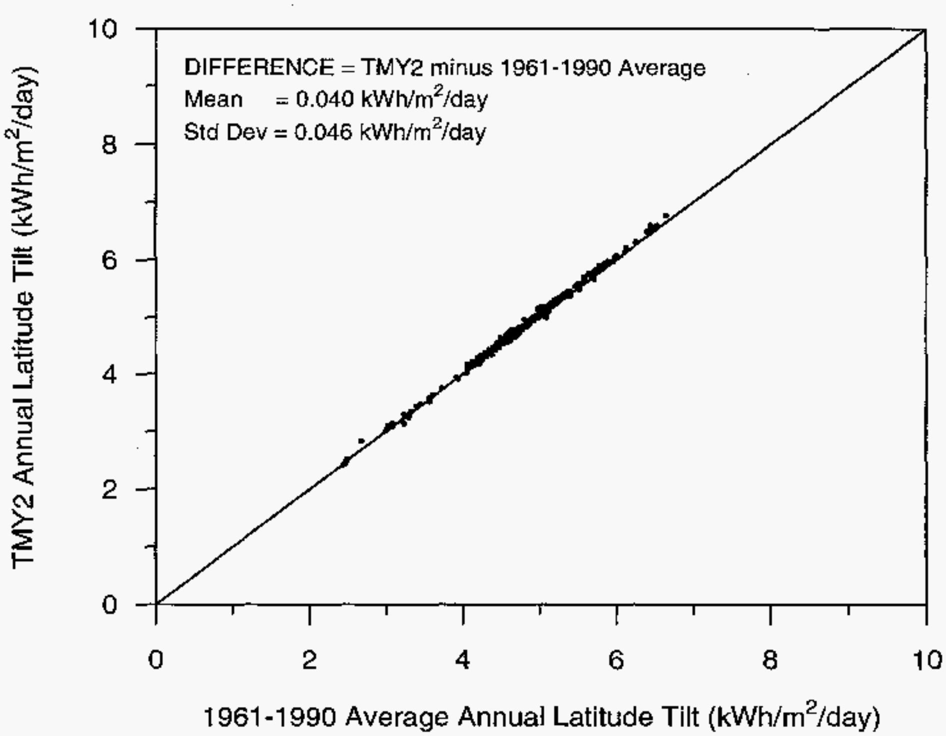

Figure 4-6. **Comparison of annual averages of latitude tilt solar radiation when calculated using NSRDB and TMY2 data**

Heating and Cooling Degree Day Comparisons

Degree days are the difference between the average temperature for the day and a base temperature. If the average for the day (calculated by averaging the maximum and minimum temperature for the day) is less than the base value, then the difference is designated as heating degree days. If the average for the day is greater than the base value, the difference is designated as cooling degree days.

Monthly and annual heating and cooling degree days (base 18.3°C) calculated from the TMY2 data sets were compared with those for the same stations from NCDC's data tape, "1961-1990 Monthly Station Normals All Elements." This data tape includes temperature and degree day normals for about 4775 stations in the United States and its territories. The normals are averages computed by NCDC for the period 1961–1990.

Results of these comparisons are shown in Figures 4-7 through 4-10. TMY2 values for all stations are plotted against their respective 30-year average from NCDC's data tape. As seen for solar radiation, agreement is better on an annual basis than on a monthly basis.

Table 4-2 provides 95% confidence intervals, determined as twice the standard deviation of the differences between TMY2 and NCDC values, for TMY2 monthly and annual heating and cooling degree days. The confidence intervals are given in units of degree days. Differences between TMY2 and NCDC 30-year values should be within the confidence interval 95% of the time.

Table 4-2. 95% Confidence Intervals for Monthly and Annual Degree Days

	Confidence Interval (±degree days, base 18.3°C)	
Parameter	Monthly	Annual
Heating Degree Days	45.6	182
Cooling Degree Days	28.2	98

