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Solar Radiation Data Sources, Applications and Network Design

April 1978

Prepared For
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Solar Technology
Environmental Resources & Assessments Branch

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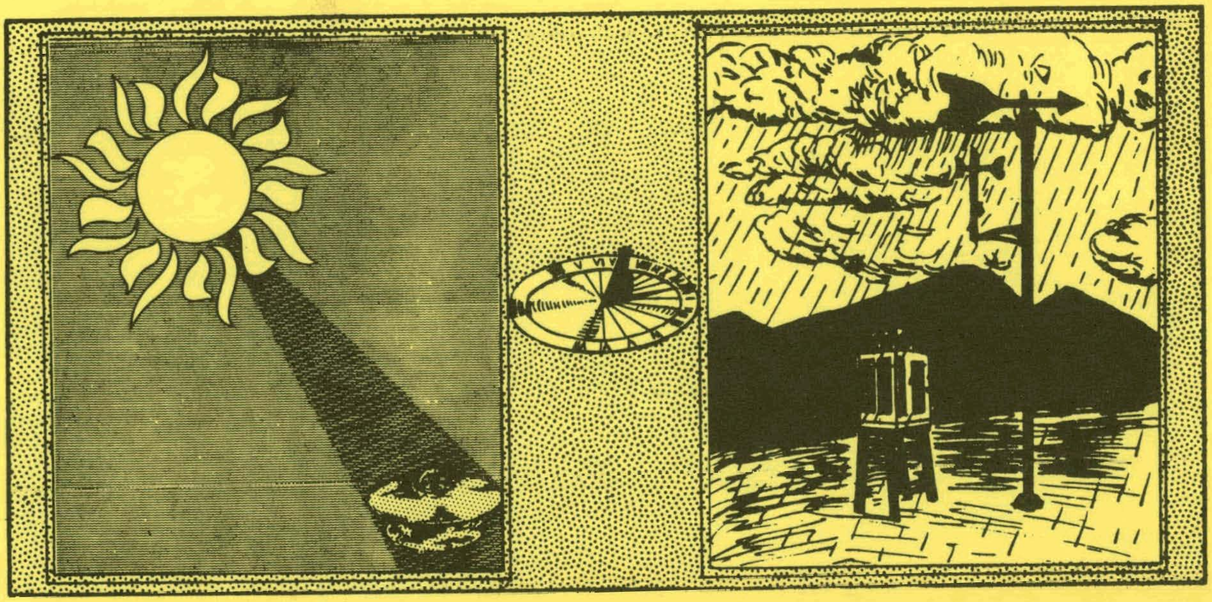

DISCLAIMER

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Solar Radiation Data Sources, Applications and Network Design

April 1978

Prepared By
The Kenneth E. Johnson Environmental and Energy Center
The University of Alabama

For
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Solar Technology
Washington, DC 20545

Under Contract No. EG-77-S-05-5362

ABSTRACT

A prerequisite to considering solar energy projects is to determine the requirements for information about solar radiation to apply to possible projects. This report offers techniques to help the reader specify requirements in terms of solar radiation data and information currently available, describes the past and present programs to record and present information to be used for most requirements, presents courses of action to help the user meet his needs for information, lists sources of solar radiation data and presents the problems, costs, benefits and responsibilities of programs to acquire additional solar radiation data.

The first chapter provides extensive background information about solar radiation data and its use. The remaining chapters provide specialized information about recording, collecting, processing, storing and disseminating solar radiation data and may only be useful for reference if the requirement has been satisfied in the early pages.

The report includes several Appendices which provide reference material for special situations.

Who should measure solar radiation? This question should be answered only after gaining a thorough understanding of all parts of this report. The Department of Energy, Division of Solar Technology in conjunction with the National Oceanic and Atmospheric Administration, Universities, State Energy Offices and other organizations are sponsoring projects to define the solar energy resource for most applications. This report describes those projects for potential users of solar energy to avoid duplication, conserve resources and to assure that all planned projects provide meaningful contributions for the future exploitation of solar energy.

FOREWORD

With the advent of the world energy awareness, precipitated by the drastic oil price increases in 1973 and subsequent actions by oil producing companies, there was an urgent need to evaluate alternate energy sources. Because the sun, for the foreseeable future, will be a source of renewable energy, it is a prime resource for investigation. Exploitation of the solar energy in various forms appears technically feasible and logical, promises to become economical and appears to be necessary for our social survival. There is not enough information presently available to answer, or even anticipate, all of the problems that will be encountered in exploiting the solar energy in each of its forms. A large scale program is now underway to increase our knowledge to effectively use solar energy.

Fortunately, a few dedicated scientists have been interested in the sun and its effects on the earth and have provided much of the basic knowledge to describe the solar processes. Unfortunately, attempts to gather information on a large scale and of the quality now needed met with little success due to a lack of an obvious need or "motivation".

The world population, and most notably the American public, is now motivated and seeking information concerning the direct use of solar energy. In many cases, however, it appears that people are going in many directions at once. The purpose of this book is to provide some order of direction so that individuals and organizations who wish to exploit solar energy will know where solar radiation measurements are currently being recorded and where data is available. Also, it is designed to help the reader understand the complexities involved in collecting solar radiation data and for processing it into useable information.

A distinction is noted between data and information - - data is useful only if it conveys information helpful in reaching a decision - - as expressed by Mr. Daniel J. Fink, Vice President and General Manager of the Space Division of the General Electric Company, in a keynote address at the MSFC/UAH sponsored Data Management Symposium in Huntsville, Alabama, October 1977.

Because the solar radiation will be the input for any solar system, it is necessary to understand and evaluate this input for sizing solar systems and many other uses. To put it differently, we need to know the number of miles per gallon of gas we can realize before we buy a vehicle. But even more pertinent is whether there are any gallons of gas available, or how many. It is this question regarding solar energy that must be put in perspective. We fully intend to answer this question for the public to the best accuracy possible. Because the solar energy reaching the earth's surface is variable, we do not expect an ultimate answer with the present state of knowledge of the atmosphere. However, we do expect, with prudent cooperation from all of us, to gain adequate knowledge to make solar energy systems a viable, economical, clean, replenishable energy resource of the future.

Your indulgence and careful consideration of the essentials of this book will help you in participating in the broader application and early exploitation of solar energy.

Frederick A. Koomanoff
Chief, Environmental Resource Assessments Branch
Division of Solar Technology, DOE

PREFACE

This book provides guidance in locating, understanding and using solar radiation measurements and, if determined necessary, feasible and economical, setting up solar radiation data networks.

Following the oil embargo in 1973, an understandable and almost immediate interest arose in the potentiality of solar energy for future uses, both domestic and industrial, in the United States. However, at that time, few individuals, even among engineers, fully understood the complexities involved in measuring, recording, interpreting, and disseminating solar radiation data. Many newcomers to the field quickly learned that such data as then existed contained many errors. Some of the problems had accrued because of apathy to record keeping, and others were inherent due to variations in the environment and the accuracy of the instruments utilized in sensing the data. Predictably, there was an initial rush to acquire instruments and take personal observations, which, just as predictably, later subsided.

Today, the pace is less hectic. More attention is being given to problems involved in solar radiation measurement. This book is designed to provide information to assist in the solution of such problems.

In engineering and technology, as in the general development of life, one must learn to walk before learning to run. Therefore, there is a rather lengthy introduction in this book to assist in the process. In it, solar radiation measurements, instruments, data, and related topics are generally discussed; and references are made to relevant reports and books. It provides background material essential to the more detailed and technical contents which follow. While this book relies to a degree on references to already published materials in order to avoid needless duplication, many new concepts for the design and operation of solar radiation data networks are provided.

Providing such general instructions from which someone may take specific actions is challenging. The process requires a certain rapport between author and reader, and readers are not expected to take the same or similar actions because of different situations. At best, one may only hope to minimize actions which are unproductive. A network inherently implies cooperation. While this book may provide the background for that cooperation, it will not replace existing, "personalized", well-coordinated guidelines for an operating network.

The major emphasis of this document is to provide information on establishing the true requirement and uses of solar radiation networks so that any resulting networks that are established will provide useful data.

This book is devoted largely to direct, diffuse, and global aspects of solar radiation. While terrestrial radiation may become part of a network requirement, including it in the primary discussion is an unnecessary complication. Fortunately, Dr. Kinsell Coulson devotes two chapters of his book entirely to terrestrial radiation.* If terrestrial radiation measurements become necessary in a network, the reader should refer to this very useful work.

The authors have drawn heavily on a wide variety of sources in writing this book. Among these are the reports of the World Meteorological Organization (WMO); the National Oceanic and Atmospheric Administration (NOAA); the Meteorological Service of Canada, which established a 54-station solar radiation network during the 1960's; and informal information from the Tennessee Valley Authority (TVA) that operates a 12-station network.

Huntsville, Alabama

Eugene A. Carter
David L. Christensen
Baker B. Williams

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*Solar and Terrestrial Radiation, Methods and Measurements, New York, Academic Press, 1975

ACRONYMS & ABBREVIATIONS USED IN THIS REPORT

ARL - Air Resources Laboratories, NOAA, Boulder, CO

CIE - International Commission on Illumination

DoE - Department of Energy, Washington, DC

EDS - Environmental Data Service, NOAA, Washington, DC

EPA - Environmental Protection Agency, Washington, DC

ERDA - Energy Research and Development Administration, Washington, DC

ERL - Environmental Research Laboratories, Boulder, CO

ETR - Extraterrestrial Radiation

HUD - Housing and Urban Development, Washington, DC

IOLM - International Organization for Legal Metrology

IPS - International Pyrheliometric Scale, 1956

IRC - Information Referral Center

JEEC - Johnson Environmental and Energy Center, UAH, Huntsville, AL

LST - Local Standard Time

MSFC - Marshall Space Flight Center/NASA, Huntsville, AL

MOR - Meteorological Optical Range

NASA - National Aeronautics and Space Administration, Washington, DC

NCAR - National Center for Atmospheric Research, Boulder, CO

NCC - National Climatic Center, (NOAA), Asheville, NC

NOAA - National Oceanic and Atmospheric Administration, Washington, DC

NSF - National Science Foundation, Washington, DC

NWR - NOAA Weather Radio

NWS - National Weather Service, (NOAA), Washington, DC

SCE - Southern California Edison, Rosemead, CA

SEO - State Energy Offices

SERI - Solar Energy Research Institute, Golden, CO

SI - International System of Measurements

TST - True Solar Time

TVA - Tennessee Valley Authority

UAH - University of Alabama in Huntsville

UNEP - United Nations Environment Program, UN Headquarters, New York, NY

USIERC - US International Environmental Referral Center, EPA, Washington, DC

WEST - Western Energy Supply & Transmission Associates

WMO - World Meteorological Organization, Geneva, Switzerland

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1.0 INTRODUCTION

The 1970's have seen the generation of a large demand for information on the temporal and spatial characteristics of solar radiation. Scientists, engineers, economists and others are reviewing the feasibility of utilizing solar energy to supplement the conventional fossil fuel supplies of the world. It is largely in response to this demand for solar radiation measurements that this document was prepared.

The sun has been a known source of abundant energy for centuries. Using solar energy on a small scale has been interesting, and exploiting it on a large scale is intriguing. Many questions arise as to the information required and courses of action to be followed for a large scale exploitation of solar energy, which thus far in the present concept of a replenishable energy source has evaded our modern society. This book will address those factors concerning measurement, collection, storing, recovering and using solar data to provide information required for users to reach decisions which lead to increased use of solar energy and to help decrease or replace the consumption of fossil fuels. One must not lose sight of the fact that solar radiation is the primary replenishable ingredient in food production, also as someone has reminded us, it is the best means of snow removal.

The prime question one must address before beginning to use solar energy is to determine what information is required about the solar energy resource, i.e., what information is required to help reach better decisions for specific solar energy applications? This book provides the reader with information about currently available data, projects and plans which are designed to meet many or most needs. As individual requirements are identified it is expected there will be relatively few truly new requirements and most needs can be met with currently available information. This book will assist in formulating the requirement and relating this to currently available information which may be used to meet the requirements.

A prerequisite to measuring or collecting solar radiation data is to learn what information is available and how to use it. The problems and costs must be balanced against the expected benefits. This book describes the factors bearing on solar radiation data requirements for most users. It is hoped that a solution to meet your requirement will be identified early.

In learning about the measurement of solar energy many questions arise. One question is: How much energy reaches certain locations? A precise and absolute answer is not readily available. There are numerous variables involved. There have been sufficient measurements taken during the past 100 years to indicate that accurate measurements of solar radiation are not an easy task. Fortunately, these early measurements made by "pioneers" in their field provide a scientific basis on which to expand and refine knowledge about solar energy. Solar radiation measurements are of limited value

1.0 Continued

unless they are recorded in conjunction with other meteorological parameters. These parameters include wind speed, temperature and humidity as a minimum and may include wind direction, pressure, cloud cover, precipitation and other factors. The atmospheric measurements and their relation to solar energy applications are addressed in detail in Section 3.4.

Another question is: What measurements are available and how can they be used? The extensive first chapter in this book provides such information and describes current work to improve and expand this data base. Also programs to improve the accuracy of solar radiation measurements are described. Appendix G lists addresses where data is archived throughout the world. The historical data, of course, is a record of the past. Despite the current awareness of long-term trends, the past 10 to 20 years of records probably provide the best insight as to what may be expected in the next 20-30 years. This is not to say that extreme records will not be exceeded, but a discussion of climatic trends and changes, while interesting, is beyond the scope of this work.

A further question may be: What are the problems inherent in measuring solar radiation? The procedures recommended or approved by international organizations for recording solar radiation and related environmental data are described or referenced herein. It is intended to provide the reader with an introduction to the complexities of solar radiation measurements and to provide a better understanding of their uses and limitations.

A final question may be: Are the present and planned data collection programs adequate for my needs? This question can be answered only by the reader. This book is intended to provide information about solar radiation measurements on which to base that decision. The decision should not be reached prematurely and a final decision that more data is needed should be reached only after a through understanding of how the data will meet a requirement to contribute worthwhile information. The final section of the first chapter may assist in reaching a tentative decision after the information about data currently available has been carefully reviewed.

1.1 PURPOSE AND GOALS

The purpose of this section is to serve as an introduction to the availability and use of solar radiation data, information on instruments used to measure such data, and the approaches to augmenting existing data with meaningful, worthwhile information, i.e., a data network. The goals are to provide information and references to solar radiation information that is available and its uses. Additionally, the goals include methods of introspection to determine needs and courses of action available to determine user requirements to meet present and future needs. They also include additional information to assist in the exploitation of the use of solar energy data.

1.1 Continued

Solar radiation measurements provide a gauge to indicate the amount of potential solar energy available under certain circumstances. While the radiation emitted by the sun may be considered constant, there are numerous variables which affect the solar radiation received at the surface of the earth.

The intensity of the solar radiation just outside the earth's atmosphere (extra-terrestrial radiation) varies about $\pm 3\%$ from the average value of 1.353 kW/m^2(430 Btu/ft^2hr) given by Daniels (1973) and Thekaekara and Drummond (1971). The average value is the so-called "solar constant".* The extra-terrestrial solar radiation reaches a maximum of 1.40 kW/m^2 in early January and a minimum of 1.31 kW/m^2 in July because of the varying distance of the earth from the sun as the earth moves along its almost circular but slightly elliptical orbit. It is apparent from WMO No. 309 (1972) that these values are related to the 1956 International Pyrheliometric Scale (IPS) and should be adjusted to the Absolute Scale (SI) adopted in the US in 1977, see page 1-7. The proposed adjustments are shown in Figure 1.4. These are in close agreement with the value of 1377 $J/(m^2 \cdot s)$ as used by the National Climatic Center (NCC) in rehabilitating and storing data in the Absolute Scale in the SOLMET format as described in Appendix A.

Solar radiation is absorbed by the earth's atmosphere. Certain constituents such as ozone (O_3), carbon dioxide (CO_2) and water vapor (H_2O) absorb solar radiation in specific wavelengths. Figure 1.1 from Daniels (1973), shows the effects of atmospheric absorption.

The atmosphere also scatters the solar radiation passing through it and the clouds and surface of the earth reflects another part. Figure 1.2 is a graphic representation of the effects of reflection, absorption and scattering.

The angle at which direct solar radiation is received on a surface affects the solar radiation measurement. The angle of incidence of direct (beam) radiation is the angle measured between the beam and the normal to the plane. The solar intensity on a surface is greatest when the beam radiation is normal to the surface (the incidence angle is 0°). For a complete discussion of the accepted description of angles describing the position of the sun relative to various planes and the earth's axis, see Duffie (1974).

The rotation of the earth also determines the zenith or elevation angle of the sun and affects the amount of atmosphere through which the sun's rays travel. The increased atmospheric absorption and scattering (called attenuation) thus produces a decrease in solar intensity at the surface of the earth when the sun is near the horizon as compared to solar noon when the minimum attenuation occurs.

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*Sometimes called the "solar parameter" because of the known variations.

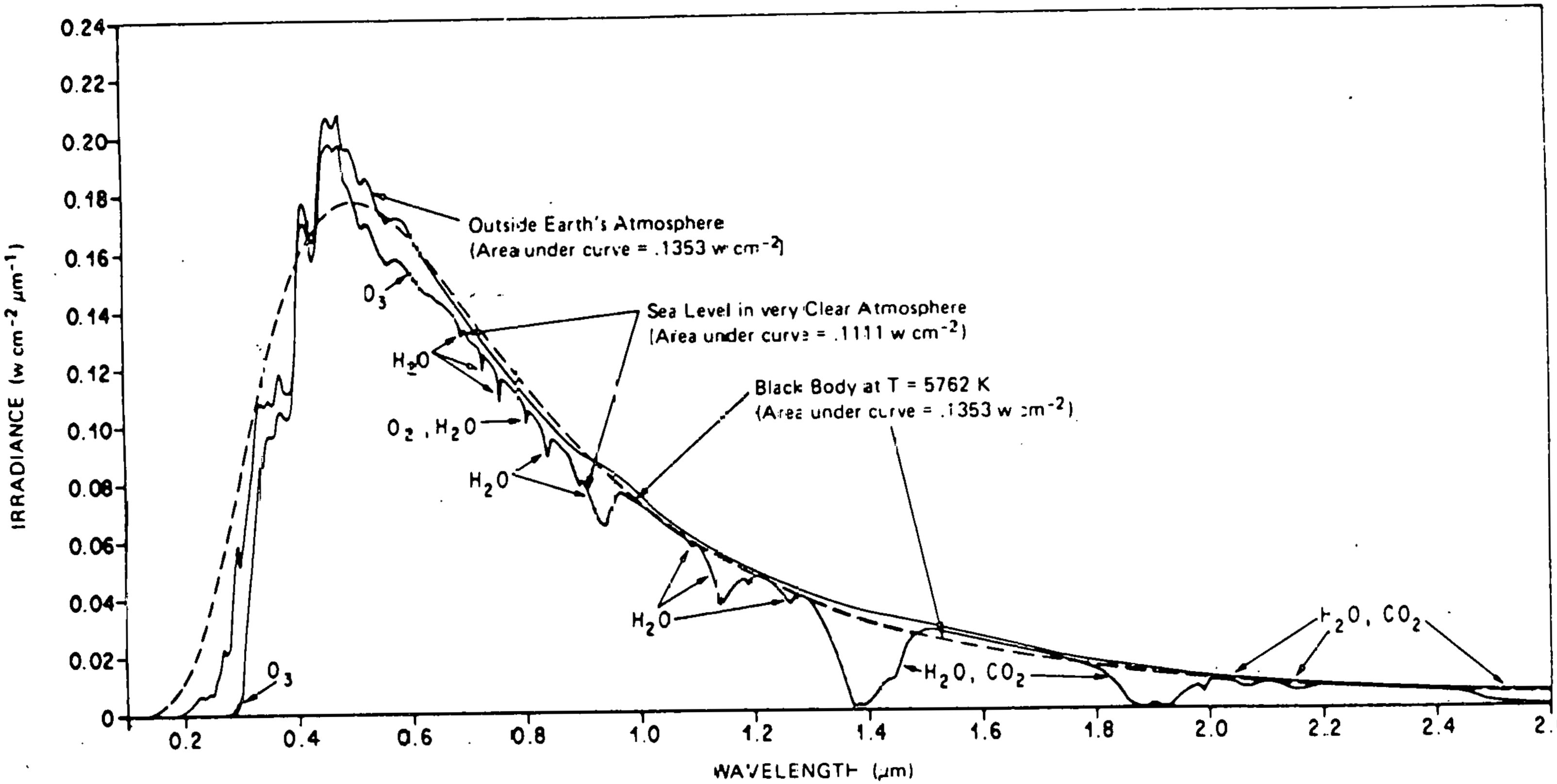

Figure 1.1 Normal Incident Solar Radiation at Sea Level on Very Clear Days, Solar Spectral Irradiance Outside The Earth's Atmosphere at 1 AU, and Black Body Spectral Irrandiance Curve at T=5762°K (Normalized to 1 AU). From Daniels (1973).

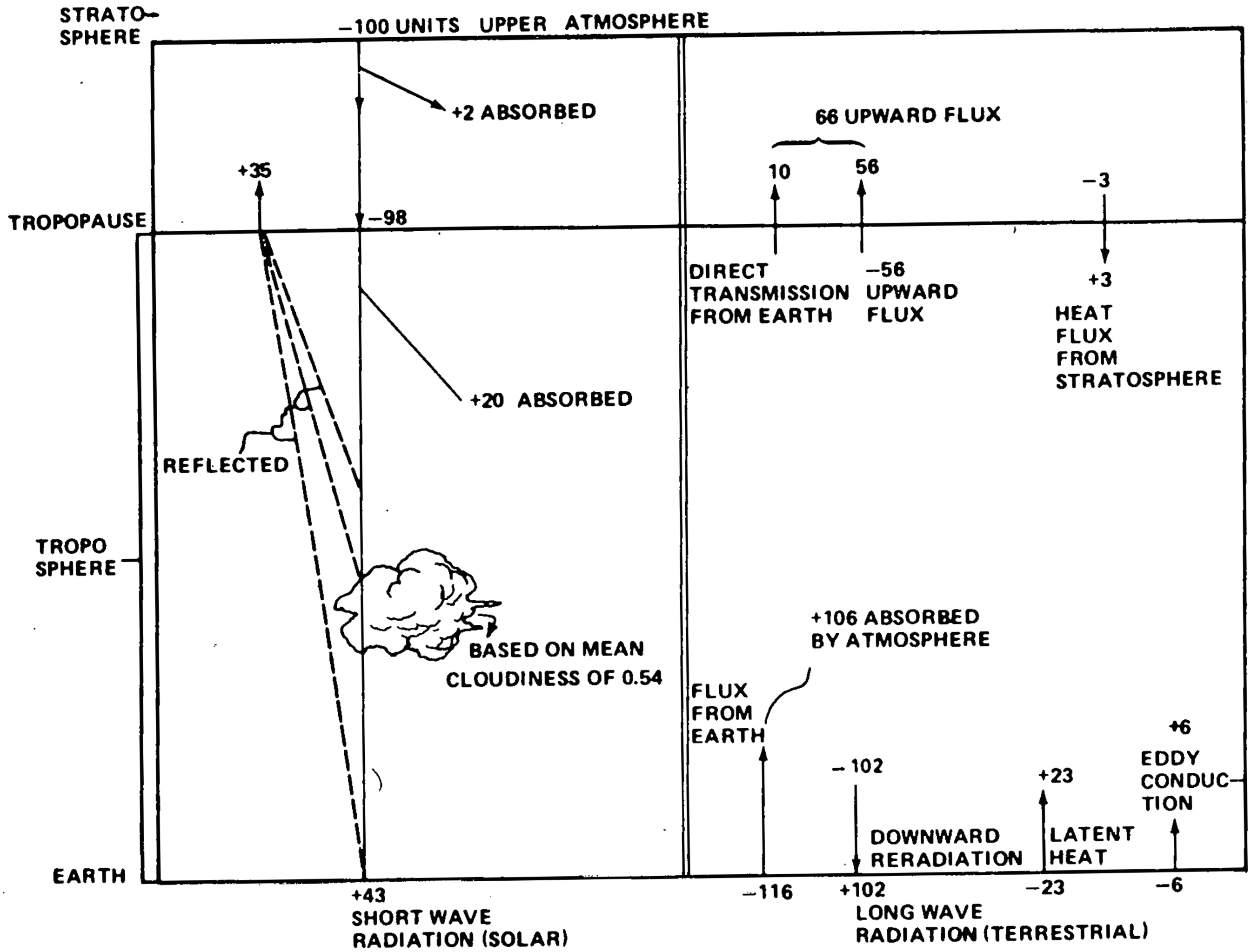

Figure 1.2 Heat Balance of the Earth - Troposphere System. Haltinger, G.J. and Martin, F.L., Dynamical and Physical Meteorology, McGraw-Hill, Inc., New York.

1.1 Continued

The large variations in cloud cover produce corresponding variations in the intensity of solar radiation. Cloud cover can reduce solar radiation by more than 90% from clear-day intensities and is the major factor (along with day-night cycles) that can determine solar energy conversion and storage design considerations.

Increased elevation above sea level reduces the amount of attenuating atmosphere overhead with a resulting increase in the intensity of solar radiation.

Because of these effects, solar radiation is continually varying in space and time to further complicate its measurements. Evaluating this spatial and temporal variation has resulted in some arbitrary values and practices which are widely accepted in measuring solar radiation. Of most significance is the practice of hourly and daily measurements of solar radiation.

However, there is currently no general agreement on the "clock time" to be used. Although mixing solar radiation measurements with Daylight Savings Time is completely unwise, hour increments are generally based on the Local Standard Time (LST) which is now used by NOAA, or on True Solar Time (TST). TST must be used in calculations involving the sun angle. Conversion from LST to TST and vice versa may be accomplished using the procedure from Duffie (1974):

$$TST = LST + E + 4\ (L_{st} - L_{loc})$$

where TST = True Solar Time

LST = Local Standard Time

E = Equation of time in minutes from Figure 1.3

L_{st} = Standard Time Meridian, for the continental US time zones are 75°, 90°, 150° and 120° west longitude for Eastern, Central, Mountain and Pacific respectively.

L_{loc} = Longitude at the recording location, in degrees west, (Note that the sun takes 4 minutes to traverse 1° of longitude.)

The equation of time accounts for the various perturbations in the earth's orbit and rate of rotation which affect the time the sun appears to cross the observer's meridian (See Figure 1.3).

A short-cut in determining TST is to calculate the LST halfway between sunrise and sunset (from the local newspaper, almanac, or sunrise-sunset tables). This time is noon (1200) TST, i.e., the sun is true south of the location. All other times may be adjusted by this difference from noon (1200) LST. For example, at a given location, sunrise is 4:56 a.m. and sunset is 6:32 p.m. (1832 on a 24-hour clock) LST. One-half the difference between sunrise and sunset is 6 hours and 48 minutes. The

1.1 Continued

6:48 added to sunrise of 4:56 is 11:44. Therefore, solar noon, and each solar hour occurs 16 minutes earlier than the local standard hour.*

The National Weather Service (NWS) previously recorded solar data in TST hourly increments. Starting with 1977 NOAA data uses LST at all locations. While hourly values recorded in the two different times are not comparable, fortunately, daily and monthly total values will not be affected by this difference in hourly values. One must keep this difference in mind because in many of the older records it is often not apparent what type of time was used in recording data.

In 1956 at Davos, Switzerland, a new "International Pyrheliometric Scale, 1956" (IPS) was established which allows corrections to previously obtained measurements for the two scales then in use (-2.0 percent to the Smithsonian scale and +1.5 percent to the Angstrom scale). All instruments manufactured from 1956 through 1976 use the IPS. A discussion of the various pyrheliometric scales is found in Thekaekara (1956). As this is being written (1977) conversion is underway to an Absolute Scale (SI). This change is based on the results of the International Pyrheliometric Conference IV. The relation between the various scales resulting from the conference are discussed by Frohlich (1973). Figure 1.4, is a summary of the relation between the scales modified from Frohlich (1973). Table 1.1 relates vertical lines in Figure 1.4 to the test instruments used in the comparisons. The use of different scales further complicates agreement on a value for the "Solar Constant" as discussed earlier. Efforts are currently underway to relate an accepted "Solar Constant" value to each prime scale in Figure 1.4.

Eppley Laboratories converted to this scale for all instruments calibrated after April 1, 1977. Eppley instruments calibrated in SI units yeild irradiance values which are 2.1% higher than values which would be obtained using Eppley instruments calibrated previously and referenced to IPS. The NOAA Network, described later, and the Canadian Network are calibrated to the Absolute Scale. All solar radiation data being rehabilitated by the NCC is in the Absolute Scale. One must resolve scale differences before using the data.

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* Sunrise-sunset tables for any location may be secured from the Nautical Almanac Office, US Naval Observatory, Washington, DC 20390. Station longitude and latitude in degrees and minutes and station elevation must be stated in requesting the tables.

1.1 Continued

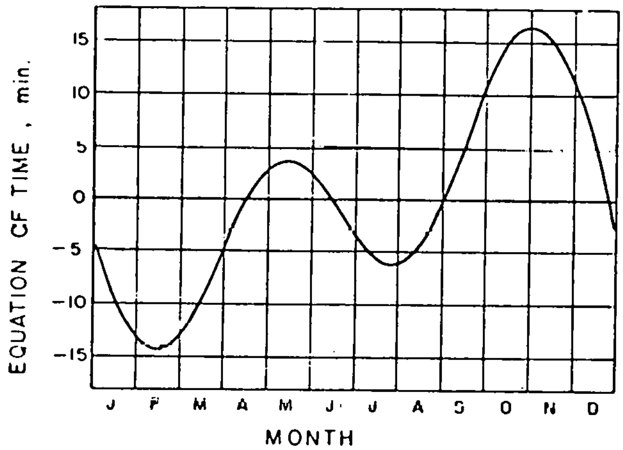
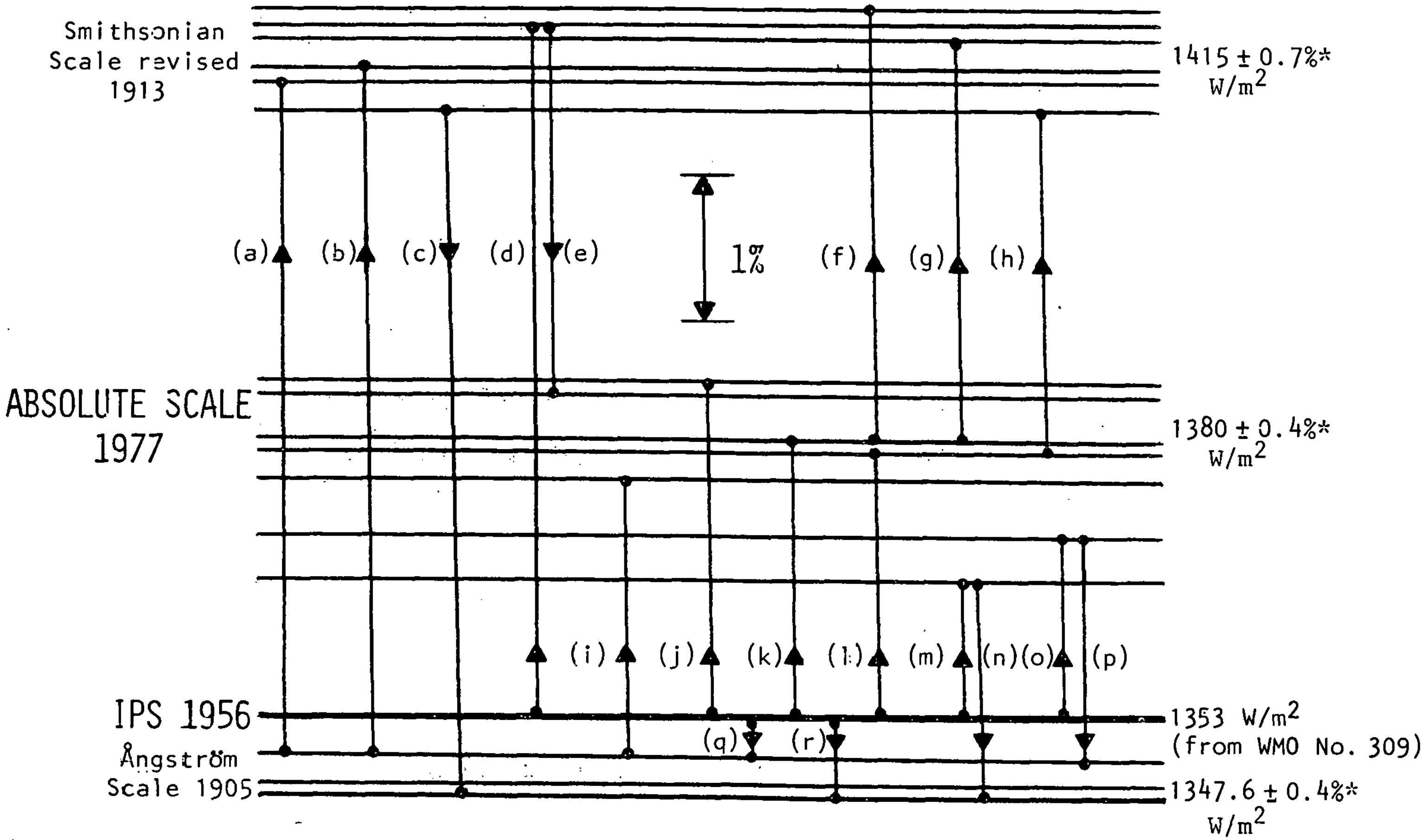


Figure 1.3 The equation of time, E, in minutes, as a function of time of year. From Duffie (1974)

There are three basic types of solar radiation, classified according to its route through the atmosphere. Direct or beam radiation is that which comes directly from the sun. Diffuse radiation results from the scattering effects due to the clouds and atmosphere and is reflected from objects without focusing. Global radiation is the sum of direct and diffuse radiation. (Diffuse radiation is about 10 to 25 percent of global radiation on clear days. On completely cloudy days, there is no direct radiation; and the total radiation received consists entirely of diffuse radiation.) The diffuse radiation on these days may be from 15 to 40 percent of clear-day total radiation depending on the thickness of the clouds, i.e., the denser the clouds the less total radiation.

The intensity of the solar radiation on a fixed surface varies a great deal during the day and depends on the orientation of the surface.



(See Table 1.1 for key to measurement relations.) *Proposed solar constant values

FIGURE 1.4 - SUMMARY OF THE RELATION BETWEEN SCALES (FROM FROELICH, 1973)

All silverdisc data are reduced to 2/4 mode measurements. For the first time the relations between radiation scales used in meteorology are stated without inherent contradictions. The following mean differences result:

Smithsonian - Absolute:	4.6% ± 0.4%
Angstom - Absolute:	2.4% ± 0.7%
IPS 1956 - Absolute:	2.0% ± 0.4%
Smithsonian - Angstrom:	5.0% ± 0.7%
IPS 1956 - Angstom:	0.4% ± 0.4%
Smithsonian - IPS 1956:	4.6% ± 0.4%

Table 1.1

Letter Key to Figure 1.4 to Show Measurement Difference of Various Test Instruments in Determining Relationship of Historical Solar Radiation Scales

(a) SD SI 13 (Davos 1034/46)
and {Å 210 (Davos 1934) / Å 158 (IPC III 1970 -1.5)}
+4.6 ±.6

(b) SD SI 50 (Davos 1934/46
and {Å 210 (Davos 1934) / Å 158 (IPC III 1970 -1.5)}
+4.7 ±.6

(c) SD T7 (Davos 1973)
and {Å 158* (IPC III 1970 -1.5) / Å 149 (Toronto 1955/59)}
-4.7 ±.5

(d) SD SI 5 (IPC I 1959)
and Å 210 (IPC III 1970)
+4.7 ±.5

(e) SD SI 5 (IPC I 1959)
and WATERFLOW (Table Mountain 1968/72)
-2.5 ±.4

(f) SD SI 13 (Davos 1973)
and {PMO (Davos 1973) / PACRAD (IPC III 1970, Davos 1972/73)}
+2.9 ±.1

(g) SD SI 50 (Davos 1934/46)
and {PMO (Davos 1973) / PACRAD (IPC III 1970, Davos 1972/73)}
+2.7 ±.1

(h) SD T7 (Davos 1973)
and {PMO (Davos 1973) / PACRAD (IPC III 1970, Davos 1972/73)}
+2.2 ±.1

(i) TINGWALDT (Davos 1930)
and {Å 210 (Davos 1934) / Å 158 (IPC III 1970 -1.5)}
+1.9 ±.5

(j) WILLSON (Table Mountain 1968/72)
and Å 210 (IPC III 1970)
+2.3 ±.5

(k) {PMO (Davos 1973) / PACRAD (IPC III 1970, Davos 1972/73)}
and Å 210 (IPC III 1970)
+1.9 ±.3

(l) NBS (IPC III 1970)
and Å 210 (IPC III 1970)
+1.8 ±.2

(m) A 158* (IPC III 1970)
and Å 210 (IPC III 1970)
+0.9 ±.2

(n) Å 158* (IPC III 1970)
and {Å 158* (IPC III 1970 -1.5) / Å 149 (Toronto 1955/59)}
-1.5 ±.0

(o) Å 158 (IPC III 1970)
and Å 210 (IPC III 1970)
+1.2 ±.4

(p) Å 158 (IPC III 1970)
and {Å 210 (Davos 1934) / Å 158 (IPC III 1970 -1.5)}
-1.5 ±.0

(q) Å 210 (IPC III 1970)
and {Å 210 (Davos 1934) / Å 158 (IPC III 1970 -1.5)}
-0.3 ±.3

(r) Å 210 (IPC III 1970)
and {Å 158* (IPC III 1970 -1.5) / Å 149 (Toronto 1955/59)}

Å 158* is Å 158 used without filter-holder.

The orientation of the surface is usually described by the azimuth angle, (east (-) or west (+) of true south) and the tilt angle which is measured from the horizontal.

For standardization, global radiation is measured on a horizontal surface, direct radiation is measured normal to the sun's rays and diffuse radiation is measured with a shadow-band over an instrument on a horizontal surface. The components of solar radiation are shown in Figure 1.5. More details on instruments and measurements are provided later.

A report by Carter (1976) lists the solar radiation data available from the National Climatic Center (NCC), Asheville, NC, and data located by the University of Alabama in Huntsville (UAH) which is recorded by numerous individuals and organizations. The Department of Energy (DOE) is evaluating these data to reclaim as much as possible for use in solar energy projects. The NCC is also reclaiming as much data as possible and making them available.

In addition to historical data, DOE in cooperation with the NOAA has established a basic, solar radiation measuring network throughout the United States. It plans to expand this network if necessary with cooperative stations to meet as much as possible of the national need for routine solar radiation data.

Some state energy offices (SEO), power companies, and other organizations also record solar radiation measurements. A thorough review of what is available through such agencies should be made before deciding what additional data are needed. Any additional data, planned or proposed, should augment existing programs and enrich the total data collection, application, storage and retrieval processes.

1.2 ATMOSPHERIC DATA RELATED TO SOLAR ENERGY

Frequently, the first chapter in meteorology books discusses solar radiation, e.g., Compendium of Meteorology (1951). Likewise, there is general agreement in such books, that the sun is the source of nearly all the earth's energy.

Because of the abundance of certain forms of energy such as water, wood, coal, oil, and the technology to use them, solar radiation has not been significantly used as an energy source. Meteorologists realize that solar radiation is a primary factor in governing atmospheric motions, but they have not had an extensive program to continually monitor and use solar radiation as a factor needed to aid in weather forecasting. Monthly weather reviews did include some information on attempts to measure solar radiation during their early publication.

1.2 Continued

Lack of technology, or perhaps more precisely, readily available, economically acceptable and easily understood technology is one of the reasons for this situation. Currently, there is an incentive to overcome these obstacles. However, certain basic information is necessary to help in doing so.

Solar radiation measurements are considered a primary means in advancing knowledge and improving technology for using the energy of the sun. Unfortunately, such measurements may mean many different things to the various people involved. They may refer to measurements outside the atmosphere, measurements on mountains or at sea level, and at various tilt angles. While all of these are important for their own purposes, this book, of necessity, will be limited to the measurement of direct, diffuse, and global radiation on a horizontal surface. Other types of near-surface measurements are also considered variations, including many currently being recorded at tilted angles to coincide with flat-plate, solar-collector orientations.

Sunshine recorders provide a simple means for a gross measurement of daily sunshine. The sun is considered shining when an object in its light casts a clearly definable shadow. The percentage of possible sunshine is the quantity of the ratio of the hours of sunshine to the number of hours between sunrise and sunset, multiplied by 100. Methods exist for estimating hourly and daily solar radiation values from sunshine percentages, see Duffie (1974). There are considerable historical data on sunshine observations as well as continuing measurements.

The dry-bulb temperature and some humidity value (wet-bulb, dew-point, etc.) have been measured with considerable accuracy at a great number of stations for many years. With any one measure of moisture, all others may be calculated. Dry-bulb temperature is frequently referred to as ambient temperature and is true air temperature with the temperature element not affected by reflection, radiation, or other thermal factors. In this book, temperature-humidity means a dry-bulb temperature and any measure of the moisture content of the atmosphere from which other factors may be calculated. These measurements are essential at the surface, and some estimate of the temperature-humidity profile aloft is desirable to predict the transmission of solar radiation through the atmosphere.

Wind speed and direction should be recorded with all solar radiation measurements and stored for future use. The wind may have an effect on the instrument; but, more importantly, it may have a significant effect on the applications of solar energy. This includes wind power as a form of solar energy transferred to motion in the atmosphere. Also, projects which combine solar and wind power to complement each other are being considered. At this time all uses of the solar energy data which may evolve cannot be foreseen. Thus, wind data should be recorded near the site of solar radiation measurements, if possible. Cloud observations, while directly applicable to solar radiation data, are quite impractical to record at every solar radiation collection site. For this reason, NWS has established its primary solar radiation sites where such observations are recorded routinely for other reasons. These observations may be inferred from a sunshine recorder, or cloud observations from a nearby NWS location may be used in conjunction with solar radiation data. Although there are no established guidelines for distances where cloud observations would be representative, those made within about 30 km (approximately 20 miles) probably would be acceptable. In seacoast, mountainous, or industrialized areas, this radius may not be a valid assumption; while in regions with similar conditions perhaps a greater distance would be acceptable. Advice from a local meteorologist and his evaluation of a proposed solar radiation measurement site could be helpful in planning such units. The DOE currently is sponsoring three studies to define the solar radiation variability in coastal, mountainous and urban areas. The results of these studies are expected to be available in 1979.

Upper-air observations, like cloud observations, are impractical solely for solar radiation sites. However, the effects of the atmospheric conditions on solar radiation received at the operating site must be kept in mind. If upper-air observations and solar radiation measurements are taken in close proximity, the data may complement each other.

There is no simple way to describe the effects of the variable atmosphere on solar radiation measurements. Atmospheric transmittance (the transparency of the atmosphere to solar radiation) is complex and dependent on the constituency of the atmosphere in the area of the solar beam. It may change rapidly in a few seconds if cumulus-type clouds are in the area, or it may be quite stable. Atmospheric transmittance varies with season, wind, water vapor, impurities, as well as other factors.

Turbidity factor and clearness number are used to evaluate atmospheric transmittance of direct solar radiation through a cloud-free path, or clear air.

