SERI/CP-642-977

October 1980

Dr. 2425

R-2800

MASTER

Insolation Resource Assessment Program Contractors Annual FY80 Review* and Report

SERI

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Operated for the
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

* August 19-21, 1980
Davis, California

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SERI/CP-642-977

Distribution Category UC-59,61,62,and 63
Conference Number 800890

INSOLATION RESOURCE ASSESSMENT PROGRAM
CONTRACTORS ANNUAL FY80 REVIEW

AUGUST 19-21, 1980

DAVIS, CALIFORNIA

SPONSORED BY:

U.S. DEPARTMENT OF ENERGY

COORDINATED BY:

SOLAR ENERGY RESEARCH INSTITUTE

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

Page

Session I:

Overview and Summary of SERI Insolation Research, Roland L. Hulstrom (SERI) 1

The Solar Energy Meteorological Research and Training Program, Region IV, Gene Clark, John E. Rudzki (Solar Data Center, Trinity University) 9

Solar Energy Meteorological Research and Training Site - Region 2, Ronald Stewart (Atmospheric Sciences Research Center) 17

Program for Solar and Meteorological Research and Training Site, Region 6, D. Portman (University of Michigan) 25

Solar Energy Meteorological Research and Training Site - Region 5, C.R. Nagaraja Rao (Oregon State University) 33

Solar Energy Meteorological Sites Program, Area 8 - Hawaii Annual Report, C.S. Ramage (University of Hawaii) 45

Solar Energy: Implementation of a Research and Training Site at Davis, California, Jerry L. Hatfield, John J. Carroll, Robert G. Flocchini, Robert Hamilton, and Peter J. Smietana (University of California at Davis) 53

Solar Energy Meteorological Research and Training Site Program for the Southeast (Region 3), C. Gerald Justus (Georgia Institute of Technology) 61

Summary of Solar Energy Meteorology Research and Training Site (Alaska) Program for the First Three Year Period, Gerd Wendler (University of Alaska) 73

Session II:

The Canadian Solar Energy Assessment Program, John E. Hay (University of British Columbia) 83

Solar Data Processing at the National Climatic Center, Vincent Cinquemani and Jackson L. Pellett (NOAA/EDIS/National Climatic Center) 91

NCC Solar Data Project and SERI World Insolation Data, Eugene A. Carter and David L. Christensen (The University Alabama in Huntsville) 101

Session III:

Measurement and Analysis of Circumsolar Radiation, Donald Grether, David Evans, Arlon Hunt and Michael Wahlig (Lawrence Berkeley Laboratory) 115

Ground-Based Insolation Measurements at Selected Field Sites, Joseph J. Michalsky and Edward W. Kleckner (Battelle, Pacific Northwest Laboratory) 123

Overview and Summary: Insolation Activities at JPL, J.R. Huning, M.S. Reid, J.H. Smith (Jet Propulsion Lab) 135

Solar Energy Resource Atlas, Donald Wright (EG&G) 143

Site Insolation and Wind Power Characteristics, Roger E. Bray (Northrop Services, Inc.) 145

SESSION I
SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING SITES (UNIVERSITY GRANTS)

OVERVIEW AND SUMMARY OF SERI INSOLATION RESEARCH

Roland L. Hulstrom
SERI

Background

The purpose of insolation research at SERI is to help develop the methods and specific solar resource (insolation) data required for assessing, characterizing, and forecasting the solar resource and the performance of solar energy conversion systems. This effort is performed in concert with the National Oceanic and Atmospheric Administration (NOAA), other national labs (L.B.L., P.N.L., and J.P.L.), several universities, and subcontractors. Such efforts are described and reported in this document. The research effort at SERI is conducted by the Renewable Resource Assessment Branch, of the General Research Division. SERI is responsible for day-to-day program management support to the Department of Energy, for the Insolation Resource Assessment Program. This paper will present a brief overview, and summary of SERI's current research tasks and highlights of their results. Detailed results are reported through SERI technical reports and the literature. Copies, or access to, such can be obtained by contacting Marie Baca, SERI, Renewable Resource Assessment Branch, 1617 Cole Blvd., Golden, Colorado, 80401.

Description

The major thrusts of the SERI insolation research are:

1) Complex and Simple Insolation Models;
2) Insolation Conversion Algorithms;
3) Mesoscale Insolation Variations;
4) Insolation Standards, Data Bases, and Products;
5) Insolation Instrumentation.

The Complex and Simple Insolation Models activity consists of the review, evaluation, and development of improved complex and simple models for calculating/predicting the broadband insolation and/or spectral solar irradiance as functions of geographical location and atmospheric conditions. The major activity to date has consisted of the evaluation and improvement of complex radiative transfer models to predict clear sky broadband insolation and spectral terrestrial solar irradiance.

The various models and approach is shown in Table 1. The SOLTRAN models are modified versions of the AFGL LOWTRAN model. For detailed discussions of such models and activities one should consult References 1-8.

The Insolation Conversion Algorithms activity consists of the review, evaluation, and development of improved algorithms for converting;

1) horizontal insolation to direct beam insolation;
2) horizontal insolation to tilted surface insolation; and,
3) direct beam and global horizontal insolation to tilted surface insolation.

The activities and approach are shown in Tables 2 and 3. Reference 1 should be consulted for details.

The Mesoscale Insolation Variations activity was just initiated during 1980. It consists of data acquisition and analyses to determine the nature and significance of mesoscale (1-100km) variations in the available insolation. Generally, it is known that their can be large variations in meteorological conditions on a mesoscale. Such variations are caused by terrain and other factors; for example, mountains, coastlines, urbanization. Such variations in meteorological conditions, especially cloud cover, will cause significant variations in the available insolation. Currently there exists a severe lack of data for quantifying such variations. The SERI activity will attempt to gather such data and derive the impact on solar energy. The FY80 activity concentrated on obtaining mesoscale insolation data by conducting cooperative activities with the NOAA PROFS program and the Bureau of Reclamation's HIPLEX program.

The Insolation Standards, Data Bases, and Products activity consists of the development and distribution of insolation data bases, standards, and products that are needed by the solar community. Recently, SERI's activity has included the implementation of the SOLMET, ERSATZ, and TMY data bases on the SERI computer. One of the major activities has been the development of a new ASTM (see Table 1) for the terrestrial solar spectrum, for various air masses. Another major activity has been the development and production of the Insolation Data Manual. This manual will contain long-term monthly averages of global horizontal insolation, temperature, degree-days, and global K_T, for 248 N.W.S. stations. The manual will be distributed in October 1980, by the SERI Solar Energy Information Data Bank.

The Insolation Instrumentation activity consists of the development of selected instrumentation for measuring solar radiation. Current efforts consist of the development of:

1) a low cost (less than $1,000) device for monitoring and logging daily and hourly global insolation;
2) a solar direct beam, automated, tracker; and,
3) a solar spectroradiometer.

Summary of Results

The following paragraphs will present only a brief review* of significant results during 1980. They will be presented in relation to the previously mentioned major research thrusts.

Complex and Simple Insolation Models

1. Solar terrestrial spectra for global, direct, and diffuse irradiance were produced with the Monte Carlo radiative transfer code. The Monte Carlo direct beam results were compared with the SOLTRAN results; in general, the comparison was favorable. (November 1979).

* Detailed results can be obtained by contacting the Renewable Resource Assessment Branch, SERI.

2. A comparison of the Dave spherical harmonics and the Monte Carlo code was performed. This comparison revealed that the two complex models compare favorably in their prediction of spectral solar irradiance. (February 1980).

3. A simplified global horizontal thermal insolation model was produced. The model uses parts of several existing models, with simplicity and accuracy determining the formalism used. The new simple model gives results in good agreement with the complex Monte Carlo and Dave models. (February 1980).

4. New and improved spectral terrestrial solar irradiance distributions for total global horizontal, total on a 37° tilted surface, diffuse on a horizontal, diffuse on a 37° tilted surface, ground reflected, and the direct solar beam were produced, with the Monte Carlo complex code. These were submitted to the ASTM for consideration for the new spectral standards. (March 1980 - July, 1980).

5. The new SERI SOLTRAN 5 computer code was made operational on the SERI computer. This model allows improved calculations of the spectral and solar thermal direct solar beam, as a function of air mass. (September 1980).

Insolation Conversion Algorithms

1. SERI took initial steps to have the Randall/Whitson-Aerospace algorithm, for converting global horizontal insolation to direct beam insolation, thoroughly documented and modified to operate on the SERI computer. (November 1979).

2. Five different conversion algorithms, for converting global horizontal and direct beam insolation to tilted surface insolation, were programmed on the SERI computer. Initial comparisons were made for Albuquerque, Boston and Fort Worth. (December 1979).

3. Measurements of insolation on various, south facing, tilted surfaces was initiated at the SERI Insolation Research Lab. (June 1980).

4. The Randall/Whitson algorithm (computer code) was successfully run on the SERI computer. This allows wide spread use and evaluation of the algorithm to proceed. The algorithm will be available from SERI. (August 1980).

Mesoscale Insolation Variations

1. The South Table Mountain (STM), solar powered, remote insolation and meteorological monitoring station was successfully tested. The station now sends data automatically, via a microwave communications system, to the SERI labs. Eight channels of data are sampled once per second, displayed in real time, and recorded on computer compatible tape. (February 1980).

2. The first stations of the mesoscale insolation network, near Miles City, Montana, were installed and tested. This network is in cooperation with the Bureau of Reclamation's HIPLEX project. (May 1980).

3. The first stations of the SERI/NOAA/PROFS mesoscale insolation network, near Denver, Colorado, were installed and tested. (June 1980).

Insolation Standards, Data Bases, and Products

1. Develpment of mean monthly K_T for the U.S. was initiated. (October 1979).
2. The complete SOLMET, SOLDAY, IDDS, and TMY data tapes were placed in the SERI tape library. (January 1980).
3. The first one minute insolation research data, from one of the eight D.O.E. university research sites, was received. The tape was successfully read and archived. (April 1980).
4. Annual and mean monthly K_T contour maps for the United States were completed. They will be published in the Insolation Data Manual, October 1980, SERI, Solar Energy Information Data Bank, SERI/SP-755-789. (June 1980).
5. New and improved standards for spectral solar irradiance were completed and submitted to ASTM for review (as described previously). (July 1980).
6. SERI received and archived 206 TMY data tapes from EG&G. (August 1980). These will be made available to the solar community.

Insolation Instrumentation

1. The first advanced, microprocessor-based, pyrheliometer solar tracker was successfully tested at the SERI Insolation Research Lab. This unit allows up to six normal incident pyrheliometers to automatically track the solar disk, for at least 30 days. (January 1980).
2. An R.F.P. for 3 advanced, multispectral, sun photometers was formulated and released. These instruments will utilize active solar trackers, battery power, and microdata loggers. They will measure atmosphereic turbidity and water vapor. (February 1980).
3. Intercomparison and calibration of four, previously developed, low-cost insolation monitors were performed at the NOAA calibration facility (Boulder, Co). These units allow the automatic recording of global insolation, on a daily basis, for up to 100 days, unattended. Initial results indicate their accuracy to be about 3-5%, for hourly insolation. This completes their development. (April 1980).
4. The newly developed SERI Spectroradiometer successfully completed acceptance tests. This instrument is capable of measuring the spectral direct, diffuse, and global solar irradiance, from .3 to 2.5μm. The spectral resolution from .3 to .880μm is .7 nanometers; and, from .7 to 2.5μm it is 12 nanometers. All solar tracking is automatic, along with data logging. (July 1980).

References

1. Hulstrom, R.L., 1978, Insolation Models, Data and Algorithms, Annual Report FY78, Golden, Co: Solar Energy Research Institute; SERI/TR-36-110

2. Bird, R.; Hulstrom, R., 1979, Application of Monte Carlo Techniques to Insolation Characterization and Prediction, Golden, Co.: Solar Energy Research Institute; SERI/RR-36-306.

3. Dave, J.V., 1978, "Extensive Datasets of the Diffuse Radiation in Realistic Atmospheric Models With Aerosols and Common Absorbing Gases", Solar Energy, Vol. 21: pp. 361-369.

4. Selby, J.E.A.; McClatchey, R.A., 1975, Atmospheric Transmittance From 0.25 to 28.5μm: Computer Code LOWTRAN3, Bedford, MA: Air Force Cambridge Research Lab: AFCRL-TR-75-0255.

5. Bird, R.; Hulstrom, R., 1979, Aerosols and Solar Energy, Solar Energy Research Institute, Golden, Co.: SERI/TP-36-309.

6. Ireland, P.J.; Wagner, S.; Kazmerski, L.; Hulstrom, R.L., 1979, "A Combined Irradiance-Transmittance Solar Spectrum and Its Application to Photovoltaic Efficiency Calculations" Science, Vol. 204, pp. 611-613

7. Bird, R.E.; Hulstrom, R.L., 1979, Direct Insolation Models, Solar Energy Research Institute, Golden, Co., SERI/TR-36-344.

8. McClatchey, R.A.; Fenn, R.W.; Selby, J.E.A.; Volz, F.E.; Garing, J.S., 1972, Optical Properties of the Atmosphere (Third Edition), Bedford, MA: Air Force Cambridge Research Lab; AFCRL-72-0497

Table 1. Milestone Chart for Complex Radiative Transfer Models

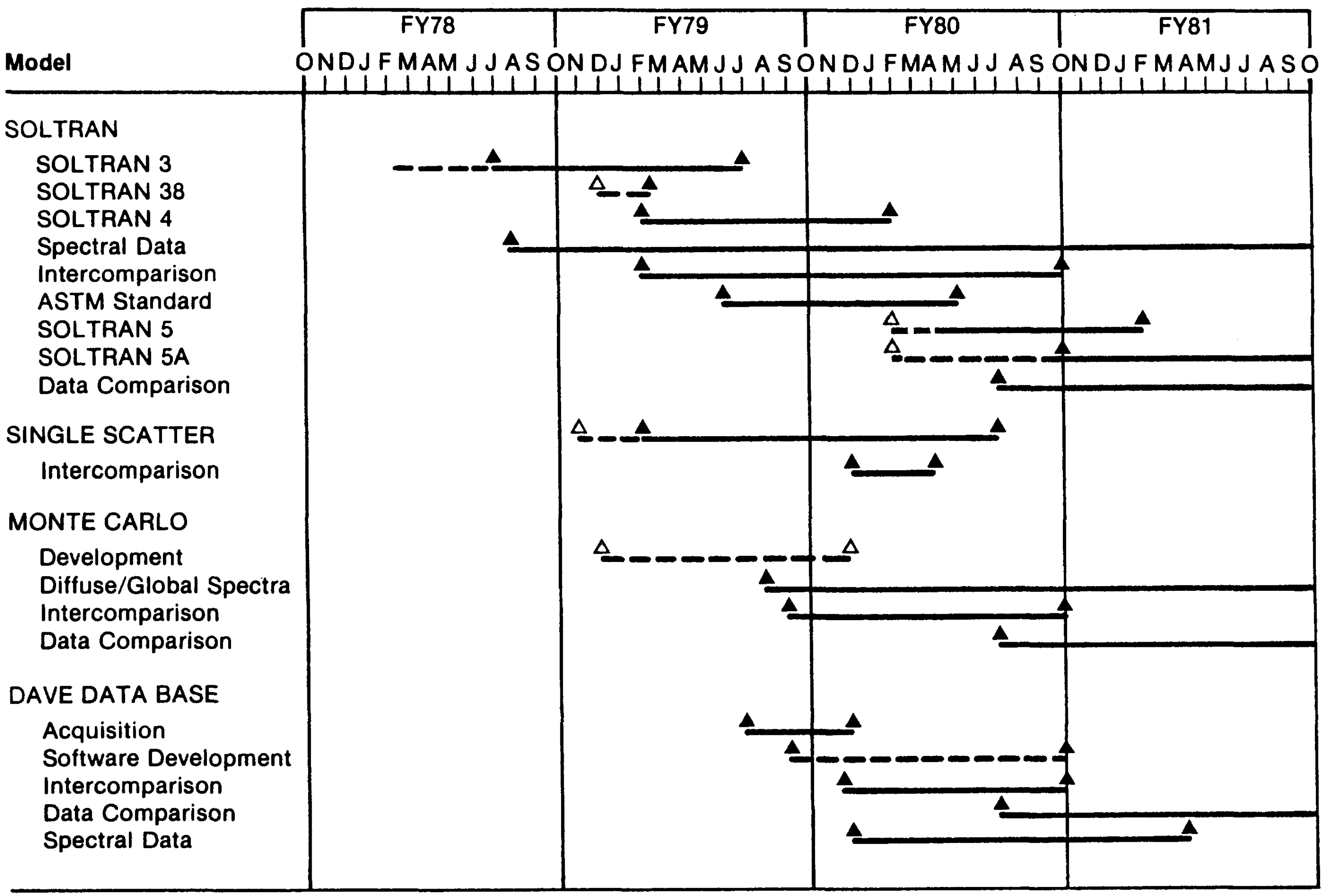


Table 2. Evaluation and Development of Horizontal to Tilted Surface Insolation Conversion Algorithms

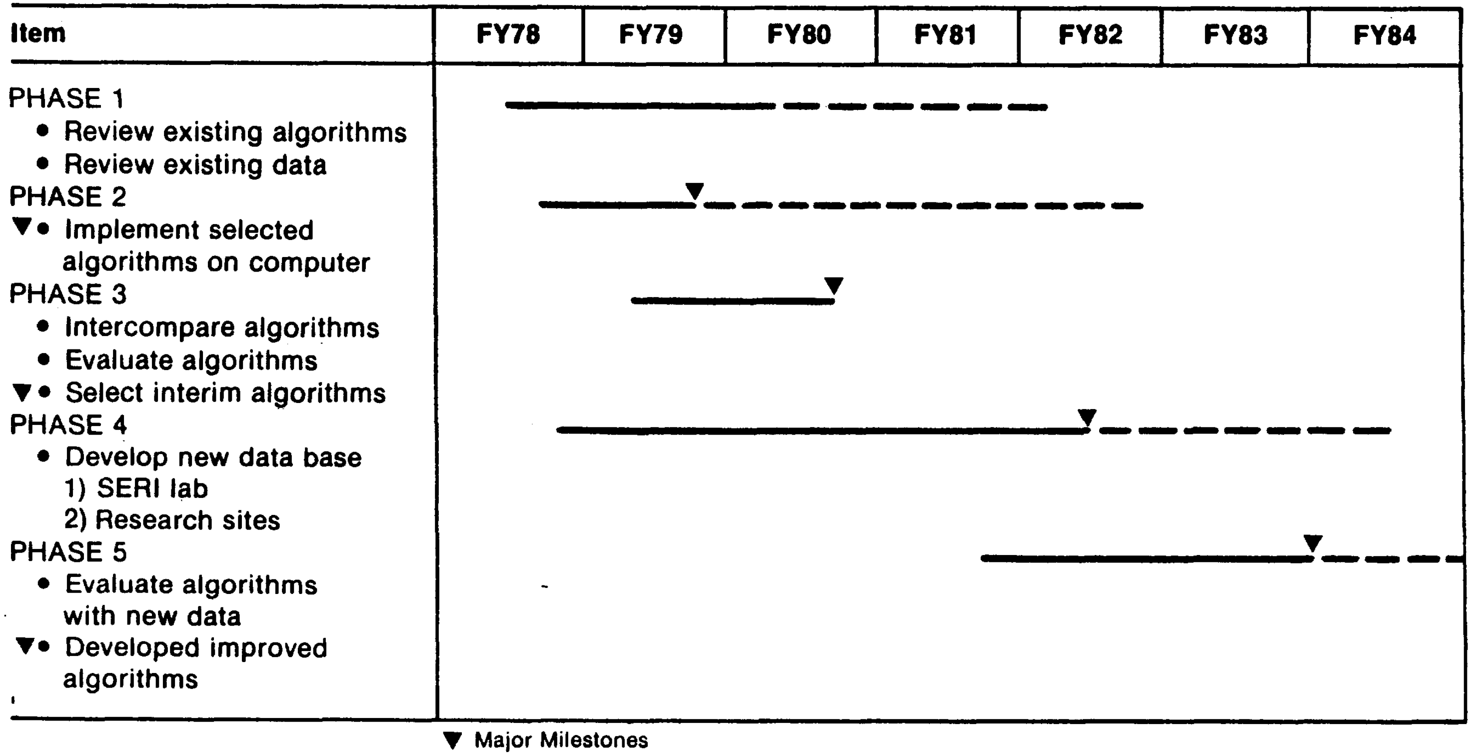
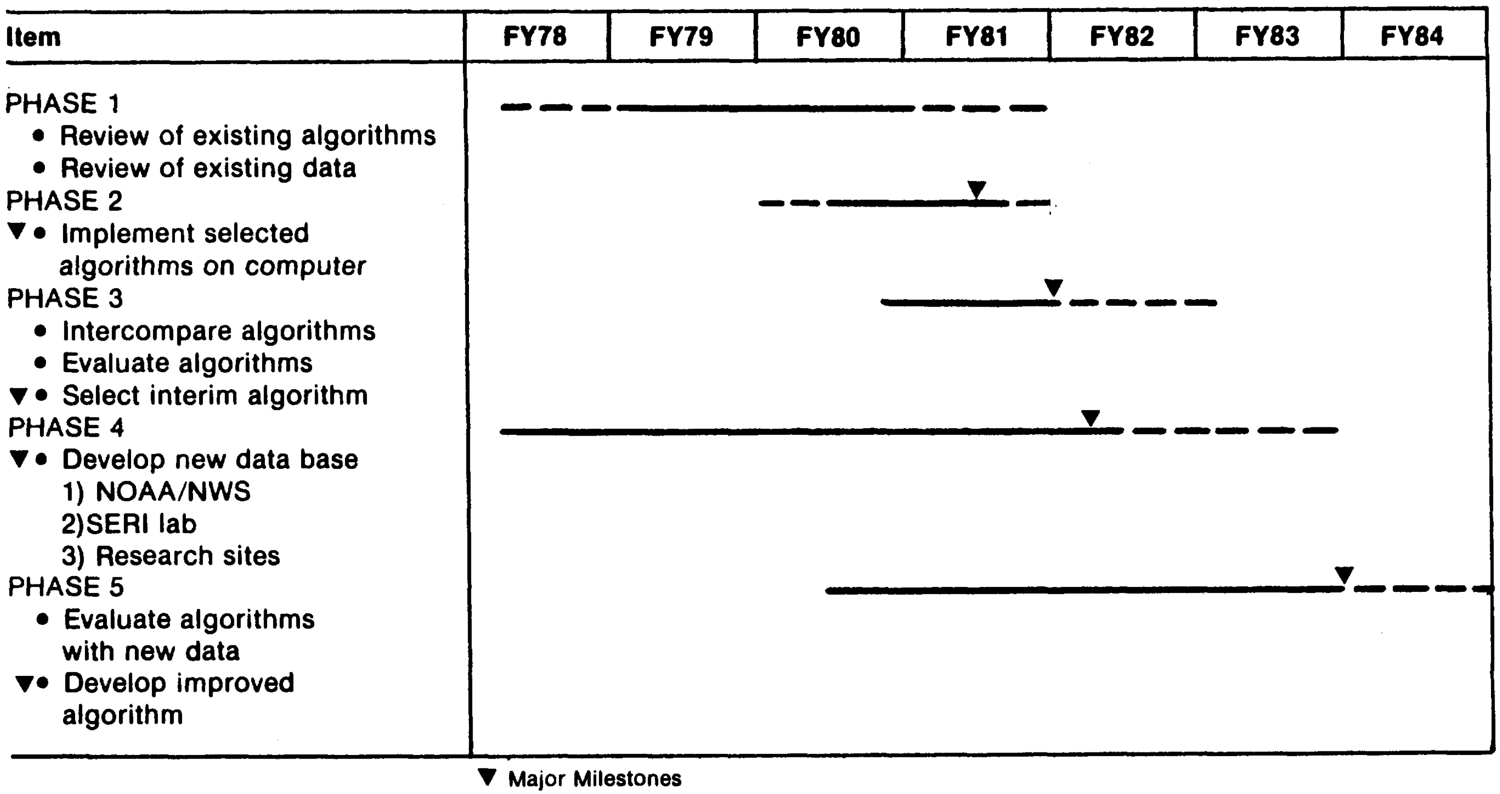


Table 3. Evaluation and Development of Horizontal to Direct Beam Insolation Conversion Algorithm



THE SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING PROGRAM REGION IV

Gene Clark - Principal Investigator
John E. Rudzki - Project Manager
Solar Data Center
Trinity University
715 Stadium Drive Box 500
San Antonio, Texas 78284

The first purpose of the SEMRTS program is to establish a detailed and accurate solar-meteorological description of Region Four which includes Texas, Oklahoma, Arkansas, Kansas, Louisiana, and Missouri. This descIption will be based on a computerized, hourly, typical year data base derived from several years of one-minute data collected in San Antonio, hourly data at additional sites including Houston, Waco, and Arlington, Texas, and the long term record at the National Climatic Center of the National Weather Service in Asheville, N.C. To improve the collected data's quality, research is conducted in the fundamental limitations of existing solar instrumentation and the design of improved instrumentation.

The second purpose is to offer training in the use of this data. A master's degree program in applied solar energy is now offered by Trinity University, and a doctoral program in physics (with specialization in solar applications) by Baylor University. To reach a wider audience, conferences, workshops, and visual aids such as taped slide presentations are being produced.

The Solar Data Center, Trinity University, manages the SEMRTS program with Baylor University (Waco, Texas - Dr. Merle Alexander) and the University of Houston (Houston, Texas - Dr. Richard Bannerot) under subcontract. Informal agreements to furnish data are being negotiated with the University of Texas at Arlington and the University of Arkansas.

The program began October 1, 1977 and is expected to be completed on September 30, 1982. The most significant milestone will be August 1, 1981 when a full year of one-minute quality controlled data will have been collected.

Related to the SEMRTS program at Trinity are the Sam's Center Solar Heating and Cooling Demonstration Project[1], consisting of a solar plant with 1600 tracking Northrup collectors; a Regional Assessment of Evaporative, Radiative, and Convective Cooling Processes and Systems in the United States[2]; and the Passive Test Facility[3], 2 identical 800 sq.ft. buildings designed as test beds for various passive cooling techniques.

Previous significant progress includes, May, 1978, primary site operational and start of data collection; November, 1978, asymmetrical response of the Eppley Precision Spectral Pyranometer (PSP) measured and the effects of direct insolation striking the body of tilted PSP's evaluated; November, 1978, 25 hours of instrumented aircraft flights over Waco and San Antonio, Texas, the coal-fired generating plant in San Antonio, and the lignite fueled generating plant in Fairfield, Texas; November, 1978, the development of computer models estimating tilted surface irradiance and comparison with measured data; November, 1978, a conference on "Energy Alternatives for the City of San Antonio"; March, 1979, measurement of the time constants of the Eppley Normal Incidence Pyrheliometer (NIP); March, 1979, maps of contours of solar irradiance on variously tilted surfaces and contours of nocturnal cooling rates for wet and dry surfaces drawn for Region IV; and September, 1979, preliminary measurement of the angular response of the NIP and estimates of error due to misalignment.