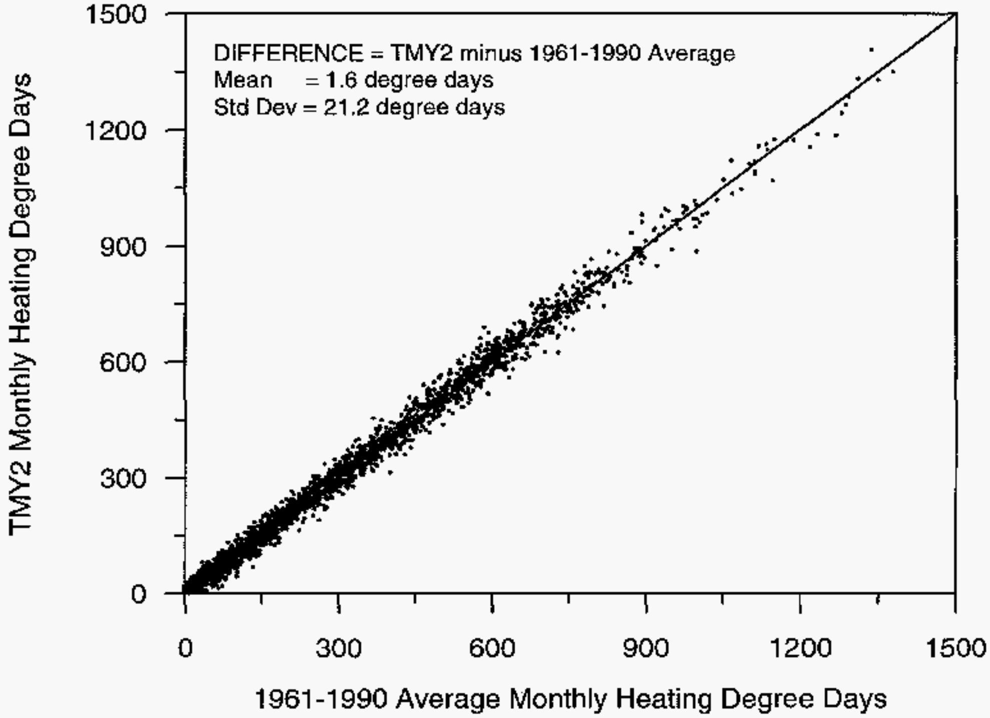

Figure 4-7. Comparison of monthly heating degree days for NCDC and TMY2 data

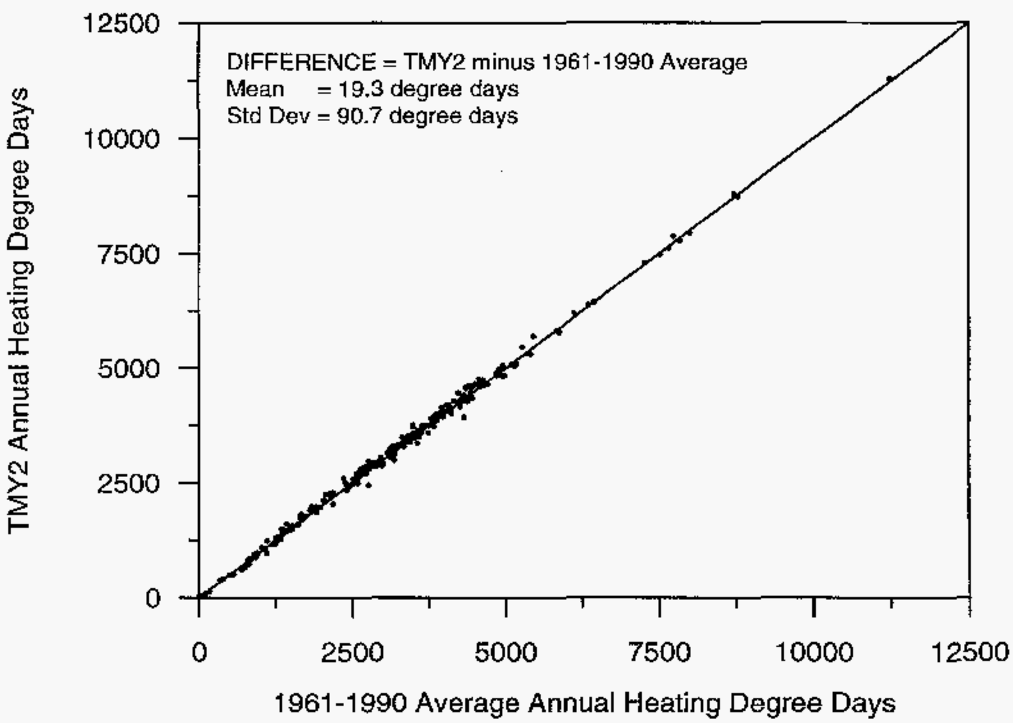

Figure 4-8. Comparison of annual heating degree days for NCDC and TMY2 data

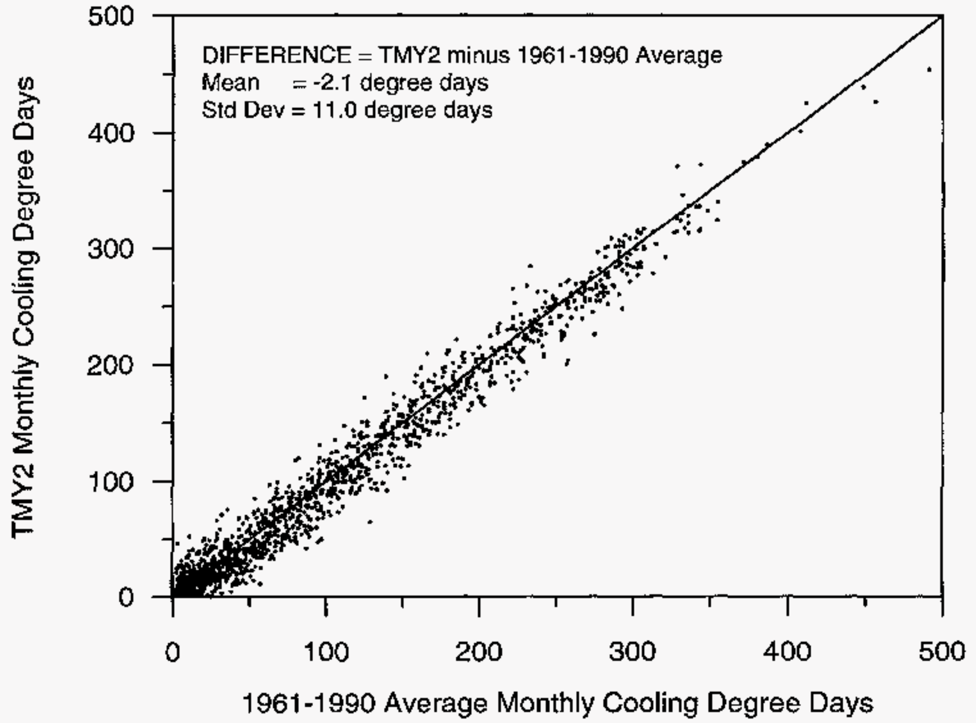

Figure 4-9. Comparison of monthly cooling degree days for NCDC and TMY2 data

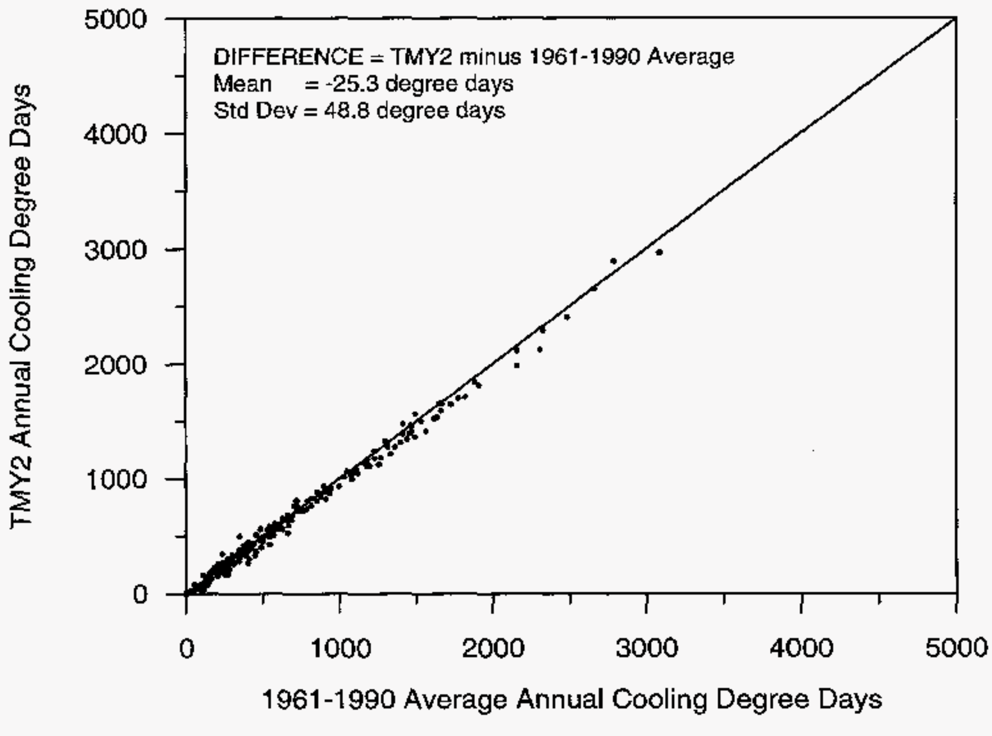

Figure 4-10. Comparison of annual cooling degree days for NCDC and TMY2 data

References

Marion, W.; Wilcox, S. (1994). *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*. NREL/TP-463-5607. Golden, CO: National Renewable Energy Laboratory.

APPENDIX A

Procedures for Developing TMY2s

The TMY2s were created based on the procedures that were developed by Sandia National Laboratories (Hall et al. 1978) to create the original TMYs from the 1952–1975 SOLMET/ERSATZ data. Modifications to the Sandia method were made to better optimize the weighting of the indices, to provide preferential selection for months with measured solar radiation data, and to account for missing data. This appendix begins by summarizing the Sandia method, and then it discusses departures from the Sandia method that were used to create the TMY2 data sets.

Sandia Method

The Sandia method is an empirical approach that selects individual months from different years of the period of record. For example, in the case of the NSRDB that contains 30 years of data, all 30 Januarys are examined and the one judged most typical is selected to be included in the TMY. The other months of the year are treated in a like manner, and then the 12 selected typical months are concatenated to form a complete year. Because adjacent months in the TMY may be selected from different years, discontinuities at the month interfaces are smoothed for 6 hours on each side.

The Sandia method selects a typical month based on nine daily indices consisting of the maximum, minimum, and mean dry bulb and dew point temperatures; the maximum and mean wind velocity; and the total global horizontal solar radiation. Final selection of a month includes consideration of the monthly mean and median and the persistence of weather patterns. The process may be considered a series of steps.

Step 1—For each month of the calendar year, five candidate months with cumulative distribution functions (CDFs) for the daily indices that are closest to the long-term (30 years for the NSRDB) CDFs are selected. The CDF gives the proportion of values that are less than or equal to a specified value of an index.