Robinson (1966) describes the Linke turbidity factor as the only measure of turbidity which is suitable for an evaluation of total radiation measurements. It is an indication of the amount of haze and water vapor in the air. It was defined by Linke as the turbidity factor which indicates how many atmospheres of pure air produce the same total depletion (or result in the same intensity) of direct solar radiation, as measured by an instrument sensitive to all wavelengths.

In accordance with the definition and the mathematical derivation, it is clear that the turbidity factor can never be less than unity. A turbidity factor of 1.5 represents a rather clear atmosphere while a turbidity factor of, say, 5.0 refers to very turbid air. For the derivation and use of the turbidity factor the reader is referred to Robinson (1966). Also, other means of representing turbidity are described, such as the Ångstrom turbidity coefficient and the Kurzstrahlung turbidity factor which provide measures of the haze content only. The Schwepp generalized turbidity coefficient, also described, provides more information about the nature of aerosols and the atmospheric humidity than other methods.

The clearness number is described by Threlkeld (1970), and the estimate of atmospheric clearness numbers in the U. S. is shown in Figure 1.6.

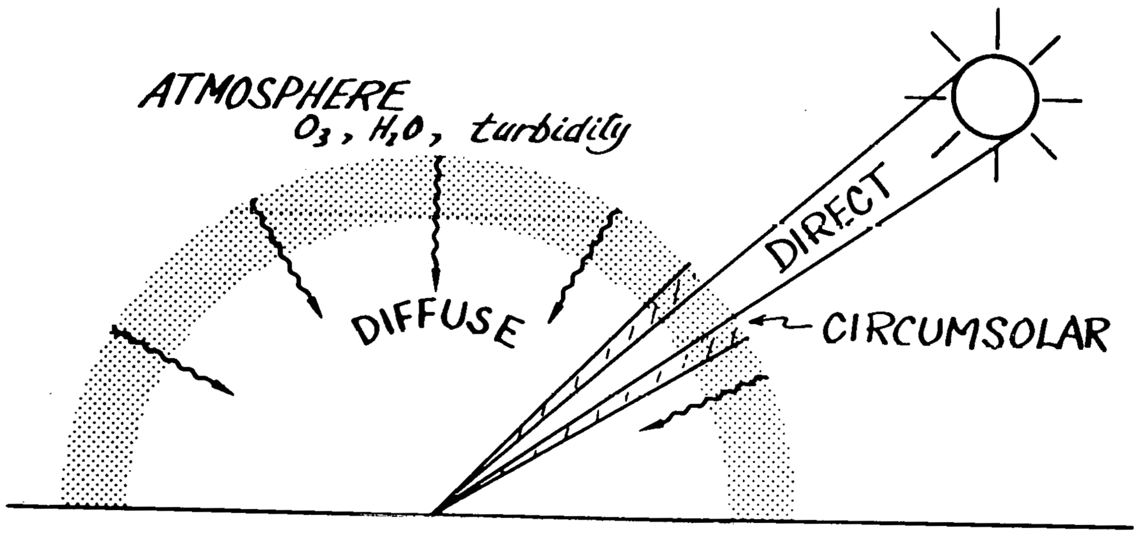


Figure 1.5 Components of Solar Radiation

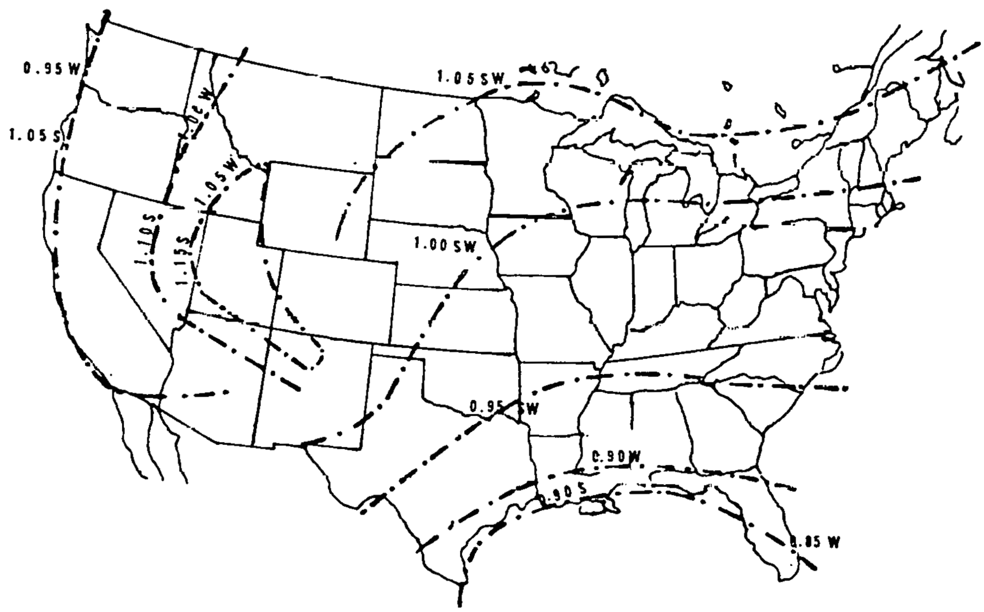


Figure 1.6 Clearness Numbers, S - Summer
and W - Winter over the US

1.2 Continued

The clearness number was derived empirically to make the calculated direct solar radiation values closely correspond with the mean observed values at Blue Hill, Massachusetts; Lincoln, Nebraska and Madison, Wisconsin throughout the year. The procedure defines a basic atmosphere at a sea level location consisting of 2.5 mm of ozone, 200 dust particles per cc and a percipitable water depth varying from 0.20 inches in winter months to 1.10 inches in summer months. Calculations were made using appropriate transmission factors for this basic atmosphere for north latitudes of 30, 36, 42 and 48 degrees by months and hours of the day. Those figures (not shown here) show direct solar radiation at normal incidence in Btu per (hour) (square foot) for various daylight hours throughout the year.

Several calculations for atmospheric clearness number were made for various localities where recorded radiation was not available by dividing the calculated radiation based upon clear-day precipitable water for the locality by the calculated radiation for the basic atmosphere. These calculations were used in constructing Figure 1.6.

The clearness number concept is offered as a convenient way of correlating experimental data. The developers of this approach believe that this provides a simple and reasonably accurate method of estimating for engineering purposes the incidence of direct solar radiation during clear days. See Threlkeld (1970) for a complete description and use of the procedure.

Atmospheric pressure, albedo of surrounding area, snow cover, etc. are also important in solar radiation measurements to lesser degrees.

The new SOLMET format (for hourly data) being used by NCC is the accepted format for solar radiation and atmospheric data. All new data collected should be organized and stored in this format as shown in Appendix A. A SOLDAY format (for daily data) is being developed by NCC but is not available at this writing.

NOAA Weather Radio (NWR) is an additional source of approximately real-time atmospheric data which can be recorded and used in conjunction with solar radiation data. Several states have a cooperative arrangement with the NWS. In any case, the nearest NWS station can provide advice to prospective users of its services.

1.3 ATMOSPHERIC DATA APPLICATIONS FOR SOLAR ENERGY

Throughout this book the uses for solar radiation data are considered for the purposes of planning, operational management, and research. Planning requires considerable historical data by which past information can be used to predict future availability levels of solar energy. Management, as designers and users, are especially concerned with the operation of solar energy systems. Specific and near real-time data are required rather than large amounts of historical data. Data for research may require various forms but always with a high degree of accuracy, more so than for the other two purposes. These categories of data application may overlap, although data primarily for one purpose may often be applicable for others.

1.3 Continued

Lists of known historical data are included in a report by Carter (1976), which includes data archived at the NCC, as well as much other data. The procedures for requesting these data are given in Section 1.4.

A recommendation of the Solar Energy Data Workshop (1973) was "to establish a catalog of the radiation data base which exists by individuals or organizations in the U. S. other than that archived at the National Climatic Center, NOAA". Little action was taken to implement this recommendation until late 1975 when the University of Alabama in Huntsville, with support from the Marshall Space Flight Center (MSFC) and the ERDA began the search for such data. It culminated in the report by Carter (1976). Almost as many additional locations were found as were already in the NCC archives. While some of the data are in reports and on magnetic tape, most of them are on strip charts. All of these data require a qualitative evaluation to determine their compatibility with data in the NCC archives. Work is continuing to reclaim worthwhile data and to maintain listings of new data as it becomes available.

The requirements for real-time data are generally localized. They may be needed for on-site evaluation of projects, or they may be required for operational comparison of projects in which case several locations may be involved. In the foreseeable future, "total energy management" will probably generate the need for real-time data and daily predictions of solar and wind energy expected over a region served by a power company. Currently, there are no procedures to meet this requirement; but as the requirement evolves, the mechanisms will be available through the NWS network. Further research will more fully evaluate the real-time needs and uses of solar energy data. Figure 1.7 shows the NWS basic solar-radiation data network. This network, along with cooperative stations, probably will become the basic data source for future large-scale, real-time data requirements.

1.4 SOURCES, ASSESSMENT, AND USE OF ATMOSPHERIC DATA

This section provides information about various data sets related to solar energy and where and in what form they are stored. It also includes information on how to obtain such data.

The NCC of NOAA is the basic national archive for solar radiation and related meteorological data. Requests for these data should be sent to the Director, National Climatic Center, Federal Building, Asheville, NC 28801.

Solar radiation and related weather data are corrected, quality-controlled, summarized, published, and distributed by the NCC. Basic records are microfilmed, placed on punch cards and magnetic tape. The data are retrieved as needed by other government agencies, universities, corporations, and individuals. The NCC has the capability of reproducing original records, microfilm, punched cards, special data tabulations, and magnetic tapes to satisfy such requested needs. If the data requested are not in a published or summary form, the NCC will try to furnish the data at the lowest cost. The amount charged is solely used to defray the expenses incurred. However, an agreement of details, elements, results,

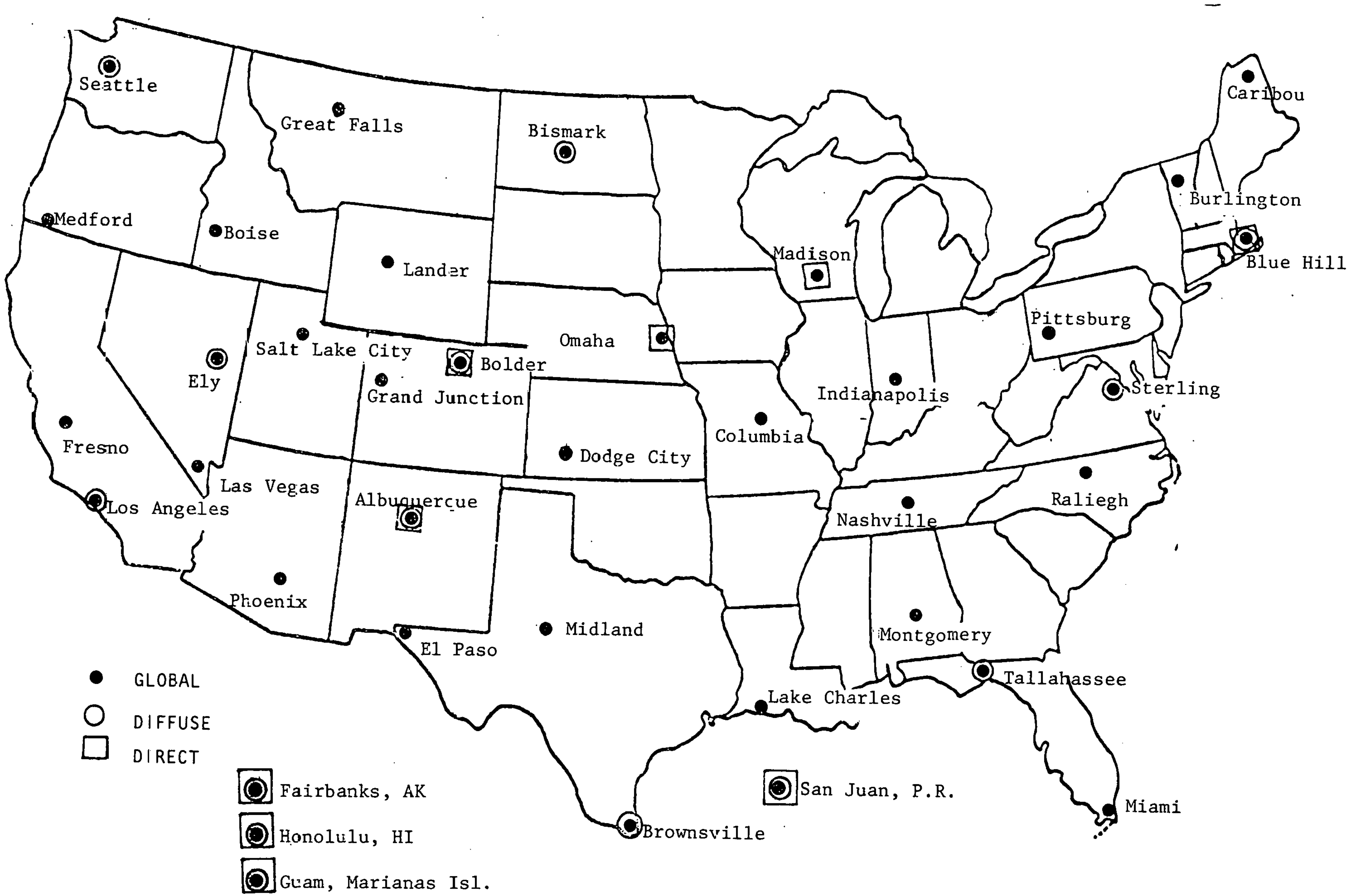


Figure 1.7 NOAA Solar Radiation Network, January 1978

cost, etc. between the requesting agency and the NCC must be completed before the NCC will begin work on a project. For example, an architect may want a trivariate (three-element) frequency distribution of temperature by groupings of wind speed and relative humidity values to correlate with solar radiation data and sun orientations for designing a house with solar heating and cooling. The NCC will assist in determining the climatological data requirements but will not assist in interpreting climatological information and applying the information to specific problems. This task would be an infringement on the work of the private meteorological consultant.

A request for information to the NCC should include precise information on the final use to be made of the data; geographical area and period of recorded interest; annual, seasonal, monthly, etc., basis for the answer; and units of measurements to be used. Additionally, information should include significance of daily variation format for the final result, and the date by which the data are needed.

NCC is a center under the Environmental Data Service (EDS) of the NOAA. Other centers under the EDS are the Environmental Science Information Center, Washington, DC; the Center for Experiment Design and Data Analysis, Washington, DC; the National Geophysical and Solar-Terrestrial Data Center, Boulder, CO; and the Center for Climatic and Environmental Assessment, Columbia, MO.

These organizations are not equipped nor do they have the personnel to supply the detailed climatological services which the NCC can provide. However, they can provide information and publications within their specialty, and they may be of assistance in investigations in a proposed energy project.

Solar radiation and meteorological observations are made by the NWS offices of the NOAA. Most of the climatological data at the NCC was obtained from the NWS. Figure 1.8 depicts the NWS offices which have recorded solar radiation observations.

As mentioned previously, comparatively little attention was given to solar radiation observations prior to 1973. Therefore, calibration, digitization, and sensor deterioration errors are found generally in such earlier solar radiation observations as are now on record.

The NCC, in collaboration with the DOE has reconstituted some of the solar radiation data taken at the NWS offices between 1951 and 1975. Hourly solar radiation data have been so processed for 26 solar radiation sites, and daily solar radiation data have been similarly reworked for 25 solar radiation sites. See Figure 1.9. These solar radiation and related meteorological data are stored in a standard format and are available upon request from the NCC.

In the future, solar radiation data to be accepted for archiving in the NCC must meet criteria established by NOAA. The NOAA requirements are included in Appendix E.

Figure 1.8 Location of Solar Radiation Stations with Data Archived at the National Climatic Center, Asheville, N. C. Numbers indicate more than one station in area.

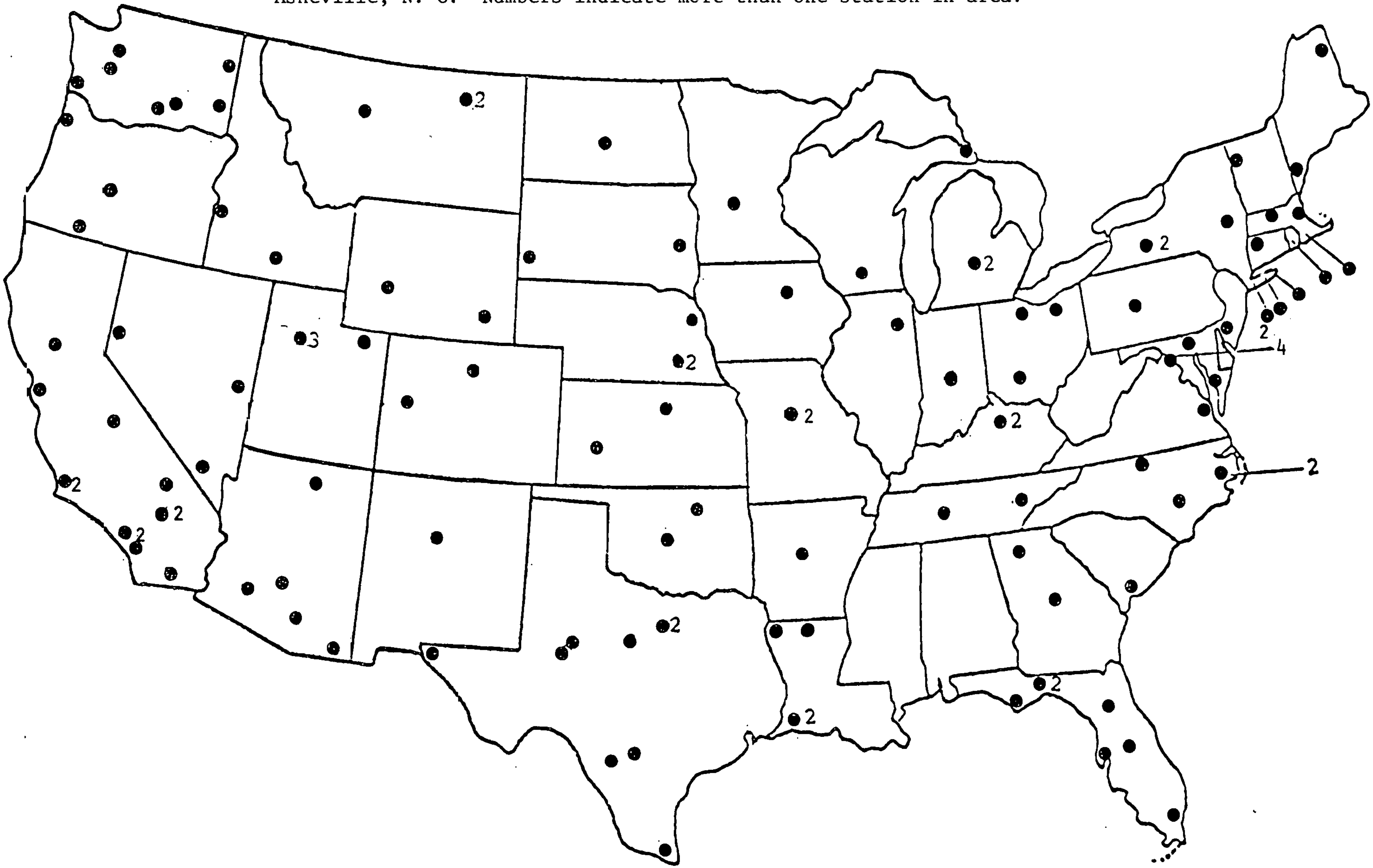


Figure 1.9 Solar Radiation Data Rehabilitation Stations

Many states have agencies, variously called energy centers, atmospheric research centers, resources development centers etc., which collect, organize, and publish solar radiation data. Examples of these publications are listed in Carter (1976).

Most of the states have a State Energy Office (SEO) which acts as a clearinghouse for data on energy projects within the state. This source is a valuable one in planning any energy project and can be contacted through the state governor's office.

Outside the U. S., the Canadian Meteorological Service has an organization similar to the NCC. It is called the Atmospheric Environment Service, Climatic Data Processing Division, located at 4905 Dufferin Street, Downsview, Canada. Solar radiation data from southern Canadian stations should be of aid to projects near the northern border of the U. S. The NCC will also have these data.

The National Solar Heating and Cooling Information Center is operated by the Franklin Institute Research Laboratories, Philadephia, PA, for the Department of Housing and Urban Development (HUD) and the DOE. It is oriented primarily toward information on the application of solar energy, particularly toward building design with solar heating and cooling. Nevertheless, this center also can furnish a list of sources covering solar-radiation data.*

The National Center for Atmospheric Research (NCAR) is operated by the University Corporation for Atmospheric Research and is sponsored by the National Science Foundation (NSF). The NCAR provides a technical note, "Data Sets for Meteorological Research", Jenne, (1975). Although the information in it is primarily for meteorological research, several sources of sets with solar radiation data in the U. S. and foreign countries are given.

In addition to the solar radiation data provided by NWS stations, which have been reconstituted, the DOE in cooperation with the NOAA is also examining additional sites to augment the historical data at the NCC as shown in Figure 1.10. A joint program is underway to upgrade instrumentation and develop improved standards for sensor calibrations and for observing and recording solar-radiation data at the basic 38-NWS station network (Figure 1.7).

The Atmospheric Sciences Research Center of the State University of New York in Albany can provide extensive data concerning the northeastern region of the U. S.

At present, the only method to obtain detailed and accurate data on solar irradiance is to have a radiation sensor at the site where the data are needed. However, the DOE also has a number of research studies underway which will provide design data allowing engineers to estimate solar irradiation in certain areas. A procedure developed by NOAA is available through the Air Resources Laboratory (ARL) of the NOAA (see page 6-3).

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*The address is: P.O. Box 1607, Rockville, MD 20850

Figure 1.10 Location of Solar Radiation Stations With Data Not Archived at the National Climatic Center, Asheville, N. C. Numbers indicate more than one station in an area. Reference Carter (1976)

1.4 Continued

The International Referral System (IRS) is a network of national and international "focal points" engaged in developing and operating directories of sources of environmental information under the auspices of the United Nation's Environment Program (UNEP).

The Environmental Protection Agency (EPA) has been designated as the U. S. national "focal point" and is named the U. S. International Environmental Referral Center (USIERC). The purpose of the system is to link users and "sources" of environmental information in a way that provides for the transfer and use of environmental information on a global basis. Information from USIERC is available in 26 broad categories, two of which are "Atmosphere and Climate" and "Energy Resources".

Further information about USIERC or a specific request for information in the category of interest should be addressed to USIERC, U. S. Environmental Protection Agency, 401 M Street S. W., Room 2902 WSM, Washington, D. C. 20460. If a specific request is made, the requester will be furnished with a listing of sources which are likely to have the desired information. There are no charges for referral services, but charges for transfer of substantive information and terms of payment are determined by the source and the user. For a listing of the "Focal Points" of other nations in UNEP, see Appendix G.

The WMO promotes standardization of meteorological observations and ensures the uniform publication of observations and statistics. This organization can direct a requester to a source of data or to a list of publications which could assist in a solar energy project. In December 1976, WMO published an inventory of radiation measurements for north and central America (Latimer, 1976). Requests to the organization should be addressed to Secretariat of the World Meteorological Organization, Geneva, Switzerland.

In late 1977 the DOE established eight Solar Energy Meteorological Research and Training Sites. The Sites are located to serve regions of the U. S. They are located as follows:

REGION	
1 Southwestern	University of California Department of Meteorology Davis, California
2 Northeastern	State University of New York Atmospheric Sciences Research Center Albany, New York
3 Southeastern	Georgia Institute of Technology School of Aerospace Engineering Atlanta, Georgia
4 South-central	Trinity University Physics Department San Antonio, Texas

1.4 Continued

REGION

5 Northwestern	Oregon State University Department of Atmospheric Sciences Corvallis, Oregon
6 North-central	University of Michigan Department of Atmospheric Science Ann Arbor, Michigan
7 Arctic	University of Alaska Geophysical Institute Fairbanks, Alasaka
8 Pacific	University of Hawaii - Manoa Meteorology Department Honolulu, Hawaii

The purposes of these sites are to provide research and training for the regions in which they are located. The types of measurements to be taken and other responsibilities are being determined at the time of this writing.

1.5 IDENTIFYING USERS AND THEIR NEEDS

A potential user of solar radiation data is a person seeking solar energy information to help him reach a decision. This chain, from data to decision, is not easily identified and taking wrong paths may be more harmful than useful. Managing this chain successfully is as important as the data itself. It is the final decision which governs the data collection requirements and intermediate processes.

Since the decision is paramount, the correct formulation of the problem is essential to govern the intermediate steps. Therefore, the general steps to analyze user needs are:

1. What decisions need to be reached?

2. Formulate the problem in terms of information needed to reach the decisions?

3. What information is required and in what form?

4. What data are currently available to provide information?

5. What additional data are needed to supplement current information?

6. What is the most economical and efficient means of securing this data in the time available?

While the preceding analysis is suggested for each potential user, the details of each analysis may be different. A complex task is to be expected, compounded by the number of potential users. It is therefore prudent to meet as many requirements as possible with data and information currently available. Next, and more difficult, is to identify those who are seeking data and information primarily because it is nice to have. Such individuals frequently will be unable to formulate a real problem. Appendix C is added to this handbook to further help the network manager in analyzing potential users' real data requirements.

1.6 SAMPLING THE ATMOSPHERE

To the statistician, solar radiation measurements are samples of data to be used as a challenge to estimate the true numerical population, or in this instance: what is the real-world solar radiation? The primary errors involved are the sampling error (error inherent in the instrument and measurement), the spatial error (error in interpolating between stations), and temporal error (error in sampling times due to variability of the parameter with time). Therefore, the goal is to minimize these three errors.

The meteorological approach to such data sampling is first to determine the amount of acceptable and reasonable error. Then, by combining the possible errors, determine how the required accuracy is attainable. Gandin (1970) provides an approach for determining the distance between stations in meteorological networks for various parameters. Briefly, using data in Russia, he calculated that the desired distance between solar radiation reporting stations, is, on the average, 150 to 200 km (a maximum of 500 km) and should be specifically adapted to the physical and geographical conditions of the region. Appendix B is an explanation of this approach, with examples using U. S. solar radiation data.

The measurement error is minimized by improving the quality of the instrument and strict attention to maintenance and calibration requirements. However, this must be accomplished with cost effectiveness in mind. The sampling time must meet the needs but not be overestimated. As stated earlier, hourly, daily, monthly and annual data are the usual time intervals. It is a common practice to request the best resolution possible, but in many cases such a request is not justified.

The economic approach is first to envision the network with as few stations as possible and then to refine it only as economy permits. A good rule is that the more evenly the network is arranged (as permitted by such factors as regularity of the terrain), the greater is the economy achieved. If there are budget considerations which may not allow the selection of optimum distances between stations, then the area of coverage could be limited.

The user approach to sampling must be based on knowledge of the meteorological and economic approaches, but it also must determine if data for point sources (such as an individual solar energy project) or area information (such as an area under consideration by a power company) are required. Networks frequently may be required to meet these requirements simultaneously

If the point-source requirements can be satisfied, the meteorological approach is quantified by percent of area error versus the number of stations. The economic approach is quantified by the cost versus number of stations; this information may be graphed as shown in Figure 1.11 .

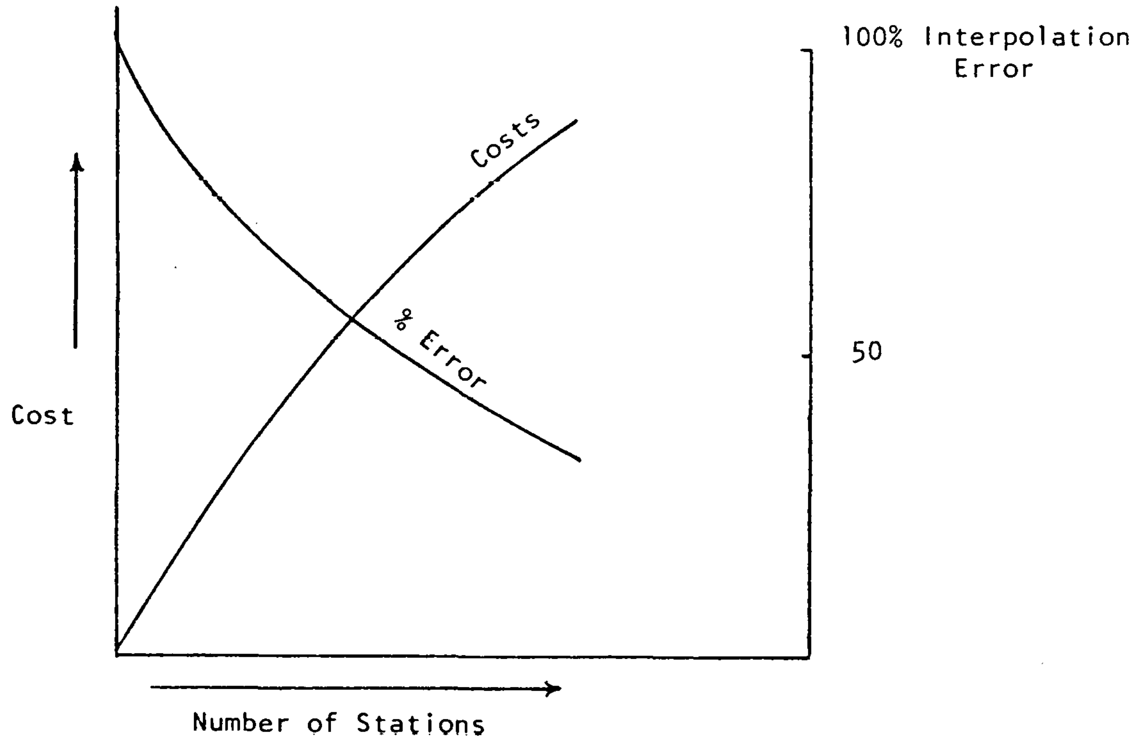

Figure 1.11 Number of stations estimation vs. cost and percent interpolation error.

NOTE: This information is a valuable tool in deciding on the size and configuration of a proposed network.

Additional information concerning specific costs of installing and operating solar radiation data collection sites is included in Chapter 8.

1.7 OBTAINING DECISION-MAKING INFORMATION

One method of optimizing the opportunity for success in balancing the problems and the costs of establishing a solar radiation data network is through a detailed systems analysis. Such an analysis can be extremely beneficial by increasing the rational quality of decisions.

Early systems analysts believed that their predecessors relied too much on heuristic decisions, based on hunches and intuition stemming from personal experience. In many cases this experience was insufficient to insure the best solution to complex and often new problems. Actual experience adds much to the art of decision-making, yet how applicable are these experiences to future programs? More recent approaches indicate that the type of judgement inherent in this balancing of programs and systems can no longer be intuitive or rely on past experience alone. The range of choice is too broad. The number and types of alternatives are too great.

Perhaps the greatest contribution of systems analysis lies in illuminating a problem - unveiling its nature, providing insights, and, if necessary, pointing out the need for more information. This close scrutiny makes analysis an effective means of clarifying the decision-making process to all concerned in a project.

To achieve explicitness and to provide insight unattainable in other ways, systems analysts attempt to be as specific as possible. Therefore, where appropriate, they tend to stress quantitative analysis, including such disciplines as economic theory, operations research, and statistical mathematics. Systems analysts also try to measure that which is measurable but never contend that decisions themselves can be calculated. In the analysts' role as advisors, they have the obligation of making both their conclusions and rationales as explicit as possible.

A decision maker should be given the opportunity to study the reasoning supporting a conclusion. The reasoning itself is often constructive in helping to frame thoughts for decision making. A large number of sources for information must be relied upon; therefore, the decision-maker faces the formidable task of not falling captive to the onslaught of facts and numbers. Without proper safeguards, an avalanche of works and numbers could become overwhelming. On the other hand, assurance is needed that all pertinent information is included, which must be examined independently and systematically to see if it conforms to reality and logic, hides biases, and, in general, contains other elements that might lead to making unwise decisions.

It has been suggested that systems analysis is a research strategy, a perspective on the proper use of the available tools, a practical philosophy of how best to aid a decision-maker with complex problems of choice under uncertainty. The technique can be characterized as a systematic approach to helping a decision-maker choose a course of action. By investigating the full problem, one can search out objectives and alternatives and compare them in the light of their consequences. By using an appropriate framework, insofar as possible, an expert judgement and intuition can be brought to bear on the problem.

1.7 Continued

While definitions vary as to the precise meaning of systems analysis, most observers and practitioners generally describe it as a method of systematically using logical and, in many cases, quantitative techniques for identifying and illuminating alternative courses of actions. These alternatives usually are evaluated in terms of their costs versus their effectiveness. If properly portrayed, the explicit presentation of these alternatives should result in better decisions. The systems analyst should contribute to the decision-maker's understanding of the problem but should not suggest or make final decisions. Systems analysis then represents a widely accepted approach to problem solving and must receive due attention in the area of planning and establishing solar radiation data networks.

While this philosophical digression may seem out of place to conclude a chapter primarily presenting information, the digression is designed to offer a framework for the information which may be used to help you reach a decision. The authors provide the information concerning the potential role of the systems analyst. The reader reaches the decision most suitable for his situation. If you have found a source or sources of solar radiation data which may be used or adopted to meet your needs, both you and the authors have succeeded.

The remainder of this book provides further and more detailed information about solar radiation networks. It is intended that justifying additional data collection and networks will become increasingly difficult. Continuous re-evaluation and long-range planning is essential. The plan must be thoroughly justified and, if implemented, should contribute necessary information to increase the use of solar energy. Appendix C provides a detailed methodology for applying systems analysis techniques to the development of solar radiation measuring networks.

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2.0 DEVELOPMENT OF A SOLAR RADIATION DATA NETWORK

The costs associated with measuring, recording, collecting, using, storing, and retrieving solar radiation data and the necessary fiscal and manpower constraints require careful planning and justification for each data project. Indicated data needs likewise require a careful analysis to insure that they are based on actual requirements. Pressure to expand the data base both in number of data-collection points and in the types and quality of data collected is becoming apparent. Thus, it is essential that use of the data be optimized to extract maximum amount of solar radiation information, consistent with needs, from the limited resources available for the data-collection activities.

Network design is becoming more critical to solar energy data systems. This results from the increasing use of solar energy and the greater economic importance of decisions based on the data systems. A data network should thus be considered in broader terms than just for the measurements of solar radiation and atmospheric variables.

2.1 THE USES OF SOLAR RADIATION DATA IN NETWORK REQUIREMENTS

The uses for solar radiation data influence the network requirements. The three major uses for data are for planning, for management, and for research. Planning usually requires extensive data with a "long" time base to determine the natural variability of the phenomena. Management, on the other hand, may require less data; but that which it does require may be in near real time for daily management for determining operational efficiency. Generally, research requires intensive data of higher precision than for other uses. The different uses are partly competitive for resources, and network design must consider the trade-offs among the various data uses.

In order to consider the trade-offs in a rational framework, the objectives which the design of the network is to achieve must be defined. This is often the most difficult part of the network problem. What are the actual objectives of a network? Is it really needed? The answers can be easily stated in generalities but not clearly defined in detail.

The major objective of general regional data is to reduce the uncertainties in solar energy planning. The definition of the time and space variation of solar radiation data help the planner to predict more accurately the possible future for a project. The energy manager may expect more data will increase the efficiency of operation of existing systems which is likely not the case. The researcher or the research manager may likewise wish to increase the overall effectiveness of the research program and assume that a larger data base can help to achieve this goal. Unless properly designed and managed, increased amounts of data can actually reduce the overall efficiency and quality of the network.

2.1 Continued

Mathematical statements which can assess the trade-offs among the various components of the data program and turn generalities into specifics is a basic need in network design. In order to design a network in some ideal sense, one should define the costs and the benefits of data. Then one should state these costs and benefits in a mathematical form as an objective function. However, maximizing the "worth" and minimizing the "cost" of the objective function, subject to well-defined constraints, may not always yield the optimal design for the network. These steps are not always simple or straightforward and overriding interests such as "pride of ownership" or "keeping up with so & so" may enter the picture.

The generalities stated earlier are very difficult to quantify. Stating the objectives in mathematicl terms is difficult, but even more difficult is the quantification of the objectives. In order to quantify objectives, therefore, an objective function must be constructed and the coefficients for that function must be defined. Although this may not be done explicitly in every case, design of a network requires such quantification. For an optimal design, the decisions must be compatible with the objectives and decisions underlying solar-energy systems planning and management. The coefficients in an objective function assess the trade-offs among the various data uses.

Costs and benefits of data must be assessed for inclusion in any network-design procedure. Costs are definitely the easier of the two to handle. However, there are uncertainties even in the cost estimates. Historical records are usually available which contain past allocations or budgets for data collection, processing, and dissemination. True costs are not usually available without considerable interpretation, but allocations are at least a fair index of costs. Projections of future costs are more uncertain. The development of data technology has transformed data collection and costs in the last decade. The growing use of the digital computer and the adjustment of data collection devices and procedures to interface with the computer is one obvious example. Computer costs are particularly difficult to estimate unless the computer system is dedicated solely to the data system. Data collection and relay by satellites is on the near horizon. The impact of such satellites on data programs and costs may be major tomorrow or it may be negligible, with increased or decreased costs. The more we evaluate true costs, the more uncertain they become.

What has been said of costs is equally true of benefits from data networks. What is the worth of data? While changing technology affects costs, it affects benefits even more. Benefits of data are related to the uses and widespread application of the data. The worth of data may also be measured in terms of the impact of the data upon network design and management decisions. Also, potential benefits which may be lost because of the lack of data can be taken as a measure of the worth of data. Such measurements for project design are rather straightforward,

2.1 Continued

even though they often contain a great deal of uncertainty. For other than project design, however, the uses for data and their effect on any resulting decision are diverse and diffuse. Predicting uses of the future is at best an inexact art.

In order to circumvent the problems of uncertainty and difficulty in determining cost and worth of data, most network-design criteria are developed around surrogate measures. The most popular such measure is the establishment of accuracy criterion such as Benson (1962), Carter and Benson (1971), Benson (1972), and Kagan (1972). To do so, data are collected in such a way as to minimize the variance of the estimate of some atmospheric characteristic subject to a budgetary constraint. Different regions may have entirely different relations of accuracy to density of the network. This deficiency can be partially overcome by the use of equivalent years of at-site record as a criterion as described by Moss and Karlinger (1974). Thus, regions may have widely different accuracies, but their adequacy in terms of information as measured by equivalent years of record may be the same.

The use of surrogate values may be a necessary expedient, but the fiction must not be treated as fact. Accuracy is a means to an end. The relation of worth to accuracy may be direct in some instances but it also may be quite complex. Thus, the level of accuracy should be treated as a design variable rather than as the criterion for an objective function in the design of a network.

At given points in space, the time series of events constitute the basic set of data pertaining to a specific phenomenon. The utility of historical data is measured by the extent to which they may be used to reduce the uncertainty as to what the series will be in the future.

Given the stochastic nature of atmospheric phenomena, observed time series must be described in terms of statistical parameters, among them being means, variances, serial and cross correlation coefficients, and return periods for certain classified events, such as extended periods of little or no solar radiation.

Because of the finite length of an observed time series of solar radiation data, only estimates of the parametric values can be obtained. For a given length, the magnitude of the sampling error may be measured by this variance of the estimated value of the parameter. A characteristic feature of atmospheric events is that they are not independently distributed in time. This dependence, measured in part by serial correlation, leads to larger sampling errors than are associated with independent events (Motalas and Langbein, 1962). Consequently, serial dependence affects the level of uncertainty in planning decisions, the extent of which depends upon the generating mechanism of the sequence of events and the particular parameters being estimated. Hourly and daily solar radiation values are bounded for any given location; while temperatures, wind speed, and quantity of precipitation, for example, are unbounded. In general, estimates of unbounded parameters have larger sampling errors than bounded parametric estimates for sequences of equal length.

2.1 Continued

Information is likely to be desired at sites where solar radiation is not measured. On the basis of regionalization of information at the measured sites, estimates of parameters at the unmeasured sites may be obtained. The standard error of a regionalized parametric estimate for an unmeasured site provides a basis for determining whether data need be collected at the site to obtain an estimate having a smaller standard error. Criteria may be established in relation to optimizing a network of measured sites for this determination as shown by Matalas (1967). In evaluating the need for data collection at the measured sites, it is necessary to consider that part of the standard error of the parametric estimate that is attributed to time-sampling error in relation to that part attributed to error in the regional relation. See Matalas and Gilroy (1968). The regional relation may also be used to evaluate the need for additional data collection at the measured sites. The DOE currently is sponsoring a program to evaluate the limits of spatial interpolations between solar radiation measurements to determine the amount of solar radiation received at the surface of the earth at locations where measurements are not available. It is believed that results from this study will provide sufficient information to negate the need for more dense networks.

For evaluating the needs of data at measured and unmeasured sites by means of techniques of regionalization, it is necessary to specify acceptable levels for the standard errors of the regionalized parametric estimates. These levels may be stated in terms of an equivalent length of record, so that regions with different variability of the data will have differing network configurations as described by Carter and Benson (1971).

The concept of equivalent years of record is a step beyond an accuracy criterion. An arbitrary error criterion might lead to the concentration of all or most of the data collection in an area of great natural variability. In fact, a criterion of this type may be unattainable in such an area. A regionalization technique offered by Gandin (1970) includes all elements of meteorological station networks. (See Appendix B).

Each change in criterion for network design changes the optimal allocation of resources within the network. Ideally, each change should be toward that network which is optimal in terms of decisions which are based on the data. Decision theory attempts to assess the network in those terms and to handle the economic aspects of network design in an explicit manner.

Decision theory is in reality, a way of thinking rather than a theory. It's purpose is to analyze the network in terms of the impact of data on decisions. Collecting more data should reduce the element of uncertainty in decision-making. The value of the reduction in uncertainty is the measure of benefits of data. These benefits can be compared to the cost of the data as shown by Davis and Dvorandhik (1971) and Davis et al. (1972).

2.1 Continued

In order to apply decision theory one must determine the decisions which will be based on the data, how the data affect those decisions, and, in particular, how the data affect the expected value of the decision-maker's objective function. Decision theory also attempts to include attitudes toward risk (or risk aversion) and provides a framework for including "soft" information based on experience as well as "hard" information based on data measured in the network or for network design.

Most of this discussion is concerned with global radiation. However, most, if not all of it applies equally well to the problems of direct radiation required for solar concentrators or other special data.

Solar data network design is only now in a developing stage. Because of the increasing interest in solar energy, care must be taken to assure that special requirements are considered.

2.2 THE USERS AND THEIR REQUIREMENTS

It is necessary at this point to identify the potential users of solar-radiation data. For the purposes of this book, a network within the political boundaries of a state is considered a basic network. Because DOE coordinates network programs through the state organizations, it is deemed best to initially structure the basic network within a state and then, if desired, combine state networks or portions thereof for regional cooperation. The Solar Energy Research Institute (SERI) at Golden, CO, will probably operate through regional affiliates, each of which is envisioned as a consortium of states. Therefore, the state network is the basic unit even if organized in a regional network. However, combining of intrastate networks into a regional network creates unique problems with individual solutions. The situations are similar to intrastate networks but more complex, especially the problems of funding, size, and cooperation. With the exception of governmental organizations, the procedures herein are applicable to any organization or group considering a solar radiation data network such as a power company or consortium of other interested groups.