DESCRIPTION

Measurements being made at the primary station, Trinity University[4], and the secondary sites at Baylor University and the University of Houston are given in Table 1. Also listed in Table 1 are the instruments used and the calibration source. In addition to the station measurements, Baylor University operates a Cesna 336A recently equipped to record digital data including global insolation on the horizontal, dry bulb temperature, nephelometer measurements of backscattered light, NO_x and O_3 concentrations, and particulate filters.

Facilities supporting the solar instrumentation include an IBM 3031 computer at Trinity, a Honeywell 036 at Baylor, and airborne data analysis support equipment at Baylor including a Zeiss scanning electron microscope and a proton induced X-ray analyzers to study the composition of particulates.

The data acquisition system at the primary station is controlled by a Hewlett-Packard 9825A controller. The system layout is shown in Figure 1.

Data has been collected since May, 1978. The earlier data has gaps due to system power outage failures (now corrected with an uninterruptible power supply). Currently, better than 98% of the minute data for the required and research parameters (Table 1) is being collected.

Quality control of the data begins with careful maintenance and calibration of the instruments. A station log is maintained of all activity taking place at the primary station. Daily, a check is made of the back-up strip chart recordings and hourly averages to detect any malfunctions. Beginning July, 1980, first-order automatic quality control has been written into the control computer software[5]. Finally, the data is compared against accepted computer models to compare the measured against the theoretical data and to further check the operation of the instrumentation[6].

A principal application of the data has been to model passively cooled structures in San Antonio[3]. Frequent use of the data is made in the training programs, particularly thesis work, and in answering questions from the public.

On-going research tasks or studies include:

1. Relative humidity (R.H.) guage calibration. Purpose: Develop a technique or apparatus to periodically calibrate the site R.H. guage. A calibration cell using saturated solutions of salts (after Louis Greenspan, NBS Journal of Research) was built and used to calibrate the station guage. But comparison with dewpoint-dry bulb measurements show that an error still exists. Approach: Analyze the trade-offs between building or buying a traceable standard to refine the calibration.

2. Quality control of infrared measurements. Purpose: Resolve the discrepancy between measurements made by the Eppley PSP, the Funk-type radiometer, and the Eppley Precision Infrared Radiometer (PIR). Theoretically, Funk - PSP = PIR. In practice we find as much as a 40% discrepancy near noon on a clear day. Approach: Analyze the operating principles of each of the instruments, establish the fundamental limitations of each, and set limits to the equality above. Then make careful measurements to confirm the limits.

3. Accuracy of misaligned NIP's. Purpose: Determine empirical relationship between tracking errors and accuracy of data. Approach: Measure the errors introduced by mistracking one NIP compared to another correctly tracking NIP. Repeat on different serial numbered NIP's.

4. PSP cleaning frequency vs. accuracy. Purpose: Establish an empirical relationship between frequency of PSP cleaning and accuracy. Estimate maximum cleaning interval for acceptable error. Approach: Compare response of PSP cleaned daily with PSP cleaned weekly and PSP not cleaned at all.

5. Tilted PSP ground plane reflectance stability. Purpose: Determine a material or coating for tilted PSP ground planes which has a long-term reflectance stability. Approach: Measure and record reflectance of existing painted aluminum ground planes. Measure and record the reflectance of different ground plane materials, all exposed to the same weather.

6. Limitations on tilted PSP measurements. Purpose: Determine the errors in tilted PSP measurements due to inaccurate cosine responses and sensor misalignment. Approach: Using the alignment jig (see below) and a rotating, level table, determine if the PSP sensor plane is parallel with the reference bubble level.

7. Turbidity photometer development. Purpose: Develop a turbidity meter that is more accurate than the Volz sun photometer. Approach: Modify two Eppley NIP tubes to accept narrow band filters and E.G. & G. photodiodes.

8. Validate estimation models for tilted surface irradiance. Purpose: Identify and develop accurate estimation models for solar radiation received on tilted surfaces. Approach: Compare estimation models with tilted surface data.

9. Effects of urban pollution on direct and total solar irradiance. Purpose: Develop empirical relationships between widely measured indicators of turbidity and direct and total solar irradiance. Approach:

Correlate ground level and aircraft measurements of solar irradiance with turbidity and visibility measurements.

SUMMARY OF RESULTS (FY1980)

Collection of the one minute, first-order quality controlled data[7], began August 1, 1980. The record heat wave in July required a complete re-wiring of the control room. The major heat producing equipment had to be moved to another location away from the computer and an air conditioner installed to keep the room temperature within equipment temperature limits. Data collected from May, 1978 to July, 1980 is now being re-formatted and quality controlled. Table 1 and Figure 1 list the measurements made and the data acquisition and processing system at the Trinity University site.

Analysis of the Funk-type infrared radiometer showed severe dry nitrogen leaks around the sealing gasket and mis-orientation of the instrument level. Retrofit rings were designed, machined, and distributed to all the program's stations. A retrofit level adapter was also designed to ensure correct leveling of the sensor[8].

Low reflectance ground planes for tilted PSP's were designed and installed. A sensitivity analysis showed that accurate alignment of tilted PSP azimuth and tilt are very important to get high quality data from tilted PSP's. To measure the former alignment of the tilted PSP's and to accurately align the PSP's in the future, an alignment jig and technique was designed[9]. We have confidence that the tilted PSP's are now pointed to the desired azimuth and direction to within 2 arc-minutes. To facilitate precise adjustment of the tilt and azimuth, a ball-joint mounting was also designed.

Initial results of measurements of NIP response to misalignment are reported in reference 4. A misalignment of only 2^{o} results in a decrease in NIP response of about 8%.

RECOMMENDATIONS

1. Recommend that the flagging criteria[7] for the global ultra-violet radiometer be changed to:

$$GLO(UV) \simeq 0.08\ GLO(WG7)$$

with tolerance of 20%, $(0.08 \pm .016)$ for

θ_o's $< 85^{o}$ and

$GLO(WG7) > 15\ kJ/m^2\text{-min}$

2. Recommend that the flagging criteria[7] for the downward total irradiance measured by a Funk radiometer be changed to:

$$GLO(WG7) + \sigma(T_a - 20^{o}K)^4 < Funk < GLO(WG7) + \sigma T_a^{\ 4}$$

where T_a is the ambient dry bulb temperature in ^{o}K.

TABLE 1 - Measurements Made at Trinity University Site

Part I - Radiation Parameters

Measurement	Instrument	Calibration Source	Location
A. Basic			
1. Global	Eppley PSP with WG-7 dome	National Oceanic & Atmospheric Adm. (NOAA) Boulder, Colorado	T=Trinity University B=Baylor University H=University of Houston
2. Diffuse	Derived from global and direct	N/A	T, B, H
3. Direct	Eppley NIP with WG-7 window	NOAA	T, B, H
4. Downward Infrared (0.3μ-50μ)	CSIRO, Funk type Model 622	Manufacturer, periodic from secondary standard	T
5. Total on surface, latitude tilt, pointed south	Eppley PSP with WG-7 dome	Transfer standard from NOAA	T
6. Global, filtered	Eppley PSP with RG-2 dome	Transfer standard from NOAA	T
7. Global, UV	Eppley UV Photometer	Manufacturer	T
B. Research			
1. Global, filtered	Eppley PSP with OG1 and RG8 domes	Transfer standard from NOAA	T
2. Direct, filtered	Eppley NIP with Schott glass filter wheel	Transfer standard from NOAA	T=only for 1 yr. Msmts. stopped due to ambiguity in inst. response time.
3. Total on tilted at lat. +10°, -10°S. (pointed south) and 90° at 4 cardinal points	Eppley PSP's with WG-7 dome	Transfer standard from NOAA	T
4. Downward infrared tilted at 45°N. and 90°N.	CSIRO, Funk type 622	Manufacturer, periodic from secondary standard	T

Part II - Meteorology

Measurement	Instrument	Calibration Source	Location
A. Basic			
1. Temperature	Texas Electronics (TE) Thermistor Bridge Model 3015F	Manufacturer	T, B
2. Dew Point	TE Relativity Humidity Sensor Model 2013-2	Manufacturer	T, B
3. Wind Speed and Direction	TE Windspeed Transmitter Model 2011-A	Manufacturer	T, B
4. Pressure	TE Electric Barometer	Comparison with mercury barometer	T, B
5. Precipitation	TE Tipping Bucket Rain Gauge	N/A	T
6. Cloud Cover	None	N/A	Obtain from local NWS station
7. Percent Sunshine	Campbell-Stokes Sunshine Meter	Manufacturer	T

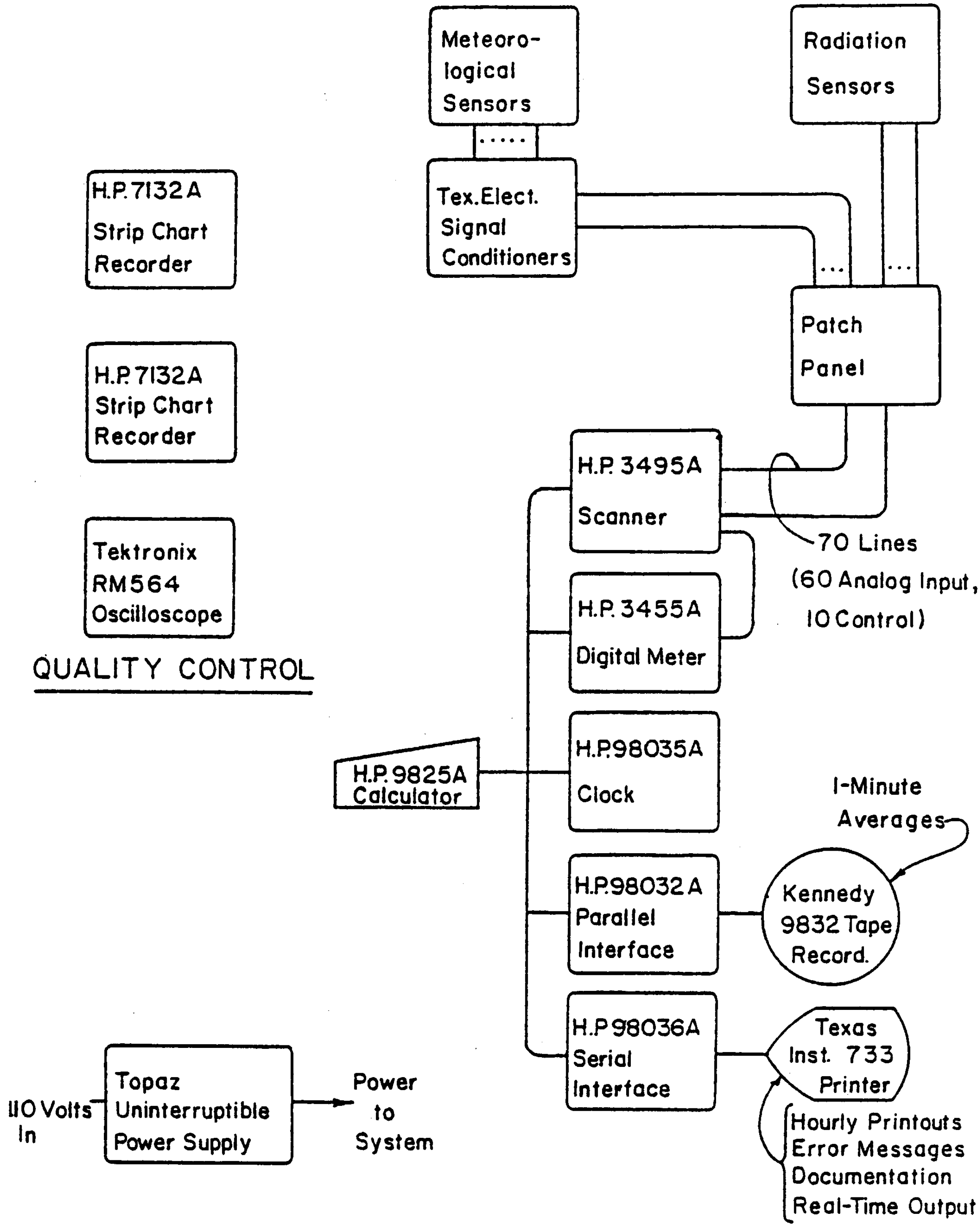


FIGURE 1 - Data Acquisition and Data Processing System at Trinity University Site

3. Recommend that DOE support the development of an absolute IR calibration standard. Measurements in the IR are very important to the development of passive heating and cooling techniques. We are preparing a proposal to develop such a standard.

REFERENCES

1. Solar Heating and Cooling Demonstration Project Summaries, U.S. Department of Energy, DOE/CS-0009, U.S. Government Printing Office, May, 1978.

2. Loxsom, F.M., Clark, G., Allen, C., "A National Assessment of Passive Nocturnal Cooling From Horizontal Surfaces", Proceedings of the 4th National Passive Solar Conference, Kansas City, Mo., October 3-5, 1979.

3. A Proposal to Design, Construct and Monitor an Experimental Passively Heated and Cooled Residence in a Subtropical Marine Climate, Trinity University, Department of Engineering Science, San Antonio, Texas 78284.

4. Rudzki, J., Clark, G., Loxsom, F., Micek, L., "The Solar-Meteorological Research Program for the South-Central U.S.", Proceedings of the ASME 1980 Winter Annual Meeting, Chicago, Ill., November 16-21, 1980.

5. Wolff, W., Clark, G., Rudzki, J., "On-Site Quality Control of Insolation Measurements", Proceedings of the ASME 1980 Winter Annual Meeting, Chicago, Ill., November 16-21, 1980.

6. Wisneski, T., Solar Radiation Data Verification Techniques, M.S. Thesis in progress, Trinity University, Department of Engineering Science, San Antonio, Texas 78284.

7. Hulstrom, R.L., Inter-office Memorandum, Solar Energy Research Institute, January 14, 1980.

8. Rudzki, J., Averill, R., "An Improved Funk-Type Radiometer", Trinity University, Solar Data Center, San Antonio, Texas 78284.

9. Rudzki, J., "Precision Pointing of Tilted Precision Spectral Pyranometers", in preparation, Trinity University, Solar Data Center, San Antonio, Texas 78284.

SOLAR ENERGY METEOROLOGICAL RESEARCH & TRAINING SITE-REGION 2

Ronald Stewart
Atmospheric Sciences Research Center
State University of New York at Albany
Albany, N.Y. 12222

BACKGROUND

The Region 2 Solar Energy Meteorological Research and Training Site began operation on October 1, 1977 with the expectation of an initial five-year program. The Program Objectives as outlined in the original proposal included:

1. The establishment of an observation station which will produce high quality records of the significant solar radiation components and aspects of the atmosphere, such as cloud cover, turbidity, water vapor content, etc., which have an impact on the receipt of solar radiation at ground-level. Routine monitoring of these parameters as well as special analyses will be performed.

2. The establishment of an educational program in solar meteorology. This program will have offerings for matriculated students at the graduate and undergraduate levels and will also have offerings for engineers, technicians, and architects--people who need narrowly-defined technical knowledge of various aspects of solar energy.

3. The establishment of a continuing research program which will provide the opportunity for advanced students and staff to explore the relationships between incoming solar radiation and atmospheric constituents which are relevant to the use of solar energy in technological applications. The organizational format designed to carry out the stated objectives involved the Atmospheric Sciences Research Center (Ronald Stewart, Principal Investigator) and the Department of Atmospheric Science (Harry L. Hamilton, Co-Investigator).

Other related projects include cooperative efforts by the Northeast Solar Energy Center (NESEC), DOE, ARCO Solar, Inc. and the ASRC (NE-SEMRTS) which developed into a photovoltaic powered communications system for the 1980 Winter Olympics. The PV system was erected on top of the base lodge at Whiteface Mountain in full view of the spectators. Inside the lodge the system powered the communications console, a telephone system on the Alpine slopes, and the race communications system which allowed all points on the race course to communicate with each other and with the communications center. The system performed flawlessly. Twenty ARCO Solar PV panels were connected to power the 12v, 24v and 48v systems. John Sicker developed the electronic controls and spent many weekends installing and testing the system.

The PV panels will now be distributed to Lake Placid, NY High School, Adirondack Community College in Glens Falls, NY and to the ASRC with two panels becoming part of a display at the NESEC. The schools plan to use the panels (two to each school) for class demonstrations and training.

The ASRC will use some of the panels for charging the battery back-up system for the SEMRTS computer, with others being used in research projects.

In addition, sixteen students from Africa and China attended a solar energy workshop conducted by the ASRC under sponsorship of Unesco. Subjects included instrumentation, active and passive systems, wind energy and world-wide uses of solar energy. Additionally, the students constructed small solar panels and assembled a photovoltaic powered water pump (which worked very well). The SEMRTS facilities were toured to provide the students with the concept of an extensive solar-meteorology station, computer facilities for analysis, and the resultant use of data.

The discussion periods were intense as the need for technological transfer and self-reliance of the emerging nations was intertwined with the need to improve conditions as quickly as possible. The students have been given membership in the local chapter of AS-ISES (Eastern New York Solar Energy Society) to enable them to interact with researchers, developers, etc. over the next year.

Solar Energy Workshop National Weather Service Personnel
Sep 29-30, 1980

A workshop was arranged to inform NWS, MICs and OICs on the nature, measurement, and application of solar energy. This workshop has been organized by the ASRC in cooperation with Messers Stanley Wasserman and Joseph Harrison of the National Weather Service - Eastern Region. The topics presented were developed through the joint efforts of the NWS and the ASRC and are as follows:

- Theory and Practice of Solar Measurement
- The Involvement of the National Weather Service in Solar Measurement
- Forecasting Solar Radiation
- The Development of Satellite Techniques for Estimating Ground Level Solar Radiation
- Solar Energy Utilization by
  - Active Systems
  - Passive Systems
  - Concentrating Systems
  - Photovoltaics
- Wind Power Assessment and Applications
- Access to Information on Solar Utilization

The SEMRTS Region 2 was used as the focal point for this cooperative program.

Recent Academic Courses

ATM 639 Energy Seminar
Fall 1979 "Energy Alternatives and Climatic Change"
ATM 639 Energy Seminar
Spring 1980 "Small-Scale Renewable Energy Resource Development"

ATM 639 Energy Seminar
Fall 1980 "Solar Energy Applications"

DESCRIPTION

The solar radiation instruments are located on the roof of ASRC's one-story building, which is situated in a light industrial area approximately five miles from downtown Albany. The meteorological instruments are mounted on the ground and the wind instruments are mounted on a 15 meter tower. The horizon is clear above a 5° elevation in all directions. Below the 5° elevation there are several obstructions, the largest being a water tower in the southern quadrant. However, the effect of the above on data accuracy is negligible.

Building elevation:	79.3 meters above sea level
Solar instrumentation height above ground elevation:	7.68 meters
Latitude:	42°42'N
Longitude:	73°50'W

PARAMETER DESCRIPTION
Table A

PARAMETER	MODEL TYPE	SPECIFIC MODIFICATIONS
Temperature	Climatronics Motor Aspirated Temperature Sensor	-
Dewpoint	Climatronics Motor Aspirated Lithium Chloride Dewcell Sensor	-
Pressure	Yellow Springs Instrument Co., Inc.	sensor
Wind Direction	Climatronics Wind Mark III	-
Wind Speed	Climatronics Wind Mark III	-
Precipitation	MRI 8" Diameter Tipping Bucket Rain Gauge	-
Direct Radiation	Eppley Normal Incidence Pyrheliometer (NIP)	-
Global Radiation	Eppley Precision Spectral Pyranometer (PSP)	-
Diffuse Radiation	1. Eppley PSP with Shading Disc 2. Eppley PSP with Shadow Band	
Filtered Radiation (Global or Direct)	Eppley PSP or NIP with Filters:	
	1. OG530	Measures Radiation > 520 nm
	2. RG630	Measures Radiation > 620 nm
	3. RG695	Measures Radiation > 680 nm
Tilted Global Radiation	Eppley PSP @: 1. Latitude minus 10 degrees 2. Latitude 3. Latitude plus 10 degrees	Artificial Horizons are affixed to PSP's so that only sky radiation is measured (i.e. no ground reflection is measured)
Ultra-Violet Radiation	Eppley Ultra-Violet Radiometer	-

Table A cont'd.

PARAMETER	MODEL TYPE	SPECIFIC MODIFICATIONS
Infra-Red Radiation	1. Eppley Pyrgeometer 2. Swissteco Net Radiometer	Swissteco Net Radiometer: Daylight values include global radiation; night time values are infra-red only
Minutes of Sunshine	Campbell-Stokes Sunshine Recorder	-
Extraterrestrial Radiation	-	Calculated values - not measured. Represent global radiation in the absence of an atmosphere
Calculated Diffuse Radiation	Diffuse Calculated = Global - Direct*cos (Zenith angle)	
Vertical Global Radiation	LiCor Pyranometers: 1. North-facing 2. South-facing 3. East-facing 4. West-facing	An artificial horizon is affixed around the Li-Cor's so that only sky radiation is measured (i.e. no ground reflection is measured)

COMPUTER FACILITY

The SEMRTS - Region 2 computer facility consists of a Kaye Data Acquisition System and a Data General Eclipse S/140 computer.

A. Kaye Data Acquisition System

1. Kaye Ramp Scanner - 40 analog inputs

This section of the data logger converts the initial analog voltage from the instruments to a digital form.

2. Kaye Ramp Processor

Here the data is converted to real numbers and checked with alarm settings to ensure that the data is within preset limits.

3. Kennedy Incremental Tape Drive
4. Topaz Uninterruptible Power System - 1500 VA size

B. Aim Computer System

The Aim system performs real time quality control on the incoming data. The quality control procedures are the same as those described in Section V, however, the use of the Aim System enables an observer to immediately determine any problems and take steps to correct them. The Aim computer contains:

1. 20 k memory
2. 16 k ROM
3. Thermal Printer
4. LED display
5. Cassette Storage

C. Data General S/140 Computer
The Eclipse computer system contains:
1. 256 k bytes of memory
2. 6 channels of I/O
3. 25 M bytes of disc storage
4. 2 tape drives: 800 BPI and 800/1600 BPI
5. Hard and soft terminals and plotters

Quarterly Solar Climatic Summary

In January 1980, The ASRC as Northeast SEMRTS published the first issue of its solar climatic summary. Due to a favorable response from the solar community, we have committed to publishing hourly meteorological and solar data from our Albany site on a quarterly basis. This publication will be made available to architects, engineers, scientists, and other solar professionals for a nominal fee (to defray publication costs). It is anticipated that data from non-NOAA sites will be included in these reports. In addition, the data are available from the SERI and NCC.

A. Gross Daily Quality Control

After completing the instrumentation inspection, a visual check of the Kaye Data Acquisition system digital display and paper print out is performed. Solar data values are perused for reasonability; meteorological data values are compared with those from the National Weather Service located at the Albany County Airport.

B. Computer Quality Control

The ensuing quality control is used to determine questionable minute data which will subsequently be used to appropriately flag the one hour data.

The SERI suggested quality control has been implemented for the basic measurements. All data starting January 1, 1979 will be reprocessed under this quality control upon receipt of the revised basic quality control as discussed with SERI and the other sites. The research measurements' quality control is a logical extension of the basic quality control. All relations are ±20% and valid only for zenith angles $<85^o$ and intensities $> 3kJ/m^2$ unless noted otherwise.

Minimal Objective Quality Control for One Minute Basic Data

a) GLO(WG7) < 1.20 ETR Horizontal
   ETR=Extraterrestrial Radiation, 1377 w/m^2 direct beam at earth-sun mean distance
b) NIP(WG7) < 1.00 ETR Direct
c) NIP(WG7)*cos (θ_o) < GLO(WG7)
   θ_o=solar zenith angle for θ_o's $< 85^o$
d) DSB(WG7) ≤ GLO(WG7)
   within tolerance of 5% on "equals"
   Diffuse disc measurements also undergo this quality control

e) GLO(UV) ≈ 0.05 GLO(WG7)
tolerance of 60% (0.05 ± 0.03)

f) GLO(RG2) ≈ 0.63 GLO(WG7)
g) GLO(RG8) ≈ 0.51 GLO(WG7)
h) GLO(OG1) ≈ 0.75 GLO(WG7)
i) TSG(WG7) > NIP(WG7) * cos θ
θ = incident angle to surface, for $\theta < 85^{o}$
also for 33,43,53 degree tilts and North-South-East-West Vertical measurements
The zenith angle (θ_o) is calculated every minute
j) NIP (OG1) < NIP (WG7)
k) NIP (RG2) < NIP (OG1)
l) NIP (RG8) < NIP (RG2)

The ratio of the filtered NIPs to the NIP WG7 is dependent on airmass, therefore, a single ratio, as for the horizontal pyranometers, is unworkable.

Solar Irradiance Data for the Passive Designer

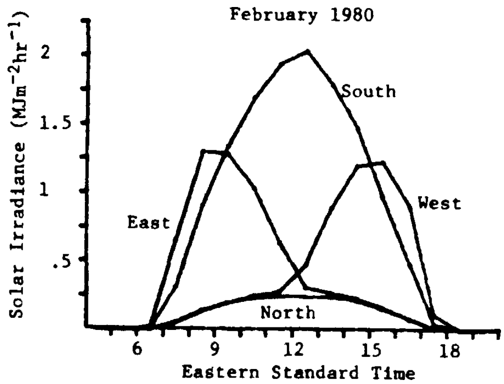
James Healey
Jack Boston
Robin J. Near

ABSTRACT

Historically solar irradiance has been measured by sensors mounted in a horizontal fashion with a full (180°) view of the sky. These data are sometimes referred to as global horizontal solar irradiance. Of interest to solar designers is the solar energy available on vertical surfaces. Calculation procedures have been developed to determine the solar irradiance striking vertical surfaces from the global horizontal solar irradiance measurement.

The ASRC, as Northeast SEMRTS, is currently monitoring twenty-five solar and meteorological sensors each minute. Among these data are horizontal global and vertical global solar irradiance. The data record for the four LiCor pyranometers, oriented vertically and facing north, south, east and west, began in February 1980. The horizontal global irradiance measurement (Eppley precision spectral pyranometer) began in January 1979.

This paper presents vertical surface solar irradiance data for Albany, NY from February - June 1980 (see accompanying figure). In addition, actual measurements of vertical solar irradiance are compared with values derived from models utilizing global horizontal data.



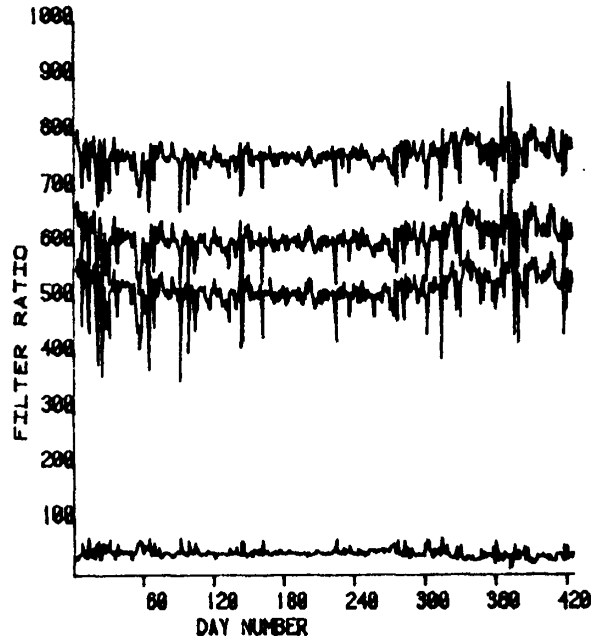
Average daily solar irradiance on vertical surfaces oriented North, South, East and West.