Candidate monthly CDFs are compared to the long-term CDFs by using the following Finkelstein-Schafer (FS) statistics (Finkelstein and Schafer 1971) for each index.

$$FS = (1/n) \sum_{i=1}^{n} \delta_i$$

where

δ_i = absolute difference between the long-term CDF and the candidate month CDF at x_i

n = the number of daily readings in a month.

Four CDFs for global horizontal solar radiation for the month of June are shown in Figure A-1. Compared to the long-term CDF by using FS statistics, the CDF for June of 1981 compared the best and the CDF for June of 1989 compared the worst. Even though it was not the best month with respect to the long-term CDF, June of 1962 was selected for the TMY2. This was a consequence of additional selection steps described in the following paragraphs.

Because some of the indices are judged more important than others, a weighted sum (WS) of the FS statistics is used to select the 5 candidate months that have the lowest weighted sums.

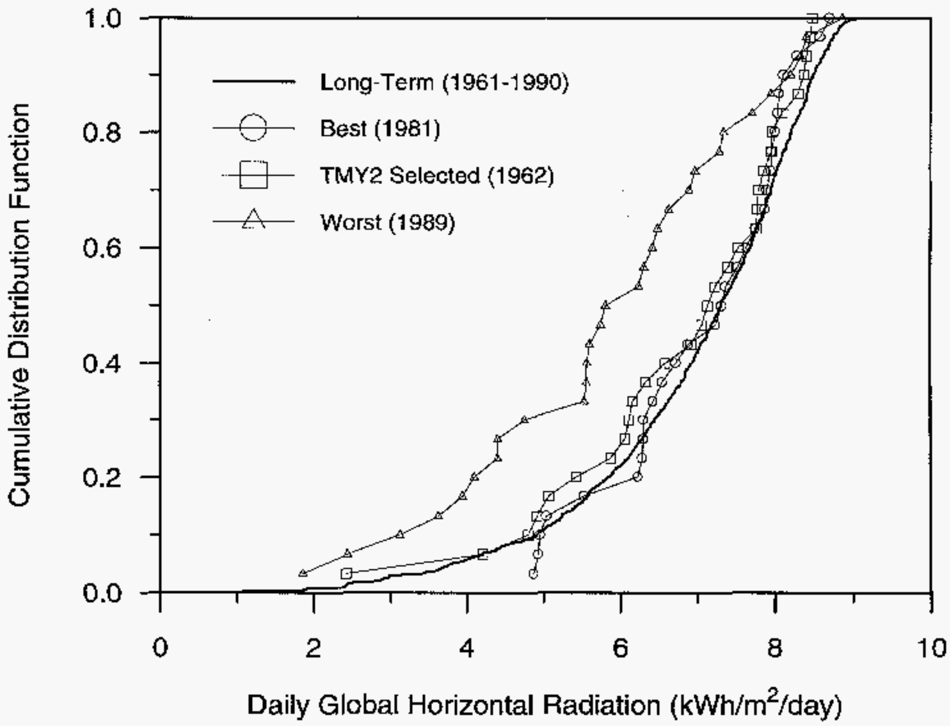

Figure A-1. Cumulative distribution functions for June global horizontal solar radiation for Boulder, Colorado

$$WS = \Sigma\, w_i\, FS_i$$

where

w_i = weighting for index

Fs_i = FS statistic for index.

Step 2—The 5 candidate months are ranked with respect to closeness of the month to the long-term mean and median.

Step 3—The persistence of mean dry bulb temperature and daily global horizontal radiation are evaluated by determining the frequency and run length above and below fixed long-term percentiles. For mean daily dry bulb temperature, the frequency and run length above the 67th percentile (consecutive warm days) and below the 33rd percentile (consecutive cool days) were determined. For global horizontal radiation, the frequency and run length below the 33rd percentile (consecutive low radiation days) were determined.

The persistence data are used to select from the five candidate months the month to be used in the TMY. The highest ranked candidate month from step 2 that meets the persistence criteria is used in the TMY. The persistence criteria excludes the month with the longest run, the month with the most runs, and the month with zero runs.

Step 4—The 12 selected months were concatenated to make a complete year and smooth discontinuities at the month interfaces for 6 hours each side using curve-fitting techniques.

Weighting and Indice Modifications

The weighting for each index plays a role in the selection of the typical months. Ideally, one would select a month that had FS statistics for each index that were better than all the other months. In practice, this is unlikely because the months might be typical with respect to some of the indices, but not others. By weighting the FS statistics, the relative importance and sensitivity of the indices may be taken into account. The Sandia weighting values and the weighting values used for the TMY2s are compared in Table A-1.

For the TMY2s, an index for direct normal radiation was added. This improves the comparison between annual direct normal radiation for the TMY2s and the 30-year annual average by about a factor of 2 (based on 20 geographically representative NSRDB stations). When only global horizontal radiation is used for the solar index, the TMY annual direct radiation values for the 20 stations were within 4% (95% confidence level) of the 30-year annual average. Using both global horizontal and direct radiation indices reduced the differences to 2%, with no adverse effect on global horizontal radiation comparisons.