The steps described in this chapter lead to the plan and organization of a solar radiation data network. The presented information also assists in completing a preliminary worksheet described in Appendix D. Section 2.5 shows how the information is used to help complete the worksheet and network organization. The steps in determining user requirements are:

1. List the potential users.

2. Determine the requirements of users.

3. Evaluate the requirements to determine if they can be met by other means; if they actually need a network; and if they will cooperate and support a network.

2.2 Continued

Determining the users requires identifying potential users, making contact with them and an iterative process to add to the list and delete those whose requirements can be met by other means. This process will probably be a continuing one since the potential group of users will probably not remain the same during operation of the network.

Determining the user requirements is also complex and difficult. The three most common methods of identifying the user requirements are through:

- Personal contact
- Questionnaire survey
- Conferences and meetings.

A thorough evaluation probably requires a combination of all three methods. Regardless of the personal contacts or the meetings, it is necessary to prepare a "Background Information Summary". Whether it is completed during personal visits, conferences, or mailed to the individual potential users, it is a valuable tool in determining and evaluating requirements.

Evaluating the user requirements requires a statistical approach as well as a comprehensive identification. The statistical work may be accomplished similar to the methods used by the Lawrence Berkeley Laboratories. In addition to a statistical evaluation, a logical evaluation must also be conducted. The logical evaluation is based on the manager's knowledge of other services and requirements which may be available as iterated earlier in this book. It is not expected that the persons who use a network will be as familiar with these types of information as are the network organizers and managers. Therefore, if requirements can be met with currently available data, it behooves network organizers to inform potential users how their requirements can be met without the need for a new or expanded solar radiation data network.

2.3 RELATED CONSIDERATIONS

The user requirements are tentative until all related considerations have been carefully evaluated. Typical of these are:

- Climate must be looked at from two points of view. First, is a review of the general climate of the area for which the network is being considered, which includes appreciation of terrain, and whether the area is homogenous or has features such as desert, mountain, ocean, etc. Next it is necessary to determine the type of related observations that may be required, with the solar radiation data, to measure the important climatic parameters.

- A review of alternatives mentioned earlier must be made to determine if they are relevant to the network under consideration. These include all currently available information from past records, data being collected by networks, satellite information, and other sources.

2.3 Continued

- The requirements for cooperative efforts necessary to assure success of the network must be listed. Inherent in the answers to surveys and personal contacts are innuendos which will help to establish the most probable type of user as well as the type of user who will cooperate in contributing data. It is essential that user surveys provide potential network managers with such information. Cooperation must be established early and will be a significant contribution to the success of any network operation.

- Communications requirements are twofold: Determination of communications required for the network data to be collected and of the communication needed to disseminate the information to users. Both areas require much attention in the early planning of a network.

- Economic or financial considerations are of paramount importance. Until now the economics of a solar radiation data network has been covered only briefly. It is time to consider the full implications of finance. As a result of the survey, meetings, and conferences, some idea should exist on the funding to be expected from various sources to make the network function. Also the time and efforts of participants in the network must be evaluated to determine if they will require financial support in order to maintain continuous operations. One must always keep in mind that a solar radiation data network may not be continuously funded. Generally it will be financed only to the extent that benefits accrue to its users.

2.4 NETWORK JUSTIFICATION AND CRITERIA

Two major considerations are necessary for justifying a network. One pertains to the results expected and the goals to be met and undoubtedly will include certain types and amounts of data at definite locations. These data must be made available to users. Goals to meet the requirements of each of the users must be expressed explicitly. In addition, there must be sustained support for the network. Such information is necessary to determine the period of time over which the network will operate. To believe that the starting of a network is solving the problem is a naive assumption. Indeed, once a network is established, the real problems actually begin. The network may not be self-sustaining or self-supporting and will continually require scrupulous management. Therefore, the goals mentioned earlier require time tables and projections into the future.

2.5 PRELIMINARY PLAN FOR NETWORK

The considerations in this chapter lead to a preliminary plan for a network. A worksheet for such a plan is included in Appendix D. Additionally, a short description of the material to be considered in each column of the worksheet is given. These columns cover generally the same information discussed earlier. They are not discussed completely in

2.5 Continued

this chapter because much of the remainder of the book furnishes additional information for such a worksheet. It must be pointed out that the network plan at this point is preliminary and, of course, flexible. If the steps listed previously have been taken, a great deal of data and information exists which must be organized. The network plan worksheet can assist in this effort. The columns and data, incomplete here, are addressed later in the book. Further assistance will be given in continuous revisions of the worksheet.

2.6 UNDERSTANDING NETWORK PROBLEMS

It is impossible to foresee all problems which will be encountered in establishing a solar radiation data network; however, many of them can be anticipated and minimized. The problems range from equipment, installation, personnel, funding, misunderstanding, etc. Most of these are discussed later. Thus, the planner of a solar radiation data network should proceed only after he has fully reviewed, considered, and understood all of this book. Even then, he should continue only if he has developed an approach to solving network problems and has the need, willingness, and resolve to carry through to realizing a network that will serve the needs of its users on a continuing basis.

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3.0 SURVEY OF EXISTING SITES AND SELECTION OF NEW SITES

A network of stations is defined as two or more stations collecting data for mutual benefit and use. Networks for collecting atmospheric data are generally considered in three classes according to the degree of concentration of stations. Atmospheric data collected with a resolution of less than 100 km is a micronetwork, and the data are micrometeorological. A network resolution with stations between 100 km and 1000 km is considered mesoscale, and data collected from stations greater than 1000 km apart are macroscale. The NWS data collection is a mesoscale network. The 35 solar radiation collection stations can be considered a course mesoscale network. As cooperative stations are added, the network will be refined. All network requirements to supplement the NWS network would probably be microscale. In this book <u>network</u>, for design purposes, means a microscale network, i.e., one with stations closer than 100 km. Thus, if one is seeking microscale data, instruments with comparable quality resolution must be used. In other words, a fine-resolution, area network requires fine-resolution quality measurements. Of course, in areas of Alaska, Hawaii and other parts of the world there may be requirements for establishing mesoscale networks.

3.1 LOCATING EXISTING SITES

Initially, the network manager will collect information about the location of existing solar radiation data collection sites. As these are investigated to determine their cooperation and to evaluate their contribution to the proposed network, additional sites will probably be identified. The SEO should be the focal points for locations of existing sites. Figure 3.1 is a map of existing solar data sites in New Mexico in 1976, from Bahm (1977). After having compiled the historical data available from such sites, they should be analyzed for their potential value in meeting the user requirements previously identified. The results are used in the network plan worksheet (see Appendix C). The network manager must demonstrate skill in evaluating the potential cooperation and contribution of each site. This book assists in pointing out potential problems. Generally, the longer the length of record of an existing site, the more valuable that data will be in providing information about the local solar energy availability.

The Tennessee Valley Authority (TVA) began collecting solar radiation data about 1967 at two locations because of the suspected effects of solar radiation on power-plant emmissions. TVA is now collecting solar radiation and other atmospheric data at eleven sites, and the use of the data has expanded to provide heating and cooling information. The data are also a base for expanding responsibilities in energy conservation and encouraging the use of solar energy. Establishing a network by an autonomous organization such as TVA simplifies problems because the prime requirements are a good manager and network support by the sponsoring organization. The Carolina Power Company is operating a network of three stations, the first of which has been in operation since 1974.

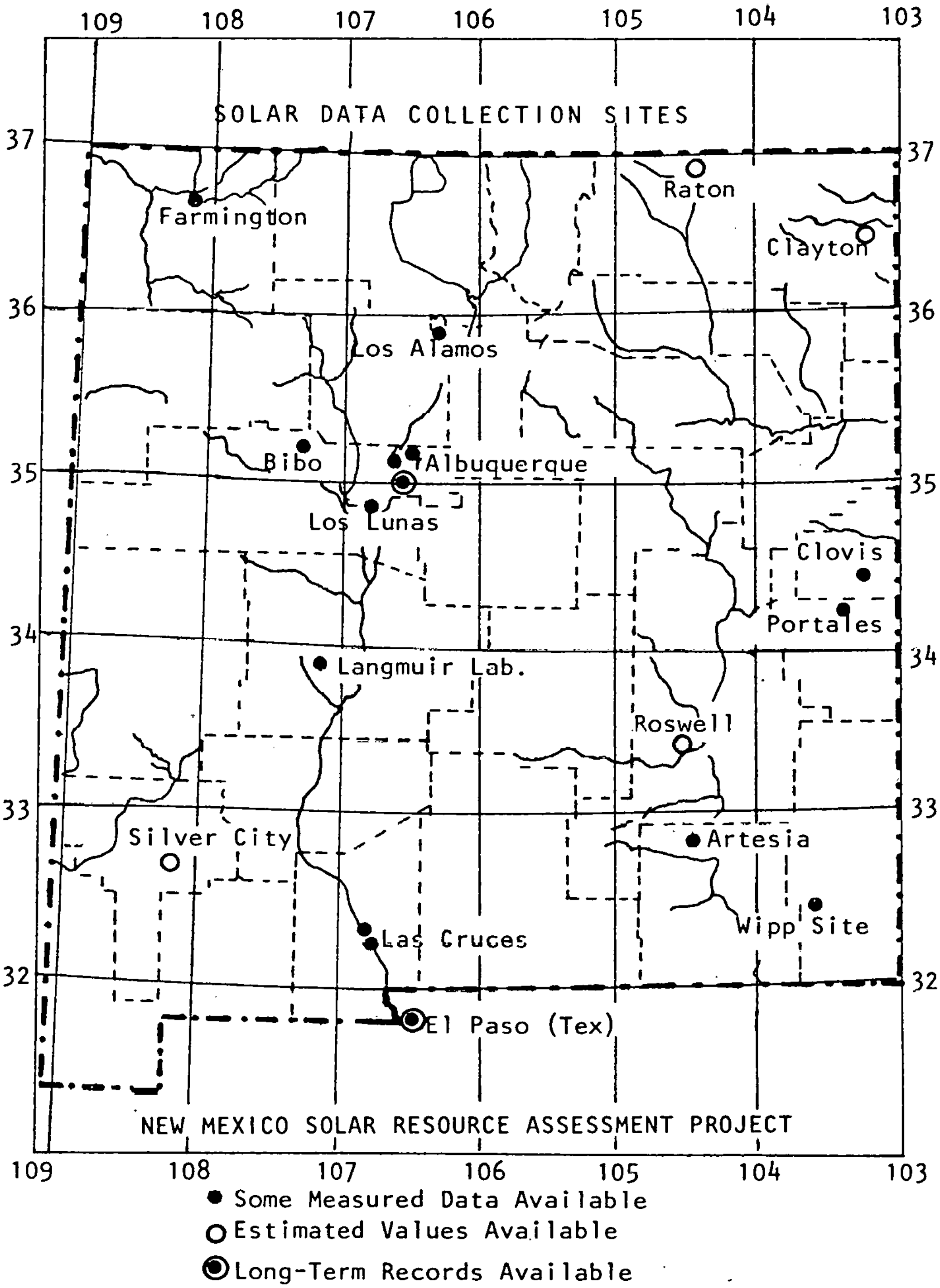

Figure 3.1 Map of Existing Solar data Sites in New Mexico

3.1 Continued

Western Energy Supply and Transmission (WEST) Associates, a consortium of 21 power and utility companies operating primarily in seven southeastern states, has funded one of their members, Southern California Edison (SCE) as project manager to coordinate its Solar Resource Evaluation Project. In 1976, SCE collected temperature, pyranometric and some pyrheliometric data from 19 locations primarily in southern California. The project for WEST Associates will extend this network to selected locations in other states. The obvious keys to the success of this network are selection of a single manager, centralized funding, a basic small network on which to expand, and annual worthwhile results available in both tabular form and on magnetic tape. The 1976 operations are described in a report by SCE (1977).

An example of a Federally sponsored program supporting an atmospheric network, which included solar radiation measurements, is described by Hosler (1975). The network, sponsored by the EPA, started operation in 1974 and terminated in early 1977. The data were collected for other than solar energy purposes but proved to be valuable in studying the contrasts of urban and rural environmental effects. This network again had a single manager but had support for a limited time only.

Auburn University, in Alabama; Clemson University, in South Carolina; and the University of Michigan, at Ann Arbor, are managing networks with two to four stations. Networks at Auburn and Clemson are sponsored by the U. S. Department of Agriculture. Reports are published annually and used for agricultural purposes. The University of Michigan data, collected from stations along the eastern shore of Lake Michigan, will be made available in the future.

State-sponsored networks are in the formative stages. It is apparent that the stations in successful networks meet the criteria listed in Table 3.1 for new sites.

3.2 POTENTIAL NEW SITES

From the map prepared of existing sites, locations of required new sites can be identified. The existing sites should be organized, if possible, into a cohesive network before new stations are selected. The primary reason for this procedure is that it is better to organize the existing, smaller network and then expand it than to have the simultaneous problems of organizing and expanding. Another reason is that as the network becomes operational, the requirements for additional stations may become clearer, i.e., more stations, less stations, or alternate locations. Also, the costs of stations are more clearly identified as the network begins operation.

The criteria in Table 3.1 must be realized for a viable station in a network.

Candidate locations and operators for network stations may be similar to those previously listed as participants in successful networks. Other

3.2 Continued

candidate site locations may include trade schools, high schools, solar-energy projects, etc. The success of each of these in contributing to the network will probably depend on dedicated and professional operation. The availability of such personnel and operation of a site could be more important than its geographical site.

The proposed site, of course, must meet minimum requirements for location in networks and for adequate exposure to the sky. These requirements are specified in WMO - No. 8. TP. 3, "Guide to Meteorological Instrument and Observing Practices", Fourth Edition (1971). The types and quality of solar-radiation sensors are also described in this WMO document and in a catalog of manufacturers and instruments, prepared by Carter (1977). Each instrument manufacturer provides information on the maintenance and recalibration requirements for his product.

TABLE 3.1 - Criteria for Considering New Solar Radiation Data Sites

1. Meets a user requirement not met in any other way.
2. Have adequate power, communications, and accessibility.
3. Has personnel to oversee operation.
4. Have funds for equipment, supplies, and operation.
5. Have a single, knowledgeable network manager with responsibility and authority to meet user requirements.
6. Must insure that network data reach the user.

3.3 SITE EXPOSURE REQUIREMENTS

A site should always be remote from the immediate influence of trees and buildings but in a location that affords a typical representation of local environmental conditions such as fog, clouds, smoke, airborne pollution, and albedo.

The principal exposure requirement for the radiometer is the freedom from obstructions to the solar beam at all seasons of the year. If practicable, a shadow should not be cast on the instrument at any time; and the elevation of any obstruction over the zenith range between the earliest sunrise and latest sunset should not exceed 5°. Also, the instrument should be located so that it receives no reflected sunlight or radiation from other sources.

3.3 Continued

The site should be accessible for daily inspection and cleaning of the sensors. Yet, the instruments should be protected from vandalism or theft.

When related atmospheric elements are measured, the nature of the exposure of the meteorological instruments is important if the measurements are to be comparable with those from other sites. Site exposure requirements for various meteorological instruments are described in WMO (1971) Guide to Meteorological Instrument Observing Practices. Extracts from this publication and from Weather Bureau Observing Handbook No. 2, Substation Observations are included in Appendix E.

3.4 RECORDING ENVIRONMENTAL MEASUREMENTS RELATED TO SOLAR RADIATION DATA

The type, frequency, and accuracy of the related environmental measurements required at a solar radiation observation site depend on the application and use of its data.

The most efficient use of sunshine is for solar radiation to stike an area or object which collects its thermal energy. The simplest application and method most generally used to take advantage of this energy is to locate the windows of a building so that solar radiation enters the windows in winter but does not do so in summer. But even with this passive method, accurate measurements of the energy available and needed should be made to maximize design of a building or an auxiliary heating and cooling system.

When more complex energy systems such as space heating and cooling, water heating, electric power generation, industrial heat processes, crop drying and irrigation are considered or built, the accuracy of atmospheric data is of even greater importance.

If data are used to develop a forecasting technique for solar radiation, all atmospheric parameters in as much detail and accuracy as possible will be required. Upper-air observations from a radiosonde station not more than 150 km from the site would be satisfactory, but detailed observations of the type of clouds and amount of them at each level and not more than 32 km, generally, from the site would also be necessary. Turbidity measurements should be made as well, and the constituents of the atmosphere should be recorded. In addition, atmospheric pressure would be necessary to determine the solar beam penetration of the atmosphere.

Most solar radiation measurements, however, are used to determine the economic benefits of a solar energy system in a specific geographical area. If accurate solar data for such an area are available, the power output of a system can be computed to determine the most effective combination with an auxiliary system and to prevent oversizing of the solar energy system, with attendant, excessive real estate, equipment, and installation costs.

3.4 Continued

The environmental measurements required are maximum and minimum temperatures by the day for the computation of degree days for heating and cooling and a high- and low-humidity measurement by the day for its relation to temperature as a comfort factor. The prevailing wind direction and speed should be determined not only for its relation to heating and cooling but also for an effective design of the structure and energy system, especially if a combination of wind and solar energy system is under consideration.

If a NWS station is in the area, a study should be made of the relationship of the NWS data to the solar radiation site. The measurement can then be correlated with NWS records to establish climatological records for the solar radiation site.

Generally, the environmental measurements of greatest value when taken with daily solar radiation values are listed in Appendix A on the SOLDAY form. The environmental parameters to be measured with hourly values of solar radiation are listed in Appendix A on the SOLMET form. An explanation of the SOLMET form is given in Appendix A, and the basic record of solar radiation and related environmental observations should be recorded in this format.

A detailed explanation of observing and recording meteorological phenomena is beyond the scope of this book. However, a brief, introductory discussion of meteorological parameters which are important in the development and application of solar energy systems is given in Appendix E. References are also listed which give in detail the requirements and techniques of making meteorological observations related to the use of solar radiation data.

3.5 REVISION OF COSTS AND NETWORK PLAN

With the site tentatively selected and located, it is necessary to review and revise the network plan worksheet (Appendix C). A preliminary estimate is possible at this point of initial expenses and operating costs. Here, too, existing sites should be examined again to determine the history of their costs and relate them to the projected costs of new sites.

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4.0 SELECTION OF INSTRUMENTS FOR NEW SITES

Proper selection of equipment is the first step in assuring the quality of the data collected by a network.

4.1 EVALUATION OF EQUIPMENT AT EXISTING SITES

If instruments are currently in use or available, one must determine if their performance meets requirements. If there is any doubt about the accuracy of them, they should be returned to the manufacturer for recertification. If the specifications of the instruments do not meet the network requirements, they, of course, must be replaced.

Table 4.1 may by used as a guide in determining the quality of solar-radiation sensors.

4.2 INFORMATION SOURCE ON INSTRUMENTS

The Catalog of Solar Radiation Measuring Equipment, by Carter (1977), provides manufacturers' specifications on most available solar radiation sensing instruments. It is a useful source for determining the quality and costs of competing instruments for a network.

A comparable report for ancillary equipment required is not available; thus, it is necessary to seek advice from manufacturers' representatives or users of such equipment, to fulfill complete equipment requirements. As discussed in Chapter 3, the precision of instruments required is linked to the distance between stations. The closer the stations are to each other the more accurate they must be.

4.3 EVALUATION OF COMPATIBILITY OF SITE INSTRUMENTATION

If time and funds permit, a "satellite" station should be set up and operated near the main station to establish the reliability of the new instruments. At a minimum, the solar radiation measuring instruments should be operated near the master network control instrument for several days. Upon receipt of a new instrument, it should be inspected and operated near the control instrument. When the instrument proves to be within the specifications, it can be relocated and installed at the new site. However, the control instrument should again be compared with the new instrument after its installation at the operational location.

In considering Table 4.1, care and attention to detail are required if the desirable standard of accuracy is to be obtained, and it is important that the staff engaged in this work be keen and of a critical disposition. Procedures described in WMO (1971) should be followed and the Regional Meteorological Research and Training Sites listed in Section 1 may be called upon for assistance.

To estimate the accuracy of radiation measurements made with radiometers the following properties of the complete system (including the measuring, recording or integrating device) will need to be evaluated as appropriate; where necessary, corrections should be applied to the observed results: (letters below refer to columns in Table 4.1)

TABLE 4.1 - The Classification of Accuracy of Radiometers

[from WMO Guide to Meteorological Instrument and Observing Practices (1971)]

	(a) Sensitivity (mW cm⁻²)	*(b) Stability* %	*(c) Temperature* %	*(d) Selectivity* %	*(e) Linearity* %	*(f) Aperture*	*(g) Time constant (max.)*	*(h) Cosine response* %	*(i) Azimuth response* %	*Errors in auxiliary equipment* Galvanometer	Milliammeter %	Chronometer
Reference standard pyrheliometer	± 0.2	± 0.2	± 0.2	± 1	± 0.5	(1)	25 s	—	—	0.1 unit	0.1	0.1 s
Secondary instruments												
1st class pyrheliometer	± 0.4	± 1	± 1	± 1	± 1	(1)	25 s	—	—	0.1 unit	0.2	0.3 s
2nd class pyrheliometer	± 0.5	± 2	± 2	± 2	± 2	(1)	1 min	—	—	0.1 unit	± 1	—
											Errors in recording apparatus	
1st class pyranometer	± 0.1	± 1	± 1	± 1	± 1	—	25 s	± 3	± 3		0.3	
2nd class pyranometer (2)	± 0.5	± 2	± 2	± 2	± 2	—	1 min	± 5–7	± 5–7		± 1	
3rd class pyranometer	± 1.0	± 5	± 5	± 5	± 3	—	4 min	± 10	± 10		± 3	
											Errors due to wind %	%
1st class net pyrradiometer	± 0.1	± 1	± 1	± 3	± 1	—	½ min	± 5	± 5		± 0.3	± 3
2nd class net pyrradiometer	± 0.3	± 2	± 2	± 5	± 2	—	1 min	± 10	± 10		± 0.5	± 5
3rd class net pyrradiometer	± 0.5	± 5	± 5	± 10	± 3	—	2 min	± 10	± 10		± 1	± 10

4.3 Continued

a. The sensitivity of the system, i.e., the smallest change in the quantity being measured which can be detected by the system.

b. The stability of the calibration factor, i.e., the maximum permissible change in this factor, percent per year.

c. The maximum error due to variation in ambient temperature.

d. Errors caused by a departure from the assumed spectral response of the receiver; the maximum error should be assessed in percent.

e. Non-linearity of the response of the system when this is assumed linear the maximum error should be assessed.

f. In the case of pyrheliometers, the effect of the circumsolar radiation, which depends on the aperture angle.

g. The time constant of the system, i.e., the time necessary to register (1 - 1/e) of a sudden change in radiation. (For observations made in this way it is necessary to wait up to four times this value to obtain a steady reading.)

h and i. The deviation of the directional response of the receiver from that assumed [usually known as the cosine response (h) and the azimuth response (i)]. For pyranometers it is convenient to assess the error in percent due to this cause when the sun is at an elevation of ten degrees on a clear day. The effect of auxiliary equipment used with pyrheliometers and disturbing effect of wind on net pyrradiometers must also be considered.

Based on these considerations, Table 4.1 has been produced showing the desirable limits for reference standard pyrheliometers, first class, second class and third class secondary instruments. Existing radiometers have been classified in the above groups by a working group of the Commission for Instruments and Methods of Observation, as follows:

1. <u>Reference standard pyrheliometer</u>

   Angstrom compensation pyrheliometer (Stockholm)
   Silver disk pyrheliometer (Smithsonian)
   Kendall Absolute Pyrheliometer

2. <u>1st-class pyrheliometer</u>

   Michelson bimetallic pyrheliometer
   Linke-Feussner iron-clad pyrheliometer
   New Eppley pyrheliometer (1958)
   Yanishevsky thermoelectric pyrheliometer

4.3 Continued

3. <u>2nd-class pyrheliometer</u>

   Moll-Gorczynski pyrheliometer
   Old Eppley pyrheilometer (before 1958)

4. <u>1st-class pyranometer</u>

   Selected thermopile pyranometers

5. <u>2nd-class pyranometer</u>

   Moll Gorczynski pyranometer
   Eppley pyranometer (called 180^{o} pyrheliometer or black and white)
   Volochine thermopile pyranometer
   Dirmhirn-Sauberer pyranometer
   Yanishevsky thermoelectric pyranometer
   Spherical Bellani pyranometer

6. <u>3rd-class pyranometer</u>

   Robitzsch bimetallic pyranometer

REFERENCES

Carter, E. A., et al. ERDA/ORO/5362-1, K. E. Johnson Environmental and Energy Center, University of Alabama, Huntsville (1977). Catalog of Solar Radiation Measuring Equipment. (ERDA-ORO/5362-1).

WMO (1971), Guide to Meteorological Instrument and Observing Practices, No. 8, TP.3.

5.0 CALIBRATION AND MAINTENANCE OF INSTRUMENTS

This chapter is concerned mainly with radiometers, but Appendix E describes other meteorological instruments and the uses of atmospheric measurements related to solar radiation. For more detailed information on the calibration and maintenance of meteorological instruments, refer to Federal Meteoroloigcal Handbook No. 1 (1970) Surface Observations and Weather Bureau Observing Handbook No. 2 (1970) Substation Observation. A general discussion of standardization of instruments, extracted from WMO (1970) Guide to Meteorological Instrument and Observing Practices, No. 8. TP. 3 follows.

5.1 STANDARDS OF MEASUREMENT

The word standard is frequently used to describe various instruments, methods, scales, laws, etc. A uniform nomenclature for standards of measurement is necessary because of their increased use in modern technological development. The International Organization for Legal Metrology (IOLM) has under consideration a draft terminology on the classification of standards. The definitions given below, which are based on the IOLM draft terminology, are used in this book.

A unit of measurement is a quantity taken as of a magnitude one, in terms of which other quantities of the same kind are measured. A standard is the physical embodiment of a unit. Thus, the unit of length is a meter, and the standard length is the international meter bar kept at Severs, France.[1] For measuring a quantity in terms of a standard on those derived from it, standard instruments are used. Unlike a standard, they measure over a range of values of the quantities involved. A standard method is a method of reproduction of the unit of measurement making use either of fixed values of certain properties of bodies of physical constants. Types of standard instruments include:

1. Standard (instrument). An instrument or device to define, maintain or reproduce the unit of measurement (or its multiples and submultiples) in order to transmit it to other instruments or devices.

2. Collective standard. A group of instruments which toegther serve as standard. The value of the collective standard is the arithmetical mean calculated from the values furnished by the various instruments.

3. Primary standard. A standard instrument which possesses the highest degree of precision.

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[1]In the SI, the meter is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels 2 p and 5 d_5 of the krypton-86 atom.

5.1 Continued

4. Secondary standard. A standard instrument the value of which is fixed by direct or indirect comparison with a primary standard or by a standard method.

5. Working standard. A standard instrument for the verification of a reference standard (see below) or for the verification of ordinary instruments the order of precision of which is the same as that of the reference standard.

6. Traveling standard. A portable standard instrument which may be carried from one place to another and still retain its calibration.

7. International standard. A standard instrument recognized by international agreement as the basis for all other standards of the given quantity.

8. Regional standard. A standard instrument designated by regional agreement as the standard for the region.

9. National standard. A standard instrument designated by a member as the standard for its territory.

5.2 PROCEDURES FOR STANDARDIZATION

In order to control effectively the standardization of meteorological instruments on a national and international scale, a system of national and regional standards has been adopted by the WMO. In general, regional standards are designated by regional associations and national standards by the individual members. Unless otherwise specified, instruments designated as regional and national standards should be compared by means of traveling standards at least once every two years. It is not essential for the instruments used as traveling standards to possess the accuracy of primary or secondary standards. They should, however, be sufficiently rugged to withstand transportation without changing their calibration.

Similarly, the instruments in operational use in a service should be periodically compared directly or indirectly with the national standards. Comparisons of instruments within a service should, as far as possible, be done at the time the instruments are issued to a station and subsequently during each periodical inspection of the station. Portable standard instruments used by inspectors should be checked against the standard instruments of the service before and after a tour of inspection, as covered in WMO Guide to Meteorological Instrument and Observing Practices. (See Chapter 1 for information about solar radiation scales.)

An accuracy of $\pm 5\%$ in the global radiation measurements can be achieved only by conscientious and continuous calibration and intercomparison of instruments and recording equipment. Installation and major maintenance of complicated instruments are best done by specialists who have a through knowledge of meteorology and its instrumentation.

5.3 OPERATOR MAINTENANCE AND INSTALLATION

Well-trained field personnel, who understand the importance of accuracy and dependability of instruments to the program, are necessary in obtaining meaningful radiation measurements.

The most important essentials of proper installation are: 1) the radiometer must be mounted on a stable support, preferably a metal base, 2) a splice-free, shielded carrier cable #22 or larger diameter should be buried or secured and protected, 3) the connection between the carrier cable and the radiometer must be weathertight.

A radiometer should be inspected at least once a day and cleaned, preferably in the morning, if conditions warrant. If pollution is excessive or ice or snow accumulates on the dome, it should be cleaned more frequently. A soft cloth or paper wiper should be used, since a scratch on the dome would change the calibration of the instrument. Figure 5-1 is a reproduction of an actual strip-chart trace which was recorded as the shadow of a flaw on the dome crossed the sensor. During the inspection, the sensor should be examined for flaking, chipping, or cracking; and the level of a pyranometer should be checked to be sure that the thermopile is horizontal if global or diffuse radiation is being measured. Also, a shade ring of an instrument must be adjusted every two or three days. Table 5.1 is a sample of a suggested daily operator maintenance log, and Table 5.2 is a sample of a suggested check list for instrument maintenance.

Radiation-recording devices should be checked daily. The operator should check for the correct time, preferably as near sunrise as practicable. The quality of chart trace and printout should be checked, and the quantity of ink and chart paper should be sufficient for continuous operation. Table 5.3 is a suggested sample for a daily radiation-recorder check list to be used in conjunction with Table 5.1.

Details on the maintenance schedule of various sensors, integrators, printers and recorders can be found in <u>NWS Observing Handbook No. 3, Solar Radiation Observations</u>.

The accuracy of radiation measurements depends on sensitivity and stability of the system, the variation in ambient temperature, the assumed spectral response of the receiver, the assumed linear response, the time constant, the deviation of the directional response of receiver from assumed cosine and azimuth response, and in case of pyrheliometers, the circumsolar radiation. Therefore, these properties need to be evaluated in determining a malfunction. Table 4.1 gives the allowable variation in each of these properties for various classes of radiometers.

<u>Radiation</u>, Ministry of Transport, Canadian Meteorological Service, is a manual of standard procedures and practices for measuring electromagnetic radiation of atmosphere, solar and terrestrial emission. This manual describes in detail the servicing and calibration tests to improve the quality of various radiation measuring devices.

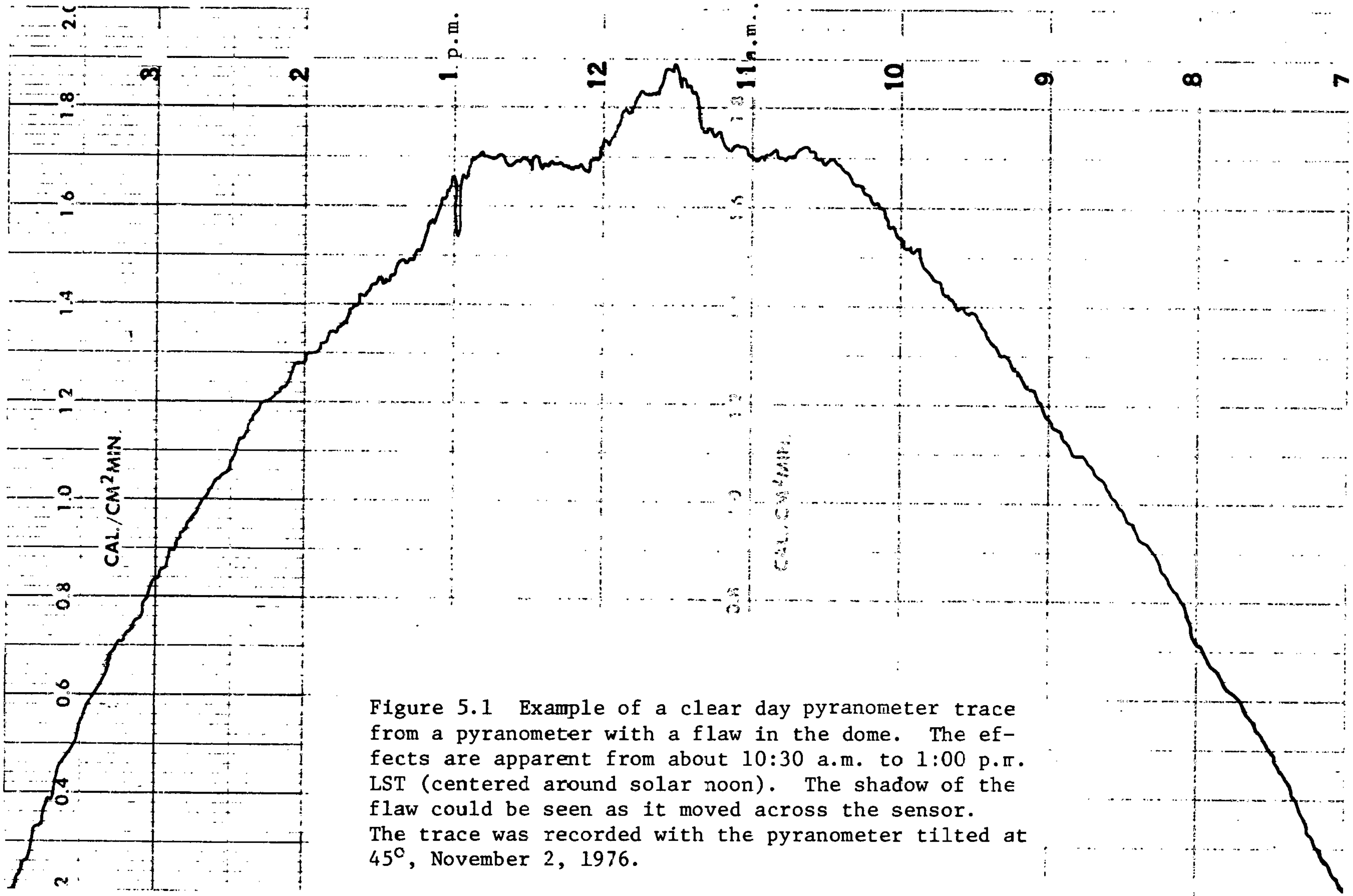

Figure 5.1 Example of a clear day pyranometer trace from a pyranometer with a flaw in the dome. The effects are apparent from about 10:30 a.m. to 1:00 p.m. LST (centered around solar noon). The shadow of the flaw could be seen as it moved across the sensor. The trace was recorded with the pyranometer tilted at 45°, November 2, 1976.

Table 5.1 - Sample Daily Operator Maintenance Log

Station: Capital City #1   Date: May, 1977

Radiometer Type: (Pyranometer-Diffuse), Manufacturer: Eppley, Model PSP, Serial #: ________, Altitude MSL: (615 Meters), Above Ground: (5 meters), Lat. $34^{o}35'$N, Long. $86^{o}45'$W

DAY OF MONTH	TIME CHECK IN TST	CHART RESET*	PRINTER RESET	RADIOMETER CLEANED	LEVELED SHADE RING ADJUSTED	ADDITIONAL TIME CHECK	CHART RESET	PRINTER RESET
1	0630	✓	✓	0730	1130 (SRA)			
2	0625	✓	✓	0600		1010	+25	+25
3	0650	+3	✓	0640				
4	0615	✓	✓	0710	1140 (SRA)			
5	0610	-4	✓	0730				
6	0635		+5	0650	0640 (LEV)			
7								
8								
9								
10								
11								
12								
13								
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29								
30								
31								

* Plus or minus minutes

NOTES:
Power failure 0940-1005 TST May 2 TST
Calibration tests May 4 0945 TST
Monthly maintenance May 5 0930 TST
Pyranometer level adjusted May 6 0640 TST
Building erected on grass plot 50 meters west of pyranometer.
Top of building 10 meters May 6
Use separate page for each radiation field measured. Corresponding notes should be made on recorder chart and printer chart for all entries made on this form.

5.3 Continued

The operator should make a brief check of the complete system at least once a month. The simplest check would be to compare the measured quantity from the system with a quantity computed theoretically using the same conditions as those under which the measuring system operated. For instance, if a global solar radiation value was obtained from the system, the operator, on a clear day (or clear midday) with no visability restrictions, should compare the measured value with the theoretically computed global solar radiation (see paragraph 6.1). A table with the acceptable limits of the value should be available at each observing station (Table 6.1).

Careful attention to daily maintenance procedures will prevent many malfunctions in the radiation measurement system. Other conditions which require an action to correct and a notation on the Solar Radiation Operator Maintenance Log are water inside radiometer bulb or cover, damage in alignment of spirit level, equipment failure such as change in chart speed of recorder, alteration of the coating on a thermopile, pyrheliometer equatorial mount needs resetting, base line setting of a recorder, a shadow on the radiometer, power failure, and any interference or instability in the system which produces a faulty reading.

Some of these conditions such as alteration of the coating on a thermopile and water inside the radiometer cover, require returning the instrument to its manufacturer. Other conditions can be corrected by following instructions in the operations manual for the instrument.

A reminder file or check list should be established for detailed maintenance and routine operation of every radiometer and associated equipment. For example, a reminder sheet for a pyranometer used to measure diffuse or sky radiation could take the form of Table 5.2.

Table 5.2 Sample Checklist For Instrument Maintenance

Pyranometer (Manufacturer-Model)	Daily	Second or Third Day	Monthly	Other Intervals	Operations Manual Paragraph or Other Refer.
Inspecting, Cleaning Glass	X				6.1.2
Checking Thermopile	X				6.1.2
Checking, Adjusting Level	X				6.1.3
Completing Solar Radiation Operator Maintenance Log	X				6.1.2
Checking, Adjusting Alignment of Shade Ring		X			6.1.4
Lengthening Stand Pipe				as required by snow depth	
Calibrate				annually	6.1.5

If the pyranometer has a strip chart recorder, the reminder sheet could take the form of Table 5.3.

5.3 Continued

Table 5.3 Sample Checklist for Data Acquisition System

Radiation Recorder (Manufacturer-Model)	Daily	Second or Third Day	Monthly	Other Intervals	Operations Manual Paragraph of Other References
Notating Recorder Chart	X				6.4
Completing Solar Radiation	X				6.4
Operator Maintenance Log					
General Condition of Equipment		X			6.5
Packing & Mailing Forms & Records			X		6.4.1
Calibrate				Every two months & when recorder adjustments are made	6.4.2

5.4 ROUTINE CALIBRATION PROCEDURES

Radiometers should be calibrated annually. A pyranometer or pyrheliometer should be compared with a standard pyrheliometer or with a primary or secondary standard pyranometer. If comparisons are conducted out-of-doors they should be conducted in all types of radiation conditions, i.e., clear, partly cloudy and cloudy days.

In addition to comparison of the instruments, tests should be performed to establish a relationship between the recorder trace value and/or magnetic tape and the printout (baseline values) and to insure that all registering devices remain sufficiently stable to produce data within acceptable limits of accuracy. These tests should be made at least every six months.

The procedures for conducting these tests will depend on the type of recorder integrator installed, but instructions for these calibrations should be in the technical manual accompanying the equipment. Periodic tests of the entire data acquisition system are important.

5.5 RECALIBRATION AND SHOP MAINTENANCE

Radiometers could be returned to the manufacturer for shop maintenance and calibration. But, to maintain a continuous record with limited radiometers, it is better to calibrate the radiometer with a substandard radiometer designated for this purpose and sent to the location of the equipment to be calibrated. The calibration and test of radiation instruments for use by the NWS network is the responsibility of the Air Resources Laboratories of the Environmental Research Laboratories (ARL/ERL), operated by NOAA. The ARL/ERL maintains a group of reference standard radiation instruments which are compared at regular intervals with recognized international standards of radiation. The facilities of this center are available to institutions and to cooperative radiation stations for the calibration of radiometers, if the data meet the requirements of NCC, NOAA, for archiving in the NCC. (See Appendix F.)

5.6 RADIATION STATION RECORDS

Notations pertaining to malfunction, maintenance, and servicing of equipment should be recorded on a solar radiation daily operator maintenance log. (See sample log and instructions in Table 5.1.)

The station name, radiation type measured, and period covered should be marked at the beginning and end of each recording and printer chart and on forms accompanying magnetic tape.

The forms for entering the observational data should be completed in detail making sure the station name, location, month, year, and time of observations are given. This information is important for identifying the observations throughout the life of the record. A copy of the observational data is retained at the station until it is certain that the original form has been received by proper authorities. Normally, observational and maintenance forms, recorder and printer charts, etc., are mailed to the proper records center the first or second day of the month and cover the previous month's record.

REFERENCES

Federal Meteorological Handbook No. 1, Surface Observations (1970) U. S. Department of Commerce, U. S. Department of Defense, U. S. Department of Transportation.

National Weather Service Observing Handbook No. 3, (1977) Solar Radiation Observations, U. S. Department of Commerce, NOAA National Weather Service.

Radiation (1971) Ministry of Transport, Canadian Meteorological Service.

Weather Bureau Observing Handbook No. 2 (1970) Substation Observations, U. S. Department of Commerce, Weather Bureau.

WMO (1971) Guide to Meteorological Instrument and Observing Practices, No. 8, TP. 3.

6.0 QUALITY CONTROL FOR THE NETWORK

After the selection of instruments for the network, it is essential that the instruments be operated and maintained within specified standards. This chapter is concerned with the operations quality control. There are some overlaps in procedures in selection of equipment, operation, and maintenance; but all have the objectives of meeting the required quality control standards in network data.

6.1 DAILY COMPARISONS OF DATA

There are three important comparisons which are fairly easy to accomplish and will add confidence in the data collected. The first two clear-day comparisons can be performed by the operator "on site" to provide him with confidence in his data, while the third method can be performed by the network quality control management.

The first and most widely used quality control of solar-radiation data is known as the clear-day solar noon comparison. This method requires a clear period near solar noon. The second method uses similar procedures and requires calculation of the total clear-day solar radiation expected. This method requires a completely cloud-free day. Calculations of the clear-day solar noon and the completely clear-day solar radiation follow similar procedures and are described in detail by Yellott (1976). Fortunately, Professors Morrison and Farber (1974) of the University of Florida have computed values for several latitudes and the hourly values centered on solar noon and daily total values, and they are given in Table 6.1. From this table one can approximate what a clear-day solar noon or clear-day total solar radiation value may be for any location in the U. S. There are two refinements which may be used to adjust this approximation to closer agreement with the measured values. One is a correction for elevation above mean sea level, and the other is an adjustment for the clearness factor. Both are described by Yellott (1976) but may be quite closely approximated. Clear-day solar radiation values may be expected to increase about one percent for each 1000 feet above mean sea level and the values in Table 6.1 may be adjusted for elevation, or exact calculations may be computed for the elevation of each station.

The clearness factor cannot be treated with as much assurance. Yellott (1974) provides an average clearness factor map for summer and winter (the same as Figure 1.6) but this is of little value on any given clear day. Therefore, a judgement may be made based on an optical observation of the path of the sun through the atmosphere. If it appears that there is an average clear atmosphere, no adjustment is needed. If the atmosphere appears to be hazy or to scatter solar radiation more than average, the amount of solar radiation expected may be reduced to an amount up to five percent, and on such days a quality control attempt should be abandoned. On extremely clear days, such as those following a cold front passage or other movement of clear air, the amount of solar radiation expected may be increased by an amount up to five percent. Some experience in applying these quality control procedures will assist in making them more meaningful so one may be alerted to possible instrument errors.