Seasonal Variation in the Solar Spectrum

Daniel W. Spencer and James Healey

ABSTRACT

One minute data from 423 consecutive days is used to measure the seasonal solar spectrum variations. The parameters measured are horizontal global irradiation with WG7, OG1, RG2, RG8 and UV filters and direct normal radiation. An average ratio of each filtered horizontal global to the clear filter is computed for each day using a least square correlation. The accompanying figure depicts the daily average ratio of the filter; WG7 measurements for January 1, 1979 through February 29, 1980. The correlation coefficient adds information about the variability of the ratio during the day. The variability of these ratios is much higher in winter than summer, for cloudy vs. sunny days, and humid days vs. dry days. The effects of optical air mass is inferred by the study of two very clear days. The effect of water vapor is inferred from the summer relative increase in the OG1-RG2 band. The UV radiation is much lower for the 1979-80 winter than the 1978-79 winter.



Daily filter ratios, top to bottom, OG1/WG7, RG2/WG7, RG8/WG7, and UV/WG7 for 1-79 thru 2-80 (1000 = 1.000 WG7).

SUMMARY

The SEMRTS Region 2 expects to continue our data acquisition and analysis program in the future. Emphasis on specific projects will alter the direction of the program at times. For instance, (1) we have begun using our data for ground truth as compared to the National Environmental Satellite Service analysis of available insolation and expect to expand this effort, (2) the forecasting of insolation by modelling techniques and/or partially based on readily available meteorological parameters, will continue, (3) our efforts to expand and improve an insolation network which will aid in the commercialization of solar energy are based on the needs of user groups, and (4) an increased effort in the analysis of spectral data will provide the first step toward a climatology of spectral data.

We have also offered to participate in a weather modification effort based on our interests of increasing available insolation and decreasing nighttime radiational cooling.

During the next year a strong effort will be made to link-up the eight SEMRTS into one to two joint proposals for a nation-wide research program.

(ASRC Publication No. 797)

PROGRAM FOR SOLAR AND METEOROLOGICAL RESEARCH AND TRAINING SITE, REGION 6

Atmospheric and Oceanic Science Department
University of Michigan
Ann Arbor, Michigan 48109

ABSTRACT

Results of work on the Program for Solar Energy Meteorological Research and Training Site, Region 6, for FY 1980 are described. Activities and accomplishments involving (1) operation of primary and mobile measurement facilities, (2) establishment of secondary stations, (3) data processing and handling, (4) data analysis and research, (5) a summer workshop and an academic course in solar energy measurement and instrumentation and (7) providing solar energy information and consultation are described.

BACKGROUND

The program has two main objectives: (1) to determine space and time distributions of available solar energy in Region 6, a ten-state area in the upper midwest*, and (2) to establish a center for education and training in solar energy and its measurement. The approach to the first main objective has three phases: (1) measuring solar irradiance and atmospheric variables, (2) collecting, processing and storing solar irradiance and atmospheric data from throughout Region 6 and (3) developing relationships and models to calculate useful solar energy information from both solar irradiance and atmospheric measurements.

There are three parts to the measurement phase:

(a) Establish and operate a primary site at the University of Michigan for the simultaneous and continuous measurement of a number of solar radiation and atmospheric variables;

(b) Construct a mobile measurement facility and operate it for various lengths of time at different locations in the region to obtain many of the same measurements made at the primary facility; and

(c) Establish facilities at several locations in the region to record total solar radiation incident on surfaces tilted southward at angles corresponding to the latitudes of the respective locations.

In addition to their main purpose in providing measurements of solar and meteorological variables, both the mobile unit and the primary measurement facility function as focal points for education and training.

---

*North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Wisconsin, Illinois, Michigan, Indiana and Ohio.

In the second phase, solar and atmospheric data from measurements throughout the region, from the primary measurement site, and from the mobile unit are collected, processed and stored. The work includes the search for available data within the region and the assembly and storage of data in disk files at the University of Michigan Computing Center.

Work in the third phase has consisted, so far, of two separate studies. The first was the development of a climatic atlas for the region to show geographical distributions of monthly mean solar irradiance estimates and atmospheric variables significant to the estimation and application of solar energy. The second was the testing of numerical models to compute available solar energy on flat surfaces of arbitrary orientation from time, place and atmospheric information.

For the second main objective specific activities have included: (1) conducting special workshops and short-term training programs in the measurement and analysis of solar radiation quantities and atmospheric variables, (2) developing and presenting a one-semester course in solar energy instrumentation and measurement and (3) communicating with the media, architects, engineers and others in industry and education to share information on available solar energy and to advise on solar energy measurement programs.

DESCRIPTION

Measurement of Solar Irradiance and Meteorological Variables

Primary Measurement Facility. Recording of nine irradiance and six meteorological variables both by analog strip-chart recorders and by a computer-controlled data acquisition system continued throughout FY 1980. The variables recorded and sensors used are listed in Table 1.

Mobile Facility. The mobile measurement facility is an 8' x 20' custom-built unit resembling a mobile home. Irradiance and meteorological sensors supported on it and the variables measured are also listed in Table 1.

Table 1
Primary Facility Measurements

Irradiance Measurements	Sensor
Global solar	PSP
Global solar (filter)	PSP with RG2 filter
Latitude-angle solar	PSP with horizon shield
Diffuse solar	PSP with occulting disk
Normal incidence solar	NIP
Ultraviolet solar	UV photometer
Global solar and infrared	CSIRO Funk pyrradiometer
Infrared (atmospheric)	Precision infrared radiometer
Sunshine duration	Campbell-Stokes recorder

Meteorological Measurements	Sensor
Air temperature	Thermistor
Dew Point	Dewcell
Wind speed	3-cup anemometer
Wind direction	Wind vane (0-540°)
Pressure	Pressure transducer
Precipitation	Potentiometric weighing gage

Mobile Facility Measurements

Irradiance Measurements	Sensor
Global	PSP
Normal incidence solar	NIP
Solar (spectral, angular)	PSP with filters and tilt mechanism

Meteorological Measurements	Sensor
Air temperature	Thermistor
Dew point	Dewcell
Wind speed	3-cup anemometer
Wind direction	Wind vane

Secondary Stations. Three stations in Region 6 were established to measure solar irradiance on inclined surfaces. They are

Omaha, NE	(NOAA SOLMET STATION)
Madison, WI	(NOAA SOLMET STATION)
Argonne, IL	Argonne National Laboratory

Each station has a PSP facing south and inclined upward from the horizontal at an angle corresponding to the station's latitude and and an analog recorder with integrator-printer. The PSP is on an adjustable supporting stand that has a specially-designed cylindrical shield to exclude reflected solar irradiance from below the horizon.

Data Handling

Data from Primary Measurement Facility. Table 2 shows the data recovery rate for the automatic data acquisition system by month for FY 1980. Data quality control procedures were developed and implemented. Basic quality control checks on the one-minute data recommended by SERI are performed on-line as the data are acquired on the DEClab 11/03. The data are stored on floppy disks and read into the UM Amdahl 470 V/8 computer three times each week.

Table 2
Data Recovery for FY 1980

October 1979	97%
November 1979	93%
December 1979	97%
January 1980	69%*
February 1980	91%
March 1980	94%
April 1980	90%
May 1980	90%
June 1980	93%
July 1980	91%
August 1980	95%
September 1980	98%

* system repaired

As soon as the data are read into the Amdahl 470V/8, they are reviewed by trained personnel using an interactive graphics program called SVIEW. Capabilities of SVIEW include: (1) displaying time series plots at the user's terminal, (2) generating hard copy plots, (3) transforming data and (4) editing and writing out files of edited data. Off-line quality control procedures making use of these capabilities have been developed, but implementation awaits clarification from SERI regarding details of the procedures.

Computer programs for converting the solar and meteorological data from an internal format to the co-operative format for NCC (hourly data) and SERI (one-minute data) were developed. Test tapes were submitted to both NCC and SERI, and the NCC tape passed the check tests. At the end of FY 1980, there had not been a response concerning the acceptability of the SERI tape.

Data from Mobile Facility. A computer tape with data from the mobile Automatic Scanning Photometer used during the August 1979 Iron Mountain experiment was received from Battelle Pacific Northwest Laboratories in April. It was then learned, however, that the data were inaccurate due to a forward scattering problem associated with the design of the instrument in use at that time. It was learned, in addition, that the wrong data logger sampling program was used for all but the first day of the experiment. Processing of global, direct and diffuse irradiances measured with the mobile facility instrumentation, nevertheless, continued.

Data from Secondary Stations. Screening, cataloging and processing of the latitude-tilted pyranometer data from the stations established at Argonne, IL, Omaha, NE, and Madison, WI, began.

SUMMARY OF RESULTS

Data Analyses

Cloudless Day Irradiances. Measurements of irradiances for a total of 75 cloudless days at the primary facility between 19 May 1978 and 30 September 1980 were analyzed to determine average cloudless-day diurnal variations and daily totals of global, direct, diffuse, atmospheric, ultraviolet, global RG2 and inclined irradiances throughout the year.

Turbidity Characteristics. Turbidity coefficients were calculated from measurements of irradiances at wavelengths of 500, 880 and 940 nm with a Volz sun photometer and at effective mean wavelengths of 454 and 669 nm with a normal incidence pyrheliometer. A total of 269 Volz measurements made between 31 October 1978 and 30 September 1980 were processed in terms of Angstrom's turbidity coefficient and wavelength exponent and in terms of precipitable water. Twenty-one of the measurements were made just prior to, during and following the passage over the primary facility of the particulate cloud from the May 1980 eruption of Mount St. Helens. A paper entitled "Effects of the Mount St. Helen Volcanic Cloud on Turbidity at Ann Arbor, MI" is being submitted for publication in the journal Solar Energy and for presentation at the Fourth Conference on Atmospheric Radiation, June 16-18, 1981, in Toronto, Ontario, Canada. The abstract of the paper is given below. A second paper discussing all measurements of turbidity made here thus far is in preparation.

Effects of the Mount St. Helens Volcanic Cloud
on Turbidity at Ann Arbor, Michigan

Edward Ryznar
Thomas S. Hallaron
Michael R. Weber

Measurements of turbidity were made at the University of Michigan irradiance and meteorological measurement facility just prior to, during and after the passage of the volcanic dust cloud from the 18 May 1980 eruption of Mount St. Helens. They were made with a Volz sunphotometer at wavelengths of 500 and 880 nm and with an Eppley normal incidence pyrheliometer at effective mean wavelengths of 454 and 669 nm.

The effects of the dust cloud on the turbidity coefficient and wavelength exponent in Angstrom's turbidity equation were evaluated with the measurements. The dust cloud increased the turbidity coefficient by a factor of about 3 compared to average clear-day values. These results are discussed in regard to effects of the large particles comprising the dust cloud on turbidity parameters.

Joint Frequency-Duration Statistics. Work began on a method of characterizing available solar energy in Region 6 in terms of joint frequency-duration statistics. Computer routines were developed to obtain, on command, statistics such as the average number of days each month having, for a given number of consecutive hours, a given level of solar irradiance within specified temperature and wind speed ranges. A sample of the output is given below.

```
          JOINT FREQUENCY - DURATION STATISTICS
                   ANN ARBOR, MICHIGAN

              790901 - 790930 ( 30 DAYS)

                 NUMBER OF DAYS WITH:

                         TEMP <    20.
                 2500. < GLBL

          FOR GIVEN MINIMUM CONTINUOUS DURATION (HOURS):
            0!   1!   2!   3!   4!
          ---+---+---+---+---
           20!  10!   7!   4!   0!
```

A program of hourly cloudiness observations for the primary facility was begun to aid in developing these statistical relationships.

Empirical relationships for estimating irradiances on arbitrarily oriented surfaces are being evaluated for their reliability for determining similar statistics for other than horizontal surfaces. The plan also includes the use of other empirical relationships, such as those developed by NOAA Air Resources Laboratory, to estimate similar statistics for stations having long-term meteorological records on tape but which do not have irradiance data.

Forecasting Solar Irradiance. A paper entitled "Subjective Forecasting of Received Solar Radiation" was accepted for presentation at the Workshop on Terrestrial Solar Resources Forecasting to be held February 2-5, 1981 in Washington, D.C. The abstract for the paper is given below.

SUBJECTIVE FORECASTING OF RECEIVED SOLAR RADIATION

Dennis G. Baker

Forecasting competitions at the University of Michigan have incorporated forecasting of solar radiation for periods from 24 to 72 hours in advance. For two years, the variable forecast has been the percent of extraterrestrial radiation falling on a horizontal surface in Ann Arbor, with verification made using the University of Michigan solar radiation monitoring station. Forecasts

made by students and faculty surpass both persistence and climatology. Although there is a lack of direct NWS guidance in objective form, some indirect information is obtained using variables such as probability of precipitation. Attempts to derive better models of received solar radiation include a MOS approach using LFM predictions available on the NAFAX facsimile circuit and a perfect prog approach using radiosonde soundings.

Education and Training

Workshops and Other Short-Term Training Programs. A workshop in solar energy measurement and instrumentation was held June 23-25 for Meteorologists-in-Charge at National Weather Service Forecast Offices in Region 6. In addition, Mr. Allen Pearson, Director of the National Weather Service Midwest Region and Mr. Dan Spencer, representing the SEMRTS for Region 2 attended. Dr. Donald Anderson, Director of the Mid-America Solar Energy Complex (MASEC) was the keynote speaker on the first afternoon.

In addition to lectures and demonstrations, the workshop included a laboratory exercise in which the participants measured spectral and angular variations of solar irradiance. The data were printed out on-line on the automatic data acquisition system and the results were then discussed in regard to models for predicting solar irradiance. The last half-day session included discussions of the solar index, a guest speaker from the State of Michigan Solar Office and a general question and answer period concerning the structure of the workshop.

Academic Course. A 3-credit, one semester course, Instrumentation for Solar Energy Measurements, was presented in the winter semester, 1980. Two one-hour lectures and one three-hour laboratory were presented each week. The course description is given below.

> Atmospheric and Oceanic Science Course No. 466:
> Instrumentation for Solar Energy Measurements.
> Principles of radiometric instruments. Measurement techniques for direct, global, diffuse, ultraviolet, and infrared radiation at the earth's surface. Other radiation-related measurement techniques including spectral analysis, turbidity, sunshine, and angular distribution. Calibration of radiation instruments. Recorder and data-handling systems. Lectures, laboratory, and field trips.

Communication and Consultation. A paper entitled "The University of Michigan Solar Energy Measurement Program" was presented by Edward Ryznar, and copies were distributed at the Second Michigan Solar Energy Association Solar Conference and Exhibit held 19-21 October 1979. On the last day of the conference, the primary and mobile measurement facilities were open to the public and were visited by conference attendees.

On 6 November, Professor Fred Bartman attended a conference in Lansing, Michigan, entitled "A Solar Electric Energy Seminar". The conference was sponsored by the Energy Administration of the Michigan Department of Commerce in conjunction with the Gilbert/Commonwealth Companies to gather information for a report to SERI on the practicality of the applications of solar electric power. This conference was the first of a series of regional meetings to be held in the United States to solicit views, opinions and reactions to solar electric power for inclusion in the report.

Since October 1979, daily totals of solar irradiance measured with the latitude-tilted pyranometer have been provided to the Ann Arbor News and the Jackson (MI) Citizen-Patriot for publication each day. An estimate of the amount of energy that would have been received, had the day been clear, and the percent of this that was actually received are also included.

The data being published in newspapers have generated several requests for similar data and other information. In addition, average daily horizontal global solar irradiance data are supplied once a month to the University of Alabama in Huntsville for publication in the National Climatic Center Solar Data Project.

Future Plans. In fiscal 1981 substantial effort is planned for the development of the Joint Frequency-Duration Statistics and relationships required to yield practical solar system design information. This work can be accelerated upon completion of data quality control routines.

Installation of two additional remote stations for measuring global solar radiation on inclined surfaces and further use of the mobile measurement facility are being delayed until adequate project funding for fiscal 1981 is assured.

At present there are no plans for special courses or summer conferences.

SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING SITE - REGION 5

C.R. Nagaraja Rao
Department of Atmospheric Sciences
Oregon State University
Corvallis, Oregon 97331

Introduction

The Solar Energy Meteorological Research and Training Site (SEMRTS) program was initiated in the fall of 1977 by the U.S. Department of Energy to meet the perceived need for a quantitative solar resource assessment for the country and for the development of quality educational and training facilities in the broad discipline of solar energy so that future manpower needs could be adequately met. The country was divided into eight regions and universities with well-established programs of research and instruction in the atmospheric sciences were entrusted with the task of setting up and administering this program initially for a period of five years. Accordingly, Oregon State University, Corvallis, was chosen as the centre for Region 5, comprising the states of Idaho, Montana, Oregon, Washington and Wyoming.

At the time the SEMRTS program was initiated, it had been recognized that an essential component of the solar resource assessment activity would be the establishment of a very comprehensive solar radiation and related meteorological data base for the region. It was decided that this data base would be made up of high resolution, research quality measurements made at the regional centre and low resolution, general quality measurements made at monitoring stations making up statewide and regional networks. These data would in turn find immediate use in solar applications and would also be used in the generation and validation of solar radiation climatological models for the region.

The various aspects of the SEMRTS program and the accomplishments to date, especially in the areas of educational, training and regional monitoring activities, have been discussed at length elsewhere (Rao and Hewson 1980). Therefore we shall focus our attention in what follows on the observational program at the regional centre; current and proposed research activities will also be touched upon briefly.

1. The Regional Centre

1.1 General

The regional centre for research and instruction in solar radiation meteorology is part of the Department of Atmospheric Sciences at Oregon State University, Corvallis, and thus can call upon the resources of the Climatic Research Institute, the Air Resources Centre and the Schools of Agriculture, Engineering and Forestry. Standard computing (CDC Cyber, PDP 1170, HP 9800 Series), weather teletype and facsimile facilities are available. Also, the visible and infrared picture transmissions of the Geostationary Operational Environmental Satellite (GOES) are routinely received.

1.2 The Field Observing Facility

The Field Observing Facility, made up of a two-story laboratory and a 48.8 m meteorological tower, is located on a University research farm about 2 km east of the main campus (Fig. 1). The radiation sensors are mounted on a roof-top platform which provides optimum exposure with practically no obstructions extending beyond 3° above the plane of the sensor elements, especially from east-north-east through south to west-north-west. Conventional meteorological measurements are made at the 10 m and 48 m levels on the tower with a modular meteorological system put together by Climatronics Corporation, Hauppague (N.Y.). The Eppley precision spectral pyranometers (PSP's) and the normal incidence pyrheliometers (NIP's) used in the measurement of various insolation parameters are Class I (WMO classification) instruments and are periodically calibrated against secondary standards maintained at the Solar Radiation Facility, NOAA Environmental Research Laboratory, Boulder (CO).

The signals issuing from the various sensors are sampled six times a minute by the automated data acquisition system built around a Hewlett-Packard Model 9825 computer. The data acquisition system has been designed to accept up to 40 channels of sequential, analog data and to process and record, in appropriate SI units their average or integrated values, as desired and as often as necessary, on magnetic tape. Generally, the one-minute values are recorded on tape and the one-hour values, when once they have been computed by the HP 9825 computer, are fed into the Hewlett-Packard Model 2631A printer. Values over as short a time interval as two minutes can be printed out, if desired.

The one-minute data are then recast into the NCC-SERI Research Cooperator Format at the main campus computer centre for transmittal to the National Climatic Centre, Asheville (N.C.) and to the Solar Energy Research Institute, Golden (CO).

A detailed description of the Field Observing Facility, including details of sensor location and performance, test and calibration techniques, the automated data acquisition system and of the data validation and quality control measures, will be found in the forthcoming OSU-SEMRTS Field Observing Facility Handbook (Rao et al, 1980).

1.3 On-Campus Laboratory

The newly constructed on-campus laboratory (100 m^2) is made up of an electronics shop, an optics dark room and a data centre and is equipped with standard electronic and electro-optical test and calibration instruments. Included amoungst the very sophisticated instruments for atmospheric optical investigations available to students and staff are photoelectric polarimeters, radiometers and a programmable reflectometer.

2. Observational Program at the Regional Centre

Listed below are the various solar radiation and related meteorological measurements made at the centre; the new Eppley filter designations--WG 295, OG 530, etc.--have been used to indicate the spectral nature of the insolation parameter being measured:

a. Direct normal irradiation (WG 295, RG 695)
b. Global horizontal irradiation (WG 295, OG 530, RG 630, RG 695)
c. Diffuse horizontal irradiation (WG 295, shadowband)
d. Global irradiation on tilted surface (WG 295, facing south, tilt angle: 44°36')
e. Global ultraviolet horizontal irradiation (Eppley UV radiometer; 290-380 nm)
f. Surface Albedo (48 m level on tower)
g. Downward atmospheric infrared irradiation (CSIRO Funk-type radiometer; 3-40 μm)
h. Duration of sunshine (Campbell-Stokes sunshine recorder)
i. Atmospheric turbidity and water vapour (Volz multi-wavelength photometers)
j. Wind speed and direction (10 m and 48 m)
   Temperature and humidity (2 m, 10 m, and 48 m)
k. Pressure and precipitation

We shall present and discuss some of the measurements under categories a, b, c, e, f, g and i in what follows.

2.1 Direct normal, global horizontal and diffuse horizontal irradiations

The diurnal variation of the total (WG 295), hourly irradiations is shown in Figs 2, 3 and 4 for three days; shown also in the diagrams are the extraterrestrial solar irradiation (ETSR) on the horizontal and the duration of sunshine--a reproduction of the Campbell-Stokes record--as a solid line under the caption 'continuous sunshine.' The duration of sunshine (PPS)--expressed as a percentage of the possible--has been used only as an indicator of sky conditions [$0 \leq PPS < 30\%$, cloudy; $30 \leq PPS < 70\%$, moderately cloudy, $70 \leq PPS < 100\%$ clear] and not as an actual measure of cloudcover since it has not been possible to establish any linear relationship between it and the mean daily cloud cover as reported by an experienced observer at the site (Fig. 5).

A noticeable feature of the measurements on a clear day (Fig. 2) is the symmetry of the irradiations about midday; also the diffuse component makes up about 15-20% of the global irradiation around noon. This is comparable to values of ∿10% predicted for a pure molecular atmosphere by Deirmendjian and Sekera (1954) for the range of solar zenith angles and surface albedos encountered. On any given day, the contribution of the diffuse component increases for larger solar zenith angles.

The behavior on an overcast day (Fig. 3) is fairly predictable in that the global irradiation is practically, entirely made up of the diffuse component. However, the diurnal variation of these various irradiations on a partly cloudy day (Fig. 4) does not lend itself to easy interpretation in view of the fact that the governing physical process is the transfer of radiant energy in a horizontally inhomogeneous, cloudy atmosphere. The solution of this problem is central to the understanding of the radiation climatology of Region 5 and is being pursued as part of the research activities.

The diffuse irradiation shown in Figs. 2, 3 and 4 is the computed value of the difference between the measured value of the global horizontal irradiation and the vertical component of the measured value of the direct normal irradiation. It is also measured with an Eppley precision spectral pyranometer used in conjunction with a shadowband. The corrected shadowband values (Y) and the computed values (X) are related as follows:

$$Y = 0.974X + 1.937 KJ/m^2 \quad (0 \leq PPS < 30\%)$$
$$Y = 0.920X + 6.066 KJ/m^2 \quad (30 \leq PPS < 70\%)$$
and $$Y = 0.888X + 16.245 KJ/m^2 \quad (70 \leq PPS < 100\%)$$

X and Y are both expressed in KJ/m^2; the intercept values amount at most to a few percent of the full scale response of the particular sensor used under 'partly cloudy' and 'cloudy' conditions. It is also apparent that the shadowband corrections are not appropriate for clear days.

Measured values of the global irradiance (W/m^2) have been compared with the computed values for the cloud-free model atmosphere described by Machta (1978) and the results are shown in Table 1. Measured values of the surface albedo and representative and extreme values of atmospheric turbidity (Table 3-4, Machta, op.cit., and local observations) and water vapour content, based on climatological records, were used in the model computations.

Table 1: Measured and computed values of global irradiance
Date: 3 May 1980 Site: Corvallis (123°13'W, 44°36'N, 91m)
Θ_o: 28°55' Surface albedo: 0.144 PPS: 97.8%

Observed value of G(WG295): 910.6 watts/meter^2
Computed values of G (watts/meter^2)

Turbidity Coefficient \ Precipitable Water (cm)	.64	.96	1.60	1.92
0.05	923.3	909.7	891.5	887.0
0.10	922.3	908.7	890.5	886.0
0.15	920.5	906.9	888.8	884.2

The cumulative frequency distributions of the one-minute and hourly irradiations over a 25-day period (1 Jan 1980 - 25 Jan 1980) are shown in Figs. 6 and 7. It is observed that 15 to 35% of the observations correspond to one-minute irradiation values of 5 KJ/m^2 or less, depending upon the sky conditions. This fact should be borne in mind while deciding upon quality control and data validation measures based on global irradiation.

2.2 Ultraviolet and downward atmospheric infrared irradiations

The results of the comparison between the UV irradiance measured with the OSU instrument and that measured with the travelling standard maintained at the University of California, Davis, are shown in Fig. 8. The departure from unity of the properly scaled ratio of the analog signals obtained with the two instruments on different days under different sky conditions may be attributed to different instrument characteristics (slewing rate, cosine response etc.).

It is observed that the ratio of the UV irradiation to the global irradiation may vary from about 4% to 7.5% with the larger values being observed under cloudier skies. It may thus be necessary to adopt a value higher tnan 4% - say 8% - for this ratio in data validation and quality control procedures.

The downward atmospheric infrared irradiation is clearly governed by the vertical humidity and temperature distributions within the first few kilometers of the atmosphere; however, it has been the practice to parameterize the ratio $R = IR/\sigma T^4$, where σT^4 is the blackbody emission of the surface air layer at temperature T°A, in terms of the surface water vapour pressure in the vicinity of the site of measurement (Kondratyev 1969). Detailed analysis of selected portions of data obtained over the past year and half have revealed the following:

a. $R = 0.6780 + .0466 \sqrt{e}$, with e the surface water vapour pressure being expressed in mm of Hg, for 336 hourly irradiation values taken over 14 'clear' and 'moderately' cloudy days;

b. $R = 0.6204 + .0775 \sqrt{e}$ for the nighttime hourly irradiation data taken over the same period as in (a);

c. $R = 0.7990 - 0.2015 \times 10^{-.2656e}$ for the daily mean hourly irradiations used in conjunction with daily mean temperatures and water vapour pressures.