Table A-1. Weightings for FS Statistics

Index	Sandia Method	NSRDB TMY2s
Max Dry Bulb Temp	1/24	1/20
Min Dry Bulb Temp	1/24	1/20
Mean Dry Bulb Temp	2/24	2/20
Max Dew Point Temp	1/24	1/20
Min Dew Point Temp	1/24	1/20
Mean Dew Point Temp	2/24	2/20
Max Wind Velocity	2/24	1/20
Mean Wind Velocity	2/24	1/20
Global Radiation	12/24	5/20
Direct Radiation	Not Used	5/20

Weightings for dry bulb and dew point temperature were changed slightly to give more emphasis to dry bulb and dew point temperatures and less to wind velocity, which is of less importance for solar energy conversion systems and buildings. Neither of the TMY weightings is appropriate for wind energy conversion systems.

The relative weights between solar and the other elements were not found to be particularly sensitive. As an indicator, annual heating and cooling degree days (base 18.3°C) were compared for the TMY2s and the 30-year period for the 20 stations. With the selected solar weighting of 50% (global and direct), annual heating degree days for the TMY2s were within 5% (95% confidence level) of the 30-year annual average. As an extreme, reducing the solar weighting to zero only reduced the differences to within 2½%. Differences between the TMY2 annual averages and the 30-year averages for cooling degree days were within 9%, for both 0% and 50% solar weightings.

As a consequence of adding the index for direct normal radiation, the persistence check in Step 3 was modified to determine the frequency and run length below the 33rd percentile (consecutive low radiation days) for daily values of direct normal radiation. This information, along with that for the other persistence indices, was then used to select the month satisfying the persistence criteria.

El Chichon Years

The volcanic eruption of El Chichon in Mexico in March 1982 spewed large amounts of aerosols into the stratosphere. The aerosols spread northward and circulated around the earth. This phenomenon noticeably decreased the amount of solar radiation reaching the United States during May 1982 until December 1984, when the effects of the aerosols had diminished. Consequently, these months were not used in any of the TMY2 procedures because they were considered not typical.

Leap Years

TMY2 files do not include data for February 29. Consequently, data for February 29 were not used in leap year Februarys to determine their candidate month CDFs. However, to maximize the use of available data, data for February 29 were included for determining the long-term CDFs.

Preference for Months with Measured Solar Radiation Data

For a station, the NSRDB may contain both measured and modeled solar radiation data. Because of additional uncertainties associated with modeled data, preference in the selection of candidate months were given to months that contained either measured global horizontal or direct normal solar radiation data. This was accomplished between Steps 2 and 3 by switching the ranking of the first and second ranked candidate months if the second ranked month contained measured solar radiation data, but the first ranked month did not.

Month Interface Smoothing

Curve-fitting techniques were used to remove discontinuities created by concatenating months from different years to form the TMY2s. These techniques were applied for 6 hours each side of the month interfaces for dry bulb temperature, dew point temperature, wind speed, wind direction, atmospheric pressure, and precipitable water. Relative humidities for 6 hours on each side of the month interfaces were calculated using psychometric relationships (ASHRAE 1993) and curve-fitted values of dry bulb temperature and dew point temperature.

Allowance for Missing Data

The NSRDB has no missing solar radiation data, but meteorological data are missing for some stations and months. Consequently, when creating the TMY2s, procedures were adopted to account for missing meteorological data. From these procedures, two classes of TMY2 stations evolved: Class A and B.

Class A stations are those stations whose 30-year meteorological data records were the most complete and that had an adequate number (15) of candidate months after eliminating any months with data missing for more than 2 consecutive hours. The minimum of 15 candidate months permitted completion of 90% of the stations without extensive data filling. As indicated in Figure A-2, as few as 15 candidate months yielded typical months that were within the range of differences established by 25 or more candidate months when comparing monthly values of direct normal for TMY2 months with monthly averages of direct normal for the 1961–1990 period. This relationship was also found to be true for global horizontal radiation and heating and cooling degree days.