TABLE 6.1 - Solar Noon and Daily Totals of Horizontal Insolation Values for Clear Days at Various North Latitudes (Btu - H/sq.ft.)

North Lat.	Jan 21		Feb 21		Mar 21		Apr 21		May 21		Jun 21	
	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total
24	249	1662	288	1998	312	2270	321	2454	322	2556	319	2574
32	209	1288	255	1724	287	2084	307	2390	315	2582	315	2634
40	164	948	216	1414	257	1852	287	2274	301	2552	304	2648
48	115	596	173	1080	220	1578	260	2106	281	2482	287	2626
56	65	282	126	740	179	1268	227	1892	255	2374	264	2562
64	16	45	77	400	134	932	190	1644	224	2236	235	2488

North Lat.	Jul 21		Aug 21		Sep 21		Oct 21		Nov 21		Dec 21	
	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total	Solar noon	Daily total
24	317	2526	315	2408	302	2194	279	1928	247	1610	232	1474
32	311	2558	302	2351	278	2014	247	1655	207	1280	190	1136
40	298	2534	282	2244	249	1788	208	1348	163	942	143	782
48	279	2474	256	2086	213	1522	166	1022	115	596	94	446
56	254	2372	225	1884	173	1220	119	688	65	284	43	156
64	223	2248	188	1646	129	892	71	358	17	46	2	2

Note: for w/m^2 multiply $Btu\text{-}H/ft^2$ by 3.1524808. Per NASA SP-7012-"The International System of Units, Physical Constants and Conversion Factors"

6.1 Continued

The Air Resources Laboratory (ARL) of the NOAA have recently developed clear day hourly and daily expected solar radiation values. These values as well as recent information about the effects of turbidity may be secured through the NOAA. Currently data for about 150 locations in the US have been modeled and are available in SOLMET format. Data for a total of about 250 locations will become available by the end of 1978.

The third method is the comparison of readings from different stations when solar radiation conditions appear similar, after resolving any local variations. Often consistently high or low values become apparent and are due to instrument error or some phenomenon of a site location which make the readings non-representative.

This method requires access to measurements from several nearby locations and is therefore best performed at collection centers.

6.2 PERSONNEL QUALIFICATIONS AND TRAINING REQUIREMENTS

With a general lack of schools for training personnel in solar radiation measurements and instruments, most individuals available are self-taught or have received training in the NWS or military weather services. However, there are plans to initiate such training in several universities in the U. S. (See Section 1 for a list of DOE supported training programs). These courses will probably begin in 1978 (see Section 1.4). There must be continuous training of new people to replace personnel due to attrition. It probably will be several years before available training is sufficient to meet anticipated requirements.

6.3 QUALITY CONTROL THROUGH USER EVALUATIONS

The user evaluation quality control is a comprehensive quality control of the entire network. While it is a reflection of the detailed data quality, it is more significant. It is discussed here to extend quality control to its ultimate requirement.

User evaluations should be sought periodically to assure objectives are being met and to make any required changes to assure quality standards are met. These evaluations are best accomplished in person with the user but may be made by evaluations of the reports of network data. Evaluation must be solicited periodically, however, as one may not assume results are satisfactory. Communications with the users must be frequent.

6.4 QUALITY CRITERIA

An ultimate objective of the quality criteria for the network must be established. This objective must be part of the operation, and all persons must be aware of the criteria. Establishing the criteria is the responsibility of the network manager. It must include but not be limited to criteria for the following items:

1. Climatological-including exposure of instruments, representativeness of site, minimum number of hours per month that data might be missed, and length of records.

6.4 Continued

2. Accuracy of instruments-including calibration of sensors and recorders-integrators.

3. Time that data must be received and available. (This will depend on the type of communications established.)

4. Accuracy tolerance in reducing data.

5. Accuracy tolerance in preparing data for storage and in summarizing data.

6. Optimum time and means of recalling data and making them available to the user.

7. Means of evaluating final products.

The quality requirements established by NCC, included in Appendix F, may be used as a guide in establishing network quality criteria.

7.0 RECORDING, PROCESSING, AND DISSEMINATING DATA FOR OPTIMUM USE

Solar radiation measurements like all atmospheric data are ephemeral and useless unless collected and processed correctly. This chapter provides information for developing a complete data-processing plan. The primary considerations are recording, collecting, formats, dissemination, storage and retrieval.

7.1 PYRANOMETERS

Pyranometers are sensitive instruments and require equally sensitive recording devices, and the two may be purchased as a unit. If one desires to use a multichannel recorder with other measurements, knowledge of the pyranometer recording requirements is essential. This following discussion of recorders is based primarily on the <u>IGY Instruction Manual, Part VI, Radiation Instruments and Measurements</u> (1958).

The approximate characteristics of three thermoelectric pyranometers are:

Eppley PSP	8-10 μV per watt meter^{-2}; 650 Ohms
8-48	10-12 μV per watt meter^{-2}; 350 Ohms
Star (Available as different model from several companies)	12-14 μV per watt meter^{-2}; 350 Ohms

Taking the maximum intensity of global radiation as 1.4 kWm^{-2} for any place on earth, it follows that, with the average pyranometer, recorders producing full scale deflection for thermopile output of 13-17 mV will yield satisfactory records. At some stations it may be desirable in winter to increase the recorder sensitivity to compensate for lower radiation intensities. For this purpose either a twin-range instrument or one of higher sensitivity is used, sensitivity being adjusted by varying the circuit resistance within limits indicated below.

It is advisable to place the electrical zero position several scale divisions inside the zero of the chart in order to allow small "depressions" of the radiometer indications to be recorded.

7.2 POTENTIOMETERS

Automatic potentiometers may read either in mV or in W/m^2. Instruments scaled in energy units are variable-range potentiometers. The range is adjusted to match the particular pyranometer with which the potentiometer is to be used.

Roll charts are usually employed, and a paper speed of 2-3 cm/hr is recommended; a wide range of speed can usually be supplied. The response time for full-scale deflection may be a few seconds if rapid balancing or change-over of circuit in the multipoint models is required or as many as 30 sec, which is preferable for a single pyranometer record because the delay matches the pyranometer response and gives better long-term reliability.

7.2 Continued

Recording potentiometers are automatically standardized at approximately hourly intervals against the incorporated standard cell. The millivolt scale should be calibrated periodically against a standard potentiometer.

Where the outputs of two or more radiometers are fed to a single recorder of multichannel type or one with an external selecting switch, the zero position can be displaced to the middle of the chart and the polarity of one or the other of the circuits reversed to produce deflections on either side of it. This is especially useful where separation of the individual traces may present some difficulty or if only a single-color trace is available.

7.3 RECORDING MICROAMMETERS

Several recording microammeters of low internal resistance are available commercially. However, they are not readily suitable for pyranometers with low sensitivity or high impedance. It is often advantageous to use a twin-channel recorder to present a second trace simultaneously, or as reserve for standardization. (The substandard can then be allowed to record alongside the permanent trace.) With a coil resistance of about 10-20Ω, a sensitivity of about 100-50μA for full-scale deflection is usual.

In most modern types of self-registering microammeters there is good stability of zero and of sensitivity; but they should be checked at least semi-annually.

Point-recording microammeters are not always linear in response; for accurate evaluation of the records, deviations should be taken into account, which can easily be done by reading the records with a graduated transparent plate.

For the diffuse radiation record, the limiting value of the radiation flux should be taken as about half that of the global radiation.

Experience suggests that, with the galvanometer characteristics described above, the extra swamping resistance (which reduces the temperature dependence of circuit sensitivity) should not be lower than about 100Ω for the total radiation circuit or proportionately higher when a higher resistance microammeter or pyranometer is employed. For recorders of this type the external resistance for critical damping is usually about 50Ω. The recommended circuit implies slight under-damping, but this is generally unimportant because there is an interval of 20-60 sec. between the separate points on the records. If possible, shunt-series arrangements for the matching of the recorder to the pyranometer should be avoided, since the simple-series circuit facilitates both calibration and maintenance. The swamping resistances, of course, should have a low temperature coefficient of resistance, being preferably wound of manganin or "minalpha" wire.

The procedure to be followed for the determination of the circuit constants and the chart reduction factor during the installation of the equipment and thereafter at suggested semi-annual intervals should provide not only for the calibration of the recording microammeter but also for the

7.3 Continued

remeasurement of the resistance of all circuit components. A small junction box close to the recorder facilitates this procedure. Generally, the best location for the galvanometer is on the inside of an outside wall where no direct sunlight falls on it.

The separate rather than simultaneous calibration of the microammeter and standardization of the pyranometer has the advantage of quickly establishing whether either instrument is changing its characteristics, should the new chart factor diverge by more than two percent over the previous one. This knowledge is especially useful when one or the other of the principal components of the radiation equipment has to be replaced and there are no facilities for immediate verification of the instrumental constants. Another advantage of deriving the millivolt sensitivity of the recorder is that with a multichannel recorder the constants of several pyranometers other than the primary one can be readily calculated. The use of the standardized portable potentiometer and a standard resistor is recommended for calibration of the recorder.

A battery or power supply, a stable resistor, variable between approximately 20,000 and 200,000Ω, and a lower-value, wire-wound resistor (about 1,000Ω) of high stability are connected in series with the recording galvanometer which has been disconnected through a switch from the pyranometer circuit. The battery current is allowed to flow for a few minutes so that a steady value of the galvanometer deflection is registered on the chart, during which time the potential drop across the known smaller resistance is measured using a portable (thermocouple-type) potentiometer. Several calibration points should be obtained to check the scale over its entire range. A commercially available, 1.5 V dry cell is a satisfactory and economical power supply for the purpose.

The resistance of the galvanometer can be measured with a resistance bridge or by a portable potentiometer. In the latter case, the potential difference across the galvanometer is measured during the determination of the sensitivity of the instrument; a switch, that disconnects the potentiometer from the known-standard resistor and connects it to the galvanometer, facilitates the measurement. If the pyranometer is in a circuit the resistance of which is being measured, it must be shielded from radiation at the time.

7.4 AUTOMATIC INTECRATORS

For various purposes and reasons such as building design and geophysical rather than of climatological character, it is desirable to have concurrent tabulation procedures, normally hourly values. Automatic integration of the record is suggested for economy of time and labor and to eliminate interpretive errors in chart evaluation.

Recording potentiometers are particularly suitable for the operation of automatic integration systems based upon either mechanical or electrical principles. Two principle models of such integrators, normally obtainable with the recorder as a supplementary built-in unit, are the Leeds and Northrup mechanical integrator and the Brown electrical integrator. Printing integrators, which can be adapted for use with thermoelectric pyranometers, are also available.

Dogniaux and Pastiels (1955) have studied the use of these integrators and suggested improvements. In particular, they recommend displacement of the zero of the integrating mechanism relative to that of the potentiometer. Their work should be consulted by anyone contemplating the use of such instruments.

7.5 INTEGRATION OF GALVANOMETER RECORDS

Microammeter records also allow automatic integration; Blackwell (1954) gives a detailed account of the development of an integrating device for deriving daily values of global radiation. The mean error ascribed to such integrating systems has been estimated as being approximately two percent.

There are many modern electronic devices for data acquisition from the sensors. Electronic strip-chart, millivolt potentiometric recorders are available to permit the exact matching of the recorder scale to the sensor. The strip-chart can now be digitized with an electronic system and results formatted for storage in SOLMET and a reproduction of the original chart recalled. Built-in integrators with visually-read digital display and also auxillary print-out equipment can be matched with the recorders. Standard types of digital voltmeters are likewise suitable.

The data acquisition system may collect, process and store measurements in any desired time increments.

Selecting the best system will be a difficult task and will depend on the capabilities available to program and maintain the equipment. It is recommended that a system presently performing, which meets your requirements, be located and a proposed system be patterned after it. Adopting new and unproven procedures for data collecting and processing is not necessary nor advisable.

7.6 COLLECTING THE NETWORK DATA

The methods selected for collecting the data are dependent on their use and the recording procedures. Network requirements may be hourly (real time) daily, weekly or monthly. Daily, or less frequent collection of data, meets most network requirements. If daily collection is desired, the use of telephone lines at night should be considered. Less frequent collection is best determined by the local situation, and reliability is generally the most important consideration.

When data are not collected daily, a standard procedure must be established when data are missed. Often such missing data for various reasons do not become apparent to the network control until too late. By this time much of the data missed cannot be recovered. With good communication and cooperation, such losses can be minimized by taking alternate actions when necessary. The collection of usable data requires both good management and positive control.

7.7 DATA FORMATS

The basic solar radiation data format is the SOLMET format described in Appendix A. Collected data should be transformed into this format as soon as possible in data processing.

Formats for presenting the data must be adapted to user requirements. The best procedure is to research formats used by others, and if necessary, make the necessary changes. Recent publications which present processed data in various formats are West Associates (1977), California Solar Data Manual (1977), New Mexico Solar Energy Resource (Bahm 1977) and the Monthly Summary of Solar Radiation Data published by the NCC, Asheville, NC.

7.8 DISSEMINATION OF DATA

Data dissemination may be in the form of raw data (hourly, daily, monthly), summaries, graphs and charts, all of which may be on magnetic tape or printed. In addition, publications of summarized and analyzed data may be prepared and distributed. The user's needs and urgency for the data provide guidelines as to the proper form. The more processing, analyzing and publishing, the longer the wait for the data; however, the results may be more valuable to the user. These considerations are all part of the user analysis and are the result of proper recording, collecting, and formatting of the data.

7.9 STORAGE AND RETRIEVAL

Storage and retrival of data are considered together to avoid cases when data may be stored efficiently but difficult to use. The requirements for subsequent use of the data must be clearly established.

The primary methods of storing the data are published reports, reports on microfilm, microfisch, or other condensed form, and electronic data storage on cards or tape. Each of the methods meets specific requirements and requires trade-offs between the most convenient form of storage and retrieval for users.

A prime consideration in establishing the best method or methods for storage and retrieval is that the volume of data will increase rapidly with time. Calculations should be made of the volume expected during the life of a project. Arrangements must be made at the start to process and handle the data on a current basis because backlogs of data are difficult to overcome, prevent meeting user requirements, and can be expensive.

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IGY Instruction Manual, Part VI (1958) "Radiation Instruments and Measurements", Pergamon Press.

West Associates (1977) "Solar Energy Measurements at Selected Sites Throughout Southern California During 1976", Project Manager: Southern California Edison Research & Development, P. O. Box 800, Rosemead, California 91770.

8.0 ECONOMIC AND UTILIZATION FACTORS

The economic factors and utilization factors are considered together to assure evaluations of results versus costs. While most operations will not require a set of business books, the network manager must be aware of the costs of various operations whether they are met through his accounting or shared expenses. Presently, reliable cost factors for solar radiation data are not available; but it is suspected that there is a wide variation. The network must be managed efficiently and results must be accurate and timely to assure continuing economic support.

At the second National Solar Radiation Workshop, sponsored by NOAA and ERDA (now within the Department of Energy, DOE), at Skyland, Virginia in September 1977, some cost figures of currently operating networks were disclosed. Generally, the people at the workshop agreed that a minimum, in 1977 dollars, for a worthwhile program would cost about $5,000 in start-up costs for each type of data, such as one pyranometer recording global radiation data. A similar amount would be required for each additional type of data, i.e., diffuse, direct or spectral measurements, etc.

An additional cost of about $5,000 annually would be required to process each type of data into useful information to be available for users.

These costs do not include administration of the network, funding and accounting, storing and retrieving data and dissiminating the information. Costs of these items may not increase directly with the increased size of the network initially, but traditionally, the management costs will increase with time at a rate of three or four percent per year.

The people at the workshop believed that increased accuracy requirements or "runaway" costs could result in these costs increasing by ten times. It was believed that only minor reductions in these costs could be realized. Suggestions were made such as using student help at universities (this may result in larger turn-over and training costs) and making or assembling data acquisition components from available and off-the-shelf items. It may be argued that while these may reduce the accountable costs, the real costs would be reduced very little and some loss may occur in quality of the results from the use of non-standard components and procedures.

The use of the network data requires continuing evaluations. Users' requirements may change; and the network manager must be one of the first to know in order to update facilities and procedures. The use of the network will probably be the most dynamic part of the operation. Not only will each user requirement change but also users may be identified. A growth in data utilization should be a network objective. It may be achieved by both active solicitations for users and by making the data more valuable through network cooperation and improvement. It is axiomatic that the more the data is used the more valuable it becomes. One approach to meet continuing requirements is to maintain a network plan worksheet (Appendix D) for one and two years in advance and make modifications as indicated.

8.0 Continued

The gathering of quality data and providing needed information on which to make better decisions should be the prime objectives of the data network designer and manager. Procedures to meet these important objectives must be accomplished in an effective, economical and expeditious manner. If the resulting data network does not provide better information and decision-making capabilities for its users, it has failed in its purpose.

By following the procedures described in this book, the reader will hopefully understand and help others to reach their objectives and goals in the effective application of solar energy to our nation's needs.

REFERENCE

The Second National Solar Radiation Data Workshop-Executive Summery, (1977), ERDA, Division of Solar Energy and NOAA.

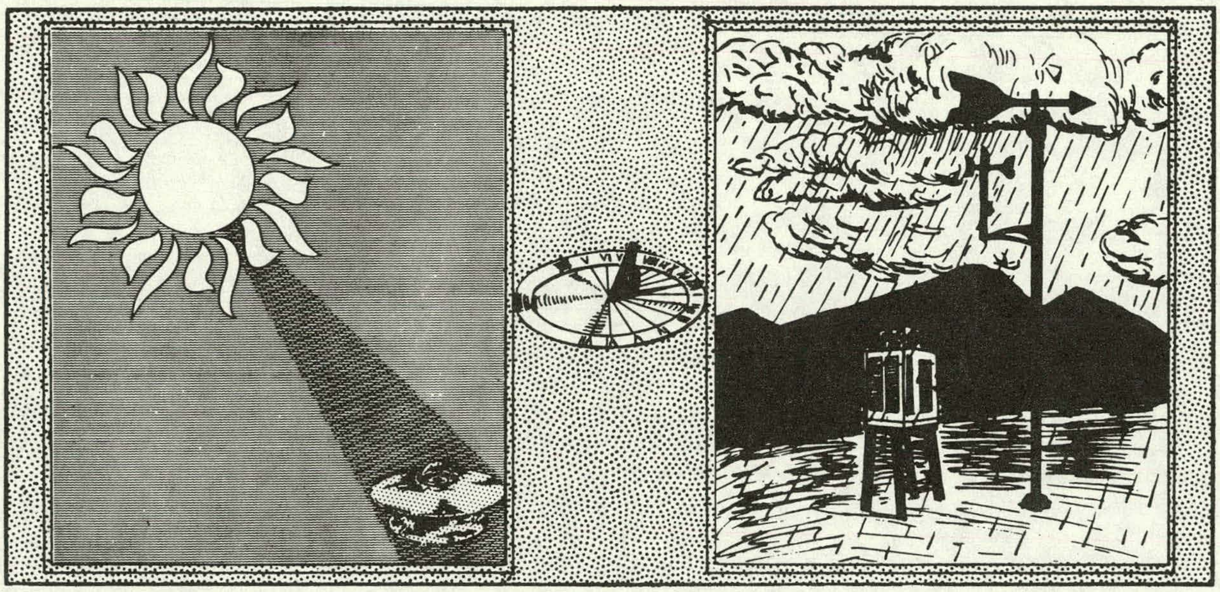
APPENDIX A

The SOLMET Volume I-User's Manual is included here so the reader will have ready access to the format of the primary solar radiation data in the U. S. Any serious user of solar radiation data must have knowledge of this format in order to relate his needs to data currently available. Also the format should be used for storing new data.

SOLMET

VOLUME 1 - USER'S MANUAL

TD - 9724



Hourly Solar Radiation-Surface Meteorological Observations

SOLMET

VOLUME I - USER'S MANUAL

TD-9724

HOURLY SOLAR RADIATION-SURFACE
METEOROLOGICAL OBSERVATIONS

December 1977

This manual has been prepared by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Asheville, North Carolina, for the Department of Energy, Division of Solar Technology, Environmental and Resource Assessments Branch, under Interagency Agreement No. E(49-26)-1041. The contents of this manual reflect the views of the contractor, who is responsible for the facts and accuracy of the data presented, and do not necessarily reflect the official views or policy of the DOE.

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INTRODUCTION

Hourly solar radiation data are available at the National Climatic Center (NCC) on magnetic tape in a card image version of Card Deck 280. The card format, designed 25 years ago, neither included all of the information required by the solar heating and cooling industry nor was it in a convenient form for use on modern automatic data processing equipment. Much of these data were digitized on station, using instructions that changed over the years, and forwarded to regional centers (later centralized at the NCC) where they were subjected to varying degrees of quality control. This historical solar radiation data base has suffered from neglect and contains serious errors resulting from a host of calibration and instrumental problems. The data were also referenced to two different international scales (Smithsonian Scale of 1913 and the International Scale of 1956) with a third scale proposed following the latest intercomparison performed at Davos, Switzerland.

With increased interest in solar radiation data it became apparent that these data must be made available in a common format that allows for inclusion of all available meteorological parameters with all known procedural and instrumental errors removed.

SOLMET is a new common tape format that is designed to provide, in a single FORTRAN compatible tape, quality controlled hourly solar insolation and collateral meteorological data that are available at the National Climatic Center. The format is a metric conversion of all parameters currently available in the Deck 280 (hourly record of solar radiation) and Tape Data Family-14 (hourly surface meteorological observations). SOLMET was designed to provide the solar energy users with easy access to all appropriate historical meteorological data that are normally available in digitized form; it will also be used to archive data from the new National Weather Service network and cooperators.

The salient features of SOLMET are that it:

1. Merges all available insolation and meteorological data into a single source.

2. Presents all data in the International System of Units (SI).

3. Provides time information so user can access the information in true solar and/or local standard time. The time of the meteorological observation is also indicated so that user will be aware of the meteorological observation that has been selected that is closest to time of the solar observation; i.e., selected to be the observation nearest to the midpoint of the solar hour. Provision is also made to handle data that are recorded in local standard time for conversion to solar time.

4. Allows for additional solar radiation parameters (such as direct and tilted, normal incidence, diffuse, net) that will be available from stations in the future. Allowance is also made in supplemental fields for additional measurements; i.e., ultraviolet, spectral, etc.

5. Eliminates undesirable format features that were inherent in the past data sources such as over-punches, blanks, etc.

6. Codes missing observations and those observations that are estimated via models (e.g., sunshine and cloud regression models).

7. Provides the user with global radiation data as they were originally observed corrected for all known scale, instrument, and calibration problems, and with a data set corrected via a standard year irradiance model. The model data are recommended for use because they are (a) serially complete, (b) converted to the PACRAD 3 international scale, and (c) serially consistent in the sense of minimizing trends caused by sensor and/or recorder degradation. Details and limitations of the model are explained in Volume 2.

FORMAT

The identification portion of the tape format contains the tape deck number, station number, true solar time of the hourly observation, and the local standard time corresponding to the true solar time. A list of stations showing latitude, longitude, elevation, periods of record, and changes in station location is given at the end of this manual.

The solar radiation portion of the tape format contains the theoretical extraterrestrial radiation on a horizontal surface based on a solar constant of 1377 $J/(m^2 \cdot s)$; direct, diffuse, net, and tilted surface radiation; three fields of global radiation -- observed data, observed data corrected for engineering changes such as recorder scales, sensor deterioration, calibration errors, etc., and observed data corrected to a standard year irradiance model; two supplemental radiation fields; and the minutes of sunshine. Appendix A at the end of this manual indicates tilt angles, types of data in the supplemental fields and any other pertinent information that will enable the user to properly interpret the data. Each radiation field contains five digits. The leftmost digit is a code to indicate estimated or modelled values, while the four rightmost digits comprise the data value. A constant of 5000 has been added to all net radiation data to insure positive values.

The surface meteorological data are a metric (SI) conversion of the airways surface observations contained in the National Climatic Center's Tape Data Family-14. The data are recorded hourly for all stations prior to

1965 and three-hourly for most stations after 1964. The airways observation that comes closest to the midpoint of the solar hour is matched with the hourly radiation data. The local standard time of this meteorological observation, as coded in Tape Data Family-14, is given in the first field of the meteorological portion of the SOLMET format. A more detailed description of the meteorological parameters than that given in this manual may be found in the Tape Data Family-14 reference manual.

TAPE CHARACTERISTICS

Each logical record is 163 bytes long. Archive files are blocked in 24 logical records (3912 bytes) per physical tape record on 1600 bpi, 9 track, EBCDIC mode, odd parity tapes. Data for the entire period of record for one station are contained on no more than two tapes. Tapes may be ordered, however, with different blocking factors, tracks and densities. At the 1600 bpi density, 24 years of record per reel of tape can be obtained, while at 800 bpi, 13 years per reel is available.

The SOLMET format is FORTRAN compatible and contains no overpunches or alpha characters. Missing or unknown data are encoded with 9's. A graphical representation of the format indicating Tape Fields, Tape Positions and Element Definition is included in this manual. Detailed information on coding for each field is also included.

BY-PRODUCTS OF SOLMET TAPES

See Appendix B.

ORDERING INFORMATION

Address requests to Director, National Climatic Center, Asheville, NC 28801. Please write the Center or call (704) 258-2850, extension 203 (FTS 672-0203) prior to ordering to insure that the desired data fields and periods of record are available and to obtain costs for tape copies.

NOTE ON VOLUME 2 - REHABILITATION OF HOURLY SOLAR RADIATION DATA

Volume 2 will contain the following:

1. Introduction - reasons for rehabilitating solar radiation data.

2. Description of rehabilitation process - will include graphs, tables, and explanations of engineering, temperature, Standard Year, and International Scale corrections.

3. Quality control of SOLMET taped data and regression models used for serial completion of data described.

IDENTIFICATION							SOLAR RADIATION OBSERVATION										
TAPE DECK #	WBAN STN #	SOLAR TIME				LST TIME	ETR KJ/m^2	RADIATION VALUES KJ/m^2									SUNSHINE MIN
		YR	MO	DY	HRMN			DIRECT	DIFFUSE	NET	TILTED	GLOBAL OBS	GLOBAL ENG COR	GLOBAL STD YR COR	A	B	
9724	XXXXX	XX	XX	XX	XXXX	XXXX	XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	XX
001	002	003				004	101	102	103	104	105	106	107	108	109	110	111

FIELD NUMBER

SURFACE METEOROLOGICAL OBSERVATION																																
OB TIME LST	CEILING dam	SKY COND	VSBY hm	WEATHER	PRESSURE kPa		TEMP °C		WIND		CLOUDS																					SNOW COVER
											TOTAL	LOWEST			SECOND				THIRD				FOURTH			OPAQUE						
					SEA LEVEL	STATION	DRY BULB	DEW-PT.	DIR deg	SPD m/s		AMOUNT	TYPE	HEIGHT dam	AMOUNT	TYPE	HEIGHT dam	SUM AMT	AMOUNT	TYPE	HEIGHT dam	SUM AMT	AMOUNT	TYPE	HEIGHT dam							
XX	XXXX	1XXXX	XXXX	XXXXXXXX	XXXXX	XXXXX	XXXX	XXXX	XXX	XXXX	XX	XX	XX	XXXX	XX	XX	XXXX	XX	XX	XX	XXXX	XX	XX	XX	XXXX	XX						X
201	202	203	204	205	206		207		208		209																					210

TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT
001	001 - 004	TAPE DECK NUMBER
002	005 - 009	WBAN STATION NUMBER
003	010 - 019	SOLAR TIME (YR, MO, DAY, HOUR, MINUTE)
004	020 - 023	LOCAL STANDARD TIME (HR AND MINUTE)
101	024 - 027	EXTRATERRESTRIAL RADIATION
102	028 - 032	DIRECT RADIATION
103	033 - 037	DIFFUSE RADIATION
104	038 - 042	NET RADIATION
105	043 - 047	GLOBAL RADIATION ON A TILTED SURFACE
106	048 - 052	GLOBAL RADIATION ON A HORIZONTAL SURFACE - OBSERVED DATA
107	053 - 057	GLOBAL RADIATION ON A HORIZONTAL SURFACE - ENGINEERING CORRECTED DATA
108	058 - 062	GLOBAL RADIATION ON A HORIZONTAL SURFACE - STANDARD YEAR CORRECTED DATA
109, 110	063 - 072	ADDITIONAL RADIATION MEASUREMENTS
111	073 - 074	MINUTES OF SUNSHINE
201	075 - 076	TIME OF COLLATERAL SURFACE OBSERVATION (LST)
202	077 - 080	CEILING HEIGHT (DEKAMETERS)
203	081 - 085	SKY CONDITION
204	086 - 089	VISIBILITY (HECTOMETERS)
205	090 - 097	WEATHER
206	098 - 107	PRESSURE (KILOPASCALS)
207	108 - 115	TEMPERATURE (DEGREES CELSIUS TO TENTHS)
208	116 - 122	WIND (SPEED IN METERS PER SECOND)
209	123 - 162	CLOUDS
210	163	SNOW COVER INDICATOR

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NOTE: Except for tape positions 001-027 in fields 001-101, elements with a tape configuration of 9's indicate missing or unknown data.

TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT	TAPE CONFIGURATION	CODE DEFINITIONS AND REMARKS
001	001 - 004	TAPE DECK NUMBER	9724	
002	005 - 009	WBAN STATION NUMBER	01001 - 98999	Unique number used to identify each station.
003	010 - 019	SOLAR TIME		
	010 - 011	YEAR	00 99	Year of observation, 00 - 99 = 1900 - 1999
	012 - 013	MONTH	01 - 12	Month of observation, 01 - 12 = Jan. - Dec.
	014 - 015	DAY	01 - 31	Day of month
	016 - 019	HOUR	0001 - 2400	End of the hour of observation in solar time (hours and minutes)
004	020 - 023	LOCAL STANDARD TIME	0000 - 2359	Local Standard Time in hours and minutes corresponding to end of solar hour indicated in field 003.
101	024 - 027	EXTRATERRESTRIAL RADIATION	0000 - 4957	Amount of solar energy in kJ/m^2 received at top of atmosphere during solar hour ending at time indicated in field 003, based on solar constant = $1377J/(m^2.s)$ 9999 = nighttime values defined as zero kJ/m^2.
102	028 - 032	DIRECT RADIATION		Portion of radiant energy in kJ/m^2 received at the pyrheliometer directly from the sun during solar hour ending at time indicated in field 003.
	028	DATA CODE INDICATOR	0 - 8	
	029 - 032	DATA	0000 - 4957	
103	033 - 037	DIFFUSE RADIATION		Amount of radiant energy in kJ/m^2 received at the instrument indirectly from reflection, scattering, etc., during the solar hour ending at the time indicated in field 003.
	033	DATA CODE INDICATOR	0 - 8	
	034 - 037	DATA	0000 - 4957	
104	038 - 042	NET RADIATION		Difference between the incoming and outgoing radiant energy in kJ/m^2 during the solar hour ending at the time indicated in field 003. A constant of 5000 has been added to all net radiation data.
	038	DATA CODE INDICATOR	0 - 8	
	039 - 042	DATA	2000 - 8000	
105	043 - 047	GLOBAL RADIATION ON A TILTED SURFACE		Total of direct and diffuse radiant energy in kJ/m^2 received on a tilted surface (tilt angle indicated in station - period of record list) during solar hour ending at the time indicated in field 003.
	043	DATA CODE INDICATOR	0 - 8	
	044 - 047	DATA	0000 - 4957	
	048 - 062	GLOBAL RADIATION ON A HORIZONTAL SURFACE		Total of direct and diffuse radiant energy in kJ/m^2 received on a horizontal surface by a pyranometer during the solar hour ending at the time indicated in field 003.
106	048 - 052	OBSERVED DATA		
	048	DATA CODE INDICATOR	0 - 8	
	049 - 052	DATA	0000 - 4957	Observed value.
107	053 - 057	ENGINEERING CORRECTED DATA		
	053	DATA CODE INDICATOR	0 - 8	
	054-057	DATA	0000 - 4957	Observed value corrected for known scale changes, station moves, recorder and sensor calibration changes, etc.

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TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT	TAPE CONFIGURATION	CODE DEFINITIONS AND REMARKS
108	058 - 062	STANDARD YEAR CORRECTED DATA		
	058	DATA CODE INDICATOR	0 - 8	
	059 - 062	DATA	0000 - 4957	Observed value adjusted to Standard Year Model. This model yields expected clear sky irradiance received on a horizontal surface at the elevation of the station.
109, 110	063 - 072	ADDITIONAL RADIATION MEASUREMENTS		Supplemental Fields A and B for additional radiation measurements; type of measurement specified in station-period of record list.
	063, 068	DATA CODE INDICATORS	0 - 8	
	064-067	DATA		
	069-072	DATA		

NOTE FOR FIELDS 102-110: Data code indicators are:

0 Observed data
1 Estimated from model using sunshine and cloud data
2 Estimated from model using cloud data
3 Estimated from model using sunshine data
4 Estimated from model using sky condition data
5 Estimated from linear interpolation
6 Reserved for future use
7 Estimated from other model (see individual station notes at end of manual)
8 Estimated without use of a model

(See model description in Volume 2.)

TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT	TAPE CONFIGURATION	CODE DEFINITIONS AND REMARKS
111	073 - 074	MINUTES OF SUNSHINE	00 - 60	For Local Standard Hour most closely matching solar hour.
201	075 - 076	TIME OF TD 1440 OBSERVATION	00 - 23	Local Standard Hour of TD 1440 Meteorological Observation that comes closest to midpoint of the solar hour for which solar data are recorded.
202	077 - 080	CEILING HEIGHT	0000 - 3000	Ceiling height in dekameters (dam = m x 10^1); ceiling is defined as sky cover of .6 or greater. 0000 - 3000 = 0 to 30,000 meters
			7777	7777 = unlimited; clear
			8888	8888 = unknown height of cirroform ceiling
203	081 - 085	SKY CONDITION		
	081	INDICATOR	0	Identifies observations after 1 June 51.
	082 - 085	SKY CONDITION	0000 - 8888	Coded by layer in ascending order; four layers are described; if less than 4 layers are present the remaining positions are coded 0. The code for each layer is: 0 = Clear or less than .1 cover 1 = Thin scattered (.1 - .5 cover) 2 = Opaque scattered (.1 - .5 cover) 3 = Thin broken (.6 - .9 cover) 4 = Opaque broken (.6 - .9 cover) 5 = Thin overcast (1.0 cover) 6 = Opaque overcast (1.0 cover) 7 = Obscuration 8 = Partial obscuration
204	086 - 089	VISIBILITY	0000 - 1600	Prevailing horizontal visibility in hectometers (hm = m x 10^2). 0000 - 1600 = 0 to 160 kilometers
			8888	8888 = unlimited

TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT	TAPE CONFIGURATION	CODE DEFINITIONS AND REMARKS
205	090 - 097	WEATHER		
	090	OCCURRENCE OF THUNDERSTORM, TORNADO OR SQUALL	0 - 4	0 = None 1 = Thunderstorm - lightning and thunder. Wind gusts less than 50 knots, and hail, if any, less than 3/4 inch diameter. 2 = Heavy or severe thunderstorm - frequent intense lightning and thunder. Wind gusts 50 knots or greater and hail, if any, 3/4 inch or greater diameter. 3 = Report of tornado or waterspout. 4 = Squall (sudden increase of wind speed by at least 16 knots, reaching 22 knots or more and lasting for at least one minute).
	091	OCCURRENCE OF RAIN, RAIN SHOWERS OR FREEZING RAIN	0 - 8	0 = None 1 = Light rain 2 = Moderate rain 3 = Heavy rain 4 = Light rain showers 5 = Moderate rain showers 6 = Heavy rain showers 7 = Light freezing rain 8 = Moderate or heavy freezing rain
	092	OCCURRENCE OF DRIZZLE, FREEZING DRIZZLE	0 - 6	0 = None 1 = Light Drizzle 2 = Moderate drizzle 3 = Heavy drizzle 4 = Light freezing drizzle 5 = Moderate freezing drizzle 6 = Heavy freezing drizzle
	093	OCCURRENCE OF SNOW, SNOW PELLETS OR ICE CRYSTALS	0 - 8	0 = None 1 = Light snow 2 = Moderate snow 3 = Heavy snow 4 = Light snow pellets 5 = Moderate snow pellets 6 = Heavy snow pellets 7 = Light ice crystals 8 = Moderate ice crystals Beginning April 1963 intensities of ice crystals were discontinued. All occurrences since this date are recorded as an 8.
	094	OCCURRENCE OF SNOW SHOWERS AND SNOW GRAINS	0 - 6	0 = None 1 = Light snow showers 2 = Moderate snow showers 3 = Heavy snow showers 4 = Light snow grains 5 = Moderate snow grains 6 = Heavy snow grains Beginning April 1963 intensities of snow grains were discontinued. All occurrences since this date are recorded as a 5.

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TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT	TAPE CONFIGURATION	CODE DEFINITIONS AND REMARKS
	095	OCCURRENCE OF SLEET (ICE PELLETS), SLEET SHOWERS OR HAIL	0 - 8	0 = None 1 = Light sleet or sleet showers (ice pellets) 2 = Moderate sleet or sleet showers (ice pellets) 3 = Heavy sleet or sleet showers (ice pellets) 4 = Light hail 5 = Moderate hail 6 = Heavy hail 7 = Light small hail 8 = Moderate or heavy small hail Prior to April 1970 ice pellets were coded as sleet. Beginning April 1970 sleet and small hail were redefined as ice pellets and are coded as a 1, 2 or 3 in this position. Beginning September 1956 intensities of hail were no longer reported and all occurrences were recorded as a 5.
	096	OCCURRENCE OF FOG, BLOWING DUST OR BLOWING SAND	0 - 5	0 = None 1 = Fog 2 = Ice fog 3 = Ground fog 4 = Blowing dust 5 = Blowing sand These values recorded only when visibility less than 7 miles.
	097	OCCURRENCE OF SMOKE, HAZE, DUST, BLOWING SNOW, BLOWING SPRAY	0 - 6	0 = None 1 = Smoke 2 = Haze 3 = Smoke and haze 4 = Dust 5 = Blowing snow 6 = Blowing spray These values recorded only when visibility less than 7 miles.
206	098 - 107	PRESSURE		
	098 - 102	SEA LEVEL PRESSURE	08000 - 10999	Pressure, reduced to sea level, in kilopascals (kPa) and hundredths.
	103 - 107	STATION PRESSURE	08000 - 10999	Pressure at station level in kilopascals (kPa) and hundredths. 08000 - 10999 = 80 to 109.99 kPa
207	108 - 115	TEMPERATURE		
	108 - 111	DRY BULB	-700 to 0600	°C and tenths
	112 - 115	DEW POINT	-700 to 0600	°C and tenths -700 to 0600 = -70.0 to +60.0°C
208	116 - 122	WIND		
	116 - 118	WIND DIRECTION	000 - 360	Degrees
	119 - 122	WIND SPEED	0000 - 1500	m/s and tenths; 0000 with 000 direction indicates calm. 0000 - 1500 = 0 to 150.0 m/s

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TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT	TAPE CONFIGURATION	CODE DEFINITIONS AND REMARKS
209	123 - 162	CLOUDS		See following explanatory "NOTES."
	123 - 124	TOTAL SKY COVER		
	125 - 126	LOWEST CLOUD LAYER AMOUNT		
	127 - 128	TYPE OF LOWEST CLOUD OR OBSCURING PHENOMENA		
	129 - 132	HEIGHT OF BASE OF LOWEST CLOUD LAYER OR OBSCURING PHENOMENA		
	133 - 134	SECOND LAYER AMOUNT		
	135 - 136	TYPE OF SECOND CLOUD LAYER		
	137 - 140	HEIGHT OF BASE OF SECOND CLOUD LAYER		
	141 - 142	SUMMATION OF FIRST 2 LAYERS		
	143 - 144	THIRD LAYER AMOUNT		
	145 - 146	TYPE OF THIRD CLOUD LAYER		
	147 - 150	HEIGHT OF BASE OF THIRD CLOUD LAYER		
	151 - 152	SUMMATION OF FIRST 3 LAYERS		
	153 - 154	FOURTH LAYER AMOUNT		
	155 - 156	TYPE OF FOURTH CLOUD LAYER		
	157 - 160	HEIGHT OF BASE OF FOURTH CLOUD LAYER		
	161 - 162	TOTAL OPAQUE SKY COVER		

NOTES: (1) Tape Configuration and Remarks for Total Sky Cover, Cloud Layer Amount, Summation of Cloud Layers and Total Opaque Sky Cover

Configuration	Remarks
00 - 10	Amount of celestial dome in tenths covered by clouds or obscuring phenomena. Opaque means clouds or obscuration through which the sky or higher cloud layers cannot be seen.

(2) Tape Configuration and Remarks for Type of Cloud or Obscuring Phenomena.

Configuration	Remarks
00 - 16	Generic cloud type or obscuring phenomena. 0 = None 1 = Fog 2 = Stratus 3 = Stratocumulus 4 = Cumulus 5 = Cumulonimbus 6 = Altostratus 7 = Altocumulus 8 = Cirrus 9 = Cirrostratus 10 = Stratus Fractus 11 = Cumulus Fractus 12 = Cumulonimbus Mamma 13 = Nimbostratus 14 = Altocumulus Castellanus 15 = Cirrocumulus 16 = Obscuring phenomena other than fog

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(3) Tape Configuration and Remarks for Height of Base of Cloud Layer or Obscuring Phenomena.

Configuration	Remarks
0000 - 3000	Dekameters
7777	7777 = Unlimited, clear
8888	8888 = Unknown height or cirroform layer

210	163	SNOW COVER INDICATOR	0 - 1	0 indicates no snow or trace of snow on ground; 1 indicates more than trace of snow on ground.

CONVERSION TABLE

To convert from	to	Multiply by
British thermal unit (thermochemical)	joule	1.054350×10^{3}
Btu (thermochemical)/h	watt	2.928751×10^{-1}
Btu (thermochemical)/min	watt	1.757250×10^{1}
Btu (thermochemical)/s	watt	1.054350×10^{3}
Btu (thermochemical)/ft^2	joule per $meter^2$	1.134893×10^{4}
Btu (thermochemical)/$ft^2 \cdot h$	watt per $meter^2$	3.152481×10^{0}
Btu (thermochemical)/$ft^2 \cdot min$	watt per $meter^2$	1.891489×10^{2}
Btu (thermochemical)/$ft^2 \cdot s$	watt per $meter^2$	1.134893×10^{4}
calorie (thermochemical)	joule	4.184000×10^{0}
cal (thermochemical)/cm^2	joule per $meter^2$	4.184000×10^{4}
cal (thermochemical)/min	watt	6.973333×10^{-2}
cal (thermochemical)/s	watt	4.184000×10^{0}
cal (thermochemical)/$cm^2 \cdot$ min	watt per $meter^2$	6.973333×10^{2}
cal (thermochemical)/$cm^2 \cdot$ s	watt per $meter^2$	4.184000×10^{4}
degree Fahrenheit	degree Celsius	$t_{oC} = (t_{oF} - 32)/1.8$
foot	meter	3.048000×10^{-1}
knot (international)	meter per second	5.144444×10^{-1}
langley	joule per $meter^2$	4.184000×10^{4}
langley	Btu per $foot^2$	3.686691×10^{0}
mile (statute)	meter	1.609300×10^{3}
millibar	pascal	1.000000×10^{2}
watt·hour	joule	3.600000×10^{3}

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APPENDIX A.1

STATION NOTES FOR 27 STATIONS WITH REHABILITATED SOLAR RADIATION DATA

General Notes

1. Field 108 - standard year irradiance - serial completion accomplished via regression estimates based on cloud/sky condition/sunshine data.