The ratio Robs/Rcal is close to unity, with a standard deviation of the order of 0.05. The correlation between R and $\sqrt{e}$ is appreciably higher than 0.5 for (a) and (b). It should be noted that (c) can be derived from the rigorous equation of radiative transfer in the water vapour absorption bands. The ratio R is generally less than unity; however, it has not been possible to establish any definite relationship between the global horizontal shortwave (WG295) radiation and the downward infrared radiation from the sky.

2.3 Surface Albedo, Atmospheric turbidity and water vapour.

The shortwave surface albedo of the field site is continuously monitored with a brace of Eppley precision spectral pyranometers (WG 295) mounted at a height of 48 m on the meteorological tower. It is found to vary between the limits of 0.090 and 0.160 in the course of a year depending upon surface and sky conditions. Also, a portable albedometer setup has been used to measure the albedo of different surfaces in the mid-Willamette Valley and along the Pacific Coast. Typical diurnal variation of the surface albedo under clear skies is shown in Fig. 9; measurements were made over a grassy area on campus.

Multi-wavelength ($\lambda\lambda$380, 500, 870, and 946 nm) Volz sun photometers have been used to make measurements of atmospheric turbidity and water vapour. It has been very hard to recover, in a consistent manner, the extraterrestrial solar irradiance values furnished by Dr. Volz from the respective Langley plots. It is suspected that very minute amounts of dust deposited on the filters in the course of measurements might be causing this discrepancy.

Analysis of the Langley plots obtained over the past year has shown that the atmospheric aerosol optical thickness (to base e) at the wavelength of 380 nm varies between the limits of 0.222 and 1.354; that at the wavelength of 500 nm varies between the limits of 0.085 and 0.677. Similarly the water vapour content varies between the limits of 0.699 and 2.384 gms/cm^2. The latter compare favourably with the values obtained from atmospheric soundings over Salem, forty miles north of Corvallis.

2.4 Availability and utilization of data

The one-minute and one-hour data tapes in the SERI-NCC Research Cooperater Format containing 32 pieces of measured, derived and computed information on solar radiation and related meteorological variables will soon be available to the public. The raw field site data and the processed hourly data print-out are stored in the Data Centre (Section 1.3).

A user survey conducted in the beginning of 1980 has revealed that the data from the regional centre at Corvallis and from the statewide monitoring network will be used by the following, amongst others--solar system designers, atmospheric scientists, architects and city planners, utility officials, state and federal energy officials, botanists and plant pathologists, agricultural scientists and medical practitioners.

3. Educational, Training and Statewide monitoring activities

Two courses, 'Solar Radiation and Meteorological Measurements' and 'Atmospheric Radiative Processes,' were developed as part of the SEMRTS project and are presently being taught. The third summer workshop on 'Solar Energy Measurement and Instrumentation' was conducted in June 1980 and was received well by the participants amongst whom were representatives of the National Weather Service.

The very extensive data on daily global irradiation at the five sites [Bend (central Oregon), Coos Bay (southwest coastal Oregon), Eugene (Willamette Valley), La Grande (northeastern Oregon) and White Horse Ranch (southeastern Oregon)] have been examined, processed and readied for publication under the direction of Prof. MacDaniels of the University of Oregon, Eugene, under a subcontract with the SEMRTS program. These data will form part of the third annual report.

Conclusion

It is recognized by the scientific community that the SEMRTS program is unique in that it draws upon the totality of skills and expertise that is available in a consortium of universities to find solutions to the problems associated with solar resource assessment and forecasting; a prerequisite for this ambitious task is the availability of a high resolution, comprehensive solar radiation and related meteorological data base over a period of 8 to 10 years so that trends, periodicities (if any) and singularities can be identified and incorporated into the solutions.

Research activities presently underway are directed towards investigations of radiative transfer in turbid, cloudy, horizontally inhomogenous atmospheres, radiative and optical properties of clouds and fogs and of insolation modelling from meteorological variables.

Acknowledgment

Messrs. Kenneth True, William Bradley, Glenn Dorsch and Tae Young Lee deserve special thanks for their significant contributions to the diverse activities at the Regional Centre. Mrs. Patricia Eckhout is responsible for the neat execution of the manuscript.

References

Deirmendjian, D., and Sekera, Z., Tellus, VI, p 382 (1954)

Kondratyev, K.Ya., Radiation in the Atmosphere, Academic Press, Inc., New York (1969)

Machta, L., Workbook for Approximate Calibration of Radiation Sensors, NOAA Technical Memorandum ERL ARL-70 (1978)

Rao, C.R.N., and Hewson, W.E., Solar Energy Meteorological Research and Training Site Program - Region 5, Second Annual Report, Department of Atmospheric Sciences, Oregon State University, Corvallis (1980)

Rao, C.R.N., True, K., Bradley, W., Dorsch, G., and Lee, T.Y., OSU-SEMRTS Field Facility Handbook (in preparation)

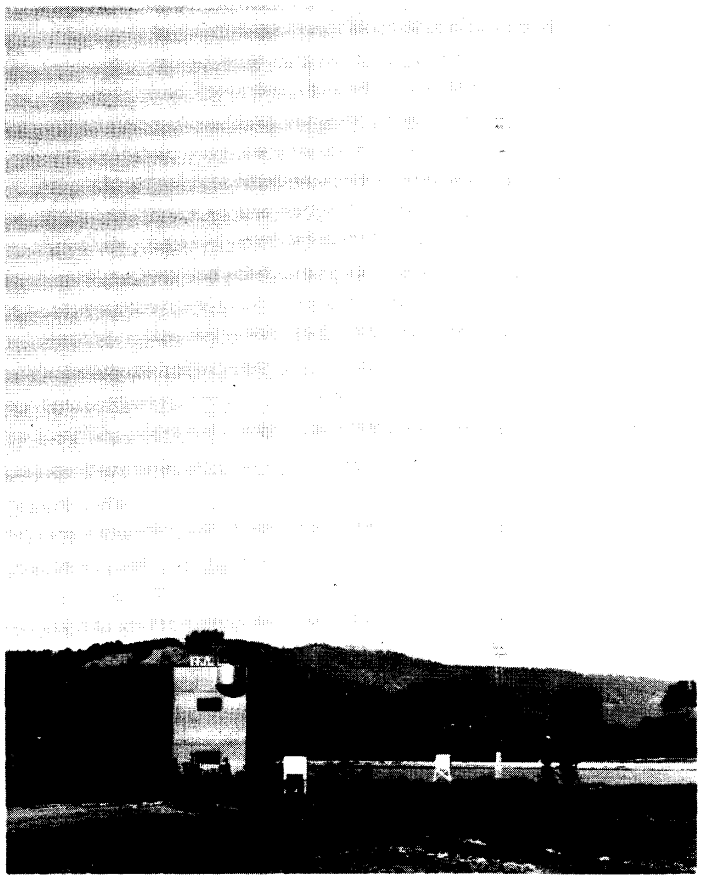


Fig. 1 The OSU-SEMRTS Field Observing Facility

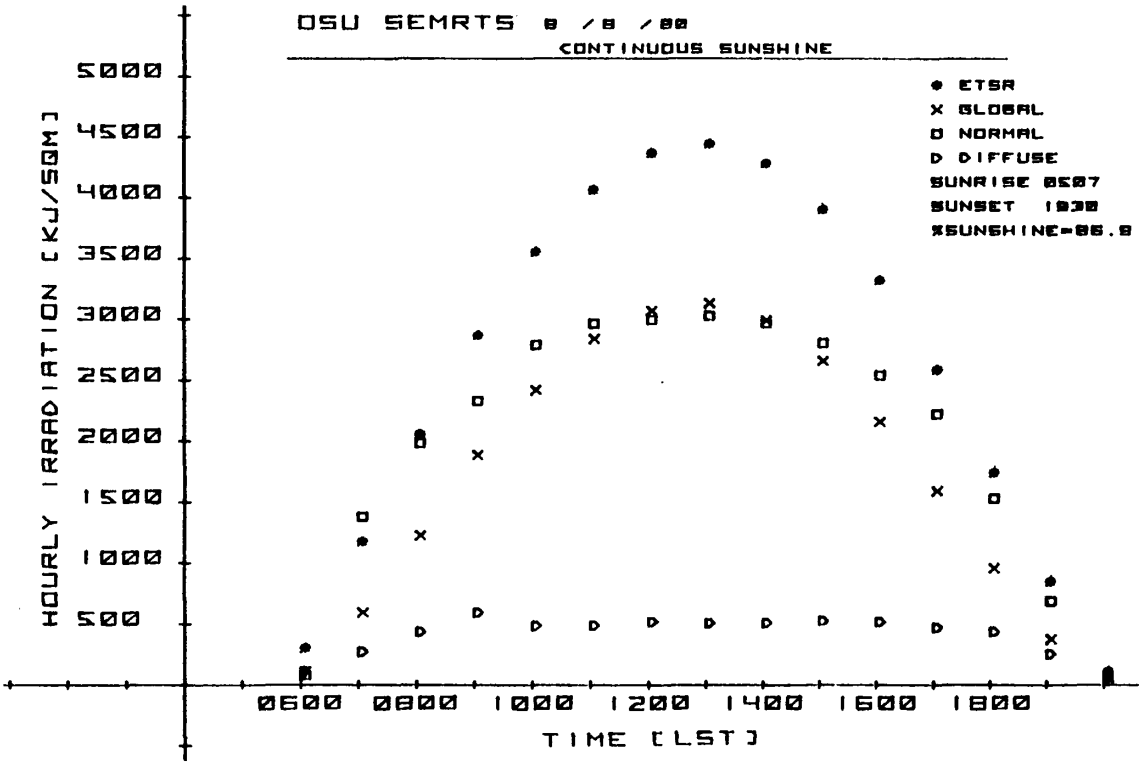


Fig. 2 Diurnal variation of the direct normal, diffuse and global irradiations (clear day)

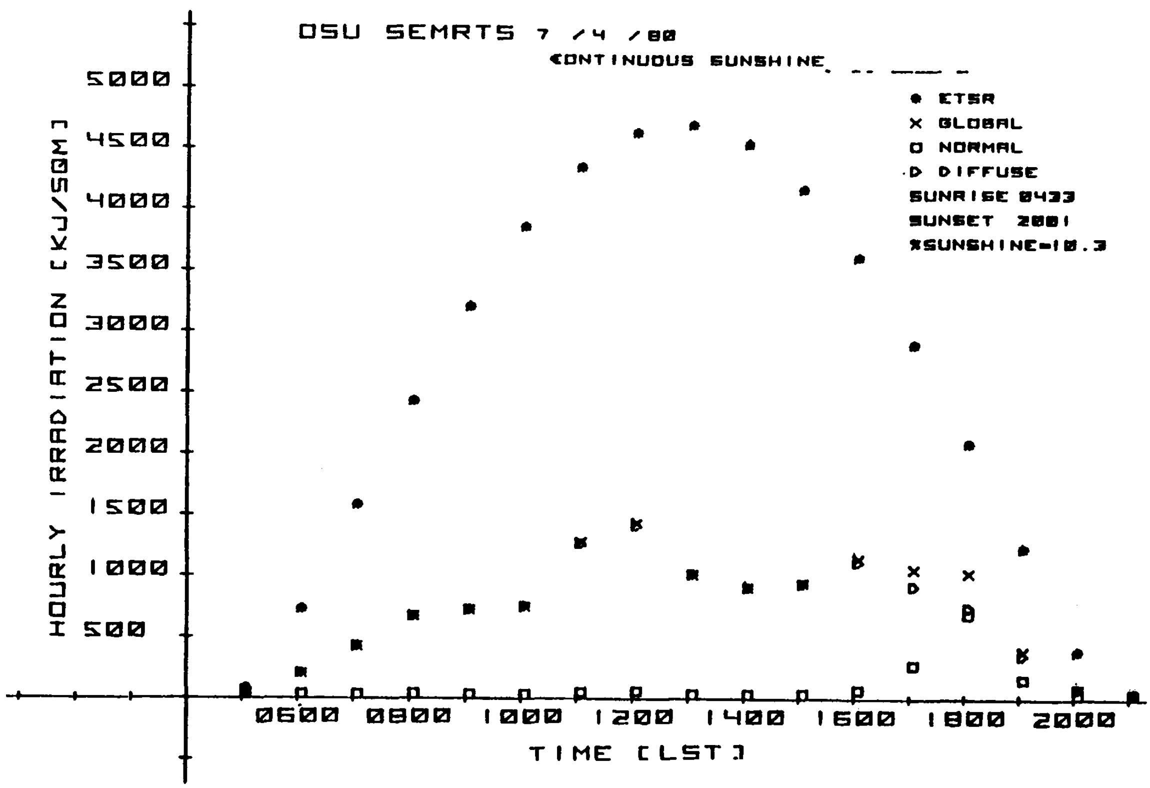


Fig. 3 Diurnal variation of the direct normal, diffuse and global irradiations (cloudy day)

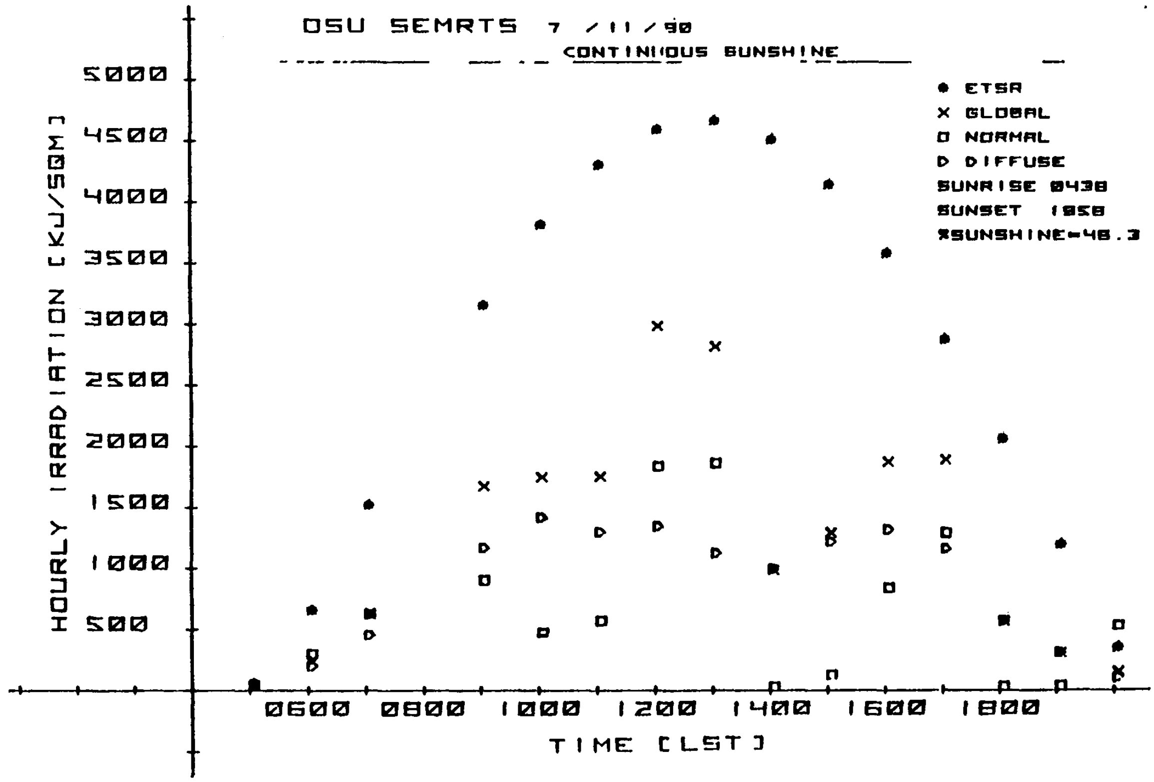


Fig. 4 Diurnal variation of the direct normal, diffuse and global irradiations (moderately cloudy day)

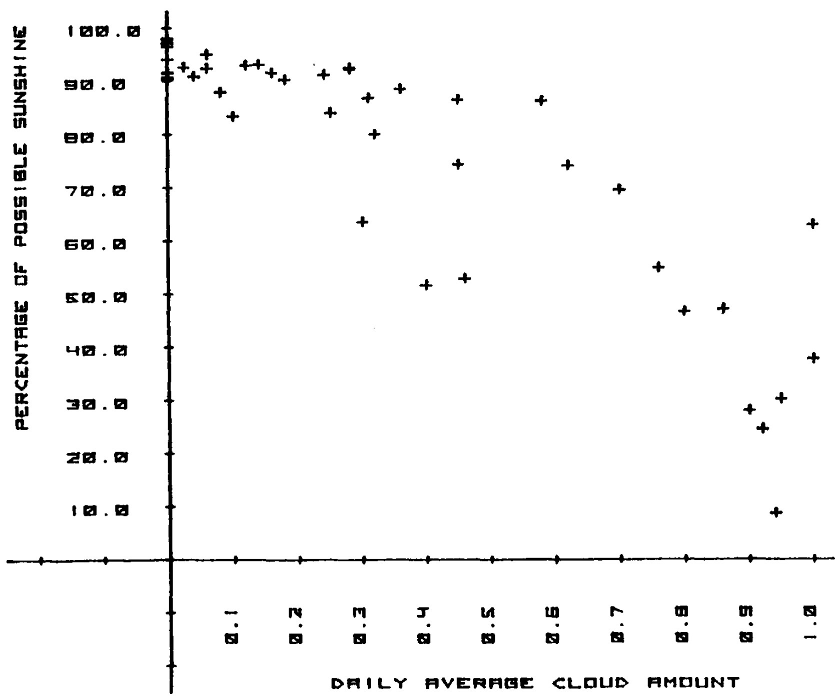


Fig. 5 Percentage of possible sunshine and daily average cloud amount

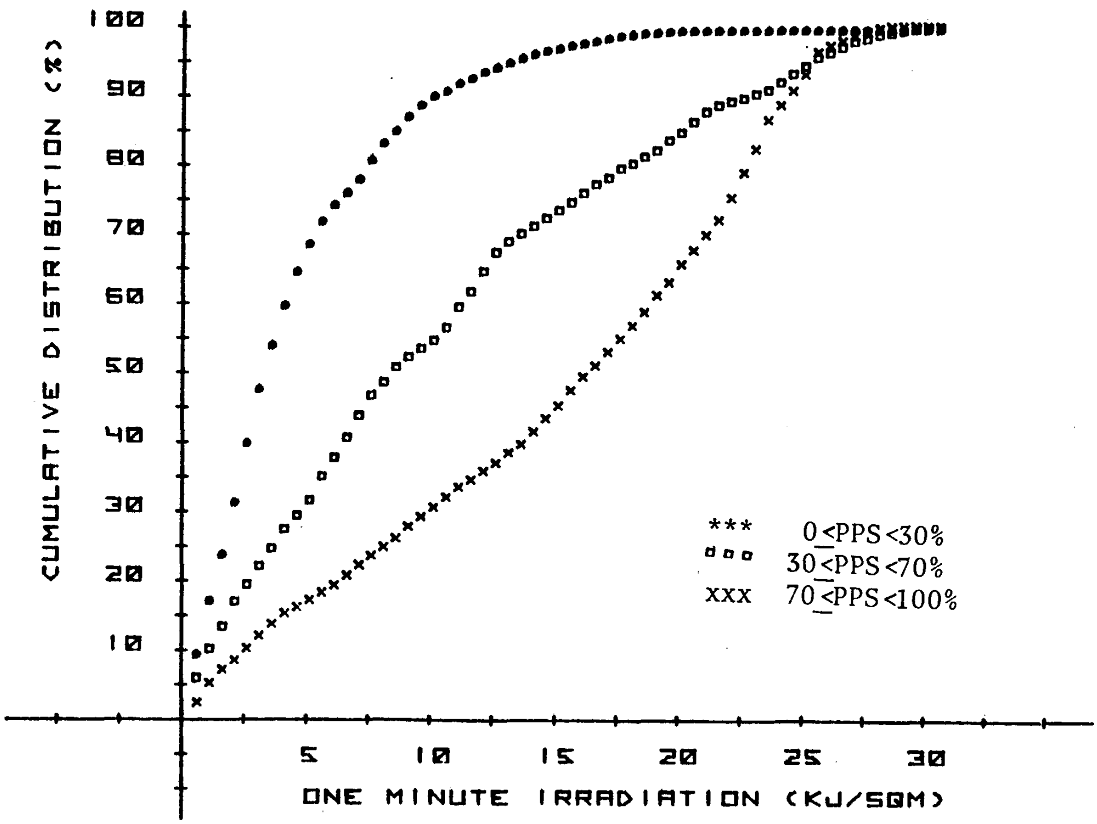


Fig. 6 Cumulative frequency distribution of one-minute global irradiation values

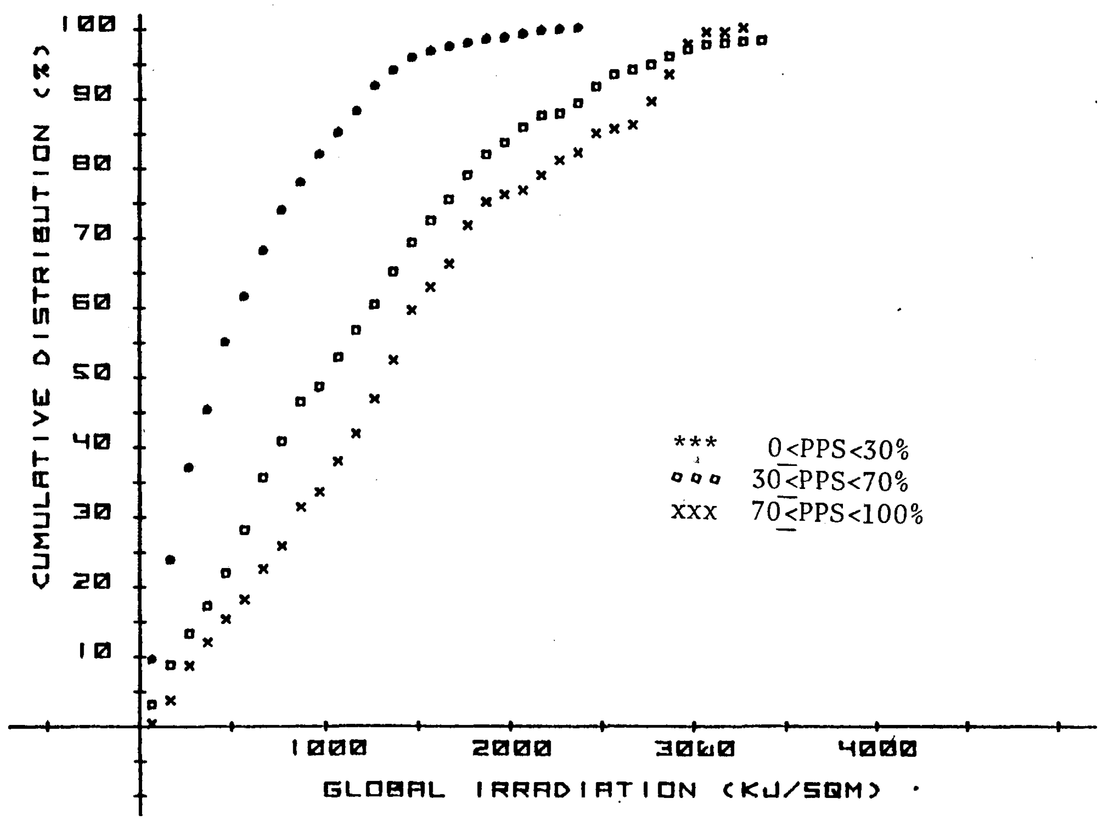


Fig. 7 Cumulative frequency distribution of hourly global irradiation values

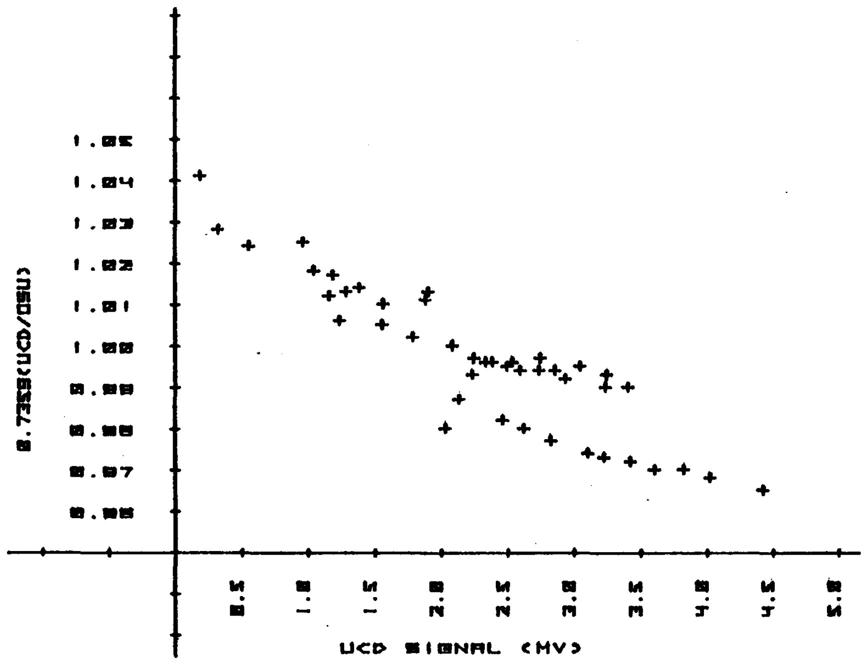


Fig. 8 Comparison of the OSU UV radiameter with travelling standard

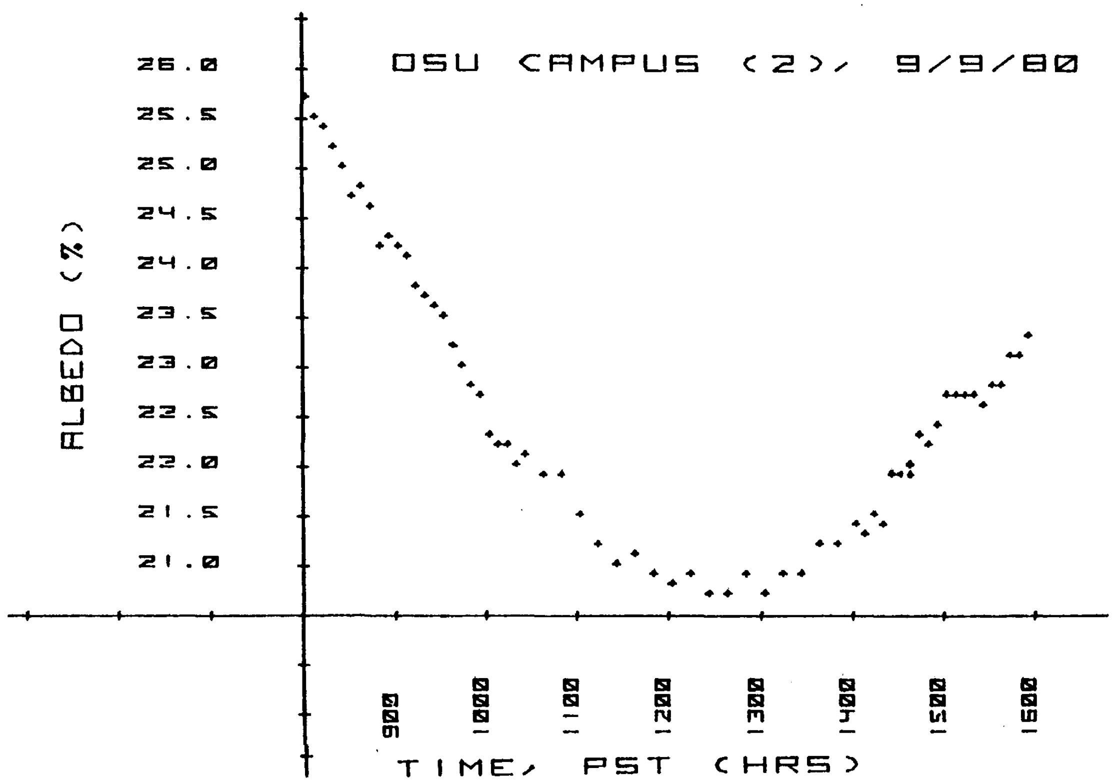


Fig. 9 Diurnal variation of the albedo of a grassy surface

SOLAR ENERGY METEOROLOGICAL SITES PROGRAM, AREA 8 - HAWAII
ANNUAL REPORT (30 SEPTEMBER 1979 to 29 SEPTEMBER 1980)

C. S. Ramage
University of Hawaii
Honolulu, Hawaii

BACKGROUND

Purpose. We expect through monitoring, research, and training programs to match and react appropriately to the rapidly developing technology of extracting economically useful power from solar energy, and to determine and help exploit the State's insolation and wind resources.