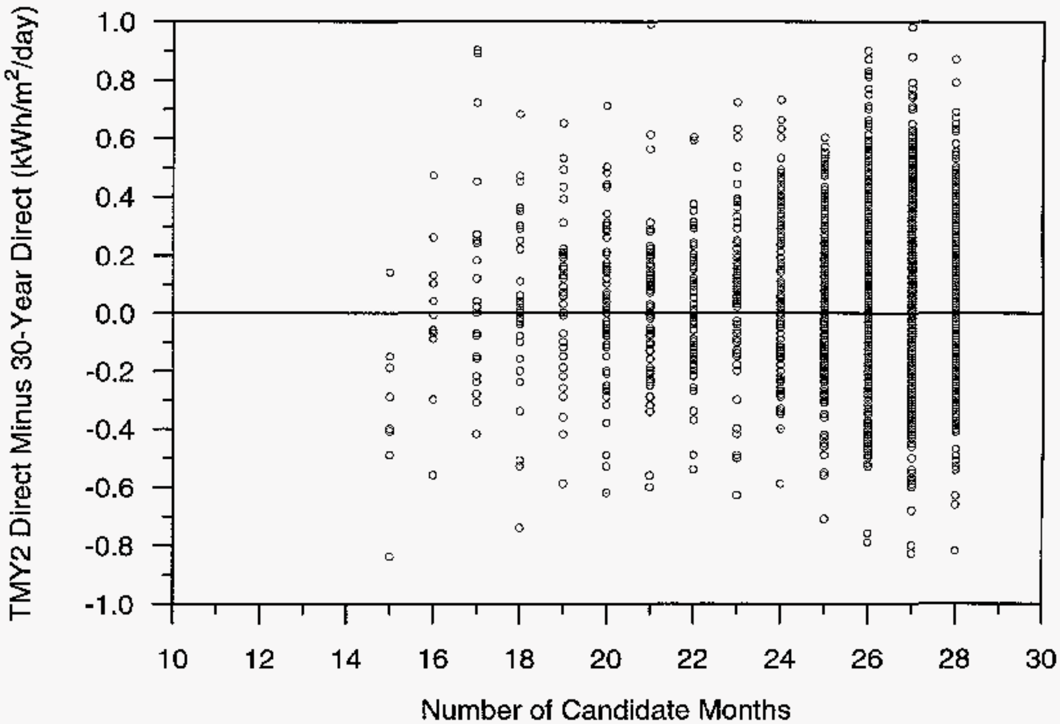

Figure A-2. Closeness of TMY2 monthly direct normal radiation to 1961–1990 monthly averages as a function of the number of candidate months

Class B stations had more missing data than Class A stations, and the data were filled for the index elements used to select the TMY2s. Other elements in Class B TMY2s were not filled and may be missing. Table 1-1 on page 5 shows elements that may have missing data values in TMY2 files for Class A and B stations.

Class A Stations. There are 216 Class A stations. Missing data for these stations were accounted for in the following fashion:

1. Long-term CDFs in Step 1, based on the 30-year period (excluding the El Chichon period), were determined using only measured data or data modeled (such as solar radiation) from measured or observed data.
2. Months were eligible to be candidate months if they had no missing or filled data for periods greater than 2 hours. This accommodated data from 1965 to 1981 that was digitized by NOAA only every third hour. For the elements used for the indices, the missing data for the 2-hour sequences were replaced with interpolated or modeled values.

Class B Stations. The NSRDB data from which the 23 Class B stations were derived have substantially more missing data than the NSRDB data from which the Class A stations were derived. This situation required filling missing data to have sufficient candidate months from which to select typical months. The additional missing data for the Class B stations resulted from such things as equipment problems and the fact that some stations did not operate at night for some or all of the 30-year period. Criteria were relaxed for Class B stations to permit filled data for periods of up to 47 hours to be used in determining the long-term CDFs, and months were eligible to be candidate months if they had no missing or filled data for periods greater than 47 hours. For Colorado Springs, Colorado, the criteria were further relaxed to permit missing data for snow depth and days since last snowfall.

Data-Filling Methods

The TMY2 data sets required filling some missing data that were not filled during the development of the NSRDB. The NSRDB was made complete with respect to solar radiation elements (NSRDB—Vol. 1 1992). This required NSRDB filling of missing data, at least for daylight hours, for elements used to model solar radiation, such as total and opaque sky cover, dry bulb temperature, relative humidity, and atmospheric pressure.

For other meteorological elements, data were not filled in the NSRDB. Consequently, to develop the TMY2s, missing data for dry bulb temperature (nighttime), dew point temperature, and wind speed required data filling to complete the selection of typical months. These elements, along with global horizontal and direct normal radiation, were used to generate statistics to determine the appropriate selection of typical months.

To maximize the usefulness of the TMY2s, other missing meteorological data were also filled, with the exception of horizontal visibility, ceiling height, and present weather. The discontinuous nature of these three elements did not readily lend itself to interpolation or other data-filling methods.

Data filling for TMY2 Class B stations was more extensive than for the Class A stations. TMY2s for Class A stations were restricted to the selection of typical months that had no more than 2 consecutive hours of data missing, whereas Class B stations could have up to 47 consecutive hours of data missing.

Two-hour gaps in data records for Class A and Class B stations were filled by linear interpolation, except for relative humidity, which was calculated based on psychometric relationships (ASHRAE 1993) using measured or filled dry bulb temperature and dew point temperature. For Class B stations, longer gaps from 3 to 47 hours were filled using filled data from the NSRDB if available; otherwise TMY2 data filling-methods were used.

The NSRDB contains filled data for total and opaque sky cover, dry bulb temperature, relative humidity, and atmospheric pressure. NSRDB data gaps up to 5 hours were filled by linear interpolation. Gaps from 6 to 47 hours were filled for the above elements by using data from adjacent days for identical hours and then by adjusting the data so that there were no abrupt changes in data values between the filled and measured data. Many Class B stations did not operate for parts of the night and/or early morning and late afternoon. For these stations, NSRDB data were filled from sunrise to sunset to allow model estimates of solar radiation. However, nighttime data were not necessarily filled.