2. Direct solar radiation data are modeled. Reference: Hourly insolation and meteorological data bases including improved direct insolation estimates. Aerospace Report ATR-78-(7592)-1.

ALBUQUERQUE, NEW MEXICO
WBAN NO. 23050
TIME ZONE: MOUNTAIN

STATION LOCATION

Solar Radiation Data							Collateral Meteorological Data						
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters		Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N35	03	W106	37	1627		520701 - 751231	N35	03	W106	37	1619

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 730703.

APALACHICOLA, FLORIDA
WBAN NO. 12832
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data							Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters		Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 750519	N29	44	W84	59	14		520701 - 701231	N30	04	W85	35	6
750520 - 751231	N29	44	W85	02	8		750601 - 751231	N29	44	W85	02	6

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751104.

B. Meteorological observations from Tyndall Air Force Base through 701231.

C. Solar instruments moved from Post Office Building to Municipal Airport 750520.

D. Meteorological observations from Municipal Airport began 750601.

E. Hourly observed solar radiation data through 751104 only; Field 108 model estimated data through 751231.

BISMARCK, NORTH DAKOTA
WBAN NO. 24011
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N46	46	W100	45	506	520701 - 751231	N46	46	W100	45	502

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 721031.

BOSTON, MASSACHUSETTS
WBAN NO. 94701
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 640605	N42	21	W71	04	102	520701 - 681130	N42	22	W71	02	5
640606 - 681130	N42	22	W71	03	48						

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 681112.

B. Meteorological observations from Logan International Airport.

C. Solar instruments moved from U.S. Post Office Building to U.S. Custom House 640606.

D. Hourly observed solar radiation data through 681112 only; Field 108 model estimated data through 681130.

BROWNSVILLE, TEXAS
WBAN NO. 12919
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N25	54	W97	26	15	520701 - 751231	N25	54	W97	26	6

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

CAPE HATTERAS, NORTH CAROLINA
WBAN NO. 93729
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 570228	N35	13	W75	41	UNK	520701 - 570228	N35	13	W75	41	3
570301 - 751231	N35	16	W75	33	6	570301 - 751231	N35	16	W75	33	2

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

B. Pyranometer located on roof of RAOB inflation building; height unknown.

C. Location changed from Hatteras to Buxton 570301.

CARIBOU, MAINE
WBAN NO. 14607
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 751231	N46	52	W68	01	195	520701 - 751231	N46	52	W68	01	190

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 721019.

CHARLESTON, SOUTH CAROLINA
WBAN NO. 13880
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 751231	N32	54	W80	02	21	520701 - 751231	N32	54	W80	02	12

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

COLUMBIA, MISSOURI
WBAN NO. 03945
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 700123	N38	58	W92	22	248	520701 - 691031	N38	58	W92	22	239
700124 - 751231	N38	49	W92	13	277	691101 - 751231	N38	49	W92	13	270

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

B. Moved from Municipal Airport to Regional Airport 691101 (meteorological instruments) and 700124 (solar instruments).

DODGE CITY, KANSAS
WBAN NO. 13985
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 751231	N37	46	W99	58	800	520701 - 751231	N37	46	W99	58	787

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

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EL PASO, TEXAS
WBAN NO. 23044
TIME ZONE: MOUNTAIN

STATION LOCATION

Solar Radiation Data							Collateral Meteorological Data						
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters		Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N31	48	W106	24	1205		520701 - 751231	N31	48	W106	24	1194

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 741217.

ELY, NEVADA
WBAN NO. 23154
TIME ZONE: PACIFIC

STATION LOCATION

Solar Radiation Data							Collateral Meteorological Data						
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters		Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
511201 - 751231	N39	17	W114	51	1914		530120 - 751231	N39	17	W114	51	1906

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 670731.

B. Hourly observed solar radiation data through 670731 only; Field 108 model estimated data through 751231.

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FORT WORTH, TEXAS
WBAN NO. 03927
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 530430	N32	49	W97	21	226	520701 - 530430	N32	49	W97	21	215
530501 - 740731	N32	50	W97	03	175	530501 - 740731	N32	50	W97	03	164

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 740731.

B. Station moved from Meacham Field to Greater Southwest International Airport 530501.

FRESNO, CALIFORNIA
WBAN NO. 93193
TIME ZONE: PACIFIC

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 751231	N36	46	W119	43	102	520701 - 751231	N36	46	W119	43	100

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 670831.

B. Hourly observed solar radiation data through 670831 only; Field 108 model estimated data through 751231.

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GREAT FALLS, MONTANA
WBAN NO. 24143
TIME ZONE: MOUNTAIN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N47	29	W111	22	1125	520701 - 751231	N47	29	W111	22	1116

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 670831.

B. Hourly observed solar radiation data through 670831 only; Field 108 model estimated data through 751231.

LAKE CHARLES, LOUISIANA
WBAN NO. 03937
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 611031	N30	13	W93	09	12	520701 - 611031	N30	13	W93	09	10
611101 - 751231	N30	07	W93	13	18	611101 - 751231	N30	07	W93	13	3

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

B. Station moved from Lake Charles Air Force Base to Lake Charles Municipal Airport 611101.

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MADISON, WISCONSIN
WBAN NO. 14837
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N43	08	W89	20	271	520701 - 751231	N43	08	W89	20	262

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 750604.

MEDFORD, OREGON
WBAN NO. 24225
TIME ZONE: PACIFIC

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
511201 - 751231	N42	22	W122	52	405	511201 - 751231	N42	22	W122	52	396

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 670831.

B. Hourly observed solar radiation data through 670831 only; Field 108 model estimated data through 751231.

MIAMI, FLORIDA
WBAN NO. 12839
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N25	48	W80	16	12	520701 - 751231	N25	48	W80	16	2

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 730712.

NASHVILLE, TENNESSEE
WBAN NO. 13897
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
520701 - 751231	N36	07	W86	41	186	520701 - 751231	N36	07	W86	41	180

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 750903.

NEW YORK, NEW YORK
WBAN NO. 94728
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 751231	N40	47	W73	58	57	520701 - 751231	N40	39	W73	47	4

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 750321.

B. Solar radiation data from Central Park and meteorological observations from John F. Kennedy International Airport.

NORTH OMAHA, NEBRASKA
WBAN NO. 94918
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
570601 - 751231	N41	22	W96	01	404	570601 - 751231	N41	19	W95	54	298

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

B. Meteorological observations from Eppley Airfield.

PHOENIX, ARIZONA
WBAN NO. 23183
TIME ZONE: MOUNTAIN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 751231	N33	26	W112	01	347	520701 - 751231	N33	26	W112	01	339

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 730619.

B. Hourly observed solar radiation data through 670630 only; Field 108 model estimated data through 751231.

SANTA MARIA, CALIFORNIA
WBAN NO. 23273
TIME ZONE: PACIFIC

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
520701 - 541031	N34	56	W120	25	80	520701 - 541031	N34	56	W120	25	71
541101 - 690331	N34	54	W120	27	82	541101 - 690331	N34	54	W120	27	72

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 690331.

B. Hourly observed solar radiation data missing 630801 - 631031.

C. Station moved from Hancock Field to Public Airport 541101.

SEATTLE-TACOMA, WASHINGTON
WBAN NO. 24233
TIME ZONE: PACIFIC

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
511201 - 751231	N47	27	W122	18	137	511201 - 751231	N47	27	W122	18	122

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 730110.

B. Hourly observed solar radiation data through 670531 only; Field 108 model estimated data through 751231.

STEPHENVILLE, TEXAS
WBAN NO. 13901
TIME ZONE: CENTRAL

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Min	Longitude Deg	Min	Elevation Meters
741001 - 751231	N32	13	W98	11	399	741001 - 751231	N32	54	W97	02	168

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751231.

B. Meteorological observations from Dallas-Fort Worth Regional Airport.

WASHINGTON, D.C. - STERLING, VA.
WBAN NO. 93734
TIME ZONE: EASTERN

STATION LOCATION

Solar Radiation Data						Collateral Meteorological Data					
Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters	Period of Record YRMODA - YRMODA	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation Meters
530801 - 601031	N38	50	W76	57	89	530801 - 621116	N38	51	W77	03	4
601101 - 751231	N38	59	W77	28	86	621117 - 751231	N38	57	W77	27	88

NOTES

A. Data in Supplemental Field A (Field 109) are observed values corrected for instrument temperature response through 751010.

B. Solar instruments moved from Silver Hill, Maryland, 530801, to Sterling, Virginia 601101.

C. Meteorological observations from Washington National Airport through 621116 and from Dulles International Airport from 621117 through 751231.

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APPENDIX A.2

STATION NOTES FOR 214 STATIONS WITH REGRESSION ESTIMATES FROM CLOUD/SKY CONDITION/SUNSHINE DATA IN FIELD 108

General Notes

1. No observed solar radiation data are available.

2. Hourly surface meteorological data are included.

3. All data are unedited.

ABBREVIATIONS USED

AL	ALABAMA
AK	ALASKA
AZ	ARIZONA
AR	ARKANSAS
CA	CALIFORNIA
CO	COLORADO
CT	CONNECTICUT
DE	DELAWARE
FL	FLORIDA
GA	GEORGIA
HI	HAWAII
ID	IDAHO
IL	ILLINOIS
IN	INDIANA
IA	IOWA
KS	KANSAS
KY	KENTUCKY
LA	LOUISIANA
ME	MAINE
MD	MARYLAND
MI	MICHIGAN
MN	MINNESOTA
MS	MISSISSIPPI
MO	MISSOURI
MT	MONTANA
NE	NEBRASKA
NV	NEVADA
NH	NEW HAMPSHIRE
NJ	NEW JERSEY
NM	NEW MEXICO
NY	NEW YORK
NC	NORTH CAROLINA
ND	NORTH DAKOTA
OH	OHIO
OK	OKLAHOMA
OR	OREGON
PA	PENNSYLVANIA
RI	RHODE ISLAND
SC	SOUTH CAROLINA
SD	SOUTH DAKOTA
TN	TENNESSEE
TX	TEXAS
UT	UTAH
VT	VERMONT
VA	VIRGINIA
WA	WASHINGTON
WV	WEST VIRGINIA
WI	WISCONSIN
WY	WYOMING

ABE	ALLENTOWN-BETHLEHEM-EASTON
BALTO	BALTIMORE
CO	COUNTY
FAA	FEDERAL AVIATION ADMINISTRATION
GEN	GENERAL
GTR	GREATER
INTL	INTERNATIONAL
MCAS	MARINE CORPS AIR STATION
MER	MERIDIAN (LONGITUDE)
MUNI	MUNICIPAL
NAS	NAVAL AIR STATION
PAC	PACIFIC
USCG	UNITED STATES COAST GUARD
WASH	WASHINGTON

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City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
BIRMINGHAM/MUNICIPAL	AL	13876	N33	34	W86	45	192	CENTRAL	4801	-	7612
MOBILE/BATES	AL	13894	N30	41	W88	15	67	CENTRAL	4801	-	7612
MONTGOMERY/DANNELLY	AL	13895	N32	18	W86	24	62	CENTRAL	4801	-	7612
ADAK/NAVAL STATION	AK	25704	N51	53	W176	38	5	BERING	4901	-	7612
ANNETTE /FAA	AK	25308	N55	02	W131	34	34	PACIFIC	4807	-	7612
BARROW/W ROGERS-W POST	AK	27502	N71	18	W156	47	4	ALASKAN	4807	-	7612
BETHEL/MUNICIPAL	AK	26615	N60	47	W161	48	46	ALASKAN	4807	-	7612
BETTLES/BETTLES FIELD	AK	26533	N66	55	W151	31	205	ALASKAN	4501	-	7612
BIG DELTA/BIG DELTA	AK	26415	N64	00	W145	44	388	ALASKAN	4807	-	7612
FAIRBANKS/INTL	AK	26411	N64	49	W147	52	138	ALASKAN	4807	-	7612
GULKANA/INTERMEDIATE	AK	26425	N62	09	W145	27	481	ALASKAN	4807		7612
HOMER/MUNICIPAL	AK	25507	N59	38	W151	30	22	ALASKAN	4807	-	7612
JUNEAU/MUNICIPAL	AK	25309	N58	22	W134	35	7	PACIFIC	4807		7612
KING SALMON/KING SALMON	AK	25503	N58	41	W156	39	15	ALASKAN	4901	-	7612
KODIAK/USCG BASE	AK	25501	N57	45	W152	20	34	ALASKAN	4511	-	7612
KOTZEBUE/RALPH WIEN	AK	26616	N66	52	W162	38	5	BERING	4501	-	7612
MCGRATH/MCGRATH	AK	26510	N62	58	W155	37	103	ALASKAN	4807	-	7612
NOME/MUNICIPAL	AK	26617	N64	30	W165	26	7	BERING	4501	-	7612
SUMMIT/SUMMIT	AK	26414	N63	20	W149	08	733	ALASKAN	4807	-	7610
YAKUTAT/STATE	AK	25339	N59	31	W139	40	9	YUKON	4808	-	7612
PRESCOTT/MUNICIPAL	AZ	23184	N34	39	W112	26	1531	MOUNTAIN	4801	-	7612
TUCSON/INTL	AZ	23160	N32	07	W110	56	779	MOUNTAIN	4810	-	7612
WINSLOW/MUNICIPAL	AZ	23194	N35	01	W110	44	1488	MOUNTAIN	4801	-	7612
YUMA/MCAS-YUMA INTL	AZ	23195	N32	40	W114	36	63	MOUNTAIN	4809	-	7612
FORT SMITH/MUNICIPAL	AR	13964	N35	20	W94	22	141	CENTRAL	4804	-	7612
LITTLE ROCK/ADAMS	AR	13963	N34	44	W92	14	81	CENTRAL	4807	-	7612

City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
ARCATA/FAA	CA	24283	N40	59	N124	06	69	PACIFIC	4912	-	7612
BAKERSFIELD/KERN COUNTY	CA	23155	N35	25	W119	03	150	PACIFIC	4801	-	7612
DAGGETT/SAN BERNARDINO COUNTY	CA	23161	N34	52	W116	47	588	PACIFIC	4811	-	7612
EL TORO/MCAS	CA	93101	N33	40	W117	44	116	PACIFIC	4503	-	7612
LONG BEACH/LONG BEACH	CA	23129	N33	49	W118	09	17	PACIFIC	4901	-	7612
LOS ANGELES/INTL	CA	23174	N33	56	W118	24	32	PACIFIC	4701	-	7612
OAKLAND/INTL	CA	23230	N37	44	W122	12	2	PACIFIC	4801	-	7612
POINT MUGU/PAC MISSILE RANGE	CA	93111	N34	07	W119	07	4	PACIFIC	4603	-	7612
RED BLUFF/MUNICIPAL	CA	24216	N40	09	W122	15	108	PACIFIC	4801	-	7612
SACRAMENTO/EXECUTIVE	CA	23232	N38	31	W121	30	8	PACIFIC	4707	-	7612
SAN DIEGO/LINDBERGH	CA	23188	N32	44	W117	10	9	PACIFIC	4801	-	7612
SAN FRANCISCO/INTL	CA	23234	N37	37	W122	23	5	PACIFIC	4801	-	7612
SUNNYVALE/MOFFETT NAS	CA	23244	N37	25	W122	04	12	PACIFIC	4503	-	7612
COLORADO SPRINGS/MUNICIPAL	CO	93037	N38	49	W104	43	1881	MOUNTAIN	4807	-	7612
DENVER/STAPLETON INTL	CO	23062	N39	45	W104	52	1625	MOUNTAIN	4801	-	7612
EAGLE/EAGLE COUNTY	CO	23063	N39	39	W106	55	1985	MOUNTAIN	4801	-	7612
GRAND JUNCTION/WALKER	CO	23066	N39	07	W108	32	1475	MOUNTAIN	4801	-	7612
PUEBLO/MUNICIPAL	CO	23068	N38	14	W104	38	1463	MOUNTAIN	4801	-	5406
PUEBLO/MEMORIAL	CO	93058	N38	17	W104	31	1439	MOUNTAIN	5407	-	7612
HARTFORD/BRADLEY INTL	CT	14740	N41	56	W72	41	55	EASTERN	4901	-	7612
WILMINGTON/GTR WILMINGTON	DE	13781	N39	40	W75	36	24	EASTERN	4801	-	7612
DAYTONA BEACH/REGIONAL	FL	12834	N29	11	W81	03	12	EASTERN	4801	-	7612
JACKSONVILLE/INTL	FL	13889	N30	30	W81	42	9	EASTERN	4801	-	7612
ORLANDO/JETPORT AT MCCOY	FL	12841	N28	33	W81	20	36	EASTERN	4801	-	7401
TALLAHASSEE/MUNICIPAL	FL	93805	N30	23	W84	22	21	EASTERN	4801	-	7612

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City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
TAMPA/INTL	FL	12842	N27	58	W82	32	3	EASTERN	4801	-	7612
WEST PALM BEACH/PALM BEACH	FL	12844	N26	41	W80	06	6	EASTERN	4801	-	7612
ATLANTA/HARTSFIELD INTL	GA	13874	N33	39	W84	26	315	EASTERN	4501	-	7612
AUGUSTA/BUSH	GA	03820	N33	22	W81	58	45	EASTERN	4901	-	7612
MACON/LEWIS B WILSON	GA	03813	N32	42	W83	39	110	EASTERN	4812	-	7612
SAVANNAH/HUNTER	GA	93802	N32	01	W81	08	16	EASTERN	4801	-	5009
SAVANNAH/MUNICIPAL	GA	03822	N32	08	W81	12	16	EASTERN	5010	-	7612
BARBERS POINT/NAS	HI	22514	N21	19	W158	04	10	ALASKAN	4901	-	7612
HILO/GEN LYMAN	HI	21504	N19	43	W155	04	11	ALASKAN	4910	-	7612
HONOLULU/HONOLULU INTL	HI	22521	N21	20	W157	55	5	ALASKAN	4911	-	7612
LIHUE/LIHUE	HI	22536	N21	59	W159	21	45	ALASKAN	5002	-	7612
BOISE/BOISE AIR TERMINAL	ID	24131	N43	34	W116	13	874	MOUNTAIN	4801	-	7612
POCATELLO/MUNICIPAL	ID	24156	N42	55	W112	36	1365	MOUNTAIN	4801	-	7612
CHICAGO/MIDWAY	IL	14819	N41	47	W87	45	190	CENTRAL	4801	-	7612
MOLINE/QUAD CITY	IL	14923	N41	27	W90	31	181	CENTRAL	4802	-	7612
SPRINGFIELD/CAPITAL	IL	93822	N39	50	W89	40	187	CENTRAL	4801	-	7612
EVANSVILLE/DRESS REGIONAL	IN	93817	N38	03	W87	32	118	CENTRAL	4801	-	7612
FORT WAYNE/BAER	IN	14827	N41	00	W85	12	252	CENTRAL	4801	-	7612
INDIANAPOLIS/WEIR COOK	IN	93819	N39	44	W86	17	246	CENTRAL	4801	-	7612
SOUTH BEND/MICHIANA REGIONAL	IN	14848	N41	42	W86	19	236	CENTRAL	4801	-	7612
BURLINGTON/MUNICIPAL	IA	14931	N40	47	W91	07	214	CENTRAL	4801	-	7612
DES MOINES/MUNICIPAL	IA	14933	N41	32	W93	39	294	CENTRAL	4501	-	7612
MASON CITY/MUNICIPAL	IA	14940	N43	09	W93	20	373	CENTRAL	4801	-	7612
SIOUX CITY/MUNICIPAL	IA	14943	N42	24	W96	23	336	CENTRAL	4801	-	7612

City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
GOODLAND/RENNER	KS	23065	N39	22	W101	42	1124	MOUNTAIN	4801	-	7612
TOPEKA/MUNICIPAL-BILLARD	KS	13996	N39	04	W95	38	270	CENTRAL	4801	-	7612
WICHITA/MUNICIPAL	KS	13998	N37	38	W97	16	424	CENTRAL	4801	-	5312
WICHITA/MID-CONTINENT	KS	03928	N37	39	W97	25	408	CENTRAL	5401	-	7612
COVINGTON/GTR CINCINNATI	KY	93814	N39	04	W84	40	271	EASTERN	4801	-	7612
LEXINGTON/BLUE GRASS	KY	93820	N38	02	W84	36	301	EASTERN	4801	-	7612
LOUISVILLE/STANDIFORD	KY	93821	N38	11	W85	44	149	EASTERN	4801	-	7612
BATON ROUGE/RYAN	LA	13970	N30	32	W91	09	23	CENTRAL	4801	-	7612
NEW ORLEANS/INTL-MOISANT	LA	12916	N29	59	W90	15	3	CENTRAL	4807	-	7612
SHREVEPORT/REGIONAL	LA	13957	N32	28	W93	49	79	CENTRAL	4807	-	7612
PORTLAND/INTL JETPORT	ME	14764	N43	39	W70	19	19	EASTERN	4801	-	7612
BALTIMORE/BALTO-WASH INTL	MD	93721	N39	11	W76	40	47	EASTERN	4901	-	7612
PATUXENT RIVER/NAS	MD	13721	N38	17	W76	25	14	EASTERN	4503	-	7612
(NO STATIONS IN MASSACHUSETTS)											
DETROIT/CITY	MI	14822	N42	25	W83	01	191	EASTERN	4801	-	7612
FLINT/BISHOP	MI	14826	N42	58	W83	44	233	EASTERN	4812	-	7612
GRAND RAPIDS/KENT COUNTY	MI	14830	N42	54	W85	40	210	EASTERN	4501	-	6311
GRAND RAPIDS/KENT COUNTY	MI	94860	N42	53	W85	31	245	EASTERN	6311	-	7612
SAULT STE MARIE/CITY-COUNTY	MI	14847	N46	28	W84	22	221	EASTERN	4801	-	7612
TRAVERSE CITY/MUNICIPAL	MI	14850	N44	44	W85	35	192	EASTERN	4812	-	7612
DULUTH/INTL	MN	14913	N46	50	W92	11	432	CENTRAL	4801	-	7612
MINNEAPOLIS-ST PAUL/INTL	MN	14922	N44	53	W93	13	255	CENTRAL	4501	-	7612
ROCHESTER/MUNICIPAL	MN	14925	N43	55	W92	30	402	CENTRAL	4801	-	7612

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City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
JACKSON/HAWKINS	MS	13956	N32	20	W90	13	101	CENTRAL	4807	-	6307
JACKSON/ALLEN C THOMPSON	MS	03940	N32	19	W90	05	101	CENTRAL	6307	-	7612
KANSAS CITY/MUNICIPAL	MO	13988	N39	07	W94	36	229	CENTRAL	4801	-	7209
KANSAS CITY/INTL	MO	03947	N39	18	W94	43	315	CENTRAL	7210	-	7612
SPRINGFIELD/MUNICIPAL	MO	13995	N37	14	W93	23	387	CENTRAL	4801	-	7612
ST LOUIS/INTL	MO	13994	N38	45	W90	23	172	CENTRAL	4501	-	7612
BILLINGS/LOGAN	MT	24033	N45	48	W108	32	1088	MOUNTAIN	4801	-	7612
CUT BANK/MUNICIPAL	MT	24137	N48	36	W112	22	1170	MOUNTAIN	4801	-	7612
DILLON/FAA	MT	24138	N45	15	W112	33	1588	MOUNTAIN	4801	-	7306
HELENA/HELENA	MT	24144	N46	36	W112	00	1188	MOUNTAIN	4801	-	7612
LEWISTOWN/MUNICIPAL	MT	24036	N47	03	W109	27	1264	MOUNTAIN	4801	-	7612
MILES CITY/MUNICIPAL	MT	24037	N46	26	W105	52	803	MOUNTAIN	4801		7612
MISSOULA/JOHNSON-BELL	MT	24153	N46	55	W114	05	972	MOUNTAIN	4801	-	7612
GRAND ISLAND/AIR PARK	NE	14935	N40	58	W98	19	566	CENTRAL	4801	-	7612
NORTH PLATTE/LEE BIRD	NE	24023	N41	08	W100	41	849	CENTRAL	4801	-	7612
SCOTTSBLUFF/COUNTY	NE	24028	N41	52	W103	36	1206	MOUNTAIN	4801		7612
LAS VEGAS/MCCARRAN INTL	NV	23169	N36	05	W115	10	664	PACIFIC	4812	-	7612
LOVELOCK/DERBY	NV	24172	N40	04	W118	33	1190	PACIFIC	4811	-	7612
RENO/INTL	NV	23185	N39	30	W119	47	1341	PACIFIC	4901	-	7612
TONOPAH/TONOPAH	NV	23153	N38	04	W117	08	1653	PACIFIC	5104	-	7612
CONCORD/MUNICIPAL	NH	14745	N43	12	W71	30	105	EASTERN	4801	-	7612
LAKEHURST/NAS	NJ	14780	N40	02	W74	20	37	EASTERN	4502	-	7612
NEWARK/INTL	NJ	14734	N40	42	W74	10	9	EASTERN	4801	-	7612

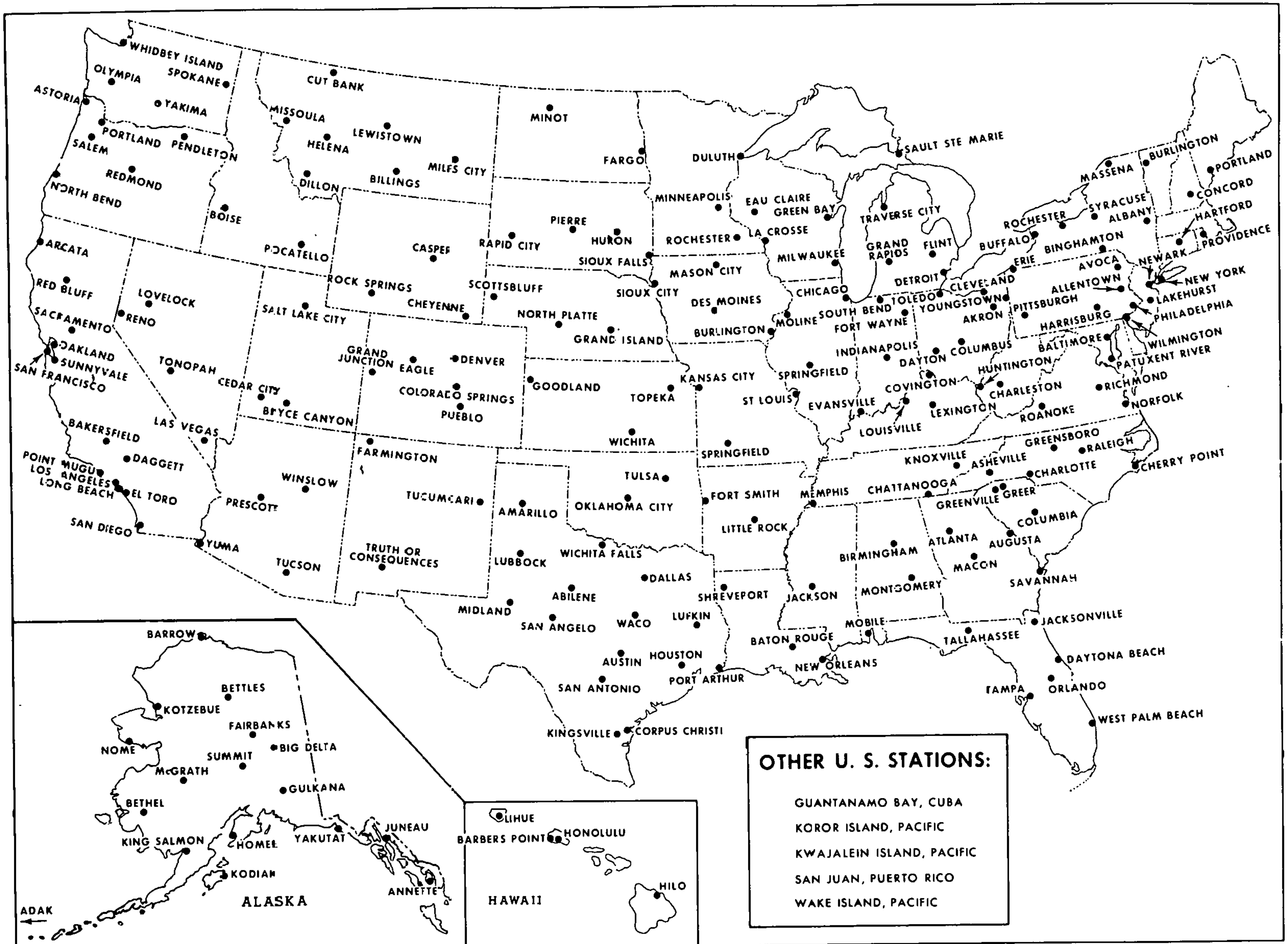
City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
FARMINGTON/MUNICIPAL	NM	23090	N36	45	W108	14	1677	MOUNTAIN	4901	-	7612
TRUTH OR CONSEQUENCES/MUNI	NM	93045	N33	14	W107	16	1481	MOUNTAIN	5005	-	7612
TUCUMCARI/MUNICIPAL	NM	23048	N35	11	W103	36	1231	MOUNTAIN	4901	-	7612
ALBANY/COUNTY	NY	14735	N42	45	W73	48	89	EASTERN	4501	-	7612
BINGHAMTON/BROOME COUNTY	NY	04725	N42	13	W75	59	499	EASTERN	4801	-	7612
BUFFALO/CREATER BUFFALO	NY	14733	N42	56	W78	44	215	EASTERN	4601	-	7612
MASSENA/RICHARDS	NY	94725	N44	56	W74	51	63	EASTERN	4901	-	7612
NEW YORK/LA GUARDIA	NY	14732	N40	46	W73	54	16	EASTERN	4807	-	7612
ROCHESTER/MONROE COUNTY	NY	14768	N43	07	W77	40	169	EASTERN	4801	-	7612
SYRACUSE/HANCOCK INTL	NY	14771	N43	07	W76	07	124	EASTERN	4501	-	7612
ASHEVILLE/ASHEVILLE	NC	03812	N35	26	W82	32	661	EASTERN	4801	-	7612
CHARLOTTE/DOUGLAS MUNICIPAL	NC	13881	N35	13	W80	56	234	EASTERN	4801	-	7612
CHERRY POINT/MCAS	NC	13754	N34	54	W76	53	11	EASTERN	4503	-	7612
GREENSBORO/REGIONAL	NC	13723	N36	05	W79	57	270	EASTERN	4807	-	7612
RALEIGH/RALEIGH-DURHAM	NC	13722	N35	52	W78	47	134	EASTERN	4807	-	7612
FARGO/HECTOR	ND	14914	N46	54	W96	48	274	CENTRAL	4801	-	7612
MINOT/INTL	ND	24013	N48	16	W101	17	522	CENTRAL	4812	-	7612
AKRON/AKRON-CANTON	OH	14895	N40	55	W81	26	377	EASTERN	4807	-	7612
CINCINNATI (SEE COVINGTON, KY)											
CLEVELAND/HOPKINS INTL	OH	14820	N41	24	W81	51	245	EASTERN	4801	-	7612
COLUMBUS/PORT COLUMBUS INTL	OH	14821	N40	00	W82	53	254	EASTERN	4801	-	7612
DAYTON/JAMES M COX	OH	93815	N39	54	W84	13	306	EASTERN	4801	-	7612
TOLEDO/MUNICIPAL	OH	14849	N41	34	W83	28	191	EASTERN	4601	-	5501
TOLEDO/EXPRESS	OH	94830	N41	36	W83	48	211	EASTERN	5502	-	7612
YOUNGSTOWN/MUNICIPAL	OH	14852	N41	16	W80	40	361	EASTERN	4801	-	7612

City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
OKLAHOMA CITY/WILL ROGERS	OK	13967	N35	24	W97	36	397	CENTRAL	4501	-	7612
TULSA/INTL	OK	13968	N36	12	W95	54	206	CENTRAL	4807	-	7612
ASTORIA/CLATSOP COUNTY	OR	94224	N46	09	W123	53	7	PACIFIC	4904	-	7612
NORTH BEND/MUNICIPAL	OR	24284	N43	25	W124	15	5	PACIFIC	4905	-	7612
PENDLETON/MUNICIPAL	OR	24155	N45	41	W118	51	456	PACIFIC	3801	-	7612
PORTLAND/INTL	OR	24229	N45	36	W122	36	12	PACIFIC	4801	-	7612
REDMOND/ROBERTS	OR	24230	N44	16	W121	09	940	PACIFIC	4801	-	7612
SALEM/MCNARY	OR	24232	N44	55	W123	01	61	PACIFIC	4801	-	7612
ALLENTOWN/A-B-E	PA	14737	N40	39	W75	26	117	EASTERN	4801	-	7612
AVOCA/WILKES-BARRE-SCRANTON	PA	14777	N41	20	W75	44	289	EASTERN	4901	-	7612
ERIE/ERIE INTL	PA	14860	N42	05	W80	11	225	EASTERN	4801	-	7612
HARRISBURG/CAPITAL CITY	PA	14751	N40	13	W76	51	106	EASTERN	4801	-	7612
PHILADELPHIA/INTL	PA	13739	N39	53	W75	15	9	EASTERN	4101	-	7612
PITTSBURGH/GTR PITTSBURGH	PA	94823	N40	30	W80	13	373	EASTERN	5209	-	7612
PROVIDENCE/TF GREEN STATE	RI	14765	N41	44	W71	26	19	EASTERN	4801	-	7612
COLUMBIA/METROPOLITAN	SC	13883	N33	57	W81	07	69	EASTERN	4801	-	7612
GREENVILLE/MUNICIPAL	SC	13886	N34	51	W82	21	317	EASTERN	4801	-	6210
GREER/GREENVILLE-SPARTANBURG	SC	03870	N34	54	W82	13	296	EASTERN	6210	-	7612
HURON/WW HOWES MUNICIPAL	SD	14936	N44	23	W98	13	393	CENTRAL	4001	-	7612
PIERRE/MUNICIPAL	SD	24025	N44	23	W100	17	526	CENTRAL	4801	-	7612
RAPID CITY/REGIONAL	SD	24090	N44	03	W103	04	966	MOUNTAIN	5011	-	7612
SIOUX FALLS/FOSS	SD	14944	N43	34	W96	44	435	CENTRAL	4801	-	7612
CHATTANOOGA/LOVELL	TN	13882	N35	02	W85	12	210	EASTERN	4801	-	7612
KNOXVILLE/MCGHEE TYSON	TN	13891	N35	49	W83	59	299	EASTERN	4801	-	7612
MEMPHIS/INTL	TN	13893	N35	03	W89	59	87	CENTRAL	4801	-	7612

City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
ABILENE/MUNICIPAL	TX	13962	N32	26	W99	41	534	CENTRAL	4807	-	7612
AMARILLO/AIR TERMINAL	TX	23047	N35	14	W101	42	1098	CENTRAL	4807	-	7612
AUSTIN/MUNICIPAL	TX	13958	N30	18	W97	42	189	CENTRAL	4807	-	7612
CORPUS CHRISTI/INTL	TX	12924	N27	46	W97	30	13	CENTRAL	4807	-	7612
DALLAS/LOVE	TX	13960	N32	51	W96	51	149	CENTRAL	4801	-	7401
HOUSTON/HOBBY	TX	12918	N29	39	W95	17	19	CENTRAL	4807	-	6905
HOUSTON/INTERCONTINENTAL	TX	12960	N29	59	W95	22	33	CENTRAL	6906	-	7612
KINGSVILLE/NAS	TX	12928	N27	31	W97	49	17	CENTRAL	4503	-	7612
LUBBOCK/REGIONAL	TX	23042	N33	39	W101	49	988	CENTRAL	4807	-	7612
LUFKIN/ANGELINA COUNTY	TX	93987	N31	14	W94	45	96	CENTRAL	4808	-	7612
MIDLAND-ODESSA/REGIONAL	TX	23023	N31	56	W102	12	871	CENTRAL	4807	-	7612
PORT ARTHUR/JEFFERSON COUNTY	TX	12917	N29	57	W94	01	7	CENTRAL	4807	-	7612
SAN ANGELO/MATHIS	TX	23034	N31	22	W100	30	582	CENTRAL	4807	-	7612
SAN ANTONIO/INTL	TX	12921	N29	32	W98	28	242	CENTRAL	4807	-	7612
WACO/MADISON COOPER	TX	13959	N31	37	W97	13	155	CENTRAL	4807	-	7612
WICHITA FALLS/MUNICIPAL	TX	13966	N33	58	W98	29	314	CENTRAL	4804	-	7612
BRYCE CANYON/BRYCE CANYON	UT	23159	N37	42	W112	09	2313	MOUNTAIN	4811	-	7612
CEDAR CITY/MUNICIPAL	UT	93129	N37	42	W113	06	1712	MOUNTAIN	4811	-	7612
SALT LAKE CITY/INTL	UT	24127	N40	46	W111	58	1288	MOUNTAIN	4801	-	7612
BURLINGTON/INTL	VT	14742	N44	28	W73	09	104	EASTERN	4801	-	7612
NORFOLK/NORFOLK REGIONAL	VA	13737	N36	54	W76	12	9	EASTERN	4801	-	7612
RICHMOND/R E BYRD INTL	VA	13740	N37	30	W77	20	50	EASTERN	4801	-	7612
ROANOKE/WOODRUM	VA	13741	N37	19	W79	58	358	EASTERN	4801	-	7612
OLYMPIA/OLYMPIA	WA	24227	N46	58	W122	54	61	PACIFIC	4801	-	7612
SPOKANE/INTL	WA	24157	N47	38	W117	32	721	PACIFIC	4801	-	7612
WHIDBEY ISLAND/NAS	WA	24255	N48	21	W122	40	17	PACIFIC	4504	-	7612
YAKIMA/MUNICIPAL	WA	24243	N46	34	W120	32	325	PACIFIC	4801	-	7612

12/77

City/Airport	STATE	WBAN No.	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Station Elev (M)	Time Zone	Period of Record YRMO	-	YRMO
CHARLESTON/KANAWHA	WV	13866	N38	22	W81	36	290	EASTERN	4902	-	7612
HUNTINGTON/HUNTINGTON	WV	93818	N38	25	W82	30	172	EASTERN	4801	-	6101
HUNTINGTON/TRI-STATE	WV	03860	N38	22	W82	33	255	EASTERN	6112	-	7612
EAU CLAIRE/MUNICIPAL	WI	14991	N44	52	W91	29	273	CENTRAL	4910	-	7612
GREEN BAY/AUSTIN STRAUBEL	WI	14898	N44	29	W88	08	214	CENTRAL	4909	-	7612
LA CROSSE/MUNICIPAL	WI	14920	N43	52	W91	15	205	CENTRAL	4801	-	7612
MILWAUKEE/GEN MITCHELL	WI	14839	N42	57	W87	54	211	CENTRAL	4801	-	7612
CASPER/WARDWELL	WY	24016	N42	55	W106	20	1612	MOUNTAIN	4801	-	5003
CASPER/NATRONA CO INTL	WY	24089	N42	55	W106	28	1612	MOUNTAIN	5003	-	7612
CHEYENNE/MUNICIPAL	WY	24018	N41	09	W104	49	1872	MOUNTAIN	4801	-	7612
ROCK SPRINGS/MUNICIPAL	WY	24027	N41	36	W109	04	2056	MOUNTAIN	4801	-	7612
OTHER U.S. STATIONS											
GUANTANAMO BAY, CUBA		11706	N19	54	W75	09	16	EASTERN	4504	-	7612
KOROR ISLAND, PACIFIC		40309	N07	20	E134	29	33	135E MER	5107	-	7612
KWAJALEIN ISLAND, PACIFIC		40601	N08	43	E167	44	3	180E MER	4901	-	5204
KWAJALEIN ISLAND, PACIFIC		40604	N08	44	E167	44	8	180E MER	5204	-	7612
SAN JUAN, PUERTO RICO/ISLA GRANDE		11631	N18	28	W66	06	15	ATLANTIC	5003	-	5505
SAN JUAN, PUERTO RICO/ISLA VERDE		11641	N18	26	W66	00	19	ATLANTIC	5505	-	7612
WAKE ISLAND, PACIFIC		41606	N19	17	E166	39	4	180E MER	4911	-	7612



REGRESSION MODELED SOLAR RADIATION DATA STATIONS

APPENDIX B

BY-PRODUCTS AVAILABLE

1. Taped Data

   a. Standard year irradiance (SYI).

   b. Direct solar radiation (for 27 rehabilitated data stations only).

   c. Clear noon irradiance (for 27 rehabilitated data stations only).

   d. Extraterrestrial radiation (ETR) with solar elevation angles.

2. Data Listings (samples follow)

   a. SOLMET data. Abbreviations used (reading left to right, top to bottom, for both double line per hour form and single line per hour form):

STN	STATION
WBAN	WEATHER BUREAU - ARMY - NAVY
DY	DAY
HR	HOUR
LST	LOCAL STANDARD TIME
ETR	EXTRATERRESTRIAL RADIATION
DIRCT	DIRECT RADIATION
DIFUS	DIFFUSE RADIATION
NET	NET RADIATION
TILT	GLOBAL RADIATION ON A TILTED SURFACE
OBSRV	OBSERVED GLOBAL RADIATION ON A HORIZONTAL SURFACE
ENGRG	ENGINEERING CORRECTED DATA
STAND	STANDARD YEAR IRRADIANCE MODEL DATA
A	SUPPLEMENTARY FIELD A FOR ADDITIONAL DATA
B	SUPPLEMENTARY FIELD B FOR ADDITIONAL DATA
SS	SUNSHINE
OT	OBSERVATION TIME

CEIL	CEILING HEIGHT
SKY	SKY CONDITION
VSBY	VISIBILITY
WEATHER	WEATHER
DRY	DRY BULB TEMPERATURE
DEWPT	DEWPOINT TEMPERATURE
DIR	WIND DIRECTION
SPEED	WIND SPEED
TC	TOTAL SKY COVER
TO	TOTAL OPAQUE SKY COVER
S	SNOW COVER
SL PR	SEA LEVEL PRESSURE
STN PR	STATION PRESSURE
LA	LOWEST CLOUD LAYER AMOUNT
LT	TYPE OF LOWEST CLOUD OR OBSCURING PHENOMENA
LH	HEIGHT OF BASE OF LOWEST CLOUD LAYER OR OBSCURING PHENOMENA
SA	SECOND LAYER AMOUNT
ST	TYPE OF SECOND CLOUD LAYER
SH	HEIGHT OF BASE OF SECOND CLOUD LAYER
S2	SUMMATION OF FIRST 2 LAYERS
TA	THIRD LAYER AMOUNT
TT	TYPE OF THIRD CLOUD LAYER
TH	HEIGHT OF BASE OF THIRD CLOUD LAYER
S3	SUMMATION OF FIRST 3 LAYERS
FA	FOURTH LAYER AMOUNT
FT	TYPE OF FOURTH CLOUD LAYER
FH	HEIGHT OF BASE OF FOURTH CLOUD LAYER

b. Standard year irradiance (SYI). Listing gives global solar radiation data (SYI and regression model) in kJ/m^2 for indicated solar hour, day, month and station.

c. Direct solar radiation. Listing presents modeled direct solar radiation data in kJ/m^2 for indicated solar hour, day, month, and station. (Available for 27 rehabilitated data stations only.)

d. Clear noon irradiance (available for 27 rehabilitated data stations only). Abbreviations used:

STA	STATION NUMBER
YR	YEAR
DA	DAY
RAD	CLEAR NOON IRRADIANCE VALUES (TOTAL HEMISPHERIC SOLAR RADIATION ON A HORIZONTAL SURFACE). DATA ARE ONE-MINUTE READINGS IN LANGLEYS AT SOLAR NOON ± 30 SECONDS, UNDER CLEAR SKY CONDITIONS
ETR	EXTRATERRESTRIAL RADIATION VALUES IN LANGLEYS (ONE-MINUTE READINGS AT SOLAR NOON ± 30 SECONDS). COMPUTED BASED ON A SOLAR CONSTANT OF 2.00 LANGLEYS/MIN.
%	RAD/ETR X 100

e. Extraterrestrial radiation (ETR) in kJ/m^2 with solar elevation (SE) angles in degrees. Listings can be computed for any latitude.

f. Data inventories

NOTE: Write or call the National Climatic Center for ordering information, such as: paper copies versus microforms, costs, etc.