Organization. A tight knit, well-trained, experienced team capable of fast professional response to rapidly changing demands, skilled in instrumentation, calibration, data evaluation, and processing techniques development, computer programming, and report preparation.

Start date. September 30, 1977 *End date.* September 29, 1982

Milestone schedule.

Milestone	1977	1978	1979	1980	1981	1982
1. General resource monitoring	----	----	----	---→		
2. Weather satellite radiation res.	----	----	----	----	----	---→
3. Baseline stations	----	----	----	----	----	---→
4. Boundary layer development studies	----	----	----	----	----	---→
5. Radiation transects	----	----	----	--→		
6. Tradewind inversion research	----	----	----	----	----	---→
7. Workshops	----	----	----	----	----	---→
8. Forecast improvement	----	----	----	----	----	---→
9. New courses	----	----	----	--→		
10. Expansion to Pacific Territories	----	----	----	----	----	---→

Relationship to other projects. In 1977, the Department of Energy invited University participation in a five-year program to make meteorological measurements related to solar energy applications and to establish regional centers for solar meteorological training and for related research. To these ends, DOE divided the country into eight regions and used competitive proposals to select eight universities to undertake the work. The eight university groups have cooperated effectively rather than competed. Since each was selected on the basis of a single set of specifications, uniformity, overlap and professional rivalry among the group might have been expected. That this is not taken place stems in part from the fact that although each group is competent to carry the DOE mandate; beyond that, their skills, experiences, and interests diverge, not too surprisingly, perhaps, for Alaska in the Arctic and Hawaii in the Tropics, but somewhat unexpected for the six regional centers in the contiguous United States. The eight centers are accumulating unequalled knowledge of the extent and quality of insolation and wind measurements made in the United States. We are also trying to explain the mesoscale time and space differences revealed by these measurements with a view of making useful forecasts.

Previous significant progress/results. In the past three years, the eight regional centers have established solar radiation baseline stations, begun surveying the solar resources in their region, evaluated instrument performance, instituted academic courses and conducted training workshops. Through six-monthly meetings, the P.I.s have exchanged information and ideas, not only among themselves, but also with contractors serving the DOE Division of Distributed Solar Technology.

KAHUA CANDIDATE SITE, HAWAII. We advised the Battelle PNL group on the site selection for the DOE MOD-2 candidate WECS site at Kahua Ranch on the Big Island. Data from our 10 m tower at Kahua were essential in the awarding of the site. Schroeder traveled to Kahua in March to meet Battelle representatives and determine the tower location.

ILIO POINT, MOLOKAI AND KAHUKU POINT, OAHU. Daniels advised the Battelle PNL group on the site selection for the MOD-2 candidate WECS sites at Ilio Point, Molokai and Kahuku Point, Oahu. Data from our Molokai field station at Ilio Point and from several measurement points at Kahuku were essential to the selection. We have consulted the developers of the wind farm in Kahuku--Wind Farm, Inc.--and have been awarded two contracts (through Bechtel and MRI) for further wind characteristics research in the Kahuku area.

SOLAR NETWORK. 1. Global radiation is measured on each major island. The key sites are: Hilo, Hawaii (Cloud Physics Observatory) (global, diffuse, NIP); Holmes Hall, Manoa Campus, Oahu (global, diffuse, NIP, diffuse). We furnish instruments and installation, take measurements and analyze data for the following sites: Wilcox Hospital, Lihue, Kauai (global, diffuse) for DOE; Lahaina, Maui (NIP, Global) for DOE; Palaau, Molokai, for DOE and Molokai Electric Company; Pepeekeo, Hawaii, (Global, Diffuse, NIP) [site was rejected on the basis of low sunlight]; Keahole, Hawaii, for DOE at OTEC site. Makiki (Oahu) long term global measurements which were begun in 1938 and had stopped in 1975 were resumed in 1976 and continued to date. By combining the data from Holmes Hall and Makiki, we are monitoring long term changes in solar radiation. 2. Transects from low levels to the crest of the Koolau Range, Oahu. Radiation is related to rainfall and evapotranspiration regimes for (a) Southeast Oahu; (b) Central Oahu. Transect sunlight measurements have been correlated with cloud cover calculated from GOES satellite pictures.

DESCRIPTION

Measurements being used. WIND. Statewide, departmental, and National Weather Service hourly wind data. Higher level winds at 90 and 180 ft at selected sites. Turbulence wind data recorded at a rate of 1/sec utilizing tethered balloons and TALA (Tethered Aerodynamically Lifting Anemometer) kites were obtained during intensive field operations. INSOLATION. Statewide hourly global, diffuse and solar tracker data.

Instruments being used. WIND. Four vans, one a 4-wheel drive, serving as mobile base stations, each van with a 10 m telescoping mast, vane and lightweight low threshold cup anemometer. Nine in-shop designed sensing heads for the TALA kite anemometer system. Four handheld TALA survey systems for spot site checks of profiles. We are developing a system to electronically record kite parameters (kite string direction and string tension) under a special licensing agreement with the manufacturer. An automatically cycling low speed wind tunnel for anemometer calibration using a precision manometer/pitot tube standard. INSOLATION. Sensors: Eppley PSP Global (3), Eppley 848 (20), Lambda silica cell (6), Eppley 848 Diffuse (5), Eppley and Lintronic NIP (3).

Data logging techniques/hardware being used. WIND. Five 8-channel and several 4-channel recorders produced in-ship operating from 110 V AC, or 12 V DC at 1 sec and 2- and 6-minute sample rates recording on Phillips cassettes. INSOLATION. Integrators: Adtech (paper tape) (00), Lintronic (paper tape) (7), Lambda silica cell (paper tape) (5), Lambda silica cell (computer tape) (1). Adtech Lintronic Lambda silica cell integrators are used which generate paper tape printouts (except at Hilo CPO where data are recorded on magnetic tape). Data are then punch to IBM cards, processed to IBM 9 trk EBCDIC magnetic tape. Printouts are generated to check for aberrations in data as a quality control measure.

Availability of data. WIND. Hourly wind speeds are available in 9 trk 1600 bpi EBCDIC magnetic tape and printout form containing hourly values with mean for each hour of the month and mean for each day of the month. Hourly wind direction values and a summary of wind statistics and monthly plot of the speed and direction are also available. INSOLATION. Data available in 9 trk 1600 bpi EBCDIC magnetic tape and printout form containing hourly solar radiation values for 0500-2000 h for each day with monthly average, maximum, and minimum for each hour, and total daily insolation with average, maximum, and minimum for the month. Summary form of the data is also available with daily totals and average, maximum, and minimum insolation for the month. Units used: Langleys (cal cm^{-2}). A listing of all insolation sites with latitude, longitude, and elevation with period of operation is available.

Quality Control. Our anemometers are calibrated before and after field programs. Fixed sites anemometers are calibrated every six months. Monthly data are plotted for easy spotting of instrumentation failures. TALA kite measurements are compared with tower instruments. We use Eppley PSP sensors calibrated at the NOAA Environmental Research Laboratories in Boulder, Colorado. These have been used as submasters for intercalibration of the Eppley 848 and Lambda silica cells.

Application of data in project. In Hawaii, our efforts in wind resource assessment have led the State to the threshold of large-scale wind energy exploitation and to spin-off programs such as a wind energy assessment for Hawaii and the Pacific Islands Region (funded by DOE through Battelle Pacific Northwest Laboratory) and boundary layer studies for Northern Oahu (one funded by the Bechtel Corporation and another by Meteorology Research Inc.). The State of Hawaii also supports our research through the purchasing of an acoustic sounder.

We are involved in varied academic and public education activities--courses, seminars, workshops, briefing of legislators, and providing data for federal and state surveys, military corps of engineers, manufacturers, development engineers, citizens interested in solar power application, and DOE-funded projects (at the University of Hawaii) extensively use our monitoring and research results.

In the early days, we were almost entirely responsible for surveying the resources. Now, as more and more organizations are participating in developing solar and wind power, we have begun to shift to a more advisory role and are emphasizing research (analysis). Continued site-specific monitoring is now being undertaken by those directly concerned with installing and operating wind and solar systems. The Hawaii Natural Energy Institute (HNEI) has purchased a supply of accumulator anemometers and 42 ft-telescoping masts to use in quick preliminary surveys or in determining best generator siting within a wind farm area.

Models/algorithms being used. We have researched different models to estimate long term wind speed for sites where only short term data are available. Seven non-parametric methods (regression equations, mean ratios, and ratios of means), and one non-parametric one (assuming annual means to be normally distributed) were tested. For the parametric method producing only an estimate of the mean wind, we assumed the variance to be made up by a short term averaging component measured at the test site and a long term averaging component measured at the long term site. Additionally, we tested a Weibull and a chi-square distribution. Both for sites operated for about a year and sites operated for only five days, the parametrically-estimated mean and the variance estimated as previously described, defining a Weibull distribution, proved superior.

Specific research tasks/studies.

1. AHUPUA'A--Instrumented vans monitored meteorology elements related to solar energy on the Island of Hawaii between 1 June and 7 July 1978. The measurement program consisted of four phases. The first two concentrated on insolation and its attenuation by orographic and sea breeze cloud. The others considered wind power potential. In addition to mobile platform measurements, supporting data were collected including satellite imagery, ground-based photography, radiometric data, and rawinsonde. A number of significant deviations from anticipated normal conditions occurred. These included a series of unusually clear days in windward Mauna Loa, anomalous convective precipitation over a leeward desert, and the passage of the remnants of a tropical storm.

2. ACOUSTIC SOUNDER (USAF Solar Observatory at Palehua) 520 m above MSL. Inversion heights are measured with the departmental acoustic sounder. However, data are sparse due to the manufacturer's design deficiencies. We are helping develop a better system.

3. KAHUKU FIELD PROGRAM--the vans were used during a 10-week program. A detailed survey was made of the wind regimes in Kahuku where the first operational wind mill farm will be located. Winds were measured using

4 tethered balloon-supported anemometers. A detailed 30 ft wind map estimate were made using the normalizing method outlined in *Models/ Algorithms used.* Vertical wind profile measurements showed a very small speed increase with height being inversely proportional to the surface speed. Turbulence reached high levels at higher locations but was very low close to the beach. A conceptual model of the wind flow and the surface modifying factors is being tested (see 5 below).

4. BOUNDARY LAYER STUDY--Kahuku Plain extending from the beach to the foothills averaging about 10 ft MSL. We hope to investigate the first boundary layer as it develops under the smooth uniform (with height) trades as air crosses the coast. Our four instrumented vans each with two continuously flying kites and one hand held kite make up the main instrumentation used.

5. BOUNDARY LAYER STUDY--Kahuku foothills. A second boundary layer seems to develop under the first as the air encounters the sharply rising foothills. We will use data collected by our vans and by three tall towers in the area. *Forecasting.* In connection with the Kahuku field program, we tried four methods to predict 1 to 4 hour winds: Ocean satellite kite winds, Lihue-Johnston Island pressure gradient, inversion records from our acoustic sounder, and climatology. The first three methods proved unsuccessful. Climatology (adding historically-determined hourly wind changes to the actual wind) gave a reasonable correlation. It was, however, not high enough to be of economic value. We will continue our forecasting research during a program this spring using kite wind observations from a ship 20-40 miles upwind of Molokai and tower winds on the windward coast of the island.

6. DEVELOPMENT OF ELECTRONICALLY RECORDING TALA KITE HEADS--we are developing a system that will automatically measure the direction of the string to the kite and the strain on the string. We will compare the system measurements to tower measurements using a fast responding bivane. The response to turbulence will be particularly investigated. We will evaluate the efforts of heating, hysteresis, aerodynamic response, power supply and string bending on the accuracy and sensitivity of the kite sensors.

7. A project to use a windmill to provide power for a nitrogen fixing fertilizer producing experiment is under way at Kahuku. From our siting survey, the operators selected a foothill high wind and turbulent site in preference to a less turbulent beach site.

8. HAMEC (Hawaii Mesoscale and Climate Project) comprised a detailed survey of the meteorology of the Big Island during the second half of June 1980. The NOAA P-3 research aircraft was used for 40 hours of multi-disciplinary research flying time. Our observational contribution included deploying four vans at key locations. The van recording systems were modified to run on battery power and incorporate data from wind-measuring kites.

9. U.S.-affiliated Pacific Islands were made a part of our original responsibility. We have advised on resource monitoring and expect to become increasingly involved in resource evaluation. (Wind energy

assessment for Hawaii and the Pacific Islands Regions--funded by DOE through Battelle Pacific Northwest Laboratory--was prepared in 1980).

SUMMARY OF RESULTS (FY 1980)

Data collected, published.

1. Insolation data for 1978, 1979, and 1980 through September have been compiled.

2. Project Ahupua'a--Solar meteorological field measurements on the Island of Hawaii, summer 1978. 3. Trade wind interactions with local winds in South Kohala. Dept. Meteor. U. Hawaii, UHMET 79-05, 61 pp. by Thomas A. Schroeder.

3. Detailed wind survey of Kahuku, Oahu. Dept. Meteor. U. Hawaii, UHMET 79-06, 127 pp. by P. Anders Daniels and N. E. Oshiro.

4. Project Ahupua'a--Solar meteorological field measurements on the Island of Hawaii, summer 1978. 4. Wind power assessment for the Waimea Saddle. Dept. Meteor. U. Hawaii, UHMET 79-07, 46 pp. by P. Anders Daniels.

5. HAMEC PROJECT REPORT, by E. Nickerson, *in prep.*

6. Siting a fertilizing producing wind mill in Kahuku, by P. Anders Daniels, *in prep.*

7. Project Ahupua'a--Solar meteorological field measurements on the Island of Hawaii, summer 1978. 5. Southern flank of Mauna Loa. by P. C. Ekern, *in prep.*

8. Project Ahupua'a--Solar meteorological field measurements on the Island of Hawaii, summer 1978. 2. Eastern flank of Mauna Loa. Dept. Meteor. U. Hawaii, UHMET 79-04, 56 pp. by P. C. Ekern and Alfred J. Garrett.

9. "Orographic Cloud over the Eastern Slopes of Mauna Loa Volcano, Hawaii, Related to Insolation and Wind." in *Mon. Wea. Rev.*, Vol. 108, No. 7, July 1980, by Alfred J. Garrett, pp. 931-941.

Recommendations, future plans. Resource monitoring programs are now becoming routine and we are encouraging development of industrial meteorology in Hawaii to undertake them. However, we shall maintain close links through our wind and radiation calibration facilities and as the State archival center.

Our own research will focus on boundary-layer turbulence measurements using kites calibrated against instrumented towers, detailed small area surveys using our four instrumented vans and attempting to devise techniques for short period (24-hour) site-specific wind and insolation forecasts. Supported partly with State and County funds, we are investigating the role of insolation in biomass production, and together with wind, its effects on evaporation and irrigation needs.

We are responding to an upsurge of interest in alternate energy among the U.S.-associated Pacific Islands, advising them on appropriate monitoring methods. We shall help evaluate the data as they are accumulated.

SOLAR ENERGY: IMPLEMENTATION OF A RESEARCH AND TRAINING SITE AT DAVIS, CALIFORNIA

Jerry L. Hatfield, John J. Carroll
Robert G. Flocchini, Robert Hamilton, and Peter J. Smietana
Land, Air & Water Resources
University of California, Davis, California 95616

Background

On October 1, 1977, the University of California-Davis started a solar energy research and training program with the following objectives:

1) To develop a well instrumented main station on the Davis Campus for making comprehensive measurements of solar radiation and related meteorological parameters, and to operate the station for routine measurements over a minimum period of four years.

2) To develop a well instrumented mobile station for making measurements of selected meteorological and solar radiation parameters. The location of the mobile station is to be at selected sites in the Western United States for various periods of time to assist in filling gaps in the regular data coverage or to investigate particular phenomena affecting the solar radiation regime.

3) To develop an education and training program at the University. The program to consist of a number of special courses, both undergraduate and graduate, for students interested in the utilization of solar energy.

This project is scheduled for completion on September 30, 1982, and represents one of eight sites throughout the United States that have similar objectives. The eight sites have begun a coordinated effort to quantify the solar resources of the United States and begin a comprehensive training program in Solar Energy.

Since the inception of this project the collection of the comprehensive data set began in September 1978 and continues to date. The mobile van has been deployed to several locations in the Western United States and to data used to verify solar radiation models that have been developed at Davis for both short and longwave radiation. These models have been very useful and data from the van has been used to compare to long-term averages collected on a given region and verify the results from past studies.

Description of Project

Measurements

The instrumentation of the main station consists of 19 separate devices, 11 of which are some type of radiation sensor and eight are for measuring relevant meteorological parameters. Most of the radiometers are mounted on the two instrument bars located on either side of the catwalk. To eliminate vibration of the instruments during servicing from the catwalk, the mounts are separated from the catwalk. One of the bars holds seven instruments (one pyrheliometer, three pyranometers, one ultraviolet radiometer, one pyrradiometer, and a Campbell-Strokes sunshine recorder), while the other instrument bar is devoted to the three shaded pyranometers and a pyregeometer in conjunction with the shading device. In addition, the variable angle pyranometer, with its goniometer, is mounted on a separate pedestal to the east of the catwalk, and the optronics spectrometer will have its own pedestal at the end of the catwalk. The radiation instruments are mounted so that all of the sensors are at the same level in order to eliminate mutual shading effects among the various devices.

Meteorological instruments consisting of an anemometer, a thermometer, and a dew point hygrometer are mounted at each of levels 1, 2, 5, 10, and 15 meters above the ground. A wind vane is at the 10 meter level. The rain gauge is of the tipping bucket type, and is located well away from obstructions which might disrupt the air flow and cause errors in the rainfall measurement. The ozone meter and particle counter are located in the instrument house, samples of ambient air being introduced through teflon tubes from the outside. The electrical barometer is also in the instrument house. The house itself is air conditioned and heated by an electrical heat pump.

On the mobile van, an 18 ft American Clipper motor home, are installed four pyranometers, a pyrheliometer, a pyrradiometer, ultraviolet radiometer, a temperature sensor, dewpoint sensor and wind speed and direction sensor. All of the units are mounted on the roof of the van with cables extending into the computer data acquisition system located in the van interior. The computer system is the same as that used at the Davis main site with data storage onto floppy disk. Data analysis and quality control is accomplished by the same programs as that used on the data from the main site.

In the month of December 1979, work was completed on the variable angle pyranometer. This instrument may now be programmed interactively to position itself normal to several points in the sky during each hour of the sunlit day. For the past nine months, we have collected data with this instrument in nine different planes;

South facing vertical	0 min after each hr
East facing vertical	5 min after each hr
East facing 45° tilt	10 min after each hr
South facing 45° tilt	15 min after each hr
West facing 45° tilt	20 min after each hr
North facing 45° tilt	25 min after each hr

North facing vertical	30 min after each hour
West facing vertical	35 min after each hour
Horizontal	40 min after each hour

We expect that this data will provide for several interesting research projects, primarily those concerned with verifying models. We anticipate taking data at other orientations than those listed above in support of future research projects.

In July of 1980, a shading band was installed at the Davis site, to augment the diffuse solar measurement. This instrument will provide us with data which can be directly compared to that from the shading disk instruments. It will also serve as a backup instrument, during times when our shading disk mechanisms might be out of service or suspected faulty.

Instruments

During the latter part of 1979, we decided that our shading disk mechanisms were in need of improvement. Trouble with the system seemed to be due to the weight of the shading arm with respect to the insufficient size of a set-screw adjusting fastener. With the advent of small monolithic stepper motor-driver circuits, a new device was designed and built with integral motor, driver, and gear-box, all in one modular package. The disk-arm is built from light-weight tubing and sheet metal and is easily adjusted in two dimensions. This unit has proved itself quite reliable over the last seven-month period. The overall quality of our diffuse data has increased dramatically since this improvement was made.

At about the same time, a new mechanism was designed and built for rotating the filter wheel attached to the normal incidence pyrheliometer. This new device uses a stepper motor-driver combination similar to the one used in the shading disk mechanisms described above. It also utilizes a simple magnetic reel switch to provide alignment and reliability feedback to the data acquisition/control system. Each minute of the daylight period, this instrument is cycled through the set of five cutoff filters, and an alignment check is made. If the filter is not aligned at the end of a cycle, a flag is set in the data stream. So far, no significant trouble has been experienced with this device.

Data Logging Techniques

Except for minor changes in the operating data acquisition program which account for the new shading disk and N.I.P. filter wheel mechanisms, few changes have been made to our data logging system. One minute records are stored on flexible diskettes in hourly files which can be accessed randomly, even while data aquisition is taking place.

One new feature allows a person to change on-site, the variable-angle pyranometer schedule. Another new system command causes the current one-minute values to be printed on the computer console.

Measurement Sites

During the past year measurements have been made in the Sierra mountains and in a large transect over the Western United States. Data with the van were collected at Brawley, California; Phoenix, Arizona; Temple and Weslaco, Texas; Manhattan, Kansas; Lincoln, Nebraska; St. Paul, Minnesota; Fargo, North Dakota; Sidney, Montana; Beartooth Pass, Wyoming; and Kimberly, Idaho. Prior to the transect, the van was set up at Davis and compared to the main site at Davis as an intercomparison of instruments.

Availability of Data

Data is available in one-minute record format and available in reduced hourly, daily, and monthly summaries. The one-minute records are stored on tape in internal format without any quality control codes. Programs to make Research Cooperator Format (RCF) tapes with quality control codes are being developed. The hourly and daily summaries are generated from the current one-minute records with SERI and programmable quality control checks. Monthly summaries are prepared from the hourly and daily values. A special log entry program has been developed which allows for entry of log book and any other type of nonprogrammable corrections to the data set.

The reduced summaries are stored in direct access disk files and available in printed form. Efforts are currently underway to put the large yearly summary onto microfiche for easier and cheaper distribution. Extensive user-oriented software has been developed to allow easy access to all data formats and to return quality control codes for each datum.

The data reduction scheme uses a linear interpolation and extrapolation method to approximate missing data points within five minute gaps. If gaps of larger than five minutes occur within an hour than the largest time partition is the one used for that hour. All one-minute values, however, are included in the daily value calculations.

Quality Control

Several improvements and additions to our system are serving the quality control aspect of the program. A fast and convenient computer graphics system is extremely useful for detecting site problems shortly after they occur. Plots can be transferred directly from the computer terminal to a "Hardcopy" unit for permanent documentation.

A new computer program residing on the data acquisition systems allows viewing of the current one-minute data values. This program is typically run each morning and afternoon, and the data is checked for possible problems.

Special Research Tasks

During FY80, an effort was made to analyze the solar radiation data collected at Davis to determine the relationship between the various components. This was accomplished on data collected during 1979 in a M.S. thesis by R. D. Sears. This involved analysis of direct, diffuse and total solar radiation to minute of sunshine data, and it was found that it was possible to develop a good predictor of all three components from sunshine data. The results compared favorably with values previously reported. Another task was to determine the seasonal relationships between direct and diffuse to total radiation and to evaluate the seasonal changes in ultraviolet to total or direct radiation.

Solar radiation data from all sources in the region have been compiled and the monthly values plotted on regional maps. This effort was done in order to determine where problems existed in the coverage of the region and the validity of using data from a number of sources. These data have helped to define where to place future sensors and also how a complete data set would compare to solar energy maps prepared from early SOLMET stations.

A comparison of the SWISSTECO and Eppley pyregeometer has been underway and the results show that more detailed analyses are needed. It has been found in the data that the SWISSTECO exhibits oscillations around sunrise and sunset with a decrease in the reading around solar noon. These aspects are continuing to be evaluated.

Utilizing the pyranometer mounted at latitude and the variable angle pyranometer studies have been conducted comparing these measurements to horizontal global radiation. For the 38' and 90° angles the discrepancies between measured values and predicted values using ASRAE procedures are large. These aspects are under further evaluation.

Data Collected and Published

Data from FY80 have been analyzed and all quality control is being exercised. The one-minute records beginning in July 1980 will be forwarded to SERI for archival and all one-hour records will be sent to NCC. In addition, printouts, microfiche, and tape records of one-hour summaries will be available at Davis. The one-minute records have been archived at Davis but are generally unavailable to the public.

Several papers describing the research accomplished during FY80 are being prepared and will be submitted to various journals. This method will serve as a vehicle of disseminating the results of this project.

Educational Program

1. Thesis

The SEMRTS program graduated two students at the Master's level.

R. D. Sears - Observed characteristics and dependencies of diffuse, direct, total and ultraviolet solar radiation at Davis, California.

C. Whan -

Manuscripts based on Mr. Sears' thesis are being prepared for submission to Solar Energy.

2. Classroom

Classes taught include Resource Science 103, Resource Science 203, Atmospheric Science 290, and Atmospheric Science 124.

Resource Science 103 (60 students - Fall 1979, projected enrollment 75 students - Fall 1980). Discusses solar energy applications in passive and active solar, wind field utilization, photovoltaics, and biomass conversion. An introduction to radiation and heat transfer is presented.

Resource Science 203 (seven students - Winter 1980). A graduate level class that provides the physical basis for the conversion of radiation into a useful form of work.

Atmospheric Science 290 - A graduate seminar class. Topics are selected each time this is offered. In the past, we have discussed design parameters with respect to climatic analyses and simple models for radiation levels on various surfaces.