The TMY2 data sets used procedures to fill nighttime data and other data not filled in the NSRDB. These procedures were used for total and opaque sky cover, atmospheric pressure, dry bulb temperatures, dew point temperatures, relative humidity, wind speed, precipitable water, broadband aerosol optical depth, snow depth, and days since last snowfall. Data elements not filled are horizontal visibility, ceiling height, and present weather.

The TMY2 data-filling procedures are described in the following paragraphs.

Total and opaque sky cover, and *atmospheric pressure* were linearly interpolated over any missing nighttime periods.

Nighttime *dry bulb temperatures* were linearly interpolated, and then the filled values were adjusted to preserve nonlinearities, such as more rapid changes in temperature near sunrise and sunset. These adjustments were based on average diurnal profiles determined for each calendar month and appropriately scaled to match the endpoints of the interpolation interval.

Missing daytime *dew point temperatures* were filled using psychometric relationships (ASHRAE 1993) and measured or NSRDB filled values of dry bulb temperature and relative humidity. The same procedure was also used to fill missing nighttime dew point temperatures if measured or NSRDB filled values of dry bulb temperature and relative humidity were available. Otherwise, missing nighttime dew point temperatures were filled by the procedure used to fill nighttime missing dry bulb temperatures—linear interpolation and then adjustment of filled values based on average diurnal profiles determined for each calendar month.

Missing nighttime *relative humidity* values were filled using psychometric relationships and dry bulb and dew point temperatures. Dry bulb temperatures used were measured or NSRDB filled or TMY2 filled, and dew point temperatures used were measured or TMY2 filled.

Missing *wind speed* data, for up to 47 hour gaps, were filled by the procedure used to fill nighttime missing dry bulb temperatures—linear interpolation and then adjustment of filled values based on average diurnal profiles determined for each calendar month.

Missing *wind direction* and *precipitable water*, for up to 47 hour gaps, were linearly interpolated. For calm winds, wind direction was set to zero (north).

Broadband aerosol optical depth values in the TMY2s are daily values provided by seasonal functions derived during the development of the NSRDB. The seasonal functions are sinusoidal with respect to the day of the year and have peak values occurring in the summer.

Snow depth and *days since last snowfall* data were available from the NSRDB for all but Colorado Springs and a few stations at southern latitudes, such as Guam and Puerto Rico. So much data were missing for Colorado Springs that no attempt was made to fill the data, and missing data for the elements snow depth and days since last snowfall were flagged as missing. For the southern latitude sites that do not receive snow, snow depth was set to zero and days since last snowfall was set to 88, meaning 88 or more days.

Quality Control

Data were checked before and after processing to ensure that data were reasonable. NCDC provided information identifying some erroneous dew point temperature data in Version 1.1 of the NSRDB, where dew point temperatures exceeded dry bulb temperatures. During processing of the NSRDB data to generate the TMY2s, dew point temperatures were checked to make sure they did not exceed dry bulb temperatures. If they did, the dew point temperature was calculated using relative humidity and dry bulb temperature, if available; otherwise, the data were considered missing.

NCDC also identified three stations (Chattanooga, Tennessee; Huntsville, Alabama; and Louisville, Kentucky) that had erroneous total sky cover data for the period 1970–1974. The cloud cover data had been set to 10 for non-3-hourly values (correct values were present every 3 hours). Consequently, modeled solar radiation for these stations and times would be erroneous. For the TMY2s, data for these stations and time periods were excluded.

Post-processing checks revealed that some of the selected TMY2 months had solar radiation values with obvious errors (diffuse radiation values were zero even though global horizontal and direct normal radiation were a few hundred watt hours). Consequently, these stations were reprocessed with the affected data being excluded. The stations with months excluded during the reprocessing because of erroneous solar data are: Boulder, Colorado (2/88, 3/85, 5/85, and 10/85); Lake Charles, Louisiana (2/80); Caribou, Maine (4/78, 7/85, and 7/72); Great Falls, Montana (10/89); Omaha, Nebraska (5/85, 5/89, and 11/81); Ely, Nevada (6/89 and 9/88); Guam, Pacific Islands (1/88, 9/79, and 9/88); El Paso, Texas (12/88); Midland, Texas (5/80 and 12/79); Salt Lake City, Utah (5/88, 8/80, and 10/89); Lander, Wyoming (3/88 and 8/80).

Calculation of Illuminance Data

To facilitate lighting and energy analysis of buildings, hourly values for global horizontal illuminance, direct normal illuminance, diffuse horizontal illuminance, and zenith luminance were added to the TMY2 data sets. These elements were calculated using luminous efficacy models developed by Perez et al. (1990). Inputs to the models are global horizontal radiation, direct normal radiation, diffuse horizontal radiation, and dew point temperature. The luminous efficacy in terms of lumens per watt is determined as a function of sky clearness, sky brightness, and zenith angle.

Assignment of Source and Uncertainty Flags

With the exception of extraterrestrial horizontal and extraterrestrial direct radiation, each data value was assigned a source and uncertainty flags. The source flag indicates whether the data were measured, modeled, or missing, and the uncertainty flag provides an estimate of the uncertainty of the data. Source and uncertainty flags for extraterrestrial horizontal and extraterrestrial direct radiation are not provided because these elements were calculated using equations considered to give exact values.