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                                                   HOURLY SOLMET
STN EL PASO, TX                                       JAN  1954                                                     WBAN 23044

DY  HR    LST  ETR DIRCT DIFUS   NET  TILT OBSRV ENGRG STAND     A     B SS OT CEIL   SKY VSBY  WEATHER   DRY DEWPT DIR SPEED TC TO S
               SL PR STN PR LA LT   LH SA ST   SH S2 TA TT    TH S3 FA FT   FH

01 0100 0109 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 00 7777 00000 0805 00000000 -02.8 -14.4 360   1.0  0  0 9
             102.28 088.66 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0200 0209 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 01 7777 00000 0805 00000000 -03.3 -15.6  45   2.6  0  0 9
             102.23 088.62 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0300 0309 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 02 7777 00000 0805 00000000 -03.3 -16.1  45   1.0  0  0 9
             102.18 088.59 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0400 0409 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 03 7777 00000 0805 00000000 -05.6 -15.6  23   4.6  0  0 9
             102.17 088.55 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0500 0509 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 04 7777 00000 0805 00000000 -06.1 -15.6  23   4.6  0  0 9
             102.13 088.52 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0600 0609 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 05 7777 00000 0805 00000000 -06.1 -15.0  23   5.1  0  0 9
             102.14 088.49 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0700 0709 0000 99999 99999 99999 99999 00004 00004 00003 00004 99999 99 06 7777 00000 0966 00000000 -06.7 -13.9  23   6.2  0  0 0
             102.23 088.52 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0800 0809 0471 71682 99999 99999 99999 00301 00274 00246 00287 99999 54 07 7777 00000 8888 00000000 -06.7 -14.4 360   3.6  0  0 0
             102.29 088.55 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 0900 0909 1374 72974 99999 99999 99999 01075 00981 00881 01028 99999 60 08 7777 00000 8888 00000000 -03.9 -14.4 360   1.5  0  0 0
             102.31 088.59 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1000 1009 2112 73330 99999 99999 99999 01807 01655 01487 01735 99999 60 09 7777 00000 8888 00000000 -01.1 -13.9 225   1.5  0  0 0
             102.32 088.62 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1100 1109 2633 73422 99999 99999 99999 02301 02122 01906 02224 99999 60 10 7777 00000 0966 00000000 003.3 -08.9 203   4.1  0  0 0
             102.23 088.59 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1200 1209 2903 73541 99999 99999 99999 02602 02409 02164 02525 99999 60 11 7777 00000 0402 00000000 006.1 -11.1 203   5.7  0  0 0
             102.08 088.49 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1300 1309 2903 73538 99999 99999 99999 02586 02404 02160 02520 99999 60 12 7777 00000 0483 00000000 008.9 -10.6 225   6.7  0  0 0
             101.88 088.32 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1400 1409 2633 73386 99999 99999 99999 02297 02143 01925 02246 99999 60 13 7777 00000 0644 00000000 011.1 -10.0 248   7.2  0  0 0
             101.74 088.22 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1500 1509 2112 73092 99999 99999 99999 01761 01643 01476 01722 99999 60 14 7777 00000 0805 00000000 011.1 -11.1 248   8.2  0  0 0
             101.73 088.22 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1600 1609 1374 72288 99999 99999 99999 01004 00938 00843 00983 99999 60 15 7777 00000 0966 00000000 012.2 -10.0 248   6.2  0  0 0
             101.75 088.22 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1700 1709 0471 70865 99999 99999 99999 00259 00241 00217 00253 99999 60 16 7777 00000 0966 00000000 011.1 -10.0 270   8.2  0  0 0
             101.73 088.18 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1800 1809 0000 99999 99999 99999 99999 00000 00000 00000 00000 99999 13 17 7777 00000 0966 00000000 011.1 -12.8 270   8.2  0  0 0
             101.77 088.22 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 1900 1909 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 18 7777 00000 0966 00000000 009.4 -10.0 270   8.2  0  0 9
             101.82 088.22 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 2000 2009 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 19 7777 00000 0966 00000000 008.3 -09.4 225   5.1  0  0 9
             101.84 088.22 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 2100 2109 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 20 7777 00000 0966 00000000 005.0 -08.9 203   4.6  0  0 9
             101.86 088.25 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 2200 2209 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 21 7777 00000 0966 00000000 007.2 -11.7 248   6.7  0  0 9
             101.79 088.25 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 2300 2309 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 22 7777 00000 0966 00000000 007.2 -11.1 248   4.6  0  0 9
             101.76 088.28 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
01 2400 0009 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 23 7777 00000 0966 00000000 006.1 -10.0 203   3.1  0  0 9
             101.75 088.28 00 00 7777 00 00 7777 00 00 00 7777 00 00 00 7777
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                                                   HOURLY SOLMET
STN EL PASO, TX                                       JAN  1954                                                     WBAN 23044

DY  HR    LST  ETR DIRCT DIFUS   NET  TILT OBSRV ENGRG STAND     A     B SS OT CEIL   SKY VSBY  WEATHER   DRY DEWPT DIR SPEED TC TO S

01 0100 0109 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 00 7777 00000 0805 00000000 -02.8 -14.4 360   1.0  0  0 9
01 0200 0209 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 01 7777 00000 0805 00000000 -03.3 -15.6  45   2.6  0  0 9
01 0300 0309 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 02 7777 00000 0805 00000000 -03.3 -16.1  45   1.0  0  0 9
01 0400 0409 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 03 7777 00000 0805 00000000 -05.6 -15.6  23   4.6  0  0 9
01 0500 0509 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 04 7777 00000 0805 00000000 -06.1 -15.6  23   4.6  0  0 9
01 0600 0609 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 05 7777 00000 0805 00000000 -06.1 -15.0  23   5.1  0  0 9
01 0700 0709 0000 99999 99999 99999 99999 00004 00004 00003 00004 99999 99 06 7777 00000 0966 00000000 -06.7 -13.9  23   6.2  0  0 0
01 0800 0809 0471 71682 99999 99999 99999 00301 00274 00246 00287 99999 54 07 7777 00000 8888 00000000 -06.7 -14.4 360   3.6  0  0 0
01 0900 0909 1374 72974 99999 99999 99999 01075 00981 00881 01028 99999 60 08 7777 00000 8888 00000000 -03.9 -14.4 360   1.5  0  0 0
01 1000 1009 2112 73330 99999 99999 99999 01807 01655 01487 01735 99999 60 09 7777 00000 8888 00000000 -01.1 -13.9 225   1.5  0  0 0
01 1100 1109 2633 73422 99999 99999 99999 02301 02122 01906 02224 99999 60 10 7777 00000 0966 00000000 003.3 -08.9 203   4.1  0  0 0
01 1200 1209 2903 73541 99999 99999 99999 02602 02409 02164 02525 99999 60 11 7777 00000 0402 00000000 006.1 -11.1 203   5.7  0  0 0
01 1300 1309 2903 73538 99999 99999 99999 02586 02404 02160 02520 99999 60 12 7777 00000 0483 00000000 008.9 -10.6 225   6.7  0  0 0
01 1400 1409 2633 73386 99999 99999 99999 02297 02143 01925 02246 99999 60 13 7777 00000 0644 00000000 011.1 -10.0 248   7.2  0  0 0
01 1500 1509 2112 73092 99999 99999 99999 01761 01643 01476 01722 99999 60 14 7777 00000 0805 00000000 011.1 -11.1 248   8.2  0  0 0
01 1600 1609 1374 72288 99999 99999 99999 01004 00938 00843 00983 99999 60 15 7777 00000 0966 00000000 012.2 -10.0 248   6.2  0  0 0
01 1700 1709 0471 70865 99999 99999 99999 00259 00241 00217 00253 99999 60 16 7777 00000 0966 00000000 011.1 -10.0 270   8.2  0  0 0
01 1800 1809 0000 99999 99999 99999 99999 00000 00000 00000 00000 99999 13 17 7777 00000 0966 00000000 011.1 -12.8 270   8.2  0  0 0
01 1900 1909 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 18 7777 00000 0966 00000000 009.4 -10.0 270   8.2  0  0 9
01 2000 2009 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 19 7777 00000 0966 00000000 008.3 -09.4 225   5.1  0  0 9
01 2100 2109 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 20 7777 00000 0966 00000000 005.0 -08.9 203   4.6  0  0 9
01 2200 2209 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 21 7777 00000 0966 00000000 007.2 -11.7 248   6.7  0  0 9
01 2300 2309 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 22 7777 00000 0966 00000000 007.2 -11.1 248   4.6  0  0 9
01 2400 0009 9999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99 23 7777 00000 0966 00000000 006.1 -10.0 203   3.1  0  0 9
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23273 SANTA MARIA, CA GLOBAL SOLAR RADIATION (SYI-CURRECTED) OCTOBER 1952

DAY/HOUR	01 13	02 14	03 15	04 16	05 17	06 18	07 19	08 20	09 21	10 22	11 23	12 24	TOTAL
1							144	784	1538	2148	2617	2834	
	2816	2572	2123	1490	735	123							19924
2							26	165	450	1193	2569	2825	
	2803	2563	2128	1487	600	98							16907
3							23	156	590	1622	2574	2774	
	2763	2542	2071	1435	565	38							17153
4							29	157	502	1550	2473	2687	
	2738	2588	2092	874	629	150							16469
5							29	256	542	1594	2391	2707	
	2707	2505	2061	1627	684	109							17013
6							58	374	1217	2064	2482	2734	
	2735	2538	2120	1492	750	103							18667
7							29	544	1576	2014	2482	2676	
	2697	2501	2071	1461	734	66							18851
8							98	704	1453	2033	2483	2691	
	2691	2459	2033	1405	671	87							18808
9							33	203	417	1230	2435	2634	
	2660	2444	2022	1379	645	81							16183
10							7	126	362	747	1457	1499	
	2736	2394	1981	1358	631	76							13565
11							7	98	402	922	1995	2572	
	2586	2364	1946	701	232	19							13844
12							7	91	308	731	1438	2565	
	2573	2362	1935	1280	526	47							13863
13							4	115	303	470	656	897	
	1610	2334	1094	952	202	4							9449
14							4	115	403	573	547	624	
	1709	1741	1766	1249	531	51							9313
15							4	54	212	367	553	727	
	782	876	776	995	542	25							5281
16							36	529	1018	592	970	670	
	441	432	352	294	185	7							5526
17							2	100	501	894	1251	1512	
	2058	1332	858	336	173	51							9069
18							7	72	251	969	2301	2541	
	2571	2084	1309	862	502	39							13500
19							15	174	473	1112	2246	2511	
	2503	2070	1860	1242	535	51							14792
20							32	471	1142	1885	2301	2507	
	2495	2259	1827	1223	480	32							16654
21							11	156	438	745	1018	1145	
	795	1602	1825	863	164	7							8769
22							4	51	211	466	825	2120	
	2442	2194	1758	1150	450	28							11699
23							4	90	815	1577	2171	2375	
	2340	2036	1725	732	90	18							13973
24							7*	209	658	1765	2199	2409	
	2434	2206	1766	1136	343	7							15139
25							4	90	302	580	962	1657	
	1763	2075	1718	1075	381	11							10618
26							4	76	390	854	1201	1599	
	2125	2194	1754	1106	400	21							11724
27							7	76	294	632	1551	2465	
	2446	2234	1245	1034	384	19							12387
28							33	359	1145	1555	1346	2099	
	2364	2184	1755	1110	395	25							14370
29							7	127	415	770	1232	1408	
	1801	1449	1077	563	242	21							9009
30							4	40	337	862	1764	2285	
	2376	2140	1643	993	284	7							12735
31							4	88	209	373	420	546	
	983	1389	1244	503	96	7							5862
MEAN							22.1	214.5	608.8	1125.5	1710.0	2048.1	
	2203.9	2085.9	1701.1	1051.8	444.5	45.8							13262.1

* = ESTIMATED AMOUNTS

TAPE DECK		PAGE NO.
9724	SOLMET	B-6

23044 EL PASO,TEXAS DIRECT RADIATION OCTOBER 1952

DAY/HOUR	01 13	02 14	03 15	04 16	05 17	06 18	07 19	08 20	09 21	10 22	11 23	12 24	TOTAL
1							461*	1797*	2771*	3264*	3364*	3416*	
	3427*	3352*	3255*	2880*	1451*	107*							29545
2							225*	1539*	2634*	3178*	3291*	3336*	
	3323*	3269*	3171*	2587*	1340*	98*							27987
3							308*	762*	2404*	3132*	3225*	3266*	
	3253*	3207*	3131*	2587*	1262*	44*							26581
4							404*	1585*	2646*	3160*	3258*	3310*	
	3315*	3260*	3154*	2434*	1199*	49*							27774
5							675*	1601*	2883*	3291*	3388*	3440*	
	3425*	3374*	3244*	2996*	1015*	113*							29445
6							43*	1342*	2717*	3337*	3439*	3484*	
	3481*	3439*	3349*	2858*	1707*	234*							29430
7							64*	1183*	2327*	3029*	3105*	3140*	
	3137*	3105*	3012*	2325*	1065*	21*							25513
8							841*	2515*	3192*	3528*	3615*	3645*	
	3609*	3492*	3205*	3003*	1997*	118*							32760
9							15*	1095*	2154*	2876*	2916*	2945*	
	2949*	2924*	2814*	2003*	745*	7*							23443
10							643*	2295*	3107*	3476*	3565*	3598*	
	3592*	3555*	3468*	3006*	1928*	337*							32570
11							60*	1099*	2246*	2861*	2903*	2932*	
	2934*	2940*	2777*	2101*	867*	19*							23739
12							107*	1214*	2351*	3097*	3174*	3213*	
	3211*	3177*	3094*	2466*	1155*	19*							26278
13							357*	2210*	3109*	3474*	3583*	3594*	
	3593*	3557*	3466*	2990*	2013*	254*							32170
14							172*	1685*	2735*	3349*	3434*	3484*	
	3487*	3438*	3351*	2917*	1635*	147*							29834
15							230*	1827*	2905*	3411*	3556*	3597*	
	3597*	3559*	3471*	2916*	1865*	213*							31147
16							784*	2536*	3232*	3507*	3579*	3622*	
	3622*	3586*	3497*	3016*	1950*	184*							33115
17						0*	1174*	1903*	2566*	3453*	3371*	2898*	
	2874*	2874*	2801*	2330*	2154*	1427*	0*						29825
18						0*	1510*	2588*	3128*	3400*	3510*	3521*	
	3519*	3514*	3427*	3209*	2571*	1286*	0*						35183
19						0*	376*	1623*	2496*	2976*	3082*	3103*	
	3104*	3092*	3013*	2732*	1623*	318*	0*						27538
20						0*	814*	2333*	2683*	3105*	3218*	3255*	
	3219*	2956*	3099*	2814*	2005*	77*	0*						29578
21						0*	10*	18*	543*	2057*	3011*	3245*	
	2043*	2141*	1017*	123*	952*	175*	0*						15335
22						0*	0*	33*	726*	2930*	3514*	3261*	
	3394*	2968*	3191*	2689*	2177*	662*	0*						25565
23							270*	10*	78*	291*	718*	380*	
	2177*	3073*	819*	847*	354*	293*							9310
24							313*	1861*	2534*	2982*	3049*	1640*	
	246*	51*	2637*	1702*	1363*	1464*							19851
25							1149*	2343*	2857*	3260*	3371*	3443*	
	3469*	2845*	2779*	2537*	1953*	1361*							31367
26							1063*	2279*	2904*	3325*	3461*	3484*	
	3511*	3448*	3333*	2980*	2253*	874*							32895
27							805*	2028*	2840*	3262*	3377*	3407*	
	3383*	3348*	3262*	2846*	1784*	569*							30911
28							1253*	2254*	2991*	3343*	3465*	3493*	
	3469*	3426*	3332*	2773*	237*	134*							30170
29							0*	7*	264*	287*	956*	3247*	
	3435*	2633*	10*	8*	22*	342*							11211
30							323*	2038*	1106*	3263*	3478*	3521*	
	3520*	3521*	3548*	3317*	356*	15*							28006
MEAN						.0	867.3	1837.0	2426.8	2930.8	3110.9	3117.4	
	3079.0	2953.3	2669.3	2345.0	1632.2	739.8	.0						27727.8

* = ESTIMATED AMOUNTS

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CLEAR NOON IRRADIANCE

STA	YR	MO	DA	RAD	ETR	%
23183	52	09	03	1.432	1.775	80.7
	52	09	11	1.458	1.736	84.0
	52	09	13	1.502	1.725	87.1
	52	09	18	1.390	1.696	82.0
	52	09	25	1.388	1.652	84.0
	52	09	29	1.354	1.625	83.3
	52	09	30	1.342	1.618	82.9
	52	10	02	1.336	1.604	83.3
	52	10	04	1.326	1.590	83.4
	52	10	05	1.340	1.582	84.7
	52	10	06	1.318	1.575	83.7
	52	10	08	1.348	1.560	86.4
	52	10	09	1.300	1.552	83.8
	52	10	12	1.286	1.529	84.1
	52	10	16	1.252	1.498	83.6
	52	10	21	1.268	1.458	87.0
	52	10	22	1.258	1.451	86.7
	52	10	23	1.244	1.443	86.2
	52	10	28	1.206	1.403	86.0
	52	10	29	1.150	1.395	82.4
	52	11	01	1.170	1.371	85.3
	52	11	04	1.142	1.348	84.7
	52	11	10	1.138	1.303	87.3
	52	11	14	1.072	1.275	84.1
	52	11	18	1.028	1.248	82.4
	52	11	19	1.036	1.242	83.4
	52	11	25	1.000	1.207	82.9
	52	11	26	.982	1.201	81.8
	52	11	28	.970	1.191	81.4
	52	12	03	.954	1.169	81.6
	52	12	08	.928	1.151	80.6
	52	12	09	.940	1.148	81.9
	52	12	12	.924	1.140	81.1
	52	12	14	.898	1.136	79.0
	52	12	22	.918	1.129	81.3
	52	12	27	.954	1.132	84.3
	53	01	02	.976	1.143	85.4
	53	01	04	.980	1.148	85.4
	53	01	05	.974	1.151	84.6
	53	01	08	.918	1.162	79.0
	53	01	09	.958	1.166	82.2
	53	01	10	.960	1.170	82.1
	53	01	16	1.020	1.198	85.1
	53	01	20	.992	1.220	81.3
	53	01	22	1.046	1.232	84.9
	53	01	23	1.038	1.239	83.8
	53	01	29	1.088	1.279	85.1
	53	02	02	1.120	1.309	85.6
	53	02	09	1.106	1.363	81.1
	53	02	11	1.190	1.379	86.3
	53	02	14	1.232	1.404	87.7
	53	02	17	1.258	1.429	88.0

MEAN HOURLY SOLAR ELEVATION ANGLE AND HOURLY EXTRATERRESTRIAL RADIATION - SOLAR TIME

STATION 12842 TAMPA FL LATITUDE 27.967

		12+13		11+14		10+15		09+16		08+17		07+18		06+19		05+20		04+21		03+22		02+23		01+24		TOT	SUN	SUN
MO	DAY	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	SE	ETR	ETR	RISE	SET
2	1	44	3539	39	3249	32	2689	22	1898	10	928	2	70													24746	6:34	17:26
2	2	44	3556	39	3266	32	2705	22	1912	11	941	2	75													24910	6:34	17:26
2	3	44	3573	40	3282	32	2721	22	1927	11	955	2	80													25076	6:33	17:27
2	4	44	3590	40	3299	32	2737	22	1942	11	969	2	85													25244	6:32	17:28
2	5	45	3607	40	3316	32	2753	22	1958	11	983	2	90													25414	6:32	17:28
2	6	45	3625	41	3333	33	2770	23	1973	11	997	2	96													25588	6:31	17:29
2	7	45	3642	41	3350	33	2786	23	1989	11	1012	2	102													25762	6:30	17:30
2	8	46	3660	41	3368	33	2803	23	2004	12	1026	2	108													25938	6:29	17:31
2	9	46	3678	41	3385	33	2820	23	2020	12	1041	2	114													26116	6:29	17:31
2	10	46	3696	42	3403	34	2837	23	2036	12	1056	3	120													26296	6:28	17:32
2	11	46	3714	42	3421	34	2854	24	2053	12	1071	3	127													26480	6:27	17:33
2	12	47	3732	42	3438	34	2871	24	2069	12	1086	3	134													26660	6:27	17:33
2	13	47	3750	43	3456	34	2888	24	2085	12	1102	3	141													26844	6:26	17:34
2	14	47	3768	43	3474	35	2906	24	2102	13	1117	3	149													27032	6:25	17:35
2	15	48	3786	43	3492	35	2923	24	2118	13	1133	3	156													27216	6:24	17:36
2	16	48	3805	43	3510	35	2940	25	2135	13	1148	3	164													27404	6:23	17:37
2	17	48	3823	44	3528	35	2958	25	2152	13	1164	3	173													27596	6:23	17:37
2	18	49	3841	44	3546	36	2975	25	2168	13	1160	3	181													27782	6:22	17:38
2	19	49	3859	44	3564	36	2993	25	2185	14	1196	3	190													27974	6:21	17:39
2	20	49	3878	45	3582	36	3010	26	2202	14	1212	3	199													28166	6:20	17:40
2	21	50	3896	45	3600	36	3028	26	2219	14	1228	3	208													28358	6:20	17:40
2	22	50	3914	45	3618	37	3045	26	2236	14	1244	4	218													28550	6:19	17:41
2	23	51	3932	46	3636	37	3063	26	2253	14	1260	4	228													28744	6:18	17:42
2	24	51	3950	46	3654	37	3080	27	2270	15	1277	4	238													28938	6:17	17:43
2	25	51	3968	46	3671	38	3098	27	2286	15	1293	4	248													29128	6:16	17:44
2	26	52	3986	47	3689	38	3115	27	2303	15	1309	4	259													29322	6:16	17:44
2	27	52	4004	47	3707	38	3132	27	2320	15	1326	4	269													29516	6:15	17:45
2	28	52	4022	47	3724	38	3150	27	2337	15	1342	4	280													29710	6:14	17:46

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DATA INVENTORY

STA	YR		01	02	03	04	05	06	07	08	09	10	11	12	ANN
93193	52	A	0	0	0	0	0	0	496	438	414	372	348	310	2378
		B	0	0	0	0	0	0	0	0	0	0	0	0	0
		C	0	0	0	0	0	0	0	0	0	0	0	0	0
		D	0	0	0	0	0	0	0	0	0	0	0	0	0
		E	0	0	0	0	0	0	0	0	0	0	0	0	0
		F	0	0	0	0	0	0	496	431	410	372	345	310	2364
		G	0	0	0	0	0	0	496	438	414	372	349	310	2379
		H	0	0	0	0	0	0	0	4	0	22	8	0	34
		I	0	0	0	0	0	0	496	431	410	372	345	310	2364
		J	0	0	0	0	0	0	0	0	0	0	0	0	0
		K	0	0	0	0	0	0	493	433	406	372	332	310	2346
		L	0	0	0	0	0	0	744	744	720	744	720	744	4416
		M	0	0	0	0	0	0	744	744	720	744	720	744	4416
		N	0	0	0	0	0	0	744	744	720	744	720	744	4416
		O	0	0	0	0	0	0	744	744	720	744	720	744	4416
		P	0	0	0	0	0	0	744	744	720	744	720	744	4416
		Q	0	0	0	0	0	0	744	744	720	744	720	744	4416
93193	53	A	334	336	400	420	474	480	496	438	414	372	348	310	4822
		B	0	0	0	0	0	0	0	0	0	0	0	0	0
		C	0	0	0	0	0	0	0	0	0	0	0	0	0
		D	0	0	0	0	0	0	0	0	0	0	0	0	0
		E	0	0	0	0	0	0	0	0	0	0	0	0	0
		F	334	336	400	420	473	432	469	426	410	372	345	308	4725
		G	334	336	400	420	474	480	496	438	414	372	348	310	4822
		H	0	0	0	0	0	48	27	9	0	0	0	2	86
		I	334	336	400	420	473	432	469	426	410	372	345	308	4725
		J	0	0	0	0	0	0	0	0	0	0	0	0	0
		K	324	333	394	420	468	480	492	433	410	369	332	309	4764
		L	743	672	744	720	744	720	744	744	720	744	720	744	8759
		M	743	672	743	720	744	720	744	744	720	744	720	744	8758
		N	743	672	744	720	744	720	744	744	720	744	720	744	8759
		O	743	672	743	720	744	720	744	744	720	744	720	744	8758
		P	743	672	743	720	744	720	744	744	720	744	720	744	8758
		Q	744	672	744	720	744	720	744	744	720	744	720	744	8760
93193	54	A	334	336	400	420	474	480	496	438	414	372	348	310	4822
		B	0	0	0	0	0	0	0	0	0	0	0	0	0
		C	0	0	0	0	0	0	0	0	0	0	0	0	0
		D	0	0	0	0	0	0	0	0	0	0	0	0	0
		E	0	0	0	0	0	0	0	0	0	0	0	0	0
		F	334	336	400	420	465	479	496	434	410	366	343	310	4793
		G	334	336	400	420	474	480	496	438	414	372	348	310	4822
		H	0	0	0	0	8	1	0	0	0	7	2	0	18
		I	334	336	400	420	465	479	496	434	410	366	343	310	4793
		J	0	0	0	0	0	0	0	0	0	0	0	0	0
		K	330	332	392	417	466	478	488	431	410	371	335	308	4758
		L	744	672	744	720	744	720	744	744	719	743	720	744	8758
		M	744	672	744	720	744	720	744	744	720	743	720	744	8759
		N	744	672	744	720	744	720	744	744	720	743	720	744	8759
		O	744	672	744	720	744	720	744	744	720	743	720	744	8759
		P	744	672	744	720	744	720	744	744	720	743	720	744	8759
		Q	744	672	744	720	744	720	744	744	720	744	720	744	8760

A=ETR E=TILTED I=FIELD A M=DRY BULB Q=TOTAL OBSERVATIONS
B=DIRECT F=GLOBAL (OBSERVED) J=FIELD B N=DEW POINT
C=DIFFUSE G=GLOBAL (SYI CORRECTED) K=SUNSHINE O=WIND SPEED
D=NET H=GLOBAL (SYI - MODEL EST) L=SKY CONDITION P=TOTAL CLOUD

APPENDIX B

This appendix describes a procedure to evaluate solar radiation data interpolated for locations between solar radiation data recording stations. This procedure, or a similar one, will help reach decisions as to the density of a network to achieve required accuracies throughout the area of interest. The procedure presented here is only one of several techniques to study the spatial variation of solar radiation received at the surface of the earth. Work is continuing to improve and simplify this and similar procedures.

The concept of forecasting time-series events is not new. Almost any variable which is observable at discrete time points may be molded into a mathematical model which may closely resemble local-time-segment observations. Once a valid model for a time series process has been established, forecasting analysis may render useful service in predicting performance or examining system modifications.

Of particular interest are stationary processes. That is, those processess which have values fluctuating about a constant mean. These processes are unaffected by a shift of the time origin, and may be modeled by taking observations at equal time periods. Within a single given process, a correlation of these time observations (autocorrelation may appropriately be used) may allow construction of a predictive model for observations at specific time increments or time lags. As stated by Montgomery and Johnson:

> For a stationary time series the mean is just
>
> $$E(x_t) = E(m + \sum_{j=0}^{\infty} \psi_j \varepsilon_{t-j}) = m + E\sum_{j=0}^{\infty} \psi_j \varepsilon_{t-j}$$
>
> and since the sum $\sum_{j=0}^{\infty} \psi_j$ converges, we take expectation of $\sum_{j=0}^{\infty} \psi_j \varepsilon_{t-j}$ term by term, yielding $\sum_{j=0}^{\infty} \psi_j E(\varepsilon_{t-j})=0$. Thus the mean of the stationary series is
>
> $$E(x_t)=m$$
>
> The variance of the time series process is
>
> $$\gamma_0=V(x_t)=E[x_t - E(x_t)]^2$$
> $$=E[\sum_{j=0}^{\infty}\psi_j\varepsilon_{t-j}]^2$$
> $$=E[\sum_{j=0}^{\infty}\psi_j^2\varepsilon_{t-j}^2 + \text{cross products}]$$
>
> and since the $\{\varepsilon_i\}$ are independent, the cross products have zero expectation, yielding
>
> $$\gamma_0=\sigma_\varepsilon^2\sum_{j=0}^{\infty} \psi_j^2$$
>
> The variance exists only if $\sum_{j=0}^{\infty}\psi_j^2$ converges.
>
> The covariance between x_t and another observation separated by k units of time x_{t+k} is called "autocovariance" at lag k, and is defined as
>
> $$\gamma_k=Cov(x_t, x_{t+k})=E[x_t-E(x_t)][x_{t+k}-E(x_{t+k})]$$

Thus the autocovariance is just like the covariance of two random variables; the prefix "auto" merely implies that we are referring to the covariance of any two observations in a time series that are k time periods apart. It is not difficult to show that the autocovariance at lag k is

$$\gamma_k = \sigma_\varepsilon^2 \sum_{j=0} \psi_j \psi_{j+k}$$

Within the framework of the Box-Jenkins methodology, time series models are characterized by their autocorrelation functions. The correlation between two random variables, say W and Z, is defined as

$$\mu_{wz} = \frac{Cov(W,Z)}{\sqrt{V(W)\ V(Z)}}$$

Thus the autocorrelation at lag k refers to the correlation between any two observations in a time series that are k periods apart. That is,

$$\mu_k = \frac{Cov(x_t, x_{t+k})}{\sqrt{V(x_t) \cdot V(x_{t+k})}} = \frac{\gamma_0}{\gamma_1}$$

is the autocorrelation at lag k. A graphical display of μ_k versus lag k is called the autocorrelation function $\{\mu\}$ of the process. Notice that the autocorrelation function is dimensionless and that $-1<\mu_k<1$. Futhermore, $\mu_k = \mu_{-k}$; that is, the autocorrelation function is symmetric, so that it is necessary to consider only positive lags. In general, when observations k lags apart are close together in value, we would find μ_k close to 1.0. When a large observation at time t is followed by a small observation at time t+k, we would find μ_k close to -1.0. If there is little relationship between observations k lags apart, we would find μ_k approximately zero".[1]

The application of forecasting technique to seasonal actinometric data by L. S. Gandin is of particular interest in that Gandin computes autocorrelation coefficients of observational data for zero time lags. These correlation coefficients are then graphically displayed as a function of inter-station distance.[2] From his formula for interpolation error for square-grid-station networks, he then computes interpolation error:[3]

$$\varepsilon = 1 - \frac{4\mu^2\ (\rho/\sqrt{2})}{1 + 2\mu\rho + \mu\rho\sqrt{2} + n}$$

where:

n = the measure of observational error (the ratio of the mean square error to the variance of interpolated magnitudes here taken to be .25).

μ = the correlation coefficient of the station under scrutiny

ρ = the station-to-station distance or the area attributed to a single station within a square-grid network.

After errors have been computed for each station, they are plotted as a function of distance. Optimal inter-station distance may then be determined by calculating optimum interpolation error for the number of states within the data of interest,

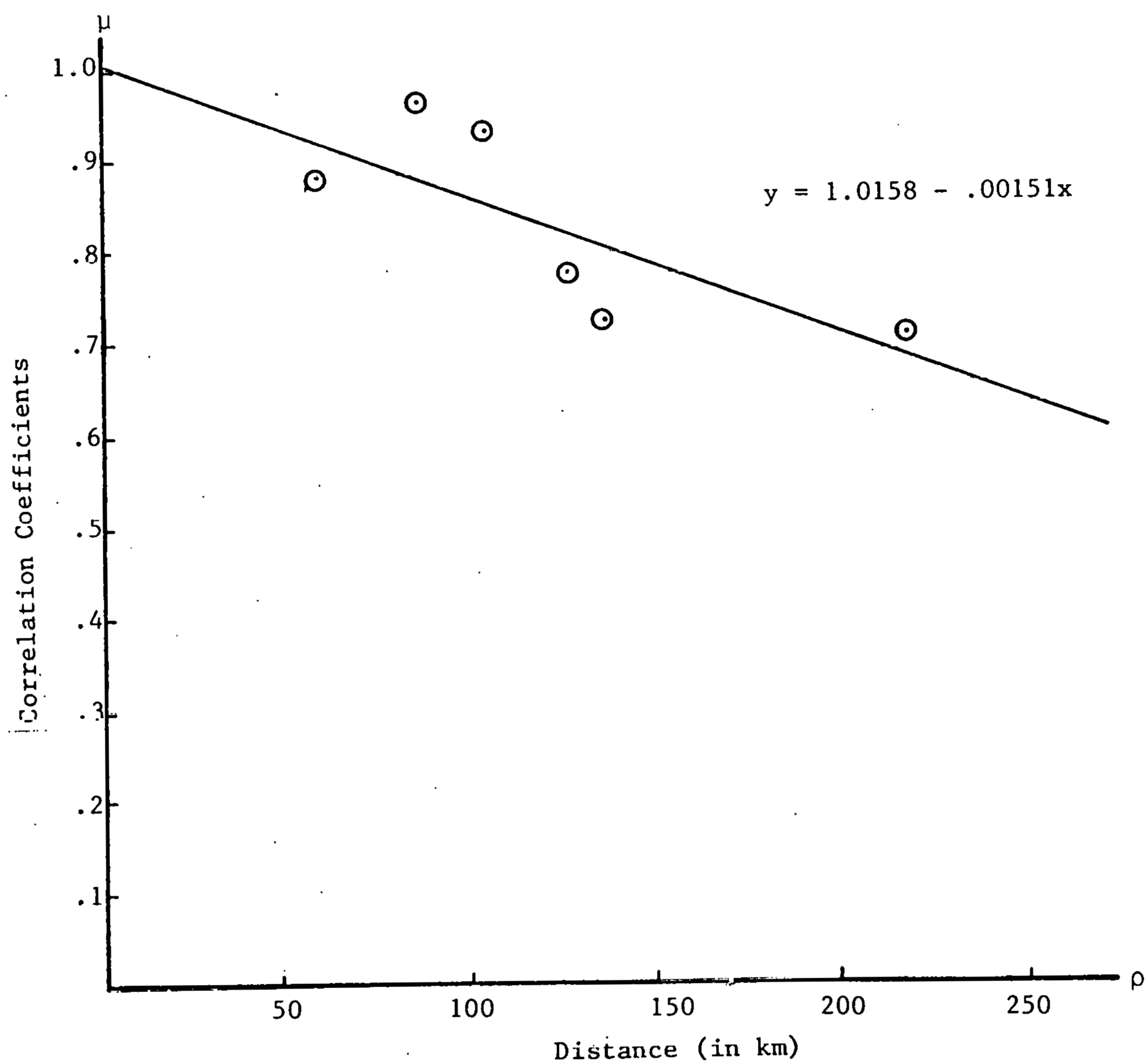
$$\varepsilon^* = \frac{1}{n^2} = .25 \text{ for } n = 2,$$

and reading the optimal inter-station distance from the graph.[4]

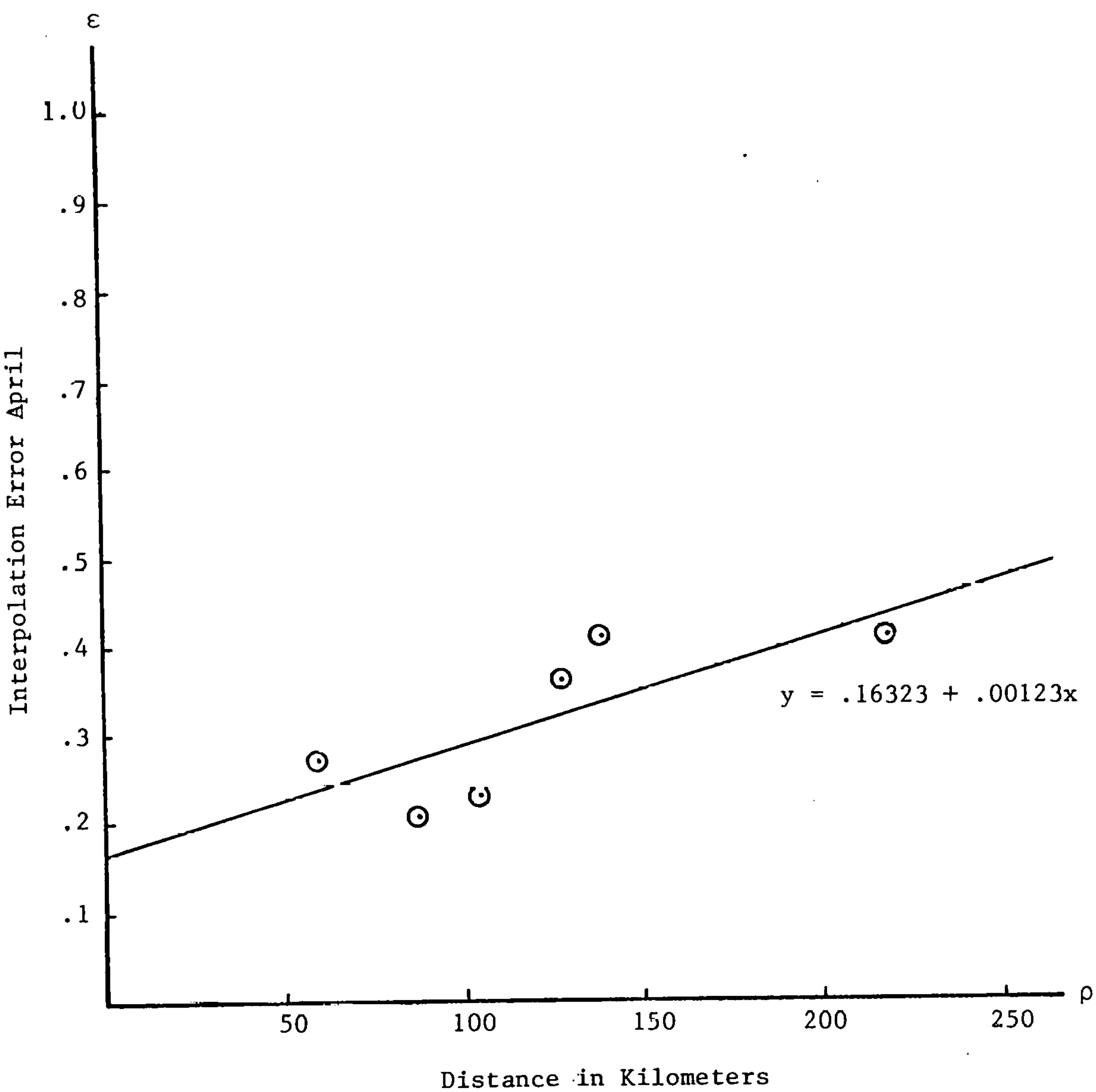
This analysis was duplicated for four actinometric stations in South Carolina. For 1970 seasonal data, individual months were examined ie. January, April and July. Analysis has yielded curves which are displayed as Graphs 1 and 2. For an optimal interpolation error of .25, the inter-station distance can be determined from Graph 2 to be approximately 75 kilometers.

Examination of Graphs 3 and 4 display Gandin's work in analyzing 48 stations within the Soviet Union. For an optimal interpolation error of .111, Gandin determines the inter-station distance to be 150 kilometers.