Atmospheric Science 124 - Meteorological Instrumentation. A portion of this course is devoted to instrumentation used for radiation measurements. This includes lectures and laboratory exercises.

3. Public Service

This grant cosponsored the "Alternate Energy Lecture Series." Speakers included: Art Rosenfeld, Harold Hay, John Kraabel, Melvin Calvin, Richard Pefley, Bryan Jenkins, Jere Justus, Daniel Yerbin, Joseph Amand, and George Abernathy.

These experts covered topics including conversion, biomass conversion, wind energy, passive, and active solar.

These seminars were open to faculty, staff, students, and the general public.

Discussion of Results

To date the program has accomplished the three objectives set forth on the project. The results that have been forthcoming are being analyzed as quickly as possible in order to provide these algorithms to the solar energy community. In our studies we have found that it is possible to estimate the direct, diffuse, and total solar radiation from minutes of sunshine data and have found a seasonal dependence on direct-diffuse relationships. Data collected on the van transect are being compared to simulated data and preliminary results indicate that the simple solar radiation model does very well under clear skies. An effort is being made to evaluate cloudy sky models on some of the data.

The comparison of angular and horizontal suggests that more research is needed to evaluate the current methods of estimating tilted solar radiation from horizontal measurements. The current algorithms do not account for seasonal variations and need to be refined to more correctly approximate these measurements. Data from the variable angle pyranometer will provide a solution to these questions.

Recommendation and Future Plans

During FY81 and 82, the emphasis of the project will be to continue high quality monitoring of the solar and meteorological data at Davis and in the Western United States. To expand our coverage of the region, a series of low-cost solar radiation integrators will be placed at selected sites to record the daily totals of solar radiation. These data will be recorded by local observers and then transmitted to SEMRTS personnel at Davis once per month. Prior to deployment, all units will be calibrated at Davis relative to the units at this site. These data will provide additional points from which to characterize the solar resources of the Western United States.

Efforts will also continue on the objective to quantify the solar resource and to characterize the variability and relationship between the various components of solar radiation. These data will then be used to verify various models of total solar and spectral radiation of the components of solar radiation.

Other projects to be undertaken during FY81 include the following:

1. Develop a measurement program to document spectral irradiance of the downward solar radiation and the spectral reflectance properties of natural surfaces and man-made materials.

2. Compare all-sky-camera determined cloudiness (amount, height, distribution and type) with daytime radiation field, i.e., direct, diffuse, and IR on horizontal planes and the global incident on a tilted plane.

3. Render the all-sky-camera determined cloudiness in standard WMO/NWS observer codes and evaluate accuracy and utility of parameterized radiative transmission models using these cloud classifications.

4. Using LOWTRAN 5, compare site measurements with model calculations for various measured or prescribed atmospheric turbidities, temperature and water vapor profiles.

5. Using LOWTRAN 5 to define the incident radiation on a surface, evaluate the need for and optimization of selective coatings for radiative coolers for various atmospheric conditions and cooler operating temperatures.

6. Using the spectral instrument, in situ aircraft measurements and LOWTRAN 5, characterize the local atmospheric spectral transmissivity and derive the total concentrations of radiatively significant variable atmospheric constituents for specific periods.

7. Utilize various measures of atmospheric transmissivity to develop statistical models describing the dependence of incident global and IR radiation on the normally measured weather variables of

cloudiness, total precipitable water, visibility, present weather, lifted index, and related parameters.

It is expected that these endeavors will be undertaken by the graduate students in the program and form the basis of Masters' theses and Ph.D. dissertations.

SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING

SITE PROGRAM FOR THE SOUTHEAST (REGION 3)

C. Gerald Justus
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, GA 30332

Background

Eight regional university Solar Energy Meteorological Research and Training Site (SEMRATS) Program sites have been established around the United States. The Georgia Institute of Technology is the SEMRATS center for the Southeastern Region, including Florida, Georgia, Alabama, Mississippi, Tennessee, South Carolina, North Carolina, Virginia, Kentucky, West Virginia, Maryland, the District of Columbia, and Delaware. Permanent monitoring sites on the Georgia Tech campus and at Shenandoah, about 80 km (50 mi) southwest of the campus site, will continuously monitor and record global, direct, diffuse, global tilted, UV, IR, and other spectral radiation parameters. A careful program of instrument and electronic calibration and quality control will insure the accuracy of these recorded data. Programs of training for students at Georgia Tech and for professionals in the field are also carried out in the area of solar energy resource assessment.

Significant earlier progress has been reported in the 1977-78 annual report (ORO/5604-78/4) which gives a complete site and instrumentation description for the Georgia Tech and Shenandoah sites, as well as a description of the data processing and quality control procedures used.

An atlas of the solar radiation resource for the southeast region has been prepared as the 1978-79 annual report (ORO/5604-80/1).

Description

The measurements being taken and instruments used are summarized in Table 1. Data are logged by an Acurex data logger and Cypher tape deck, then processed on a Data General Eclipse S-130 computer system. A combination of automatic and manual editing is used in the quality control of the data, with about 3-5 person-days per month being required in the manual editing process. At the Shenandoah site a

TABLE 1

ATLANTA, GEORGIA TECH SITE
(C.E. BUILDING ROOF ON GA. TECH CAMPUS)
RESEARCH COOPERATOR DATA DESCRIPTION

Latitude = 33° 46' 37" N
Longitude = 84° 23' 54" W
Time Zone = Eastern (5)

Element Code	Elevation MSL, m	Elevation AGL, m	Orientation Azimuth	Orientation Tilt	Spectral Band μ Lower	Spectral Band μ Upper	Description	Units
1000	326.8	34.8	0	0	0.29	2.80	Global Horizontal, Eppley PSP	kJ/m^2
1001	326.8	34.8	0	0	0.29	2.80	Global Horizontal, Spectrolab SR 75	kJ/m^2
1002	326.8	34.8	0	0	0.38	1.20	Global Horizontal, LiCor Lambda	kJ/m^2
1003[1]	326.8	34.8	0	0	0.38	1.20	Global Horizontal, Dodge Products Solar Cell	kJ/m^2
1460	326.8	34.8	180	34	0.29	2.80	Global Latitude Tilted, PSP w/artificial horizon	kJ/m^2
1461[2]	326.8	34.8	180	34	0.29	2.80	Global Latitude Tilted, Lambda w/artificial horizon	kJ/m^2
2010	326.8	34.8	-	-	0.29	2.80	Direct Normal, Eppley NIP	kJ/m^2
2011	326.8	34.8	-	-	0.29	2.80	Direct Normal, Eppley NIP (redundant)	kJ/m^2
2012[2]	326.8	34.8	-	-	0.38	1.20	Direct Normal, LiCor Lambda w/colimator	kJ/m^2
3000	326.8	34.8	0	0	0.29	2.80	Diffuse, PSP and tracking disk	kJ/m^2
3001[3]	326.8	34.8	0	0	0.29	2.80	Diffuse, PSP and tracking disk	kJ/m^2
5000	326.8	34.8	0	0	0.30	0.39	UV, Eppley TUVR	kJ/m^2
6000	326.8	34.8	0	0	2.80	60.0	IR from Total Incoming (Funk) minus Global (PSP)	kJ/m^2
6001[4]	326.8	34.8	0	0	3.5	50.0	IR from Eppley PIR	kJ/m^2
7000	326.8	34.8	0	0	0.63	2.80	Global Spectral, PSP and RG2 filter	kJ/m^2
7010	326.8	34.8	0	0	0.63	2.80	Direct Normal Spectral, NIP and RG2 filter	kJ/m^2
9000[5]	326.8	34.8	-	-	-	-	% Possible Sunshine, Campbell Stokes	%
9001[5]	326.8	34.8	-	-	-	-	% Possible Sunshine, NIP w/200 W/m^2 threshold	%
9150[6]	326.8	34.8	-	-	-	-	Rainfall	mm
9200	332.9	40.9	-	-	-	-	Wind Direction, lower level	deg
9201	343.3	51.3	-	-	-	-	Wind Direction, upper level	deg
9210	332.9	40.9	-	-	-	-	Wind Speed, lower level	m/s
9211	343.3	51.3	-	-	-	-	Wind Speed, upper level	m/s
9300	329.8	37.8	-	-	-	-	Dry Bulb Temperature, lower level	°C
9301	343.0	51.0	-	-	-	-	Dry Bulb Temperature, upper level	°C
9320	329.8	37.8	-	-	-	-	Dew Point Temperature, lower level	°C
9321	343.0	51.0	-	-	-	-	Dew Point Temperature, upper level	°C
9400	326.8	34.8	-	-	-	-	Station Pressure	kPa

(1) Not available after 10/26/79; (2) Available after 2/1/80; (3) Available after 1/10/80; (4) Available after 4/14/80; (5) Available only in hourly RCF; (6) Minute rainfall is cumulative from beginning of hour.

similar but less complete set of instrumentation is used. Data at that site are logged on an EG&G data logger and tape cassette recorder, and are processed on the Georgia Tech CYBER computer system, with a similar quality control procedure. Table 2 shows a comparison of global horizontal data from the period April 1979 through June 1980 from the two sites. The rms difference of the monthly averages is 3.3%, with Shenandoah (the rural site) showing the higher values.

TABLE 2

Monthly Avg. Daily Total Global Horizontal Radiation, MJ/m^2

Year	Month	Atlanta, Ga Tech Campus Site	Shenandoah Industrial Park Site	% Difference
1979	APR	18.0	18.2	1.2
	MAY	18.3	-	-
	JUN	21.2	21.7	2.1
	JUL	17.4	17.9	3.1
	AUG	19.1	-	-
	SEP	12.3	12.9	5.5
	OCT	14.7	15.3	4.0
	NOV	9.9	10.4	4.6
	DEC	8.2	8.3	1.2
1980	JAN	6.1	6.3	3.5
	FEB	12.3	12.6	2.3
	MAR	13.1	13.6	3.0
	APR	*	18.9	-
	MAY	*	19.9	-
	JUN	*	21.4	-
				rms 3.3%

*not yet processed

Hourly averages from both the Georgia Tech campus site and the Shenandoah site will be made available in Research Cooperator Format through the National Climatic Center in Asheville. It is planned that the one-minute data from the Georgia Tech site for July 1980 through June 1981 will be archived at SERI.

Specific research results reported here deal with: 1) model comparisons of the Watt (1978) and the Bird (1980) direct beam models against observed direct normal, 2) relative measurement error assessments for global, direct, and tilted surface radiation of the Eppley PSP against Spectrolab SR 75, the Lambda LiCor, and the Eppley 8-48. 3) global and direct regressions against percent available sunshine, 4) comparisons of Campbell-Stokes vs pyrheliometer derived percent available sunshine, 5) isotropic (Liu and Jordan, 1963) model radiation on a tilt vs observed and anisotropic (Klutcher, 1979) model radiation on a tilt vs observed, 6) various methods for displaying ratios of diffuse radiation to other parameters, 7) observed variations of UV vs relative air mass and amount of cloud cover, and 8) a suggested method

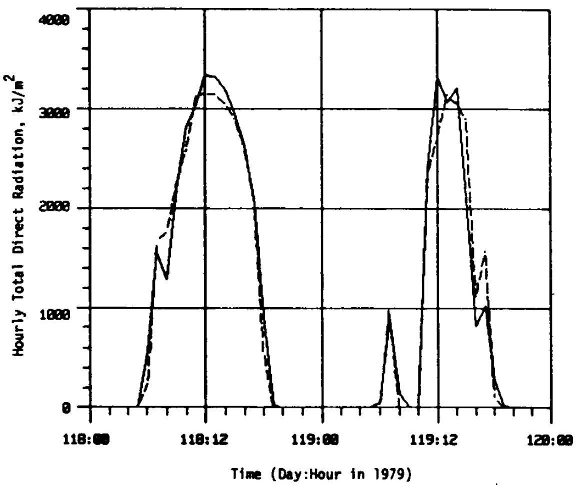


Fig. 1. Measured (solid line) and Watt Model (dashed line) Values for Direct Normal Radiation on a Clear Day (118 = April 28) and Partly Cloudy Day (119 = April 29) in 1979.

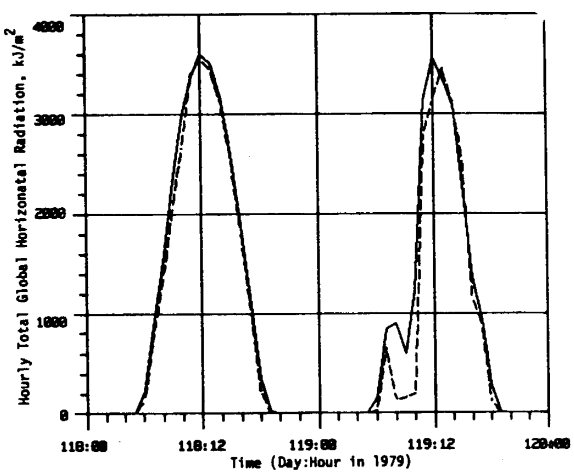


Fig. 2. As in Fig. 1 for Global Horizontal Radiation.

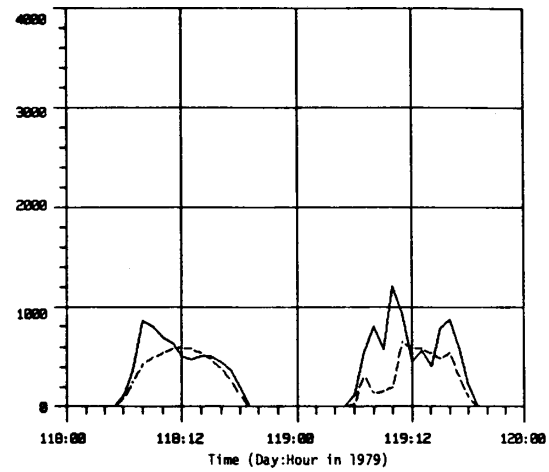


Fig. 3. As in Fig. 1 for Horizontal Diffuse Radiation.

to improve IR measurement from the Funk radiometer and Eppley PIR.

Summary of Results

Figures 1-3 illustrate the ability of the Watt model to reproduce some features of observed direct, diffuse, and global radiation on relatively clear and on partly cloudy days, using the simple fractional cloud cover modifier to account for cloud effects. In a comparison of one year of data (April 1979-March 1980), the Bird model did slightly better reproducing the observed direct than did the Watt model (standard error of least squares fit = 277 kJ/m^2 for the Bird model vs 336 kJ/m^2 for the Watt model). The rms errors in monthly mean direct values were about 7% for the Bird model and 12% for the Watt, using climatological values of precipitable water and turbidity. Further studies are underway using observed turbidity from Volz photometer readings and precipitable water from the nearest upper air sounding station (Athens, GA). The Watt and Bird models currently have about 20 times the error achievable by measurement, since comparison of redundant pyrheliometer readings (on separate trackers) showed an rms of 15.4 kJ/m^2 or about 0.6% for the same one year period.

Figure 4 gives a plot of the hourly ratio of global to horizontal extraterrestrial versus hourly percent sunshine. Note the "end effects" at 0 and at 100 percent sunshine, where there is more spread and an apparent shift in average value from the values approaching these end points. The zero point end effect is also evident in Figure 5 for the daily global/ETR ratio versus daily percent sunshine. However, the end

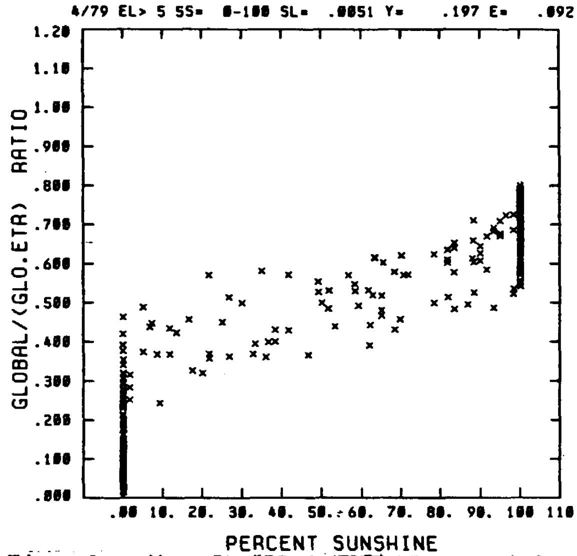


Fig. 4. Hourly Global/(Extraterrestrial on Horizontal Surface) versus Percent Available Sunshine for April 1979.

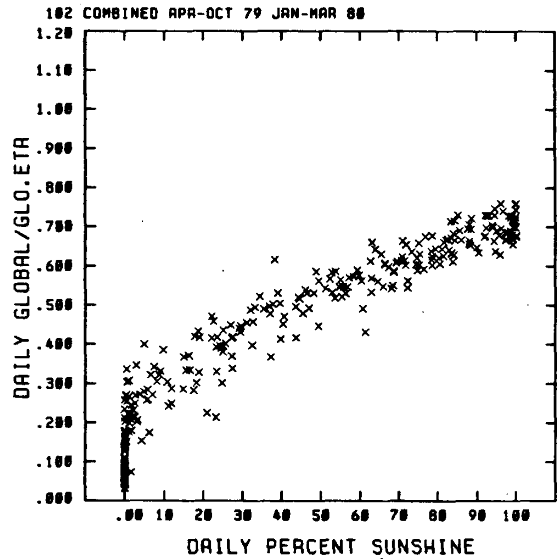


Fig. 5. Daily Global/(Extraterrestrial on Horizontal Surface) versus Daily Percentage Available Sunshine for April-October 1979, January-March 1980.

effect at 100 percent sunshine is not so evident as for the hourly data.

Figure 6 shows that hourly direct ETR versus percent sunshine has a similar end effect at 100 percent, but not 0. This relation also is non-linear between the end point limits. Figure 7, like Figure 5, shows less of an end effect for the daily data than for the hourly data.

In Figure 8, hourly percent sunshine measured by the Campbell-Stokes sunshine duration recorder is compared with percent sunshine determined by totaling the time within the hour when the pyrheliometer indicates direct beam radiation over a threshold of 200 W/m^2. This figure shows fairly wide dispersion between percent sunshine determined by these two methods (standard error of linear regression = 15.4%). Two sources of discrepancy affect these results. At low sun angles, the direct beam often exceeds the 200 W/m^2 threshold while the Campbell-Stokes produces no measurable burn trace. For strong sunlight between intermittent clouds, the Campbell Stokes burn strip often looks continuous or nearly-continuous (100% or near 100% sunshine) while the pyrheliometer readings correctly show only intermediate values of percent sunshine. The first type of error would tend to fill the lower right of the plot in Figure 8, while the second type of error would tend to fill the upper left. Because of the more-or-less symmetrical pattern about a one-to-one regression line in Figure 8, however, an adjustment of the threshold above or below 200 W/m^2 would not appreciably affect the rms error between Campbell-Stokes derived and pyrheliometer-derived percent sunshine. On a monthly average basis, the Campbell-Stokes and pyrheliometer percent sunshine measurements agreed within 1 to 7% for April 1979 - March 1980, with an rms deviation of 4%. Larger discrepancies were

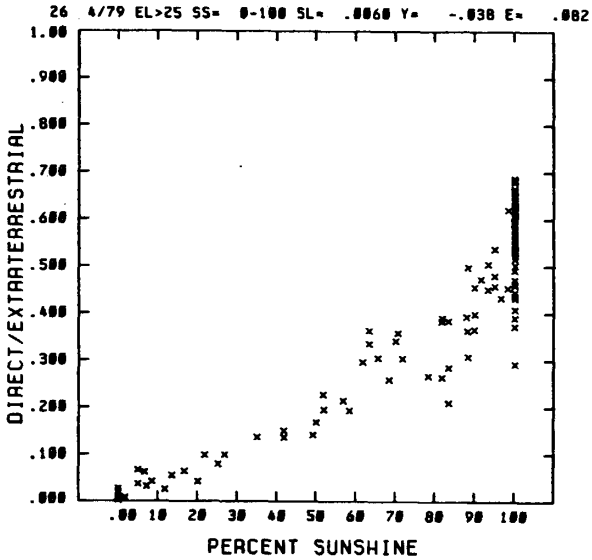


Fig. 6. Hourly Direct/Extraterrestrial versus Percent Available Sunshine for April 1979.

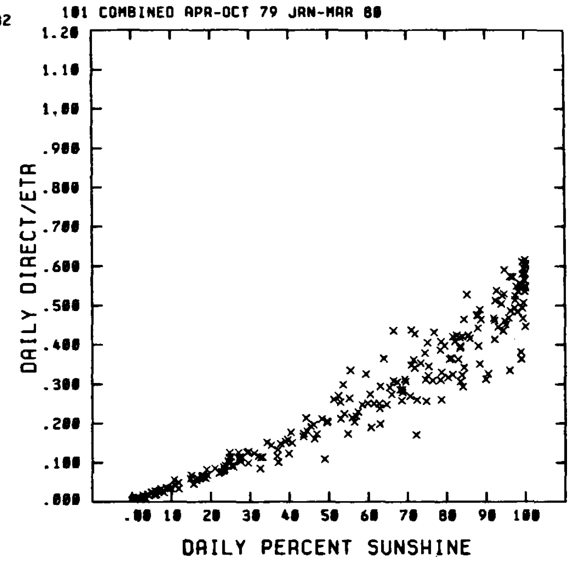


Fig. 7. Daily Direct/Extraterrestrial versus Daily Percent Available Sunshine for April-October 1979 and January-March 1980.

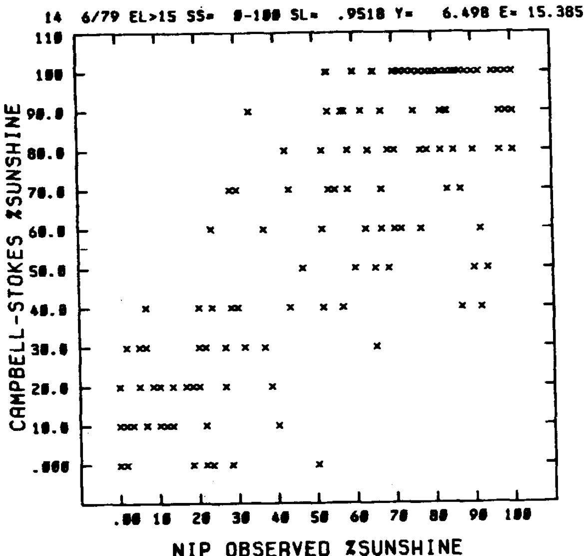


Fig. 8. Hourly Percent Sunshine from Campbell-Stokes Recorder Versus Percent Sunshine from Pyrheliometer (Threshold 200 W/m^2) for June 1979.

found between the pyrheliometer derived percent sunshine and the monthly average percent sunshine determined by the Foster sunshine switch at the nearby (15 km distant) Atlanta airport. Here monthly differences ranged from 3 to 17%, with an rms of 10%. These results may have great significance on methods to estimate radiation from percent sunshine data (as in the "Ersatz" data set which currently forms the basis for much solar energy design).

Various plotting schemes for diffuse radiation have been used. Figures 9-12 compare some of these plotting schemes. For example, the form in Figure 10, diffuse/(horizontal ETR) versus global/(horizontal ETR) was used by Randall (1977) in his direct beam model. The diffuse plot is used by Randall in the following way: first, the measured global radiation is used in a regression relation to estimate the direct beam (including a random perturbation part), second, the diffuse radiation implied by this combination of measured global and modeled direct is compared with upper and lower bounds for diffuse implied by plots such as Figure 10; if the estimated diffuse exceeds these bounds, a new direct beam value is estimated until a diffuse within the proper bounds results.

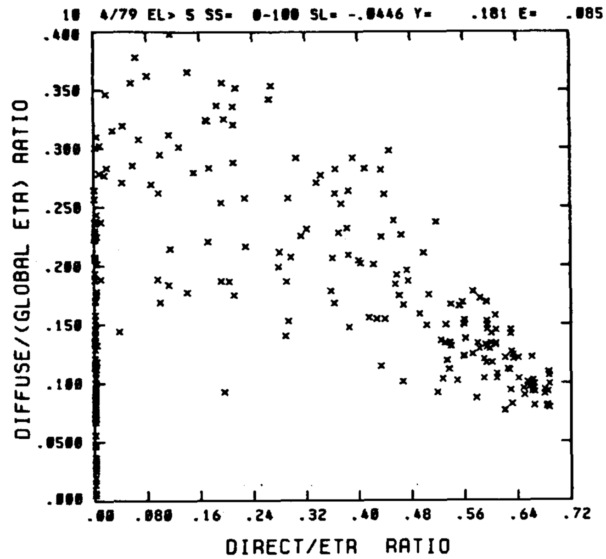


Fig. 9. Hourly Diffuse/(Extraterrestrial on Horizontal Surface) versus Direct/Extraterrestrial for April 1979.

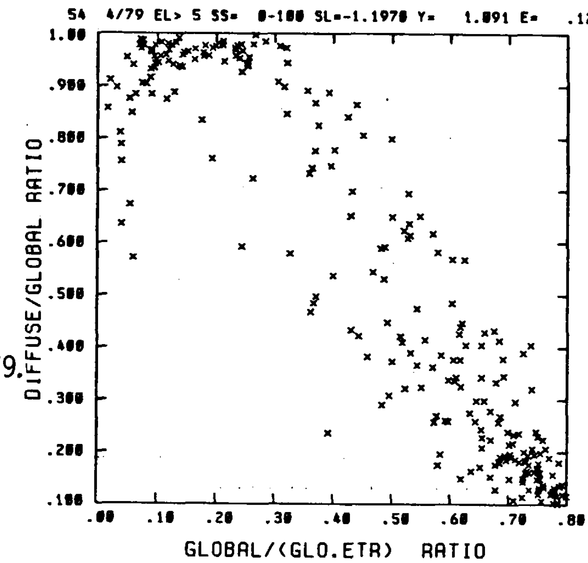


Fig. 11. Hourly Diffuse/Global versus Global/(Extraterrestrial on Horizontal Surface) for April 1979.

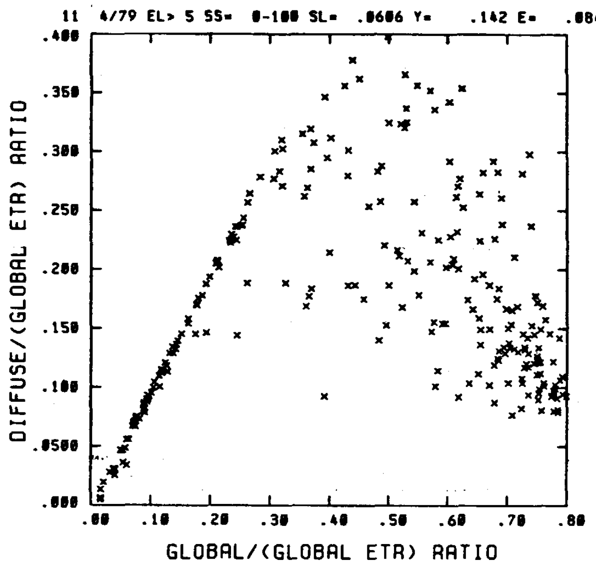


Fig. 10. Hourly Diffuse/(Extraterrestrial on Horizontal Surface) versus Global/(Extraterrestrial on Horizontal Surface) for April 1979.