Usually, the source and uncertainty flags in the TMY2 data files are the same as the ones in the NSRDB, from which the TMY2 files were derived. However, differences do exist for data that were flagged missing in the NSRDB, but then filled while developing the TMY2 data sets. Differences are also present for illuminance and luminance data values that were not included in the NSRDB. Uncertainty values apply to the data with respect to the time stamp of the data, and not as to how “typical” a particular hour is for a future month and day. The uncertainty values represent the plus or minus interval about the data value that contains the true value 95% of the time.

The uncertainty assigned to modeled solar radiation data includes only the bias error in the model and not the random error component, which could be several times larger for partly cloudy skies. For partly cloudy skies, an hour can be composed of large or small amounts of sunshine, depending on whether the sun is mostly free of the clouds or occluded by the clouds. Consequently, modeled hourly values may depart significantly from true values for partly cloudy skies. The uncertainty assigned to modeled solar radiation data represents the average uncertainty for a large number of model estimates (such as for a month). When averaging large data sets, random errors tend to cancel, leaving only the bias error.

Uncertainties for values of illuminance and luminance were determined by taking the root-sum-square of the two main sources of error: (1) uncertainty of the solar radiation element (global horizontal, direct normal, or diffuse horizontal radiation) from which the illuminance or luminance element is derived, and (2) uncertainty of the model estimate.

The uncertainty of the model estimates are based on the evaluation presented by Perez et al. (1990) for six test stations. To be conservative, the following model mean bias errors for the stations with the largest errors were used:

- 1.2% for global horizontal illuminance
- 1.6% for direct normal illuminance
- 2.3% for diffuse horizontal illuminance
- 1.2% for zenith luminance.

The uncertainty of the illuminance data value was then determined as the root-sum-square of the model uncertainty and solar radiation element uncertainty.

The use of the bias error, instead of bias and random error, is consistent with the approach in the above paragraph concerning the assignment of uncertainty values to modeled solar radiation elements. Consequently, it also has the same implications. The assigned uncertainty is representative of the average uncertainty for a large number of model estimates (such as for a month), but the actual uncertainty of the individual modeled illuminance and luminance values is greater than indicated.

For meteorological elements, relative uncertainties from the NSRDB were used. These uncertainties do not portray a quantitative evaluation of the uncertainty of the meteorological elements, but rather give relative uncertainties based on the data and the manner in which they were derived (NSRDB–Vol. 1 1992).

The source and uncertainty flags for the solar radiation, illuminance, and meteorological elements are presented in Tables 3-3 through 3-6 on pages 21 and 22.

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APPENDIX B

Key to Present Weather Elements

Appendix B provides the key for the present weather elements included in the TMY2 format. The TMY2s use a ten-digit number for present weather, whereas the older TMYs used an eight-digit number. Also, the weather occurrence values for the TMY2s have different meanings from those for the TMYs. For example, TMY2s use a nine to indicate "none," whereas TMYs use a zero to indicate "none."

Table B-1. Present Weather Elements in the TMY2 Format

Field Position	Element	Values	Definition
114	Observation Indicator	0 or 9	0 = Weather observation made 9 = Weather observation not made, or missing
115	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 1 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, or else unknown or missing if Observation Indicator element equals 9
116	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, or 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
117	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, or else unknown or missing if Observation Indicator element equals 9 (See next page for notes.)

Table B-1. Present Weather Elements in the TMY2 Format (Continued)

Field Position	Element	Values	Definition
	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
118	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, or 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.
119	Occurrence of Snow Showers, Snow Squalls, or Snow Grains	0 - 7, 9	0 = Light snow 1 = Moderate snow showers 2 = Heavy snow showers 3 = Light snow squall 4 = Moderate snow squall 5 = Heavy snow squall 6 = Light snow grains 7 = Moderate snow grains 9 = None if Observation Indicator element equals 0, or else unknown or missing if Observation Indicator element equals 9
120	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, or 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 B-1. Present Weather Elements in the TMY2 Format (Continued)

Field Position	Element	Values	Definition
121	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, or else unknown or missing if Observation Indicator element equals 9 Notes: These values recorded only when visibility is less than 11 km.
122	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, or else unknown or missing if Observation Indicator element equals 9 Notes: These values recorded only when visibility is less than 11 km.
123	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, or else unknown or missing if Observation Indicator element equals 9

APPENDIX C

Unit Conversion Factors

Table C-1 contains a table of unit conversion factors for converting SI data to other units.

Table C-1. Conversion Factors

To Convert From	Into	Multiply By
degrees Centigrade	degrees Fahrenheit	C° x 1.8 + 32
degree days (base 18.3°C)	degree days (base 65°F)	1.8
degrees (angle)	radians	0.017453
lux	foot-candles	0.0929
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
millibars	pascals	100.0
millibars	atmospheres	0.0009869
millibars	pounds per square inch	0.0145
watt-hours per square meter	joules per square meter	3600.0
watt-hours per square meter	Btu's per square foot	0.3170
watt-hours per square meter	Langleys	0.08604
watt-hours per square meter	calories per square centimeter	0.08604