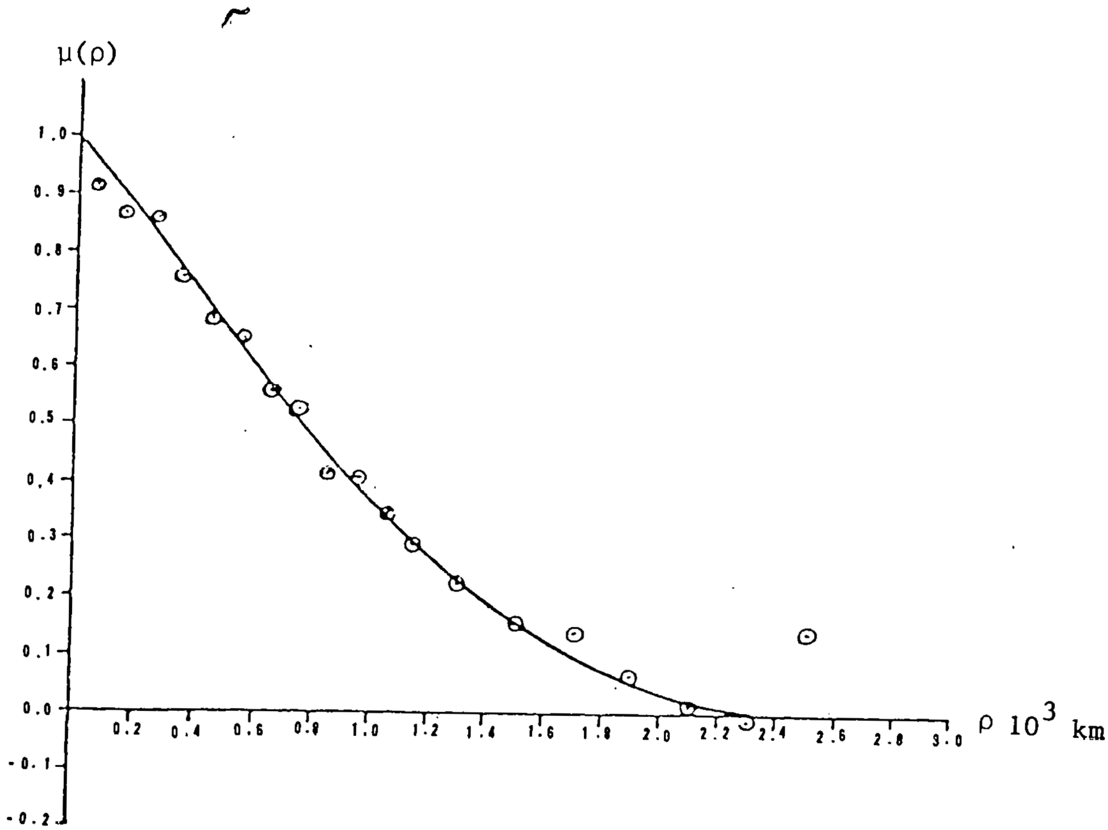
In comparison of a 4-station network with a 48-station network, it must be said that only a demonstration of Gandin's technique has been



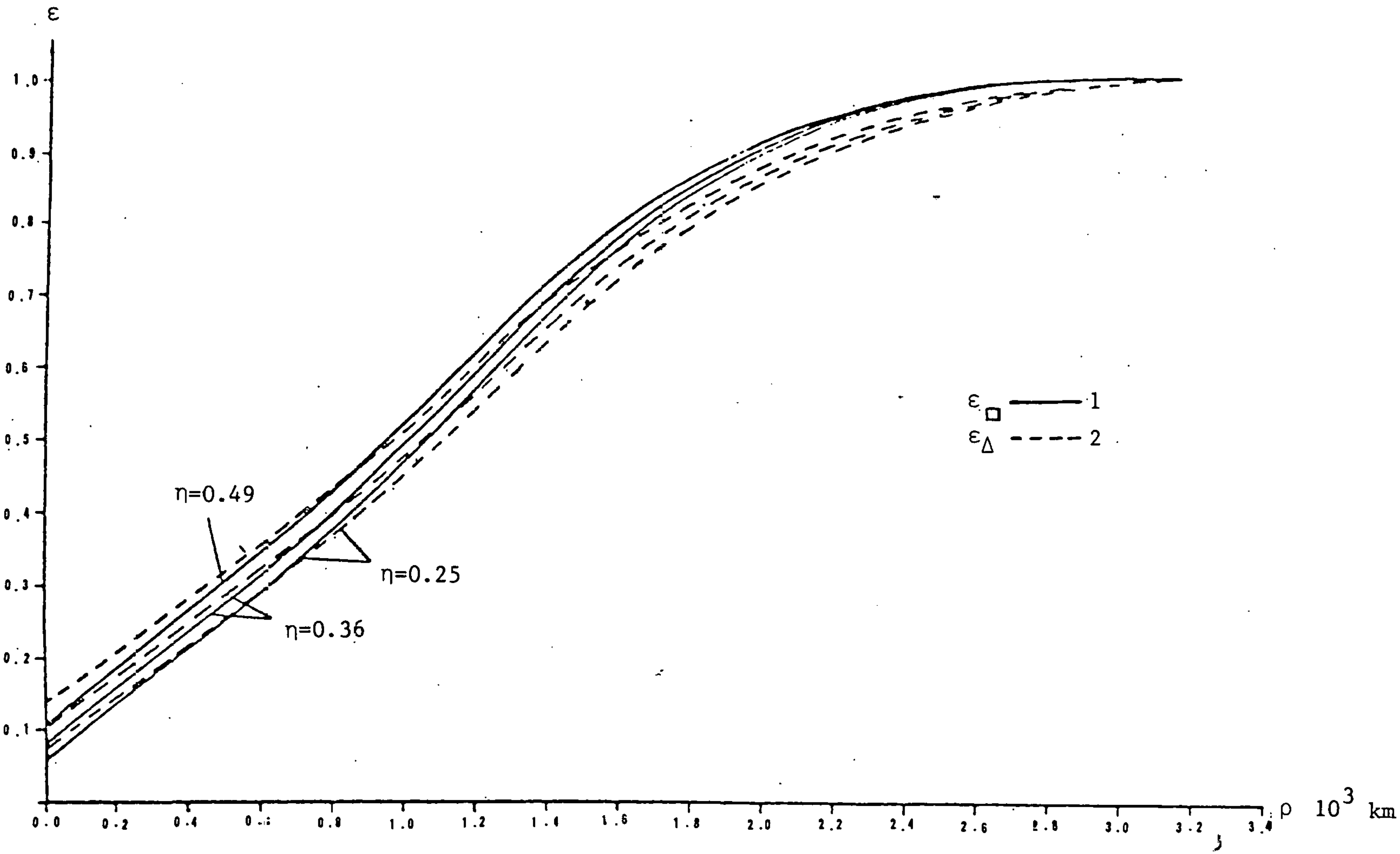
Graph 1 - Correlation Coefficients for Four Stations in South Carolina (April)



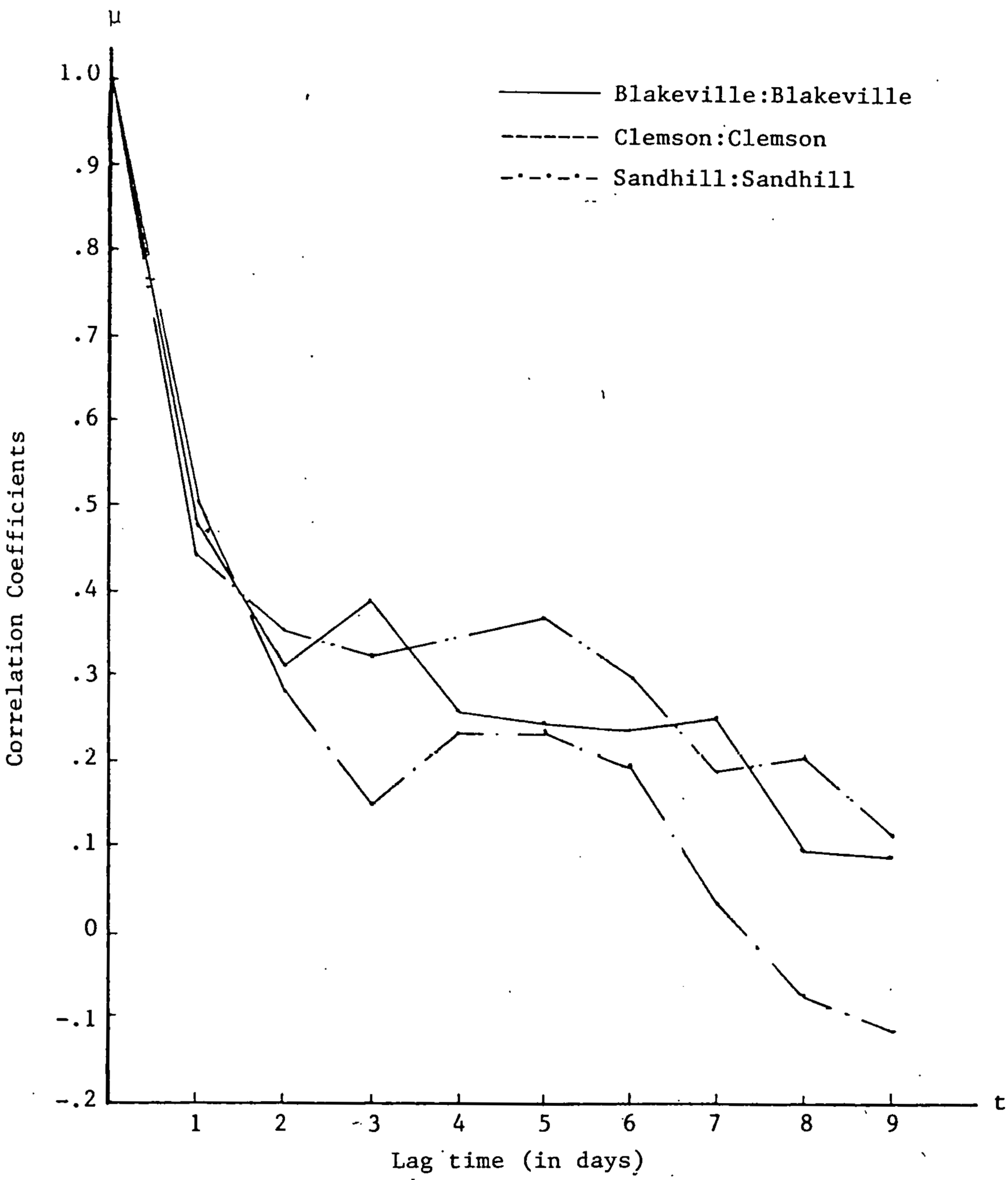
Graph 2 - Interpolation Error as a Function
of Inter-section distances



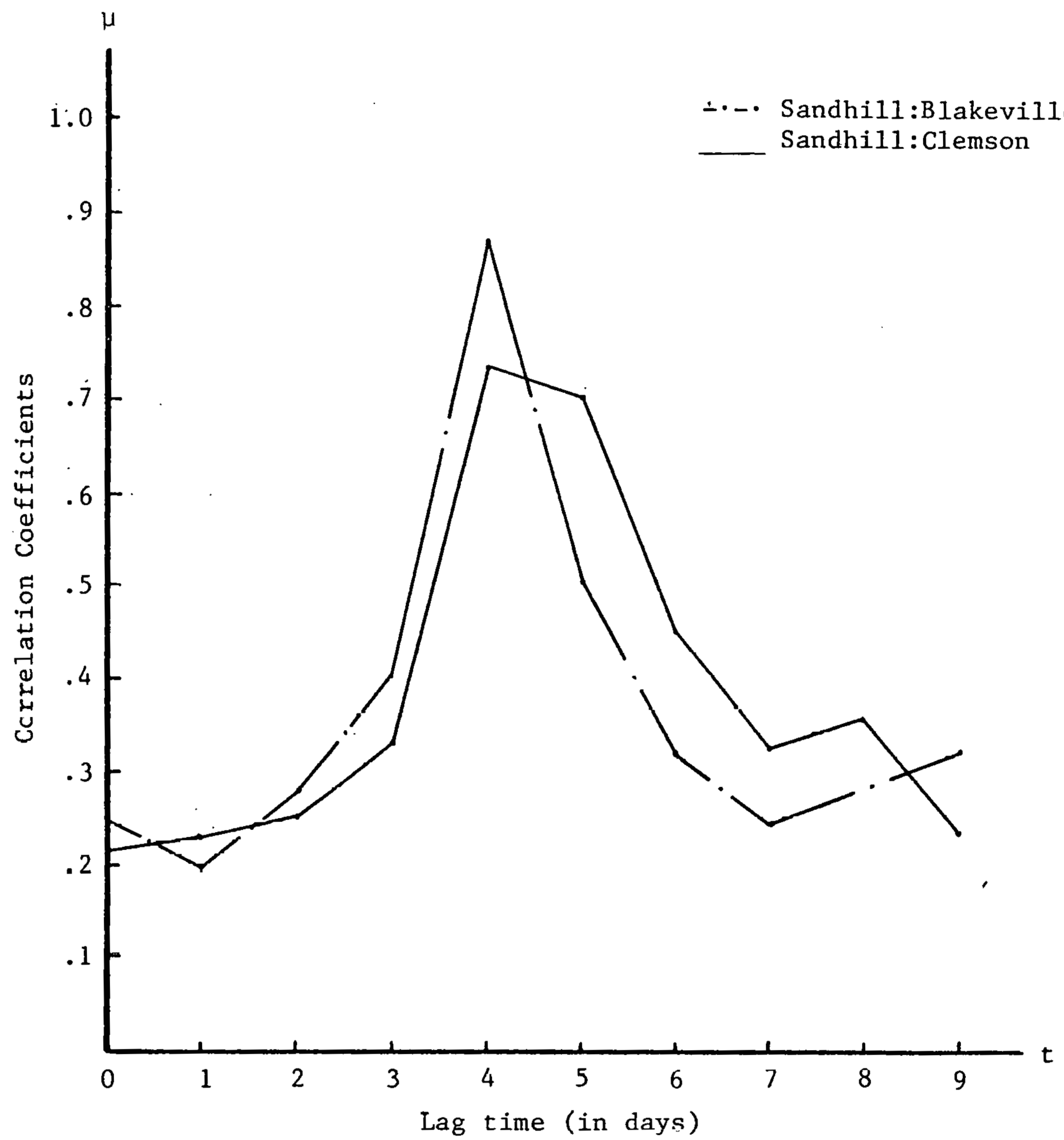
Graph 3 - Autocorrelation function of monthly totals of global radiation. Summer.



Graph 4 - The relationship of measure of optimum interpolation error in the center of square, $\varepsilon_{\square}$ and of triangle, ε_{Δ}, to ρ for different values of the measure of observation error η. Stations are supposed to be situated at the apices of the indicated squares and triangles.



Graph 5 - Autocorrelation of three
Stations in South Carolina



Graph 6 - Correlation of Data at Sandhill, S.C with Blakeville and Clemson, S.C.

attempted. Moreover, the least-square fit could not be presumed to overlay Gandin's curves exactly since the aerological contours of the regions are different and since the period of records are not the same. Also an optimal interpolation error value of .111 should be used to coincide with Gandin's network, if a true comparison were to be effective.

In conclusion, to further investigate this technique, data from a larger number of stations should be examined. This would create more data points for curve-fitting and would result in more meaningful results.

The purpose of explaining this procedure is to provide a first order approach for evaluating the value of solar radiation measurements interpolated to intermediate points. This will, in turn, help to evaluate or justify the need for additional data in the network area. Additional studies of this and other methods of determining optimum spacing of stations are in progress, and the reader is advised to seek the latest methods for determining the quality of interpolated data between stations.

[1] Montgomery, D. C. and L. A. Johnson, Forecasting and Time Series Analysis (1976), New York: McGraw-Hill Book Co., p. 190.

[2] Gandin, L. S., United Nations, Estimation of Maximum Permissable Distance Between Actinometric Stations, CCl - v/Doc. 30, Appendix B, World Meteorological Organization, p. 4.

[3] Gandin, L. S., United Nations, The Planning of Meteorological Station Networks, WMO - No. 265. TP. 149, World Meteorological Organization (1970), p. 13.

[4] Gandin, loc cit., p. 2.

APPENDIX C

This appendix describes procedures which may be used to analyze the data requirements of potential users of solar radiation data.

APPENDIX C

Data managers need to identify their actual program management and user requirements and a definition of overall systems criteria is also needed to assure that all program factors are carefully evaluated. Standardization of terms, the formats and the definitions for the data are likewise necessary to allow effective development of the overall system. Data users usually require rapid data gathering, handling and dissemination of the results of the program and the identification of necessary funds and expertise are required by both the data managers and user to allow maximum benefits from the program.

By evaluation of the user requirements of solar radiation data in more depth, the following needs become quite apparent during the initial design phases:

First, the user requirements must be defined by classifying and locating both the data and the users. The users of solar radiation data must be identified and procedures established to meet their requirements, not necessarily through the use of a new network program, but possibly by using alternate methods which should also be considered. If a new network is required, it should be evaluated on the basis of several considerations such as:

- availability of measuring sites and facilities
- availability of trained personnel
- prospects for continuous operation
- assessibility for routine maintenance
- cost effectiveness.

Thus, a definition of the potential interest and needs, the data volume requirements, the interface requirements and a cost and benefit analysis should be performed before proceeding with the development of a new network.

Analytical techniques to evaluate the user community should be developed and applied. These might include:

- direct user contacts through the use of meetings, telephone surveys, etc.
- questionnaires and surveys to identify actual needs
- categorization of the data requirements and the users
- publish availably data sources and currently available data for review and further refinement.

Several methods and related costs should be considered to disseminate the potential results of the network program. Handbooks, Data Users' Guides, computerized data bases and various other data storage and retrieval techniques should be compared before proceeding with the final network design.

It is also desirable that a systems analysis approach be made before proceeding with the final network design. Several discrete steps should be performed in order to perform this analysis. A statement of the need should be made as a clear statement of the goals and objectives for the program. Performance specifications should be described to meet the expected system output and to insure that the system is reliable. Related design specifications should likewise be developed to meet the proposed hardware and software requirements, the estimated cost of the system, and the proposed step-by-step schedule for overall development. Then the general feasibility of the network can be investigated, including the technical, economic, and institutional factors which will relate to user acceptance. Throughout the process, various changes and alternatives should be evaluated and, if possible, fed back into the original statement of goals, objectives and performance specifications. In this way, the overall systems analysis can be refined and, hopefully, the final output will be closely matched to the user needs. (See Figure 1.)

One obvious need from the work to date is for a document to describe various standards for solar radiation measurements, including a detailed description of site and instrumentation requirements, data acquisition requirements, quality control, dissemination techniques, and other measurement programs. In addition, the standardization of instrumentation mounts, connectors, etc., is also needed on a common basis.

A knowledgeable network manager will be required for any resulting network programs. This manager will need a broad background in solar radiation measuring instruments, and an awareness of present data that is available including the recording, processing, storing and retrieval techniques; the formats needed for summarizing the data; a background in cost management; and a dedication to continue the network operating procedures on a sustained basis. Finally, continuous review must be made of the costs and the potential results, as well as actual results, to assure that the network output continues to meet the user requirements at minimum justifiable costs.

<u>Methodology for Network Development</u>

The planning and development of an effective methodology for the development of solar radiation measuring networks requires the integration of particular sets of functions into the body of the methodology and an output which achieves the designated requirements and stated objectives. The output can be in the form of a flow diagram, a listing, or a matrix (or possible combinations of these), showing pertinent considerations for each functional element. Methodology is essentially a plan or projection of what is to be accomplished in order to reach valid goals and how it will be done. It must include the elements of:

- identifying and documenting needs
- selecting among the documented needs those of sufficient priority for action
- detailed specifications of outcomes or accomplishments to be achieved for each selected need
- identification of requirements for meeting each selected need, including specifications for eliminating the need by problem solving
- a sequence of outcomes required to meet the identified needs

FIGURE 1

PROCEDURE FOR NETWORK SYSTEMS ANALYSIS

1. STATEMENT OF NEED
    2. STATE GOALS AND OBJECTIVES
        3. STATE WHAT THE SYSTEM WILL DO
            4. PERFORMANCE SPECIFICATIONS
                - EXPECTED OUTPUT
                - REACTION TIMES
                - RELIABILITY
                5. DESIGN SPECIFICATIONS
                    - PROPOSED HARDWARE
                    - PROPOSED SOFTWARE
                    - COST OF SYSTEM
                    - SCHEDULES
                    6. GENERAL FEASIBILITY
                        - TECHNICAL
                        - ECONOMIC
                        - USER ACCEPTANCE
                        - INSTITUTIONAL FACTORS

ALTERNATIVES

CHANGES

- identification of possible alternative strategies and tools for accomplishing each requirement for meeting each need, including a listing of the advantages of each set of strategies and tools (methods and means).

Thus, the determination of what is to be done and the identification of requirements for doing it effectively and efficiently become the primary tasks of methodology development.

A systematic approach is necessary when planning and developing a viable methodology for locating solar radiation measuring stations and establishing related networks. Both the needs of the potential user and the current status and capabilities of measuring technology must be considered and evaluated to provide innovative design techniques and develop new program plans. Inherent problems and requirements for the desired system should be determined and discrete tasks and schedules developed for meeting the objectives of the planning effort. In addition, the priorities of potential users must be considered as well as the availability of any new technology. The methodology should then establish priorities and schedules, recognize and identify program barriers and their possible elimination, specify the resources needed for program development and operation, and establish, on a task basis, all steps involved in the total program. While applying a systems analysis approach, the classic feedback loop must also be administered if the effectiveness of the applied technology and resulting benefits are to be evaluated and measured.

The methodology that was developed to meet the objectives of this handbook required the consideration of a number of factors. Not only was it necessary to closely evaluate the multiple levels and fragmented structure of the solar radiation data user community; the varied capabilities, interest and potential activities of data supplying agencies also needs detailed investigation.

In order to incorporate the various considerations imposed on the basic methodology, a number of basic design factors should be assessed, including the following requirements:

- encourage participation by user community in the early planning phases of the program
- include a commitment by the network sponsor for full implementation
- develop operational elements that can interface and allow effective communication between the developer and the user
- adapt to rapid change and future modifications as they become apparent
- incorporate sampling, demonstration and simulation systems to develop interest and a demand from potential users
- identify common interests of potential users and potential funding sources to meet their respective objectives.

Application of Detailed Methodology

The following methodology is generalized in form but can accommodate a number of variable functions and inputs. Likewise, it can be broadly applied to meeting objectives and system requirements other than energy applications of solar radiation data. A diagram of the development approach for this methodology is shown in Figure 2. It is recommended that the network planner apply this methodology development plan and resulting methodologies to each user level. To assist this activity a description of each functional element in the methodology development is given below:

- Requirements and Objectives - This element applies to meeting the basic needs of the user, the design requirements of the methodology and the overall objectives of expanding network utilization. All aspects must be clearly stated and defined if a feasibly methodology is to be developed.

- Constraints - Policy, financial physical, situation, organizational and communication barriers must be considered among others, for both the "developer" and "user" in this element. Many of these types of barriers, apply to both the user community and the network developer. In the case of energy applications for the network, the financial and organizational barriers appear to be predominant.

- Capabilities - The capabilities element again applies to those of the developer and the user community. In addition, the interface function must also be evaluated for capabilities (as well as policies, etc.). Resources and new technological approaches are of paramount interest. And the network capabilities for educational and technology transfer applications should also be considered and, hopefully, expanded for broad dissemination.

- Statement of Approach - After considering detailed factors developed in the constraints and capabilities elements of the methodology, a statement of approach (and possible restatement of the basic objectives) is required. This provides a translation in suitable terms for the next analytical step.

- Develop Possible Methods - In this case, a listing of methods and techniques for network development should be evaluated for applications unique to the user's needs. Demonstration programs and the use of consultants, seminars, and meetings are examples of possible methods for aiding in the evaluation. In each case, prime consideration should be given to attaining the stated objectives.

- Screening and Selection Criteria - This key element requires careful analysis of such critical parameters as risk, cost-effectiveness, performance, and timing based largely on the establishment of priorities and the refinement of policy decisions. Constraints and methods of all types provide the basic inputs for consideration. This filtering process then allows application of the selected methods for further evaluation.

- Evaluate Selected Methods - The next requirement is a "trade-off" study which considers and compares the developed priorities of the selection process and identifies the methods and tasks to be implemented. From this evaluation, certain modifications to the

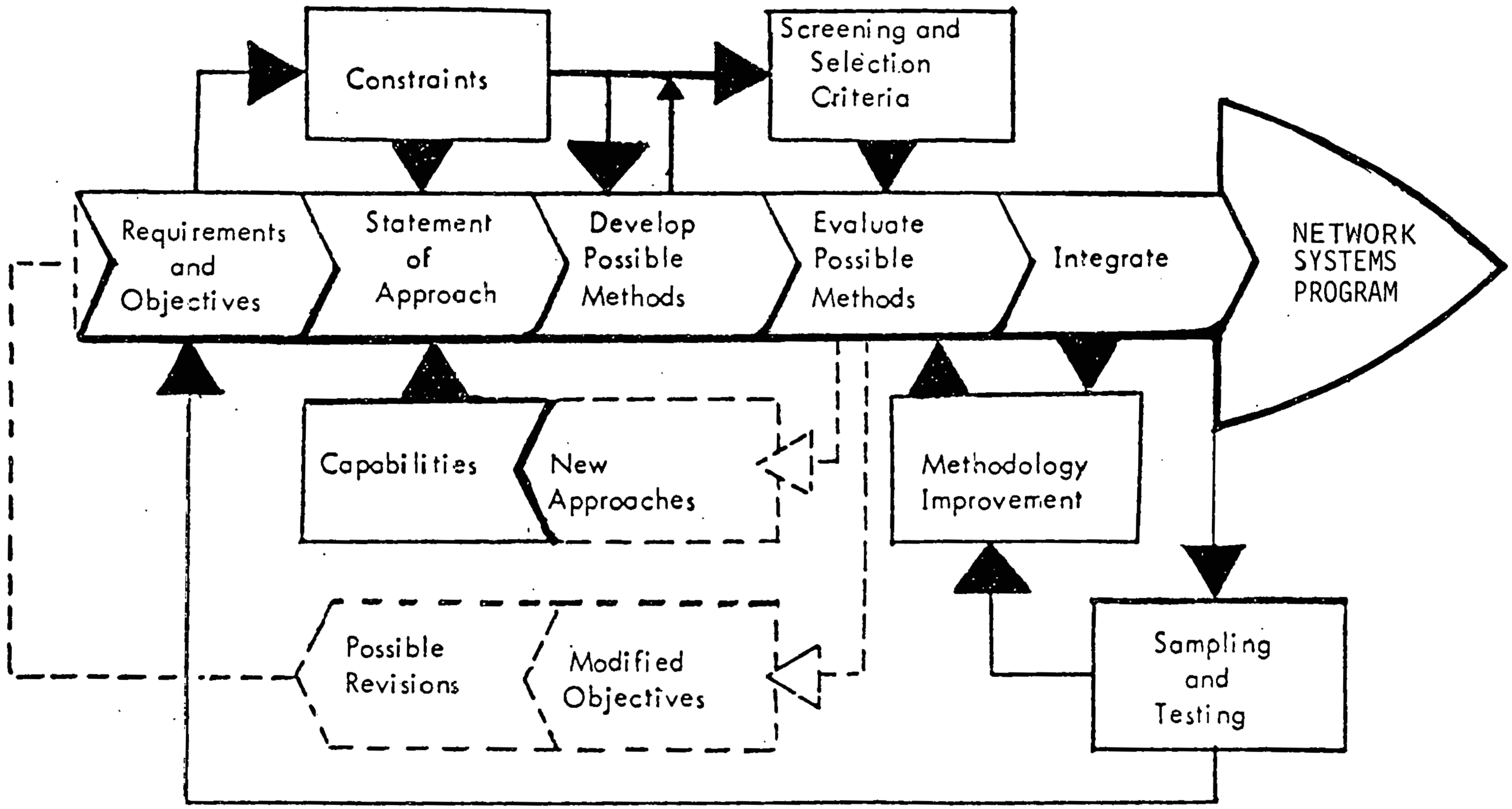


Figure 2 Overall Program Development for Network Systems

original objectives may become apparent and new approaches may evolve to refine the capabilities elements. Potential programs for expanding the utilization of the network at each user level would be identified by this stage and a tentative plan of action should be outlined to match the needs and interests of all parties involved.

- Integrate - In this most important element, synthesis would be performed to integrate the selected methods into a well-defined and functional program. A number of methodologies could be developed because of the diverse nature of both the user community and various potential applications for the network and because of the multiple facets of their interface in the operational mode. Likewise, alternate or "backup" methods may evolve or short term samples made to further refine the methodology prior to the display of its finally developed form.

- Sampling and Testing - A determination of effectiveness of the developed methodology should be made. A variety of sampling and testing methods will likely evolve, including the use of interviews, workshops, demonstrations, and questionnaires. By sampling and testing the developed methodology, improvements and refinements can be accomplished. Feedback loops to investigate the possibility of revising the original objectives or further refining the methodology should also be applied. Verification testing and other simulation programs could be developed which could also prove to be extremely useful for testing the operational system.

- Futures Analysis - Throughout the methodology development process, as shown in Figure 2, the futures context must be considered as the third dimension. Each element of the methodology has an alternate future. Particular attention must be given to potential changes in objectives, capabilities, and constraints among the developers, the users, and their interface functions. As an example of an important consideration for evaluating the user community, projections of network station changes based on shifts in solar energy activities must be carefully reviewed for related impact on all activities. The conclusions in this phase of the program should also consider future funding trends.

- Display of Output - The developed methodology for meeting a particular set of objectives and requirements may take a variety of forms. Usually, a flow diagram or matrix of some type is prepared to assist in communication and to more clearly show the flow of activities required and their relationships. A data bank or Management Information System (MIS) should also be developed to incorporate, maintain, and control the large number of possible considerations within each of the basic elements of the methodology. A typical methodology for the development of solar radiation data users might allow numerous methodologies which could be developed and displayed. However, it is essential that a clearer definition of the basic policy issues and "front-end" decisions be made. Otherwise, many false starts and unrealistic planning could evolve.

Applying the Methodology to Specific Network Programs

To apply the methodology process shown in Figure 2, a large number of discrete steps and evaluations must be made. A flow of information from the potential user to the network developer is needed to establish user needs, priorities, capabilities, constraints, resources, and other critical characteristics of interest. This information may come from many sources and the use of consultants having a direct working knowledge of solar radiation field will be essential to the task. Information flow from the network developer to the potential user is likewise a critical phase in applying the methodology. Proven methods used on related programs should be used and expanded where possible. New methods of dissemination are likewise needed to cross-link the network capabilities and the user community.

The next step in applying the methodology will require key decisions by the developer relating to stimulation of new applications from the network program. This step is a "chicken and egg" type of thing between perceived user requirements and a responsive concept to meet these requirements. Scenarios which clearly state potential user benefits can enhance this interaction and should be developed for this purpose.

During the course of early follow-on activities, preliminary flow charts which can display a methodology for a particular level of user application for the network should be developed. Also, sampling of the proposed methodology is needed by requesting comments from selected contacts made during the program. In this way, developed methodologies can be tested by an early review of their validity and content.

In summary, any developed methodology should at least address the following considerations:

- Long-range planning strategies
- Understanding of user needs and priorities (user description and justification)
- Technological assessment of the state-of-the-art at time of program operation
- Cost-effectiveness of selected methodologies compared to alternatives
- Program objectives clearly stated and related to overall strategies
- Pricing plan (cost of goods and services)
- Life cycle analysis
- Technical feasibility
- Alternate approaches
- Schedule of key events
- Implementation tasks
- Key management decision policy
- Clear communication channels
- Motivational aspects

APPENDIX D

Results of Appendix "C" may be translated into the network design requirements which can be met with the "Network Plan Worksheet" described in this appendix. Columns in the Network Planning Worksheet such as (2) solar radiation measuring equipment, (8) funding sources, and (9) personnel training requirements may need to be cross-referenced to more detailed plans for a sustained operation. A suggested coding is provided but may be modified to meet specific needs.

NETWORK PLAN WORKSHEET

(1) Station Number and location	(2) S.R. Measuring Equipment	(3) Data Acquisition Equipment	(4) Meas. Requirements	(5) Other Meteor. Measurements	(6) Data Collection Method	(7) Period Required	(8) Funding Source	(9) Personnel Train. Req.	(10) disposition of Data	(11) Users of the Data	(12) Other Comments

SUGGESTED CODES FOR NETWORK PLAN WORKSHEET

Column

(1) Station Number and Location (longitude, latitude, and elevation above MSL)..........

Allow one line for each type of solar-radiation data to be measured such as total horizontal, direct, diffuse or various tilt angles.

(2) Solar-Radiation Measuring Equipment..........

Identify the type of equipment to be used, including serial number, if known, and cross-reference to calibration and maintenance history.

(3) Data Acquisition Equipment..........

Show method of reading the measurements such as strip chart, electronic data acquisition etc.

(4) Measurement Requirements..........

Code: H - Hourly total radiation

D - Daily total radiation

M - Monthly total radiation

H,D or $M_{o_{xx}}$ - Tilted measurements, xx no. of deg. tilt

O - Other

(5) Other Meteorological Measurements..........

A_1 - Recorded on site

A_2 - Secured from nearby recording site (NWS)

A_3 - Other

Type of Measurements:

W_{sd} - Wind speed and direction

T - Temperature

T_H - Some humidity measurement

P - Pressure

O - Other

Column

(6) Data-Collection Method (from site to network management)...........

M_d - Mailed daily; w - weekly; m - monthly.

E_d - Electronic transmission daily; h - hourly.

(7) Period Required...........

Starting date and estimated ending date in month/year.

(8) Funding Source...........

Indicate source of funds and periods funds are available.

(9) Personnel Training Requirements...........

Indicate the initial and continuing training requirements for sustained operation.

(10) Disposition of the Data...........

S_m - Coded in SOLMET format and stored at NCC.

S_d - Coded in SOLDAY format and stored at NCC.

P_h - Published as hourly data; d - daily; m - monthly.

C_n - Consolidated as network data.

O - Other

(11) Users of the Data...........

Develop individual network code from survey of user requirements. One must avoid this as a catch-all. Each use must be justified and continue to meet criteria outlined elsewhere in this report.

(12) Other Comments...........

(Include reference to a detailed description of the site although there is not sufficient space on this form for the complete description).

APPENDIX E

This appendix briefly describes the environmental phenomena related to solar radiation measurements and the instruments used to measure the meteorological parameters. The site exposure requirements for the instruments and the accuracy requirements for the measurements are also listed.

APPENDIX E

ENVIRONMENTAL MEASUREMENTS RELATED TO SOLAR RADIATION MEASUREMENTS

SECTION

I. Meteorological Parameters Which are Important in the Development and Application of Solar Energy Systems

II. Extracts from Guide to Meteorological Instrument and Observing Practices, WMO (1971)

A. General and On Site Exposure Requirements for Mercury Barometers, Thermometers, Psychrometers, Wind Equipment and Sunshine Recorders

B. Summary of Accuracy Requirements for Surface Measurements

III. Extracts from Weather Bureau Observing Handbook No. 2, Substation Observations (1970)

On Site Exposure Requirements for Shelters and Precipitation Gauges

I - METEOROLOGICAL PARAMETERS WHICH ARE IMPORTANT IN THE DEVELOPMENT AND APPLICATION OF SOLAR ENERGY SYSTEMS

This discussion briefly describes the meteorological phenomena related to solar radiation and the standard measurement requirements for data to be compatible with other locations. Publications which explain in detail the methods of observing and recording meteorological phenomena are listed in the references.

The standards and requirements listed in this appendix might not be applicable when testing a given energy system at a particular site, but for comparative purposes with other sites, standard measurements, in addition to special testing measurements, should be taken. A summary of accuracy requirements for surface measurements from WMO (1971) is included in this appendix.

The listed meteorological measurements are necessary not only to evaluate effectively the solar radiation data but for their application to other energy projects. The use of solar energy is just evolving, and the meteorological parameters discussed in this appendix will play an important role not only in this evolution, but in the development of other energy sources.

1.0 TEMPERATURE

Temperature may be defined as a measure of the hotness or coldness of a body. The major concern, in relation to solar radiation measurements, is the temperature of the free air (ambient temperature) which is moving just above the surface of the earth. A height of between 1.25 and 2 m above ground is the level given by the World Meteorological Organization (WMO) (1971) to obtain the surface air temperature.

The measurement of the ambient temperature is a relatively simple procedure if the nature of the atmosphere is considered, as well as the fact that heat can flow to or from the sensor, which is the thermometer, by conduction, radiation and convection. Therefore, the sensor should be isolated from all heat and cold sources except the air, to obtain the true air temperature.

A shelter with a double top and louvered sides which permits air to circulate freely is the usual housing for a mechanical thermometer which can be liquid expansion, vapor pressure or a bimetallic strip. An electrical thermometer, resistance or thermocouple, normally is made with the proper housing as an integral part of the unit.

The ground over which the thermometer is located should be representative of the surrounding area. A detailed discussion of shelters including exposure and readings of maximum, minimum and regular liquid thermometers is given in the Weather Bureau Observing Handbook No. 2, Substation Observations (1970).

Very little maintenance is necessary for the mechanical thermometers except the sensors should be cleaned. The electrical type thermometers require routine maintenance and calibration and operations manual for the instrument in use should be followed.

The scale of temperature measurement generally used in most parts of the world is the Celsius scale (t^oC). The Celsuis scale in terms of the absolute thermodynamic Kelvin scale (T^oK) is given by the relationship $t^oC=T^oK - 273$ or the Celsius scale can be determined by an instrument, interpolating smoothly between the normal ice point (0^oC) and the normal boiling point of water (100^oC).

To convert from Celcius scale to Fahrenheit scale multiply degrees Celsius by 1.8 and add 32. Ambient air temperatures are generally recorded to tenths of degrees in the scale used. In the U. S. the Fahrenheit scale is still in use. Plans are underway to convert to the Celsius scale in 1978 but it may be many years before historical records and summaries are converted.

Summaries of temperature data are straightforward and may by grouped by hours, days, months, seasons or years. The average temperature for a day is accepted as the sum of the maximum and minimum temperatures divided by two.

The air temperature is an important meteorological parameter in most forms of energy conversion and in the application of energy. The temperatures applied often are the daily maximum and minimum temperatures which are used in the computation of heating and cooling degree days.

2.0 HUMIDITY

Water can exist in the atmosphere in three states; as liquid, ice and gas. Water in a gaseous state is called water vapor. The amount of water vapor in the air can be expressed in many terms; relative humidity, vapor pressure, dewpoint, wet bulb, absolute humidity, specific humidity and mixing ratio. If any one of the humidity values is known, along with ambient temperature and pressure, all others may be calculated.

The term most commonly used in relative humidity, which is the ratio, expressed as a percentage, of the amount of water vapor in the air to the amount of water vapor the air, under same pressure and temperature, could hold if it were saturated. When the word humidity is used alone, it is generally accepted to mean relative humidity.

Four general types of sensors are used to measure air humidity: psychrometers (thermodynamic method) hair hygrometers (method using the change in dimensions of hygroscopic substance, electrical resistance (method using the change in an absorptive substance), and dew or frostpoint hygrometers (condensation method).

Psychrometers and hair hygrometers are most widely used. Hair hygrometers are not generally as accurate as psychrometers. The general requirements for psychrometers as taken from WMO (1971) are listed in Section II-A.

Psychrometric calculators, nomograms, or psychrometric tables are used to obtain the relative humidity from known values of wet and dry-bulb temperatures. However, the calculators, nomograms, and tables have to be appropriate for the elevation of the observation site.

The hygrothermometer is used extensively for obtaining the dewpoint and ambient air temperatures. This instrumental system uses dial indicators or recorder traces and remote sensors as thermometers. A calculator or psychrometric table is used to obtain the relative humidity from values of dewpoint and ambient air temperatures indicated by the hygrothermometer.

Detailed observing and operational procedures for various psychrometers and hygrothermometers are given in <u>Federal Meteorological Handbook No. 1, Surface Observations (1970)</u>.

The same precaution should be taken with psychrometers and hygrometer as are taken with thermometers concerning shelter and exposure site, and maintenance is similar. The hygrometer should be cleaned at frequent intervals with distilled water and a soft, lint-free cloth.

The hygrothermometer requires weekly calibration checks which consist of comparing the readings with simultaneous values from a ventilated shelter-mounted psychrometer. The hygrothermometer also requires fairly frequent service which is described in its maintenance manual.

The amount of water vapor in the air (the humidity) determines to a large extent a person's comfort factor both in winter and summer. Humidity is related to heating and cooling systems not only in relation to a comfort factor, but also to condensation and evaporation, which depend on humidity and are a direct factor in many heating and cooling systems.

Water vapor plays a key role in the hydrologic cycle. Its molecular weight is 18 compared to the average molecular weight of air of about 28. Thus, evaporation near the surface of the earth results in water vapor rising and, with other atmospheric processes, transporting energy into the atmosphere. The energy is released as the water vapor condenses in the cooler air aloft.

Generally, summaries to determine the moisture from historical records are combinations of class intervals of temperature and the associated moisture value such as relative humidity or dewpoint classes.

3.0 WIND

The wind, movement of air, is the result of four forces; atmospheric pressure gradient, centrifugal, coriolis and frictional. But, the energy which produces the wind comes from the sun, either directly as uneven heating of the earth's surface or indirectly as condensation of water vapor.

Wind velocity, as defined by WMO (1971), is a three-dimensional vector quantity with small-scale random fluctuations in space and time superimposed upon a larger-scale organized flow.

Wind, as used in this section, is the horizontal motion of the air past a given point about 10 meters above open terrain. Open terrain is defined in WMO (1971) as an area where the distance between the anemometer and any obstruction is at least ten times the height of the obstruction. The vertical component is small compared to the others and is generally measured only for special studies. The absence of apparent motion of the air is termed "calm".

Wind direction is defined as the direction from which the wind is blowing and should be reported in degrees to the nearest ten degrees using an 01 . . . 36 code. For example, 36 will indicate a true north wind. The direction is determined by averaging the observed direction over a 1, 5 or 10 minute period. Of course, numerical averaging requires special treatment near 360 degrees.

Wind speed, the magnitude of motion of the air, should be reported in meters per second and should represent an average over a 1, 5 or 10 minute period.

The wind vane is the sensor for measuring wind direction. Middleton (1941) describes a wind vane as a body mounted unsymmetrically about a vertical axis, on which it is free to turn. The end offering the greatest resistance to motion of the air goes to leeward. The most satisfactory method of indicating the direction involves the use of self-synchronous motors, one at the transmitter (vane) and one at the receiver. Various types of recorders are used with the self-synchronous motors for continuous direction recordings.

The anemometer is the instrument for measuring wind speed. Middleton (1941) used the following classification for anemometers: rotation anemometers, pressure-plate anemometers, bridled anemometers, pressure tube anemometers and anemometers depending on cooling. In recent years more sensitive anemometers have been developed for special studies such as sonic anemometers which detect the variations in the transmission of sound waves due to wind and thus provide a measure of the wind.

The cup and propeller of the rotating type anemometer are most commonly used and consist of two subassemblies, the rotor and the signal generator. A large number of signal generators are available and the choice is largely a matter of the type of data processor and readout used.

The WMO (1971) lists the attainable and satisfactory characteristics for wind speed sensors as: range, 1 to 50 m/s; linearity, ± 0.5 m/s; distance constant, 2 to 5 m. The distance constant varies directly as the moment of inertia of the rotor, inversely as the air density and depends in addition on a number of geometric factors as indicated by MacCready and Jex (1964).

The maintenance and calibration of the wind sensors will depend on the system in use. Normally, very little maintenance is required on the direction sensor and a frequent visual check can be made on wind direction and compared with the direction dial or recording.

The maintenance and calibration procedures in the operations manual of the particular wind speed sensor used should be followed. Usually if there are several indicators on the system and a retransmitter is used, the indicators should be calibrated monthly.

The wind direction and speed are important parameters in many energy applications. The prevailing wind directions in summer and winter are factors to consider in locating and orienting a building. The design could diminish the effect of the cold winds and use to advantage the winds of summer. The wind speed is a major factor if a cooling tower, evaporation or drying process is involved in the energy application. The average wind speed, the frequency of wind speed in various class intervals, and the extreme wind are the primary considerations in the design of wind power systems.

In the United States wind speed is recorded to the nearest whole mile per hour for a five minute average preceding the time of observation. In the metric system meters per second are used. Plans are to convert to the metric system in the U. S. by 1979.

Wind speed is generally summarized by the frequency of occurrence in various class intervals. These class interval summaries are directly applicable for computing power in the wind. Extreme wind speeds are frequently studied by the application of statistical extremal theory in order to evaluate the return period and probability of occurrence of destructive winds in 5, 10, 50, or 100 years.

Wind direction is much more complex to present in summaries. Combinations of wind directions and speeds are generally presented in "wind roses" - a specially constructed circular graph. A complete explanation is beyond the scope of this paper and one should consult a meteorologist for studies of wind direction and wind gusts.

4.0 OTHER PARAMETERS

The following meteorological measurements are used mainly for the evaluation and application of solar radiation data.

4.1 CLOUDS

The amout of the sky that is covered with clouds is referred to in this section as cloudiness. The Federal Meteorological Handbook No. 1, Surface Observations (1970) expresses this value in tenths, and WMO (1971) recommends that a scale of eights be used for cloud amounts. The clouds do not have to be opaque.

There are three general types of clouds: cumulus, stratus and cirrus. The cumulus type is composed generally of larger drops of water and has clearly defined edges. The stratus type is composed of smaller water droplets and the edges are ill-defined and diffused. The average volume-median drop diameter is near 21 μ for cumulus type and near 15 μ for stratus type clouds according to Houghton, (1951). The cirrus type are high clouds composed of ice crystals.

If a cloud touches the surface of the earth, it is called fog. For a complete description of cloud forms see WMO International Cloud Atlas (1956).

The major obstacle in depleting the solar beam is the cloudiness. Therefore, a gross estimate of cloudiness can be made from solar radiation measurements and vice-versa. A sunshine recorder can be used also to obtain a gross estimate of the amount of cloudiness. The sensitivity of a sunshine recorder is set generally so that no sunshine is recorded if an object does not cast a clearly definable shadow. Other instruments have been developed which give an estimate of the cloudiness, but at present the only practical means of obtaining the cloudiness is by visual observations.

The heights of the clouds can be obtained by several methods: aircraft reports, timing the ascent of a balloon into the base of a cloud when the ascensional rate of the balloon is known, radar, estimating and by reflecting a light from the base of the cloud to a hand held instrument or electronically obtaining an angle measurement and computing the base of the cloud by triangulation. The held instrument can be used only during nighttime. The electronic instrument used to obtain cloud heights by reflecting a light from the base of clouds is called a ceilometer and is the most practical method.