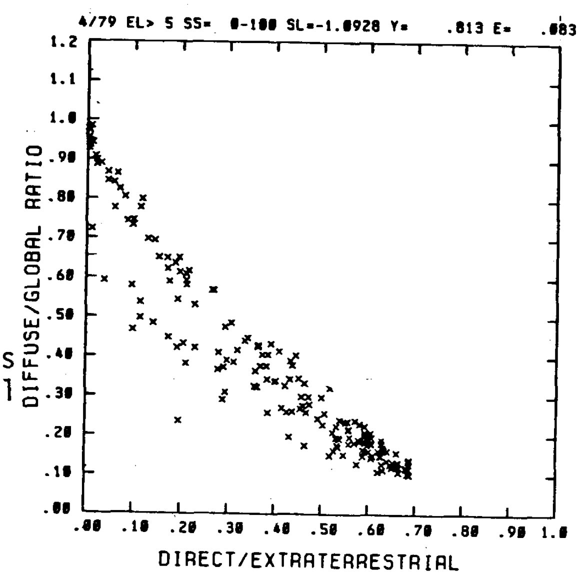


Fig. 12. Hourly Diffuse/Global versus Direct/Extraterrestrial for April 1979.

The diffuse plot in the form of Figure 12 may be more suited for this purpose. This plot shows the ratio of diffuse-to-global versus the direct-to-ETR ratio. For a given measured global and Randall-modeled direct, Figure 12 would seem to give a tighter range of allowed diffuse values because of the smaller scatter than in Figure 10. It should be noted that the abscissa and ordinate in Figure 12 are not entirely independent, being a plot of (global minus direct)/global versus direct, i.e., values of diffuse/global must go to 1 as direct approaches zero. However, similar constraints apply on some of the other plots which show higher degrees of scatter, e.g., in Figure 10 diffuse/(global ETR) must equal global/(global ETR) when the global is small (low direct beam).

Figure 13 gives results for February 1980 of a comparison between the Eppley PSP and the Spectrolab SR75. The standard error of the regression is 17.1 kJ/m^2, with a regression slope of 0.992. For the one year period April 1979 - March 1980, the rms standard error of regression was 16.9 kJ/m^2 and the 12 monthly regression slopes averaged 0.999 with a standard deviation of 0.005. The Eppley PSP and Eppley 8-48 were also compared, as were the Eppley PSP and Lambda LiCor photo cell radiometer. For the PSP/8-48 comparison, the rms standard error of regression was 42.3 kJ/m^2 and the average monthly regression slope was 0.983 ± 0.016 (std. dev.). For the PSP/LiCor comparison, the rms standard error of regression was 38.7 kJ/m^2 and the average monthly regression slope was 0.982 ± 0.024 (std. dev.). These results show that the Lambda LiCor used as a global horizontal pyranometer has errors which are 2-5 times larger than the PSP (but at about 1/10th the cost of the PSP). The Lambda LiCor and Eppley 8-48 show comparable errors, despite the higher cost (by about a factor of 6) for the 8-48 compared to the LiCor.

Recent measurements with a Lambda LiCor on a latitude tilt indicate comparable errors. Two months data show rms regression error of 55 kJ/m^2 compared with the tilted PSP. A collimated LiCor sensor to measure direct beam shows 45 kJ/m^2 standard error of regression when compared with Eppley pyrheliometer measurements. Inherent accuracy of the pyrheliometer, mentioned earlier, is about 15 kJ/m^2.

The Klutcher (1979) anisotropic sky radiation model for insolation estimation on tilted surfaces has been compared to observed, and with the isotropic sky radiation model of Liu and Jordan (1963). Figure 14 shows the Klutcher model (computed from measured direct and horizontal diffuse) versus observed radiation and a latitude tilted surface (with artificial horizon to suppress foreground reflected radiation). For this plot, May 1979, the regression slope is 1.005 and the standard error of regression is 42.1 kJ/m^2. For the year April 1979 through March 1980, the rms standard error of regression was 40.4 kJ/m^2 for the Klutcher model versus observed, compared to 42.0 kJ/m^2 for the Liu and Jordan versus observed. The average regression slope was 1.001 ± 0.014 for the Klutcher comparison versus 0.968 ± 0.021 for the Liu and Jordan comparison. Thus, the Liu and Jordan tended to underestimate the observed tilted radiation, but with a residual scatter comparable to that of the Klutcher model. For the period April - September 1979, the Klutcher model yielded 45.6 kJ/m^2 rms standard regression error

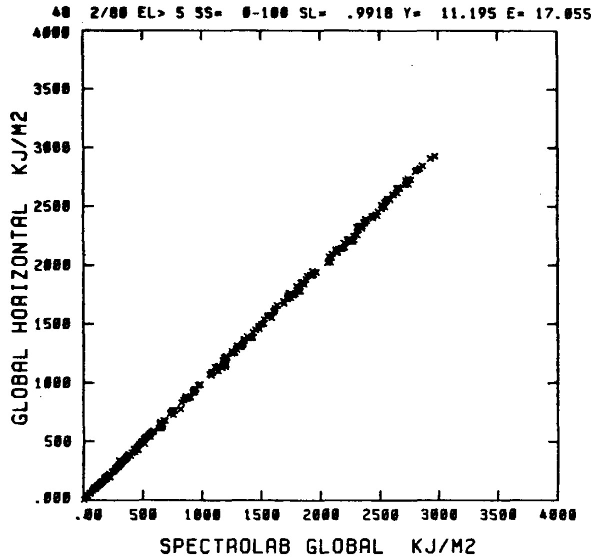


Fig. 13. Hourly Global from Eppley PSP vs Global from Spectrolab SR75 for February 1980.

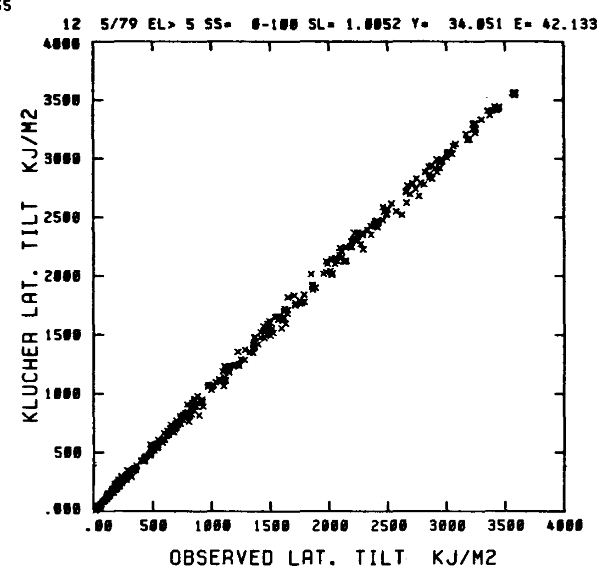


Fig. 14. Hourly Klutcher Model Latitude Tilted Global versus Observed for May 1979.

compared to 33.1 kJ/m^2 for the Liu and Jordan. In October 1979 through March 1980, the trend was reversed with 34.3 kJ/m^2 rms standard error of regression for the Klutcher model versus 49.2 kJ/m^2 for the Liu and Jordan model. These results suggest that the Klutcher model is better during low sun angle (cold season) months but that (if the tendency of Liu and Jordan to understimate the observed is removed) the Liu and Jordan model is actually better, on average, in the warm season months when frequent cumulus cloud conditions occur as in Atlanta.

Figures 15-18 show results of ultraviolet (UV) at 0.30-0.39μ as a function of relative air mass and cloud cover. Under clear skies (99-100% sunshine), Figure 15 shows that the UV/Global ratio is about 5.2% at relative air mass 1 and 4.5% at relative air mass 2, with a steady decrease with air mass. These results are consistent over the year of observation from April 1979 through March 1980. In contrast, for cloudy skies (0-1% sunshine) Figure 16 shows much more scatter of UV/global ratio and not nearly so much trend with air mass. When plotted as UV versus global, as in Figures 17 and 18, clear sky values display a concave-upward, non-linear trend of UV versus global for clear skies, but a concave-downward, non-linear trend of UV versus global for cloudy skies. This illustrates the well-known effect that the suntan and skin cancer producing UV can actually be greater for a given amount of global radiation on a cloudy or partly cloudy day than for the same amount of global radiation on a clear day.

Significant controversy has been raised by the SEMRATS measurements

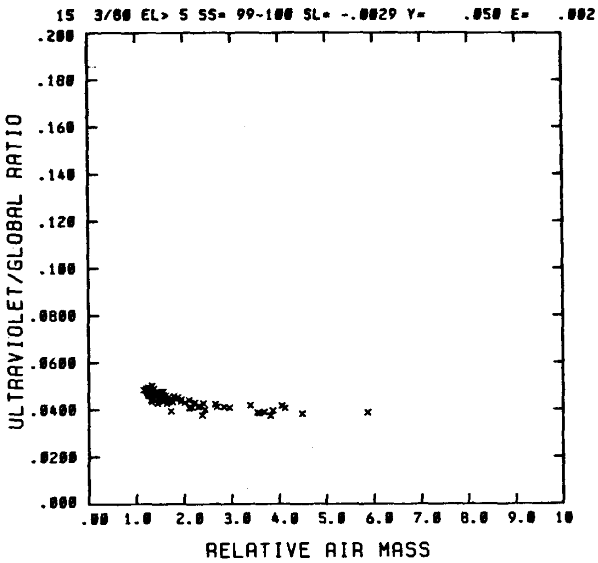


Fig. 15. Hourly Ultraviolet (0.30-0.39μ)-to-Global Ratio versus Relative Air Mass for March 1980, Clear Skies.

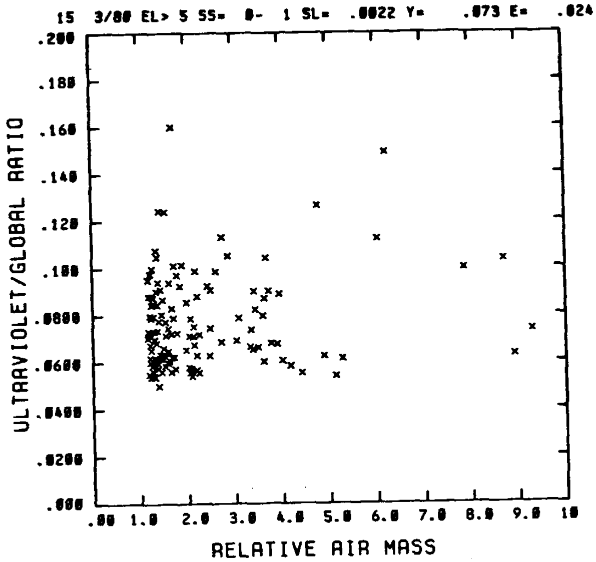


Fig. 16. Hourly Ultraviolet (0.30-0.39μ)-to-Global Ratio versus Relative Air Mass for March 1980, Cloudy Skies.

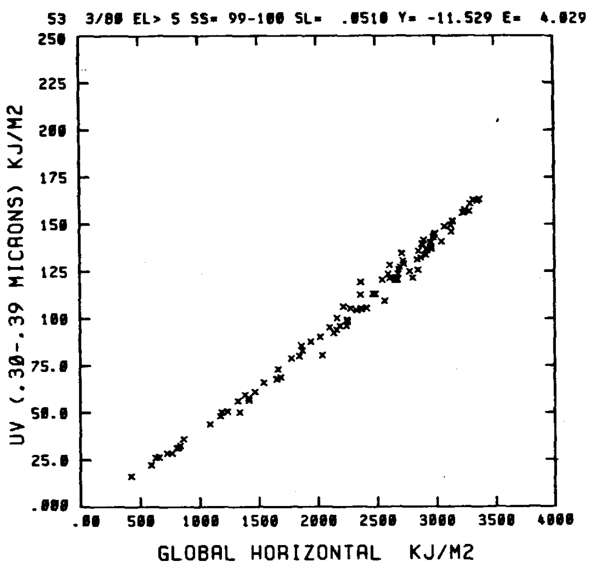


Fig. 17. Hourly Ultraviolet (0.30-0.39μ) versus Global for March 1980, Clear Skies.

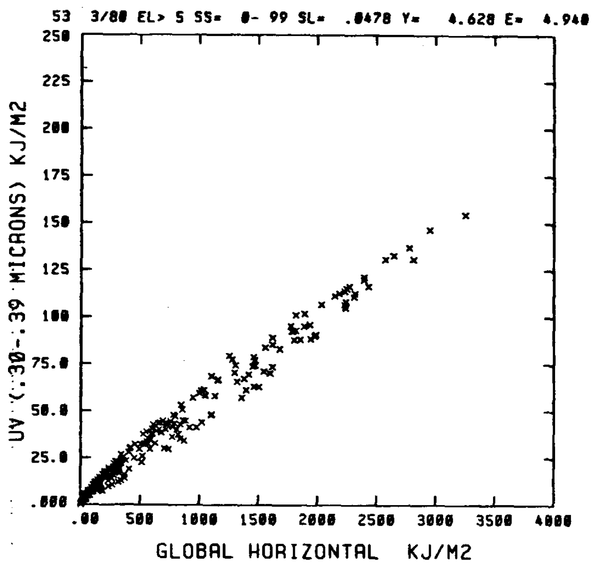


Fig. 18. Hourly Ultraviolet (0.30-0.39μ) versus Global for March 1980, Overcast and Partly Cloudy Skies.

about the proper calibration and operation of IR measuring instruments such as the Funk radiometer and Eppley PIR. Comparison of the Georgia Tech Funk radiometer with the travelling standard indicated about 10% discrepancy between the IR calibration coefficient and the shortwave coefficient of the Georgia Tech instrument, as determined by sun/shade tests. The Swissteco factory calibration of the Funk radiometer indicates much closer comparison between shortwave and IR calibration coefficients. Sun/shade tests of the Eppley PIR at Georgia Tech have shown that this instrument also responds to shortwave solar radiation (with a shortwave sensitivity about 8% of the IR sensitivity). Let the IR calibration coefficient for the Funk radiometer be a, as determined by comparison with the IR travelling standard, and its shortwave calibration coefficient be b, as determined by sun/shade tests, i.e., $(\text{Volts})_{IR} = IR/a$; $(\text{Volts})_{SW} = SW/b$, where the total voltage signal is $\text{Volts} = (\text{Volts})_{IR} + (\text{Volts})_{SW}$. Then the IR radiation from the voltage out of the Funk and its cavity temperature T_c can be computed by

$$IR_{FUNK} = a[\text{Volts} - SW/b] + \sigma T_c^4 \qquad (1)$$

where SW is the measured shortwave (global) radiation. If the Georgia Tech results are typical, the factors a and b can be as much as 10% different. For the Eppley PIR, let its IR calibration be c, as determined by comparison with the IR travelling standard, and its shortwave calibration be d, as determined by sun/shade tests. Then IR radiation from the Volts out of the PIR can be computed by

$$IR_{PIR} = c[\text{Volts} - SW/d] \qquad (2)$$

where SW is again the measured shortwave (global) radiation. If the results at Georgia Tech are typical, the ratio c/d will be small (e.g., <10%).

References

Bird, R. and R. L. Hulstrom (1980): "Direct Insolation Models," SERI/TR-335-344, January.

Klutcher, T. M. (1979): "Evaluation of Models to Predict Insolation on Tilted Surface," Solar Energy, 23, 111-114.

Liu, B. Y. H. and R. C. Jordan (1963): "Daily Insolation on Surfaces Tilted Toward the Equator," ASHRAE Journal, 3 (10), 53-59.

Randall, C. M. and M. E. Whitson, Jr. (1973): "Hourly Insolation and Meteorological Data Bases Including Improved Direct Insolation Estimates," Aerospace Corporation ATR-78 (7592)-1.

SUMMARY OF SOLAR ENERGY METEOROLOGY RESEARCH AND TRAINING SITE (ALASKA) PROGRAM FOR THE FIRST THREE YEAR PERIOD

Gerd Wendler
Geophysical Institute
University of Alaska
Fairbanks, Alaska 99701

BACKGROUND

Purpose:

In brief, the purposes of the SEMRTS (Alaska) program are:

1. To establish an accurate solar radiation measuring program in Alaska.
2. To develop university classes on solar radiation and related subjects.
3. To train interested students in the field of solar radiation and energy research.
4. To provide public awareness of solar energy and other alternative forms of energy.
5. To develop programs of research on different aspects of atmospheric radiation.

The program objectives were outlined in detail in the original proposal submitted to ERDA, Office of University Programs in June, 1977. Furthermore they were summarized in the report prepared for the "First DOE Environmental Resource Assessment Branch, Quarterly Contractors Program Review, 22-24 February, 1978". Hence, we do not repeat these objectives in this report.

Personnel:

Although from the onset of the program there has been a constant flux in personnel, the following personnel contributed in one way or another to the success of last year's program:

Baldridge, James N., computer programming
Creech, Barbara, computer programming
Curry, Edith I., data analyst
Eaton, Frank D., Dr., research associate
Hall, Martie, data analyst
Hartley, Jero, data analyst
Hill, Molly, electronic technician
Jayaweera, Kolf, Dr., co-principal investigator
Kodama, Yuji, graduate student
Mimkin, Gil, (IMS) design engineer
Nagashima, Yoshito, graduate student
Ohtake, Takeshi, Dr., professor
Venable, Jesse, computer programming
Wendler, Gerd, Dr., principal investigator
Wise, Jim, (AEIDC, Anchorage) state climatologist

Changes in expertise with time reflect the needs and evolution of the program. Organization of the program can be seen from descriptions after the above names.

Milestone schedule (Figure 1), start and end dates:

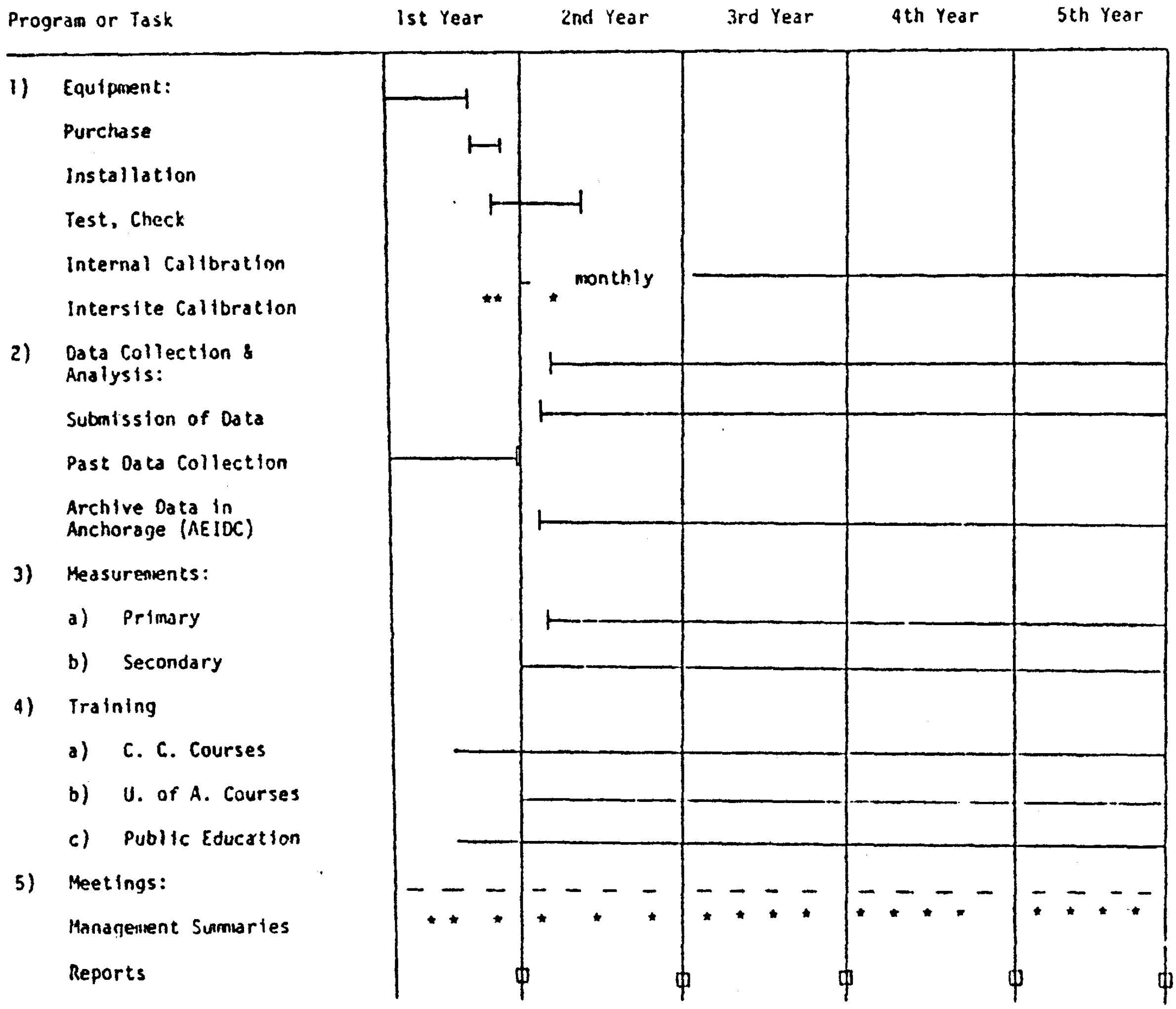


Figure 1. Milestone Chart for the SEMRTS (Alaska) project.

The starting date for the program was October 1, 1977 with a scheduled ending date of September 30, 1982.

Relationship to other projects:

The primary purpose of collecting the solar radiation data under the SEMRTS is for assessment of solar energy. We have found considerable interest and received innumerable requests for the data from engineers, building contractors, architects and scientists.

The SEMRTS program also partially supported a study concerning multiple reflection between ground surfaces and clouds. This study was in cooperation with a cloud physics study concerning artificial dissipation of arctic stratus clouds. Cloud physics measurements from the cloud study project were used in the radiation study.

The SEMRTS was also involved at Lake Minchumina, Alaska where another study concerning the effects of a lake on its surroundings was carried out. The SEMRTS program supported radiation measurements (as well as a graduate student to perform this aspect of the study) which were taken over the lake and surrounding land. In summer during the daytime (and in spring) the water surface is colder than the surrounding land masses. This decreases the amount of cumulus development above the lake, thereby increasing the amount of direct solar radiation. At night (and during fall) the water is warmer than the surrounding land. This increases the amount of fog and low level clouds above the lake thereby making the net radiation less negative. Both the increased solar radiation during the day and decreased long wave radiation losses at night make the radiation balance more positive for the area above the lake. By the establishment of several stations, one above the lake, others at various distances from the lake (with the closest being at least the distance of the diameter of the lake), we will be able to investigate these different radiation climates quantitatively.

Previous significant progress results:

Since the last section of this paper "Summary of Results (FY 1980)" deals with last years' results exclusively, only previous studies will be mentioned here. Two have been discussed in the previous section and will not be repeated.

In the spring of 1979 we measured the energy balance of the earth's surface for the snow melting period in Fairbanks. The largest change during the annual cycle in the energy balance is experienced with the melting and the re-establishment of the snow cover. This effect is especially pronounced in spring, as the amount of global radiation is largely due to the already long diurnal daylight and the low amount of cloudiness. As long as the snow cover is present, a great deal of the solar radiation is reflected; i.e. 85% for dry, fresh snow and about 45% for wet snow. After the snow cover has disappeared the albedo drops to values around 15%. Therefore, much more solar energy is absorbed and available for heating which explains the drastic temperature increase in Interior Alaska after the snow has disappeared. We utilized our mobile station for this study. At the moment we are at the state of data analysis.

Jim Wise analysed Alaska solar radiation data from 1952 through 1975. The stations included in the analysis are Annette, Barrow, Bethel, Fairbanks and Matanuska. The analysis is daily radiation by month and includes means, extremes, medians, and standard deviations with all amounts of cloudiness and also with selected cloud amounts with the exception of Matanuska, where cloud data are not available. Solar radiation with various clouds is graphed by latitude and a method is suggested for estimating solar radiation for locations with cloud amount data available. There are 46 such locations in Alaska. A 27 page report is available from J. Wise, AEIDC, University of Alaska, 707 A Street, Anchorage, Alaska 99501.

A major research effort supported by this project is to examine atmospheric turbidity within the Alaskan region. Due to the low population density in Alaska as well as lack of substantial industry, relatively small amounts of anthropogenic aerosols are injected into the Alaskan atmosphere. However, large forest fires frequently produce high levels of particulate material, and dust storms in certain areas are also common. Several Alaskan volcanoes also periodically introduce tremendous amounts of natural aerosols into the atmosphere, often penetrating into the stratosphere. As part of our continuous monitoring program to investigate atmospheric turbidity in the subarctic atmosphere, we are measuring the direct solar beam component with a Normal Incidence Pyrheliometer mounted on a solar tracker, incoming radiation with pyranometers equipped with WG7, OG1, RG2 and RG8 filters as well as ultraviolet radiation. Values are compared to "clear sky" conditions and the turbidity is calculated from the measurements.

On a case study basis, a Linke-Feussner Pyrheliometer equipped with broad band filters and two Volz sunphotometers with interference filters are used. The interference filters range from 380 nm to 940 nm. With the ensemble of measurements, information on the aerosol distribution as well as precipitable water can be obtained. In addition, one of the Volz sunphotometers is equipped with a device to measure the scattering function of skylight. Measurements of the scattering function in the solar almucantar combined with extinction values will be used to describe the particulate matter in the subarctic atmosphere.

A paper by F. Eaton and G. Wendler entitled "Atmospheric Turbidity Determinations in Interior Alaska" was presented at the Spring Meeting of the American Geophysical Union in Washington D.C. on May 28-June 1, 1979. Following is an abstract of the presentation from EOS, A.G.U.:

Recently one of the eight Solar Energy Meteorological and Training Site Programs of the U.S.A. was established at the Geophysical Institute, University of Alaska. Several aspects of atmospheric radiation are being investigated within various climate regimes of the Alaskan region. This paper presents results of atmospheric turbidity determinations by measuring extinction of the direct solar radiation with braodband and interference filters. Standard methods of evaluation are used and results are compared to calculations of "clear sky" conditions. Scattering function measurements of skylight taken in the solar almucantar will also be presented. The interior Alaskan atmosphere is characterized by low levels of anthropogenic aerosols but occasionally high production of particulate matter from forest fires and dust storms is found. A combination of extinction and scattering function values is used to describe the nature of this particulate matter.

Alaska is divided into four distinct climatic regimes, a southerly maritime climate, a transitional climate, a less moist climate in Interior Alaska, and an arctic climate north of the Brooks Range. Under the project, the relationship of cloud effects on solar energy for the climatic zones is being investigated. A method is presently being developed using hourly recorded values collected at the Fairbanks Airport. So far two years of data have been analyzed by examining the relationship of global radiation with various types of clouds and cloud thicknesses as a function of solar elevation angle. However, the quality of the existing data proved to be too poor to establish meaningful relationships. The work will commence when our own data set is sufficient.