The height of the clouds is recorded in dekameters (tens of meters) and if cloudiness covers over one-half of the sky and is opaque, the height is referred to as the ceiling. When the clouds are composed of layers, the ceiling is the base of the highest layer which gives a total of over one-half when added to the lower layers. At present in the U. S., cloud heights and ceiling are reported to the nearest hundred feet up to 5,000 ft., and to the nearest 500 ft. from 5,000 to 10,000 ft. and to the nearest 1,000 ft. above 10,000 ft. (Conversion to the metric system is scheduled to be completed by January. 1979.)

4.2 PRECIPITATION

Precipitation is water which falls to the earth in the form of a liquid (rain or drizzle) or solid (snow, snow pellets, snow grains, ice pellets, hail or ice crystals) or freezes upon impact with the ground (freezing rain, freezing drizzle, rime or glaze).

It is interesting to note in comparing cloud droplets with raindrop size that the average raindrop diameter in light rain is near 1.3 mm and in heavy rain near 2.0 mm. Seldom will raindrops over 6 mm occur as the rate of fall breaks these large drops into smaller ones, according to Daniels, (1976).

Measurements are made of the vertical depth of the water or water equivalent (liquid content) of all forms of solid precipitation which fall to the ground during a known period of time. The WMO (1971) recommends that the amount of precipitation be measured in millimeters, to the nearest 0.2 mm if the amount is 10 mm or less. Larger amounts of precipitation should be read to two percent of the total. Precipitation in the U. S. has been measured in inches and hundreths. Precipitation less than 0.005 inch is recorded as a trace. Snowfall is also measured by the depth of fresh snow covering a horizontal surface. The depth of snow is measured in centimeters. One centimeter of fresh snow is equivalent to one millimeter of rainfall. This is a rough approximation as the ratio depends on the texture of the snow.

Precipitation gauges consist essentially of an open cylinder having a fairly sharp upper edge and provided with means for collecting and measuring all precipitation falling into it.

For non-recording gauges, it is necessary to know the area of the receiver and to have a collector with a dip rod of the proper graduation to obtain the depth or amount of precipitation. It is also possible to measure the precipitation by weighing.

Recording gauges can be divided into two main classes: those that record the total amount of precipitation which has fallen since the time the record started, and those that record the intensity of the rainfall at any instant.

Recording precipitation gauges can be classified into float, tipping bucket, and weighing types.

An extract from Weather Bureau Observing Handbook No. 2, Substation Observations (1970) concerning the exposure of precipitation gauges is included in Section III.

Precipitation changes the albedo of the surrounding area and thereby affects the terrestrial and solar radiation, especially if the precipitation deposited a blanket of snow and cloudiness is in the area.

4.3 ATMOSPHERIC PRESSURE

Atmospheric pressure is the weight of a vertical column of air, of unit area, extending to the outer limit of the atmosphere. Atmospheric pressure can be measured by mercury barometers, aneroid barometers, or hypsometers. Hypsometers depend on the relationship between the boiling point of a liquid and the atmospheric pressure and have been of only limited application. The mercury barometer is the most accurate instrument for measuring atmospheric pressure, but the aneroid barometer has the advantage of portability and convenience. The aneroid barometer reading should be compared frequently with the reading from the mercury barometer, and the mercury barometer should be compared with a standard mercury barometer or another mercury barometer in the area semi-annually.

The WMO (1971) recommends that the millibar (mb) be used for reporting pressure for meteorological purposes, and the millibar which is equal to 1000 dynes/cm^2 has been used by meteorologists. However, if the International System of Units (SI) is used, the pressure should be reported in millimeters of mercury (mm Hg) or Pascals. A Pascal is equal to a Newton/m^2. The National Weather Service plans to convert to the reporting of pressure in kilopascals (kPa) and hundredths by 1979.

A kilopascal is equal to 10 mb, and a millibar is equal to 0.750062 mm Hg or 0.029530 in Hg under standard conditions. Standard atmospheric pressure at sea-level is considered to be 1013.2 mb, 29.92 in Hg, 760.0 mm Hg, or 101.32 kPa.

Details on the proper maintenance and reading of barometers are given in the Federal Meteorological Handbook No. 1, Surface Observations (1970).

As the solar beam enters the atmosphere it is depleted by scattering, reflection, and absorption. Therefore, the atmospheric pressure at a particular location is an important factor in determining the amount of atmosphere the solar beam has to penetrate before striking an object at the surface of the earth.

Atmospheric pressure is generally converted to a hypothetical sea-level pressure for synoptic comparison with other stations and to support aircraft operations. For solar energy applications the atmospheric pressure at the station (station pressure) is more valuable and should be used in computations.

4.4 VISIBILITY

Visibility, as used here, is defined as the greatest distance an object can be identified when observed against a background of sky or fog. At night, the visibility is defined as the greatest distance stationary lights of moderate intensity unfocused can be identified. Prevailing visibility as defined in Federal Meteorological Handbook No. 1 (1970) is the greatest horizontal visibility prevailing throughout at least half of the horizontal circle which need not necessarily be continuous.

In the metric system visibility is reported in kilometers and hectometers (hundreds of meters). Until 1979 visibility in the U. S. will be reported in miles with certain fractions of miles if the visibility is less than three miles.

In 1957, the WMO recommended the adoption of a new measure of the optical state of the atmosphere, the meteorological optical range (MOR), defined as:

> The meteorological optical range is the length of path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp at a colour temperature of 2700°K to 0.05 of its original value, the luminous flux being evaluated by means of the photopic luminosity function of the international commission on illumination (CIE), WMO (1971).

The photopic state is defined as the visual response of a normally sighted observer to the stimulus of light incident on the retinal fovea.

MOR would then be reported in luminous flux, luminous intensity, luminance, and illumination with the adoption of this recommendation.

The most practical means of obtaining the prevailing visibility is by visual observations. But, for nighttime measurements or if suitable visibility objects are not present or the visibility is required in a specific sector, an instrument for visibility measurements would be more practical. A visibility instrument either measures the attenuation or extinction coefficient of a long column of air or measures the scattering of light from a small volume of air. The visibility instrument most commonly used in the transmissometer which measures the decrease in brightness of the beam from a small projector at a distance of a few hundred meters by means of a photo-electric device placed at the focus of a condensing lens. This type of instrument requires frequent checks and calibration. Also, a television camera and receiver can be used to observe special reference lights.

Visibility measurements are valuable in evaluating solar radiation data from stations which have no measurements of the transparency of the atmosphere to solar radiation, that is, transmittance, turbidity or clearness factor. The computation of the decrease in the solar beam as it penetrates the atmosphere is very complex. One of the factors in this depletion is atmospheric pollution, and the visibility gives a gross estimate of the impurities in the atmosphere.

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II-A EXTRACT FROM GUIDE TO METEOROLOGICAL INSTRUMENT AND OBSERVING PRACTICES

(WMO Report No. 8., TP. 3, 1971)
"ON SITE EXPOSURE REQUIREMENTS"

1.0 GENERAL

The nature of the exposure of meteorological instruments is a significant factor in the measurement of some meteorological elements and, therefore, in order that observations at different stations may be comparable, the exposures must be similar. A plat of level ground 9m by 6m and covered with short grass is satisfactory for the outdoor temperature and humidity-sensing instruments provided it is suitably sited. It should be away from the immediate influence of trees and buildings and in such a position as to afford a fair representation of surrounding conditions. The station should, as far as practicable, not be upon, or close to, steep slopes, ridges, cliffs, or hollows. It is also important to avoid the immediate vicinity of large buildings. An exception is made in the case of precipitation measuring instruments, which require a suitable distribution of trees and shrubs or equivalent to serve as a wind break without creating objectionable turbulence.

2.0 MERCURY BAROMETERS

It is important that the location of the barometer at a station be selected with great care. The major requirements of the place of exposure are uniform temperature, good light, a solid vertical mounting, and protection against rough handling. The instrument should therefore be hung or placed in a room in which the temperature is constant or changes only slowly and in which gradients of temperature do not occur. It should be shielded from direct sunshine at all times and should not be placed near any heating apparatus nor where there is a draught. It is always preferable to hang the mercury barometer on an inside wall.

A stratification of temperature is often found in a room which is otherwise suitable; the top of the mercury column of the barometer may then be as much as two or three degrees warmer than the cistern. For very accurate work the best position would be in a windowless, unheated basement room with a small electric fan to prevent any stratification of temperature.

In order to obtain uniform conditions for reading the barometer, it is advisable to use artificial lighting for all observations. For this purpose an illuminator, which provides a white and slightly luminous background for the mercury meniscus and, if necessary, for the fiducial point, is indicated. If no illuminator is used, care should be taken that the meniscus and the fiducial point are provided with a light background, by means of pieces of mild glass, or a sheet of white paper or plastic. Artificial light should also be provided for reading the barometer scale and the attached thermometer. However, care should be taken to guard against heating of the barometer by the artificial light during a barometer reading.

The barometer should be mounted in a place where it is not subjected to vibration, preferably on a solid wall. The instrument must be exactly vertical. Errors due to departure from verticality are more important in the case of unsymmetrical barometers. Such a barometer should be mounted with its axis of rotation vertical, which can be done by mounting the instrument so that a true setting of the mercury surface to the fiducial point remains correct after rotation of the barometer through any angle.

To protect the barometer from rough handling, dust and air currents, it is recommended that the instrument be placed in a box with a hinged door. A barometer will not give a true reading of the static pressure if it is influenced by a gusty wind; and its reading will fluctuate with the wind speed and direction, the magnitude and sign of the fluctuations, depending also on the nature of the openings of the room and their position in relation to the direction of the wind. At sea, the error is always present due to the ship's motion. A similar problem arises if the barometer is installed in an air-conditioned room.

It is possible to overcome this effect to a large extent by making the cistern of the barometer air-tight except for a lead to a special "head" exposed to the atmosphere and designed to ensure that the pressure inside it is the true static pressure.

All of these requirements apply to aneroid barometers as well.

3.0 THERMOMETER, GENERAL REQUIREMENTS

To give a representative reading of the air temperature, thermometers should be protected from radiation from the sun, sky, earth and any surrounding objects but at the same time they must be adequately ventilated The two methods of protection now in general use are the louvered thermometer screen, and the polished metal shields used in the Assman psychrometer. In either case the equipment should be installed to ensure that the measurements are representative of the free air circulating in the locality and not influenced by artificial conditions such as large buildings and expanses of concrete or tarmac. As far as possible the soil cover beneath the instruments should be short grass or the natural earth surface of the area.

4.0 PSYCHROMETERS, GENERAL REQUIREMENTS

Equipment used for psychrometric observations should, as far as practicable, conform with the following recommendations:

- The wet and dry bulbs should be ventilated and protected from radiation by a minimum of two polished unpainted metal shields which are separated from the rest of the apparatus by insulating materials or by a louvered screen and one polished metal shield.

- At sea-level, air should be drawn past the bulbs at a rate not less than 2.5m/sec and not greater than 10 m/sec if the thermometers are of the types ordinarily used at meteorological stations. For appreciably different altitudes, these air-speed limits should be adjusted in inverse proportion to the density of the atmosphere.

- Separate duct should be provided for the two thermometers.

- If the louvered screen is used, the entrance of the ducts should be located to give the true ambient temperature, and the air should be delivered above the screen to prevent recirculation.

- The greatest care should be taken to prevent significant amounts of heat from a motor being transmitted to the thermometers.

- The water reservoir and wick should be arranged so that the water will arrive at the bulb with sensibly the wet-bulb temperature.

- Measurements should be taken at a height between 1.25 and 2 m above ground level.

To obtain high accuracy with psychrometers, it is desirable to arrange for the wet and dry bulbs to have approximately the same lag coefficient. With thermometers having the same size of bulb, the wet bulb has an appreciably smaller lag than the dry bulb. The fabric covering the wet bulb should be a good fit round the bulb, and extended at least two cm beyond it.

5.0 WIND EQUIPMENT

The standard exposure of wind instruments over level, open terrain is 10 m above the ground.

Where a standard exposure is unobtainable, the anemometer should be installed at a height where its indications are reasonably unaffected by local obstructions and represent as far as possible what the wind at 10 m would be if there were no obstructions. This practice will usually necessitate placing the anemometer at a height exceeding 10 m by an amount depending on the extent, height, and distance of the obstructions, but general rules are impracticable because local conditions differ widely.

Special precautions must be taken to keep the wind equipment free from sleet and ice accumulations. In some localities it may be desirable to provide some form of artificial heating for the exposed parts. Sleet and ice shields have been designed for particular types of wind equipment.

6.0 SUNSHINE RECORDERS

Two essentials for correct exposure of sunshine recorders are that the site should provide an uninterrupted view of the sun at all times of the year when it is above the horizon and that the recorder should be firmly fixed to a rigid support. With regard to the former, since sunshine is rarely bright enough to be recorded when the sun's altitude is less than three degrees, obstructions subtending less than this angle vertically can be disregarded. Where a satisfactory exposure cannot be obtained at ground level, it is desirable to install the recorder on the roof of a building. To determine the effect produced by obstructions, a survey should be made of their bearings, elevations, and angular widths. The amount of possible sunshine they would cut off can then be calculated by the methods of spherical trigonometry.

II-B - Summary of Accuracy Requirements for Surface Measurements

Element	*Climatology*	*Aeronautical meteorology* §	*Synoptic meteorology*	*Maritime meteorology*	*Hydrometeorology*	*Agricultural meteorology*
I. *Cloud*						
1. Cloud amount	$\pm^1/_8$ or $\pm^1/_{10}$	• $\pm^1/_8$	$\pm^1/_{10}$	—	—	—
2. Height of cloud base	• ±30 m up to 1 500 m ±300 m from 1 500 m to 9 000 m ±1 500 m from 9 000 m to 21 000	• ±15 m up to 150 m ±10 % from 150 m to 300 m ±20 % above 300 m	+ ±10 m up to 100 m +10 % above 100 m	—	—	—
3. Direction of cloud movement	—	—	• ±10°	—	—	—
II. *Atmospheric pressure*						
1. Pressure	§ ±0.3 mb	±0.5 mb	±0.1 mb	+ ±0.1 mb	—	—
2. Tendency	—	—	× ±0.2 mb	• ±0.2 mb	—	—
III. *Temperature*			§			
1. Dry bulb temperature	× ±0.1°C	× ±1.0°C	±0.1°C	±0.1°C	—	+ ±0.1°C
2. Extremes	±0.5°C	—	±0.5°C	—	—	±0.5°C
3. Sea surface temperature	0.2°C	—	±0.1°C	±0.1°C	—	—
IV. *Humidity*			§			
1. Wet bulb temperature	× ±0.1°C	—	±0.1°C	—	—	•—
2. Relative humidity	× ±3 %	—	±5 % up to 50 % ±2 % above 50 %	—	—	±1 %
3. Dew point	±0.5°C	+ ±1°C	—	±0.1°C	—	±0.1°C
4. Vapour pressure	±0.2 mb	—	—	—	—	[illegible]

Climatology:

• A mean value of one minute is needed.

§ The value is to be obtained from a single reading.

× The minimum lag of the sensor for all temperature and humidity measurements is to be such that not more than 90% of a change which is equal to the required accuracy is indicated in 3 minutes.

Aeronautical meteorology:

§ Aeronautical requirements for meteorological observations for take-off and landing and accuracy attainable appear in more detail in Attachment G, Chapter 12, Technical Regulations.

• Observations to be representative of (*a*) ILS middle marker site, or (*b*) Final approach, initial missed approach, circling approach and landing area.

× Observations to be representative of the whole runway (at average height of turbine-en-gined aircraft).

+ Observations to be representative of the whole runway (for piston-en-gined aircraft as required).

Synoptic meteorology:

+ Mean values over 1 minute are required but means of 5 individual values taken at 1 minute intervals would be acceptable.

• Instantaneous value is required.

× Difference between two instantaneous measurements of pressure.

§ All temperature and humidity measurements are to be instantaneous *in the sense that this is* the time required for taking an observation.

Maritime meteorology:

+ An instantaneous value is required but the instrument is to be sufficiently damped to provide a value within the required accuracy.

• The difference between two such values obtained as above.

Agricultural meteorology:

+ The minimum lag of the sensors for temperature measurement are to be such that not more than 90% of a change equal to the required accuracy will be indicated in 1 minute. Sampling errors are considered to exceed instrument errors.

• Required to be of sufficient accuracy to give stated relative humidity accuracy.

× Equivalent to ±0.1°C in dew point.

II-B (continued)

Element	*Climatology*	*Aeronautical meteorology*	*Synoptic meteorology*	*Maritime meteorology*	*Hydrometeorology*	*Agricultural meteorology*
V. *Wind*	*		+			
1. Direction	$\pm 10°$	* $\pm 10°$	$\pm 5°$	+ $\pm 5°$	—	* $\pm 10°$
2. Speed	± 0.5 m s^{-1}	—	* ± 0.5 m s^{-1} up to 5 m/s ± 10 % above 5 m s^{-1}	+ ± 1 kt up to 20 kt + ± 5 % above 20 kt	—	± 10 % above 1 m s^{-1}
3. Speed components	± 0.5 m s^{-1}	* ± 1 kt up to 10 kt and ± 10 % thereafter	as for speed	—	—	—
VI. *Precipitation*						
1. Total amount between two observations	0.1 mm up to 10 mm 2 % for larger amounts	—	± 0.2 mm up to 10 mm, ± 2 % above 10 mm	± 0.2 mm up to 10 mm ± 2 % above 10 mm	× ± 1 mm	0.2 mm up to 10 mm ± 2 % for greater amounts
2. Intensity	§ ± 0.5 mm h^{-1} up to 25 mm h^{-1} 2 % for greater amounts	— —	× ± 0.02 mm h^{-1} below 2 mm h^{-1} ± 0.2 mm h^{-1} between 2 mm and 10 mm h^{-1} ± 2 % above 10 mm h^{-1}	—	* ± 1 mm h^{-1}	± 5 % over periods of 15 minutes
3. Depth of snow	× ± 1 cm	—	± 1 cm below 20 cm ± 5 % above 20 cm	—	§ ± 1 cm	± 10 % of absolute value
4. Density of snow	± 0.01 g cm^{-3}					
VII. *Evaporation*	± 0.1 mm up to 10 mm ± 2 % for larger amounts					
VIII. *Radiation*						
1. Sunshine duration	± 0.1 h in any hour					
2. Solar radiation	± 1 cal cm^{-2} h^{-1}					
	* Mean values are required over periods varying from 3 seconds to 1 hour. Sensor response is to be such that not more than 90% of a change is indicated in 3 seconds. § Mean value over 1 minute is required. × Reported depth is to be the mean of several readings taken in different places. Snow cover less than 0.5 cm must be reported.	* Measurements required to be representative of (a) the lift-off and touch-down areas (at 6–10 m height above the runway level), (b) the whole runway (at 6–15 m height above the runway level).	+ Mean values over 10 minutes are required. * For forecasting purposes these limits could be relaxed to ± 1 m s^{-1}. × Mean values over 10 minutes are required. If precipitation is not continuous then actual rate at the time of precipitation is acceptable.	+ Mean values over 10 minutes are required.	× Required over 6- and 24-hour periods. * Mean values every 5, 10, 15, 30 and 60 minutes are required together with a mean value over 2 minutes if this proves possible. § Amount over 24 hours.	* Mean values over 2-minute periods are required.

Element	*Climatology*	*Aeronautical meteorology*	*Synoptic meteorology*	*Maritime meteorology*	*Hydrometeorology*	*Agricultural meteorology*
IX. *Visibility*	+0.1 km up to 5 km 1 km from 5 km to 30 km 5 km from 30 km to 70 km	±50 m up to 500 m ±10 % from 500 to 1 500 m ±20 % above 1 500 m	+ ±10 %	—	—	—
X. *Runway visual range*		• ±50 m up to 500 m ±100 m between 500 m and 1 000 m ±200 m above 1 000 m				
XI. *Waves*						
1. Wave period	—	—	—	±0.5 seconds	—	—
2. Wave height	—	—	—	±10 %	—	—
	+ ½ minute mean value is required. The minimum values are to be observed in all directions.	• Measurements required to be representative (1) for take-off, of the whole runway, (2) for landing, of the runway from the threshold up to 1 500 m.	+ To be observed instantaneously in the sense detailed under temperature.			

III - EXTRACTS FROM WEATHER BUREAU OBSERVING HANDBOOK NO. 2, SUBSTATION OBSERVATIONS (1970) U.S. DEPT. OF COMMERCE, ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION - WEATHER BUREAU "ON SITE EXPOSURE REQUIREMENTS"

1.0 SHELTERS

The ground over which the shelter is located should be, in general, representative of the surrounding area. A level, open space or clearing is desirable so that the thermometers are ventilated insofar as possible by an unobstructed flow of air. An installation on a steep slope or in a sheltered hollow is to be avoided, unless the site is representative of the area, or data from the particular site is desired. Whenever possible, the shelter should not be closer to any obstruction than four times the height of the obstruction (tree, fence, building, etc.). It should be at least 100 ft. from any area having extensive concrete or paved surfaces.

The shelter also should be installed with the bottom about four ft. above the ground, and with the door facing north (in the northern hemisphere), so that the sun cannot shine on the thermometers when the door is opened during the day.

The shelter also should be mounted rigidly to minimize vibrations. For example, vibrations from strong winds tend to displace the index of liquid-in-glass minimum thermometers, which results in erroneous readings. In some installations where errors from vibration of the shelter are frequent, the thermometers are mounted on a separate post, which enters the shelter through a hole in the bottom.

2.0 PRECIPITATION GAUGES

The exposure of a rain gauge is of primary importance in the accuracy of precipitation measurements, especially snowfall measurements. An ideal exposure would eliminate all turbulence and eddy currents, near the gauge, that tend to carry away the precipitation. The loss of precipitation in this manner tends to increase with wind speed. Obstructions which individually or in small groups, are numerous and so extensive that they reduce the prevailing wind speed, turbulence, and eddy currents near the gauge are usually beneficial in providing a more accurate catch. The best exposures are often found, therefore, in orchards, openings in a grove of trees, bushes or shrubbery, or where fences and other objects acting together serve as an effective windbreak. As a general rule in areas where objects and their distance from the gauge are generally uniform, their height above the gauge should not exceed about twice their distance from it.

In open areas, individual or small groups of isolated objects near a gauge may set up serious eddy currents. As a general rule, the height of such objects above the gauge should not exceed half their distance from it. Since it is not always possible to select sites which provide adequate protection from adverse wind effects, an open site away from isolated objects may be the only location available.

Wind shields help to minimize loss in precipitation catch. Wind effects on losses are much greater during snowfall than rainfall. Thus, windshields are not generally installed at substations in locations where snowfall constitutes less than 20 percent of the mean annual precipitation.

Good exposures are not always permanent. The growth of vegetation, trees, and shrubbery, and man-made alterations to the surroundings may change an excellent exposure to an unsatisfactory one in a relatively short time.

For the correct measurement of precipitation, the open end of the gauge (the receiver) must be in a horizontal plane. This can be checked by laying a carpenter's level across the open top of the gauge in two directions, one crossing the other at right angles. If the top is not level in both directions, the condition should be reported to the supervising official, or if the observer levels the gauge, a note should be added to the observation form giving the date the defect was discovered and the date it was corrected.

APPENDIX F

This appendix is a copy of the NCC requirements for non-NOAA Solar Radiation Measurements to be considered for archiving at the NCC.

APPENDIX F

ARCHIVING OF NON-NOAA SOLAR RADIATION DATA AT THE NATIONAL CLIMATIC CENTER

INTRODUCTION

It is recognized that valuable observations of solar radiation are collected by non-NOAA organizations. This document addresses the criteria for the acceptance by the NOAA National Climatic Center, Asheville, NC of such non-NOAA data in its archives so that they may become more generally available. The National Climatic Center is prepared to archive direct, diffuse, total or global, net, and spectral radiation, as well as radiation measured on tilted surfaces.

Archiving criteria will fall into three classes:

Class 1: These measurements will comply with all of the standards established for NOAA measurements and will be archived by the National Climatic Center. Preference will be given to those locations recording hourly measurements of solar radiation and collateral meteorological data, and to areas having a paucity of available data.

Class 2: In this category, the data, while failing the criteria for Class 1, are still of sufficient quality and utility to justify archiving by the National Climatic Center.

Class 3: In this final category, the data are not considered by NOAA to be of sufficient quality or utility to justify archiving by the National Climatic Center. The existence of these data and the organization from which they might be obtained will be on file at the National Climatic Center.

CRITERIA

<u>Class 1</u>:

A. Instrument (sensor) specifications for both pyranometer and pyrheliometer.

The specifications for NOAA pyranometers appear in National Weather Service Engineering Division "Specification for Pyranometer," January 30, 1973; other relevant information can be found in "Manual of Radiation Observations," July 1962 and in the National Weather Service Observing Handbook No. 3 "Solar Radiation Observations," March 1977. These documents can be obtained by writing to Dr. L. Machta, Director, ARL, NOAA, 8060 16th Street, Silver Spring, Maryland 20910.

1. Must have equal sensitivity to all solar wavelengths (.30-3.0μm).

2. Must have calibration traceability to the WMO primary standard pyrheliometer at the World Radiation Center, Davos, Switzerland.

3. Must agree within ±2% with the NOAA primary reference pyranometer in ARL, Boulder, CO.

4. Must be temperature compensated to ±2% over the temperature range, -20 to +40 C.

5. Pyranometer must depart by less than ±3% from true cosine response for zenith angles from 0 to 70°; less than ±7% for zenith angles from 70 to 80°.

6. Must have a linear output e.g., within ±1% over the range of 0 to 1400 w/m (1.4 kilojoules $m^{-2}s^{-1}$).

B. Recorder

1. Accuracy of ±1% or better over full scale range.

2. Capable of producing representative hourly and/or daily accumulations of solar radiation. It is preferred but not required that data be provided on true solar time scale.

3. Data should be provided to NOAA in a form mutually agreed upon with the National Climatic Center, Asheville, NC.

C. Exposure of Sensors

1. Should have essentially unimpeded field of view. No nearby objects (within about 5-10 meters) should rise above the sensor, particularly in the ENE through S through WNW segment.

2. Pyranometer should be remote from surfaces which can reflect sunlight or otherwise contribute spurious or unrepresentative radiant energy to the sensor.

3. A description of the sensor location, preferably with a photograph, should be part of the documentation for each site.

D. Maintenance, Pyranometer

1. Clean the bulb daily (2 or 3 day breaks are permissible if daily cleaning appears to be unnecessary), preferably in the morning. In highly polluted areas or if frost accumulates, more frequent cleanings may be required.

2. Check the spirit level at least once each week.

3. Recalibrate annually.

E. Maintenance, Pryheliometer

1. Clean the window daily (2 or 3 day breaks are permissible if daily cleanings appear to be unnecessary).

2. Adjust the sensor to point at the sun daily or as frequently as needed to insure that the sensor points directly at the sun.

3. Calibrate annually.

F. Maintenance, Recorder

1. Recorder calibration should be checked at least every two months and whenever recorder adjustments are made. For strip chart recorders, calibrations should be made both before and after recorder adjustments.

G. Length and continuity of record

1. It shall be the intent to obtain a solar radiation record for at least three years duration.

2. It shall be the intent to provide a continuous, unbroken record.

H. Quality control and transmittal of data

1. Quality control will be exercised by either the submitting organization or by NOAA, if the latter is approved by NOAA.

2. Data will be supplied to the National Climatic Center, Environmental Data Service, NOAA, Federal Building, Asheville, NC 28801 within 6 months after the date of observation.

3. Station history and instrumentation calibration should be made available to the National Climatic Center.

Class 2: Data not meeting NOAA standards but still acceptable for NOAA archiving.

A. Instrument specifications for both pyranometer and pyrheliometer

1. Sensitivity need not be uniform over range of 0.3 to 3.0μm but the sensitivity must be known.

2. Must agree within ±5%, directly, or through traceability, with the NOAA Primary Reference Pyranometer in NOAA-ARL, Boulder, CO.

3. Must be temperature compensated to within ±5% over the temperature range -20 to 40°C.

4. Pyranometer must depart by less than $\pm 5\%$ from true cosine response for zenith angles from 0 to 70°; less than $\pm 15\%$ for zenith angles 70 to 80°.

5. Must have approximately linear output, e.g., within $\pm 5\%$, over the range of 0 to 1400 w/m^2 (1.4 kilojoules $m^{-2}s^{-1}$).

B. Recorder

1. Accuracy of $\pm 5\%$ or better over full scale range.

2. Capable of producing representative hourly and/or daily accumulations of solar radiation. It is preferred but not required that data be provided on true solar time scale.

3. Data should be provided to NOAA in a form mutually agreed upon with the National Climatic Center, Asheville, NC.

C. Exposure of sensors

Same as Class 1.

D. Maintenance

Same as Class 1.

E. Length and continuity of record

Same as Class 1.

F. Quality control and transmittal of data

Same as Class 1, except NOAA will not provide quality control.

Class 3: Data not meeting NOAA standards and not archived by NOAA.

NOAA will maintain a register of solar radiation stations. The following information will be archived.

1. Name and location (latitude, longitude, and altitude in meters, msl) of station.

2. Name or organization operating station.

3. Type of equipment at station; sensors and recording equipment.

4. Frequency of observation or of recording of data.

5. Length of record.

6. Availability of data; address of person or organization to whom request should be made.

QUESTIONNAIRE TO IDENTIFY SOLAR RADIATION DATA

If you have solar radiation data, please complete this form and mail to:

University of Alabama in Huntsville
Johnson Environmental and Energy Center
P.O. Box 1247
Huntsville, Alabama 35807
Attn: E. A. Carter

Date ______ ________

Location where solar radiation data was recorded: lat. N_______ ° ______ '
(Use separate form for each sensor) long. W_______ ° ______ '

Instrument elevation: msl _________feet or ________meters

Description of recording site (urban, rural, grass, rooftop, horizontal surface, etc.):

____

____

Periods of record and hours of operation: ______________________

Station history (change of location, instruments, etc.):

____

____

Sensor type ___________ Manufacturer ___________ Model #________

Type of data: direct ____ global ____ spectral ____ inclined____

Frequency (minute, hourly, daily, etc.):______________________

Recorder type _________ Manufacturer _________ Model # _________

Calibration-Engineering data: (for sensor and recorder) ______________

Data format (tape, strip, circular charts—digitized hourly or daily?):

____

Is data available?________ What form?________ Strip Charts? ___________

For what period? past__________ future __________

Are records properly annotated and suitable for microfilming?___________

Collateral meteorological data available:______________________

Published data available: ______________________________

Will you release the data to the National Climatic Center for use in Solar Energy Projects? ____________________

Reporting organization and name of custodian of records:_______________

____

Mailing address: ______________________________________

Telephone number: __________________ FTS: __________________

APPENDIX G

This appendix provides addresses for locating environmental data through the United Nations Environment Program, United Nations Headquarters, New York, New York, 10017.

APPENDIX G

NATIONAL FOCAL POINTS

OF THE

INTERNATIONAL REFERRAL SYSTEM

Argentina

Subsecretaria de Planeamiento Ambiental
Secretaria de Transporte y Obras Publicas
Ministerio de Economia
Capital Federal, Bueno Aires, Argentina

Australia

The Secretary
Department of Environment, Housing and
Community Development
Lombard House, Allaba Street, P. O. Box 1890
Canberra City, A. C. T. 2601, Australia
Telephone: 475022 Telex: 62552
Cable: EHHOCODEV

Austria

Federal Ministry for Health and the Environment
Stubenring 1
A-1011 Vienna, Austria
Telephone: (0222) 57-56-55

Bangladesh

Mr. M. A. Karim
Secretary, Water Pollution Control Board,
Government of Bangladesh
Fourth Floor, 16 Abdul Gani Road
Dacca, Bangladesh
Telephone: 280882, 242925

Barbados

Ministry of Health and Welfare
Bridgetown, Barbados
Telephone: 60646

Benin

M. L. Sacremento
President
Commission Nationale de L'Environnement
B.P. 239
Cotonou, Benin

Bolivia

Sr. Gonzolo Ayoroa Patino
Ministerio de Planeamiento y Coordinacion
Casilla 3116
La Paz, Bolivia
Telephone: 2-2243

Bulgaria

Mr. Stoyanov, Chief of Information Division
Scientific Centre for Protection of Natural
Environment. National Focal Point for IRS
Industrialna, 7
Sofia, Bulgaria

Byelorussian SSR

State Committee on Nature Conservation
of the Council of Ministers
Kollektornaya Ulitsa 10
Minsk - 84, Byelorussian SSR, USSR

Canada

Mr. G. Ember
Chief of Library Services
National Research Council of Canada
Canada Institute for Scientific and Technological
Information, Ottawa Kia 052, Canada
Telephone: (613) 993-3969 Telex: 053-3115

Chile

National Commission of Scientific and Tehnological
Research (CONICYT)
Calle Canada No. 308
Santiago, Chile

Colombia

Dr. J. Carrizosa Umana
Driector General
Inderena (Office 505)
Carrera 14 No. 25-A-66
Bogota, Colombia
Telephone: 81-22-27 Telex: 044-428

Cyprus

Nature Conservation Service
Ministry of Agriculture and Natural Resources
Nicosia, Cyprus

Czechoslaovakia

Ing. Ignac Fratric
Czechoslovak Research and Development Centre
for Environmental Pollution Control
Laca, Movomestskeho 2
Bratislavia 816 43
Czechoslavakia
Telephone: (07) 36291 Telex: 92229
Cable: UNOPOLCONT

Denmark

Agency of Environmental Protection
(Miljostyreleson)
Kampmannsgade 1
DK-1604 Copenhagen V
Denmark

Ecuador

Sr. J. M. Perez
Executive Director
Instituto Ecuatoriano de Obras Sanitarias
Casilla 680
Quito, Ecuador
Telephone: 544-400

Egypt

Secretary
Council for Environmental Research
101 KASR El-Aine Street
Cairo, Egypt

El Salvador

Sr. L. A. Vieytez
Comite Nacional de Proteccion del Medio Ambiente
San Salvador, El Salvador

Ethiopia

Ministry of Plannina and Development
Provisional Military Government of Ethiopia
Addis Ababa, Ethiopia

Finland

Mr. O. Paasivirta
Ministry of the Interior
Helsinki, Finland

France

Ing. General Mannevy
Cellule de Coordination Pour L'Information
sur L'Environment
15 Rue D'Astorg
F-75008 Paris, France
Telephone: 7(01) 265-16-40

Gabon

Ministere de L'Environnement
B.P. 2217
Libreville, Gabon

German Democratic Republic

Director, Institute of Water Management
Ministry for Environment Protection and
Water Management
Schnellerstrasse 140 Berlin 119
German Democratic Republic

Germany, Federal Republic

Dr. Mobs Ministerialrat
Bundersministerium Das Innern
Referat UI 6
Rheindorferstrasse 198
D-53 Bonn 7
Germany, Federal Republic

Ghana

Mr. F.K.A. Jiagge
Secretary
Environmental Protection Council
Parliament House
Accra, Ghana

Greece

Dr. C. Kourogenis
Director of Documentation Centre
Ministry of Culture and Research
48 Vas. Konstaninou
Athens 501, Greece

Hungary

Dr. J. Arvai
Head of the Secretariat (OK VT)
National Council for Environmental Protection
P. O. Box 613
H-1370 Budapest, Hungary
Telephone: (01) 668-634 Telex: 224204 EEVM-H
Cable: EEVM-H

India

Dr. A Lahiri
Assistant-Director
Department of Science and Technology
Tehnology Bhavan. New Mehrault Road
New Delhi, 110029
India

Iraq

Dr. S. K. At-Tikriti
Secretary-General
Supereme Council for Human Environment
Baghdad, Iraq

Ireland

Mr. C. S. Curran
Head of Education and Information Division
National Institute for Physical Planning
and Construction Research
St. Martin's House, Waterloo Road
Dublin 4, Ireland

Israel

Dr. S. K. Eilati
Director, Information Centre
Environmental Portection Service
Ministry of the Interior
P.O.B. 6158 Jerulsalem 91060
Israel
Telephone: (022) 43375
Cable: MEM PNOM EPS

Italy

Professor M. Colombini
Direzione Generale Servizi Igiene Pubblica
Ministero Della Sanita
Via Liszt, 34 I-00100 Rome (Eur)
Italy
Telephone: (06) 591-6941 Telex: 61453

Jamaica

Mr. R. M. Thelwell
Principal Director, NRCA
Ministry of Mining and Natural Resources
11 Upper Musgrave Avenue
P. O. Box 101, Kingston 5
Jamaica
Telephone: 92-74600

Japan

Mr. T. Soeda
Director, Environmental Information Division
National Institute for Environmental Studies
Tatieno. Yatabe-Cho. Tsukuba-Gun. Ibaradi-Ken
Japan
Telephone: (02) 975-5-1681
Cable: KOGAIKEN TSUKUBA

Jordan

Chairman of the Council
Council for Human Environmental Affairs
National Planning Council
P. O. Box 555 Aman
Jordon

Kenya

Mr. N. W. Mbote
Deputy Director
National Environment Secretariat
Office of the President
P. O. Box 30610 Nairobi, Kenya
Telephone: 332383 Ex. 2102/3

Libyan Arab Republic

Director-General of Urban Planning
Ministry of Housing
Tripoli, Libian Arab Republic

Madagascar, Democratic Republic

Direction des Eaux et Forets
Ministere du Developpment Rural
Tananarive
Madagascar, Democratic Republic

Malta

Human Environment Council
Ministry of Health and Environment
15 Merchants Street
Valletta, Malta

Mauritania

Chef du Service de la Protection de la Nature
B.P. 170
Nouakchott, Mauritania

Mexico

Secretary-General
Technical Council
Avenida Chapultepec, No. 284 Piso 13
Mexico City 7 DF
Mexico
Telephone: 511-1029

Netherlands

Environmental Assistant of the Economic
Co-Operation Department
Secretary of the "C. I. M."
Ministry of Froeign Affairs
Plein 23, The Hague
Netherlands

New Zealand

Mr. C. K. McMahon
Commission for the Environment
P. O. Box 12-042
Wellington, New Zealand
Telephone: 72-0642

Niger

Ministere de L'Economie Rurale, Du Climat
et de L'Aide aux Populations
Naimey, Niger

Nigeria

Permanent Secretary
Federal Ministry of Housing, Urban Development
and Environment
P.M.B. 12698 Lagos, Nigeria

Norway

Mr. K. Glomnes
Ministry of Environment
Oslo Dep. Oslo, Norway

Pakistan

Dr. A. R. Mohajir
Project Manager
Pastic National Centre
No. 6 Street 22 Sector F-7/2
P. O. Box 1217, Islamabad, Pakistan

Paraguay

National Service for the Department
of the Environment (Senasa)
Asuncion, Paraquay

Philippines

Mr. B. N. Garcia
Executive Officer
National Pollution Control Commission
Pedro Gil Street, Corner Taft Ave.
P. O. Box EA-174, Manila, Philippines

Poland

Director, Instytut Ksztaltowania Srodowiska
Ul. Krzywickiego 9
02-078 Warszawa, Poland
Telephone: 210401 Telex: 013493

Portugal

Sr. J. C. Da Cunha
President
Comissao Nacional Do Ambiente
R. Sraamcanp 82 - 4
Lisboa - 1, Portugal

Romania

M. M. Nicolau
Le Secretaire General
Conseil National Pour la Protection
de L'Environment
Bucarest, Romania

Senegal

M. O. Diop, Le Directeur du Centre National
de Documentation Scientifique et Technique
Delegation Generale a la Recherche Scientifique
et Technique
61 Boulevard Pinet - Laprade, B.P. 3128 Dakar
Senegal

South Africa

The Secretary
Department of Planning and the Environment
Private Bag X213
Pretoria 0001, South Africa
Telephone: 41-1211
Cable: WEFPLAN

Sri Lanka

The Secretary
Department of Planning and Economic Affairs
Ceylinco House. P. O. Box 1689
Colombo 1, Sri Lanka

Sweden

Swedish Council of Environmental Information
Jordbruksdepartementet
Fack, S 10320
Stockholm, Sweden
Telephone: (08) 763-10-00 Telex: 11461 LOENDEP

Switzerland

Mr. W. Martin
Adjoint Scientifique
Office Federal de la Protection de L'Environnement
CH-3003 Berne, Switzerland
Telephone: (031) 61-93-39 Telex: 33330 HELV CH

Tanzania, United Republic

Mr. I. J. Mtiro, Director
Ministry of Lands, Housing and Urban Development
Urban Division
Dar Es Salaam
Tanzania, United Republic

Thailand

Dr. Prom Panitchpakdi
Secretary-General
National Environment Board
260 Suriyothai Building
Phaholyothin Road, Bangkok, Thailand

Tunisia

Le Ministere de L'Agriculture
A.B.S. La Mission Permanente de Tunisie a Geneve
58 Rue de Moillebeau
CH-1211 Geneva 19, Switzerland
Telephone: (022) 34-84-50 Telex: 22039 MPTING C

Turkey

Turkish Scientific & Technical Research
Association
Ataturk Bulvari 221
Kavaklidere, Ankara, Turkey

Uganda

Ministry of Provincial Administrations
C/O The Ministry of Foreign Affiars
P. O. Box 7048
Kampala, Uganda

United Kingdom

Mr. W. Pearson
UK/IRS - Room P3/188
Department of the Environment
2 Marsham Street
London Swip 3EB
United Kindom
Telephone: (01) 212-4842 Telex: 22801

United States

Ms. C. Alexander, Director
U.S. National Focal Point
U.S. Environment Protection Agency
401 M. Street SW (Room 2902-PM213)
Washington D.C. 20460
United States
Telephone: (202) 755- 1836 Telex: (WUD) 892578
Cable: EPAWSH

Upper Volta

M Le Directeur, Direction Des Services
Forestieres, Et de la Protection de la
Nature
P. O. Box 7044, Ouagadousou, Upper Volta

USSR

Director, Department of International Economic
and Technical Organisations
State Commettee for Science and Technology
11 Gorky Street, Moscow K-9 USSR

Venezuela

Sr. J. M. Carrillo
Ingeniero Adjunto
Ministrerio de Assistancia Social
Caracas, Venezuela

Yugoslavia

Savet Za Covekovu Spedinu I Prostorno Uredjenje
Serj, Komisijo Vijece
1170 Belgrade, Yugoslavia

Zaire

Point Focal Sir/Zaire
Department de L'Environment
Conservation de la Nature et Tourisme
B.P. 12.348, Kinshasa 1, Zaire

IRS Points of Contact

Belgium

M. A. Stenmans
Commission I/M Pour la Politique Scientifique
Rue de la Science 8
B-1040 Bruxelles, Belgium

Malawi

Mr. W. D. Chona, Secretary
National Research Council
Private Bag 301
Capital City, Lilong E 3, Malawi

IRS Regional and Sectoral Focal Points

UNEP/IRS

Mr. H. P. Mollenhauer
The Director, UNEP/IRS
United Nations Environment Programme
Box 30552
Nairobi, Kenya
Telephone: 333930 Telex: 22068/22173
Cable: UNITERRA NAIPORT

UNEP/IRS (NGO Section)
Mr. H. P. Mollenhauer
The Director, UNEP/IRS - NGO Section
United Nations Environment Programme
Box 30552
Nairobi, Kenya
Telephone: 333930 Telex: 22068/22173
Cable: UNITERRA NAIROBI