DESCRIPTION

Measurements, Instrumentation, Data Logging and Quality Control:

At our main station in Fairbanks on the roof of the Geophysical Institute, we are measuring the following parameters with the listed sensors:

1. Global Radiation, Epply PSP (WG7)
2. Global Radiation, Epply PSP (OG1)
3. Global Radiation, Epply PSP (RG2)
4. Global Radiation, Epply PSP (RG8)
5. Diffuse, (SB) Epply PSP (WG7)
6. Diffuse, (TD) Epply PSP (WG7)
7. Global (oriented south) 65 degrees, Epply PSP (WG7)
8. Global (oriented south) 90 degrees, Epply PSP (WG7)
9. Reflected shortwave radiation, Epply PSP (WG7)
10. Ultraviolet, Epply Photometer
11. Direct Solar Beam, (NIP) Epply
12. Net Radiation, Swissteco
13. Infrared Radiation, (Pyrgeometer) Epply
14. Global Radiation, (silicon cell, Lambda)
15. Temperature, 0m, Thermistor
16. Temperature, 2m, Thermistor
17. Temperature, 4m, Thermistor
18. Humidity, 2m, Hair hygrometer
19. Humidity, 4m, Hair hygrometer
20. Barometric Pressure, pressure transducer
21. Wind Speed, 3 cup
22. Wind Direction, vane
23. Precipitation, Tipping bucket heated gauge

Our data acquisition system consists of a HP 3455A voltmeter, HP 3495A scanner, HP 9825A controller, two Tektronix 4924 tape decks, a 4051 Tektronix computer with CRT, a 4662 Tektronix interactive digital plotter, a 4641 Tektronix printer and a high speed digital Decwriter III. The system is connected by direct line to the University of Alaska Honeywell computer, level 66-20, and the Geophysical Institute VAX-11/780-VMS computer for faster data handling. The data quality control is according to standards that the eight sites (SEMRTS) agreed upon. Some additional control became necessary, as we had for extended periods of time low sun angles for which the standard quality control became meaningless. A journal article (Wendler and Eaton, 1980) describes the method we used.

Additional measurement sites and availability of data:

We are running 3 more stations besides the main station in Fairbanks. One is located in Kodiak and measures global radiation on the horizontal and on an inclined (to latitude) surface facing south. The personnel of the NWS help us in running the station in this maritime climate. Another station is located in the transition climate of the maritime south and the continental interior in Anchorage. Mr. J. Wise, who is part of this project, operates this station measuring:

a. global radiation
b. global radiation on a south wall

c. global radiation facing south inclined to latitude
d. air temperature
e. humidity
f. wind speed and direction

Our last station, which has only recently been installed, is located in the arctic climate of the North Slope (Barrow). GMCC granted permission to add to their existing instrumentation. We are measuring incoming and reflected short wave radiation, as well as long wave incoming and outgoing radiation.

Fourteen months of data tapes have been submitted to the National Climatic Center, Asheville, North Carolina for Fairbanks. Approximately the same time period of data is available from the Anchorage site. The Kodiak site and Barrow site data are presently in the stage of reduction and should be available soon.

RESEARCH PROGRAM (FY 1980)

The following papers and reports were written and the following conferences attended during FY 1980:

1. "Alaska Solar Radiation Analysis" by J. Wise, 1979, AEIDC report, 27 pages.
2. "Irradiance Measurements of Arctic Stratus Clouds" by Frank Eaton and Gerd Wendler, AGU meeting in San Francisco, December 1979 (abstract published in EOS).
3. "Quality Control for Solar Radiation Data" by G. Wendler and F. Eaton, 1980, Solar Energy, Vol. 25, pp 131-138. The abstract is as follows:

Solar radiation values are difficult to predict or to estimate, due to the multitude of factors affecting radiative transfer in the atmosphere. Whether considering a network of stations or several radiation sensors at a single station, proper calibration procedures of both sensors and data acquisition systems are mandatory.

This paper presents a method whereby the interrelationships of signals received from different radiometers at a single site are systematically checked as a means of data control. The various measurements discussed include direct solar, global, diffuse solar and net radiation, albedo, measurements on inclined surfaces and in various bandpasses. The data control method is accomplished by examining ratios, combinations and comparisons of various parameters in addition to calculating some of these parameters by the use of empirical formulae.

4. "Ground Albedo Effects on Irradiance in the Arctic" by F. Eaton and G. Wendler, IAMAP International Radiation Symposium, August 1980. Ft. Collins, Extended abstract published in the proceedings of the meeting. A condensed abstract follows:

Incoming shortwave radiation was examined under different surface albedo conditions in the arctic as well as for different degrees of cloud coverage. Surface albedo for the northern Alaskan tundra was found to vary from about 80% for snow covered conditions to about 15% during mid-summer.

Arctic stratus clouds cover most of the Arctic Ocean and often *extend as far south as the Brooks Range for prolonged periods of time from April through September. Under these clouds for similar solar angles spring irradiation values were found to exceed late summer values by about 70% at Barrow, Alaska.*

Although others have explained such differences in irradiance by cloud thickness and water content in the atmosphere, we believe that multiple reflection effects between the surface and lower extent of the clouds are mostly responsible for the differences.

Airborne measurements of shortwave radiation reflected and transmitted by Arctic stratus clouds as well as surface albedo were carried out for the same cloud cover over surfaces with different surface albedos. These data show clearly multiple reflection effects on irradiance. Cloud droplet sizes and concentrations were measured simultaneously with the radiation data allowing comparison of the experimental results with those obtained theoretically.

5. "Cirrus Contrail Effects on Solar Radiation and Cloud Evolution" by G. Wendler and F. Eaton, IAMAP International Radiation Symposium, August 1980, Ft. Collins, extended abstract published in the proceedings of the meeting. A condensed abstract follows:

The first objective is to examine the effects of cirrus contrails on solar radiation. As part of the DOE sponsored Solar Energy Meteorological Research and Training Site (SEMRTS) program we are obtaining, in addition to other radiative fluxes, the direct solar, diffuse and global radiation values in one minute intervals. Normally an increase in diffuse radiation is found when comparing "clear" sky conditions with contrails to those without contrails. Effects of contrails on the direct beam solar radiation are negligible unless the contrails lie within or close to the intervening path between the solar disk and measurement point. Exact location of the contrails produces pronounced effects on attenuation or circumsolar radiation. These effects in turn are also displayed to a lesser extent in the global radiation measurements. Actual contrail formations as well as cloud conditions are documented with an all sky camera at the SEMRTS in Fairbanks, obtaining photographic imagery in one minute intervals. These photographic records are being systematically evaluated and correlated to atmospheric conditions as obtained from radiosonde observations. Evolution of individual contrails are explained as a function of air masses, seasons, etc.

The second objective is to study cloud frequencies for two stations lying on the much traveled airline route (Fairbanks and Barter Island) and the two stations which are much less impacted by plane traffic in the last 20 years (McGrath and Barrow). Trends are discussed of cloud frequencies which have occurred since the innovation of the polar flights.

6. "Analysis of Solar Radiation Measurements on an Inclined Surface in Anchorage, Alaska" by J. Wise, 1980. AEIDC, Anchorage, AK 20 p.

7. "Solar Radiation Data for Fairbanks" Wendler et al, Geophysical Institute Report, 1980. Results are given in tabular as well as graphical form. Special emphasis was given to a.) global radiation received on a horizontal surface, b.) 65^{o} incline to the south, and c.) the surface on a south-facing wall, as these measurements show the greatest frequency of requests from architects, engineers, builders as well as other members of the "solar community".

8. "Multiple Reflection Effects on Irradiance in the Presence of Arctic Stratus Clouds" by G. Wendler, F. Eaton and T. Ohtake. In press JGR (green). A condensed abstract follows:

For under a stratus cloud cover and for identical solar heights, irradiation values are about 70% higher in spring than in late summer at Barrow in Northern Alaska. A possible explanation for these differences is by interseasonal variations in cloud thickness and water content in the atmosphere. However, we demonstrate that multiple reflection is mostly responsible for it. In spring there is a very high surface albedo (∿80%), while in summer the surface albedo is low (∿15%). Hence multiple reflection between the surface and the lower extent of the stratus cloud cover is important when snow is on the ground, but fairly unimportant after the snow has melted. To verify our assumption airborne measurements were carried out for the same cloud cover, but over surfaces of different albedos, namely snow covered tundra (∿80%) broken sea ice (20-40%) and open water (4-16%). These data show clearly that if the surface albedo is raised, multiple reflection is the cause of the strong increase in irradiation.

The interaction by multiple reflections of the spectral characteristics of various ground surfaces with the stratus clouds also was found to be displayed in the spectral irradiance received from the cloud cover.

9. "Solar Radiation Measurements in Alaska" by F. Eaton and G. Wendler. Alaska Science Conference, September 1980. Anchorage, AK Abstract published in the proceedings.

STATUS AND PLANNED ACTIVITIES

In summary, we plan to do the following during the coming year:

1. Increase the research activities based on data from all four operating stations.
2. Continue new research interests to their completion. Previously listed material under "Research Program" does not represent all our activities, because several have not advanced to a state where a formal presentation appears worthwhile. More specifically, there are two: a. Modelling of Solar Radiation. The "Machta" radiation model for clear sky conditions was put on our University of Alaska computer after the program was received from Dr. Machta's laboratory. We thank them for their cooperation. As pointed out by Machta, adaptations for low solar angles and for highly reflecting surfaces have to be made before it is adaptable for our region. We are working in this direction. Further, radiation models for cloudy conditions, including the Canadian one, which take multiple reflection into account are being put on the computer and tests will be run with the data sets we have obtained so far. It will be interesting to see how well they agree for the different climatic regions of Alaska. b. Aerosols and Solar Radiation. Forest fires burn substantial acreage in Alaska, on the average over ½ million acres per year over the last 10 years. These forest fires put large amounts of aerosols into the atmosphere in which we are interested. Besides our broad band filter measurements (with a Lincke-Feussner) turbidity measurements were carried out with Volz sunphotometers. Also, actual smoke

samples collected on millipore filters were taken from the ground as well as from an airplane. We have started to analyze these samples with an electron microscope equipped with an x-ray energy spectrometer to obtain information on the physical and chemical characteristics of this particulate matter.

3. Continue educational aspects of this project and disseminate the information to the interested public.

SESSION II
NOAA, SERI, AND CANADIAN INSOLATION ASSESSMENT AND RESEARCH PROJECTS

THE CANADIAN SOLAR ENERGY ASSESSMENT PROGRAM A REVIEW

John E. Hay
Department of Geography
University of British Columbia
Vancouver, Canada

1. BACKGROUND

By necessity this paper will be a very superficial review of the Canadian program for solar energy assessment. The prime purpose will be to introduce the reader to the broad range of activity currently underway in Canada and to direct people to the source of more specific information. A comprehensive review of Canadian solar energy research activity is to be found in Hay (1977) and the Proceedings of the First Canadian Solar Radiation Data Workshop (Hay and Won, 1980) also provides a useful summary of the status of the Canadian program. The present paper will concentrate on developments which have occurred subsequent to the workshop (April, 1978).

2. MEASUREMENT PROGRAMMES

The responsibility for maintaining standards and the quality of the monitoring networks rests with the National Atmospheric Radiation Centre (NARC) of the Canadian Atmospheric Environment Service (AES). The radiation standard used at NARC is maintained with an absolute radiometer and frequent international comparisons and represents the Smithsonian Scale of 1913 reduced by 2.0 per cent (Latimer, 1973; 1980). The NARC is also concerned with instrument evaluation and development and studies include analyses of the calibration stability of pyranometers, temperature and cosine responses of pyranometers, the effect of sensor orientation on the calibration constant and the correction factors for the shadow band on a diffusometer (Latimer, 1972; 1980). The AES solar energy monitoring network currently consists of 52 stations measuring the global solar radiation and 8 stations which also measure the diffuse component, 5 stations measuring the reflected radiation (and hence the albedo) and 26 stations measuring the net (all wave) radiation (see Fig. 1 and Bristow, 1980). Data are regularly published as hourly totals and summarized values in the Monthly Radiation Summary (AES) and are also available on magnetic tape (Donegani,1980). AES has recently completed a project which will provide more extensive and useful summaries of the observed data including tabulations of long term means, standard deviations, quartiles and percentiles, extremes and analyses of energy available above specified intensity thresholds. The federal data network is, in many cases supplemented by provincial and specialized research networks (e.g. Wilson, 1980; Hay and Tooms, 1979). In addition specialized observational programs are conducted by a number of organizations and individuals. Of particular relevance are the clear sky spectral measurements of Sadler (1980). Hay and Won (1980) have attempted to document all of the research data archives available from Canadian workers.

Of particular relevance to solar energy assessment are the slope radiation measurement programs being conducted at Toronto (NARC/AES) and Vancouver (University of British Columbia). The facilities have been described by Wardle (1980), Hay (1978), 1979a), and Hay and Lamble (1979). These programs have two fundamental objectives: a) to characterize the solar irradiance of inclined surfaces using measured data and b) to evaluate and, if necessary, develop numerical models for determing the irradiance of inclined surfaces. The above references provide the results to date including a description and verification of an anisotropic slope radiation model (Hay, 1979a).

The anisotropy of diffuse solar radiation from the sky hemisphere, which is an important feature of this model, has been studied extensively by two Canadian groups. Hooper and his co-workers at the University of Toronto have developed a three component model (isotropic, horizon brightening and circumsolar) and tested it against observed data. Another group (McArthur and Hay, 1978; 1980a, 1980b) has developed a combined photographic/radiometric technique which can be used to map the radiance distribution for the hemisphere under all sky conditions.

3. MODELLING STUDIES

The finite number of measurement sites and the vastness of Canada has resulted in special attention being paid to the determination of solar radiation using numerical models and more commonly available meteorological data. These research efforts recently resulted in an ambitious programme to assess the performance of a variety of such models and to use the best model to calculate the radiation at 100 Canadian locations currently devoid of measured data. The project is outlined in Hooper et al (1979) and the detailed results are contained in MacLaren et al (1979). This latter document is also significant in that it contains detailed descriptions of the models that were evaluated, of the results a survey of "users" that lead to a definition of the desired contents of a solar radiation and meteorological data archive and of the contents of the final merged data archive. Again the archive is available in either hard copy (including summary tabulations showing energy available for certain thresholds and temperature ranges) and on magnetic tape. The numerical models used in the creation of the "derived archive" are the MAC3 (Davies et al, 1975; Davies and Hay, 1980) and the WON (Won, 1977) models for horizontal surfaces and the anisotropic slope model (Hay, 1979a) for inclined surfaces.

Canadian researchers have also used the excellent solar data archive to evaluate techniques for determining the direct and diffuse portions of the global radiation (see the review by Hay, 1977) and for calculating the global radiation from bright sunshine data. Both these approaches have recently been improved by including the effects of multiple reflection (Hay, 1976; 1979b).

4. NETWORK STUDIES (SPATIAL VARIABILITY)

Again, as a result of the vastness of the Canadian land mass, considerable attention being given to the spatial variability of solar radiation and hence to the representativeness of point observations of solar radiation. The topic has been reviewed by both Hay (1977) and Wilson

(1980) but work is continuing. Suckling and Hay (1978) have shown that the spatial variability of solar radiation does differ between distinct synoptic weather regimes (e.g. cyclonic compared with anticyclonic) and used this information in another study (Hay and Suckling, 1979) to assess the adequacy of the observation network in the cordilleran region of Canada to characterize the spatial variability of solar radiation. The large spatial variability (except under well developed anticyclonic conditions) meant that, even with a combination of observed and calculated data, spatial coverage was generally inadequate.

In another study (Hay and Tooms, 1979) a network of 12 stations covering an area 50 km by 80 km in and adjacent to Vancouver, B.C. has been used to describe the mesoscale variability of solar radiation. The observed spatial coherence can be used to demonstrate the representativeness of a point observation and the errors associated with the interpolation of data between measurement sites. The results of one such analysis are summarized in Table 1 and indicate that <u>interpolation</u> of <u>hourly</u> data over a distance of 10 km will result in a typical error of 14%. The error for <u>daily</u> data would be near 7%. These results obviously raise the question as to how, without the installation of outrageously expensive networks, are we to provide data with a spatial resolution of approximately 20 km? (This assumes that we require hourly data to within 10% at all locations, and the reader should note that the Vancouver network is located in an area of large mesoscale variability). Satellites are now being considered as a possible source of required data and the results have been encouraging. Gautier et al (1980) have demonstrated this using GOES data and a physically based model. At present the Vancouver mesoscale data are also being used to test the ability of the satellite to resolve the mesoscale variability of solar radiation.

5. CONCLUSIONS

The Canadian solar energy assessment program is very active, drawing a great amount of its strength from the availability of a high quality solar radiation data archive and a great deal of its incentive from the vastness of Canada and the inability of the 52 station network to provide all the necessary data. Special attention is being paid to the development and verification of numerical models in order to supplement the observational data base.

6. ACKNOWLEDGEMENT

The research activities of the author are supported by funds provided by the Canadian Atmospheric Environment Service and the Natural Sciences and Engineering Research Council of Canada. The encouragement of D. Wardle, K. Hanson and R. Hulstrom in these endeavors is gratefully acknowledged. Helsa Wong typed the manuscript.

7. REFERENCES

Bristow, G., 1980: Canadian solar radiation data archives. In <u>Proceedings First Canadian Solar Radiation Data Workshop</u> (J. Hay and T. Won, eds.), Atmospheric Environment Service, Toronto.

Davies, J.A., Schertzer, W. and M. Nunez, 1975: Estimating global solar radiation. Boundary-Layer Meteorol., 9, 33-52.

Donegani, J., 1980: Canada's digital climatic archive: a data base input to energy research. In Proceedings First Canadian Solar Radiation Data Workshop (J. Hay and T. Won, eds.), Atmospheric Environment Service, Toronto.

Gautier, C., Diak, G. and S. Masse, 1980: A simple physical model to estimate incident solar radiation at the surface from GOES satellite data. Submitted to Journal of Applied Meteorol.

Hay, J.E., 1976: A revised method for determining the direct and diffuse components of the total shortwave radiation. Atmosphere, 14(4), 278-287.

Hay, J.E., 1977: An analysis of solar radiation data for selected locations in Canada. Climatological Studies No. 32, Atmospheric Environmental Service, Toronto, 158 pp.

Hay, J.E., 1978: Measurement and modelling of shortwave radiation on inclined surfaces. The Third Conference on Atmospheric Radiation, Davis, California, American Meteorological Society, 150-153.

Hay, J.E., 1979a: Study of shortwave radiation on non-horizontal surfaces. Canadian Climate Centre, Report No. 79-12, Atmospheric Environment Service, 141 pp.

Hay, J.E., 1979b: Calculation of monthly mean solar radiation for horizontal and inclined surfaces. Solar Energy, 23, 301-307.

Hay, J.E. and S.J. Lamble, 1979: The Vancouver, U.B.C. slope radiation measurement and modelling programme. Solar 79 Northwest, Proceedings of the Pacific Northwest Solar Energy Association, Seattle, August, 187-189.

Hay, J.E. and P.W. Suckling, 1979: An assessment of the networks for measuring and modelling solar radiation in British Columbia and adjacent areas of Western Canada. Canadian Geographer, 23, 222-238.

Hay, J.E. and R. Tooms, 1979: The mesoscale variability of solar radiation in Vancouver, B.C. Solar 79 Northwest, Proceedings of the Pacific Northwest Solar Energy Association, Seattle, August, 190-192.

Hay, J.E. and T.K. Won, 1980: Proceedings, First Canadian Solar Radiation Data Workshop. Atmospheric Environment Service, Downsview, Ontario, 132 pp.

Hooper, F., C. Attwater, A. Brunger, J. Davies, J. Hay, D. McKay and T. Won, 1979: The Canadian solar radiation data base. American Society of Heating, Refrigerating and Air-conditioning Engineers, Transactions, 85(2), 497-505.

Latimer, J.R., 1972: Radiation measurement. Technical Manual Series No. 2, International Field Year Great Lakes, Information Canada, Ottawa, 53 pp.

Latimer, J.R., 1973: On the Angstrom and Smithsonian absolute pyrheliometric scales and the International Pyrheliometric Scale, 1956. Tellus, XXV (6), 586-592.

Latimer, J.R., 1980: Canadian procedures for monitoring solar radiation. In Proceedings First Canadian Solar Radiation Data Workshop, (J.E. Hay and T.K. Won, eds.), Atmospheric Environment Service, Downsview, Ontario.

McArthur, L.J.B. and J.E. Hay, 1978: On the anisotropy of diffuse solar radiation. Bulletin, American Meteorological Society, 59, 1442-1443 and cover photograph.

McArthur, L.J.B. and J.E. Hay, 1980a: An assessment of the techniques for determining the distribution of diffuse solar radiance for the sky hemisphere. Solar Energy (In Press).

McArthur, L.J.B. and J.E. Hay, 1980b: A technique for mapping the distribution of diffuse solar radiation over the sky hemisphere. Submitted to Journal of Applied Meteorology (May, 1980).

McLaren, J.F. Ltd., Hooper and Angus Assoc., J.E. Hay and J.A. Davies, 1979: Define, develop and establish a merged solar and meteorological computer data base. Report to Canadian Atmospheric Environment Service, 210 pp.

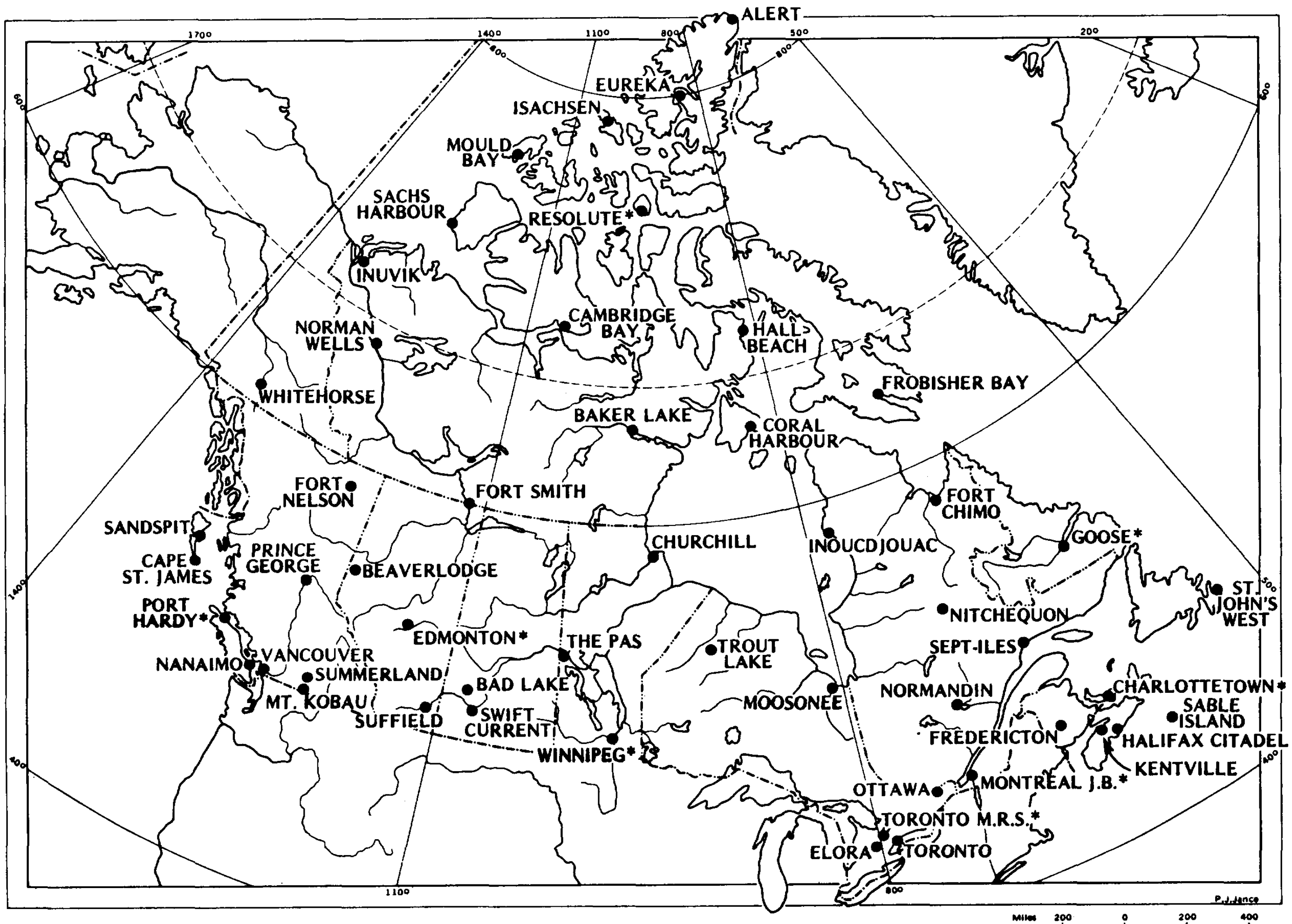
Sadler, G.W., 1980: Direct beam solar radiation band energy measurements at Edmonton, Alberta. Solwest 80, Proceedings of the Joint Solar Conference, Solar Energy of Canada, Inc. and the Pacific Northwest Solar Energy Association, Winnipeg, Manitoba, Canada, 327-331.

Suckling, P.W. and J.E. Hay, 1978: On the use of synoptic weather map typing to define solar radiation regimes. Monthly Weather Review, 106, 1521-1531.

Wardle, D., 1980: The National Atmospheric Radiation Centre solar radiation measurement programme. Solwest 80, Proceedings of the Joint Solar Conference, Solar Energy Society of Canada, Inc. and the Pacific Northwest Solar Energy Association, Winnipeg, Manitoba, Canada, 324-326.

Wilson, R., 1980: Radiation network assessment and design. In Proceedings First Canadian Solar Radiation Data Workshop, (J.E. Hay and T.K. Won, eds.), Atmospheric Environment Service, Downsview, Ontario.

Won, T.K., 1977: The simulation of hourly global solar radiation from hourly reported meteorological parameters - Canadian Prairie area. Solar Energy Update 1977, Solar Energy Society of Canada Inc., Edmonton, Paper E40, 23 pp.



* Stations also observing incoming diffuse solar radiation.

Figure 1 The global solar radiation monitoring network of the Canadian Atmospheric Environment Service.

Table 1

Errors (E) associated with the spatial interpolation of hourly and daily values of global solar radiation at Vancouver, Canada. Analysis based on distance - correlation functions generated using one year of observed data for the Vancouver mesoscale network.

HOURLY			DAILY		
Distance (km)	E ($KJm^{-2}hr^{-1}$)	% of mean	Distance (km)	E ($MJm^{-2}day^{-1}$)	% of mean
0	25.807	2.9	0	.332	2.7
5	78.838	8.9	5	.937	7.7
10	120.611	13.6	10	.878	7.2
15	160.189	18.1	15	1.197	9.9
20	168.699	19.0	20	1.427	11.7
25	205.710	23.2	25	1.465	12.1
30	222.412	25.1	30	1.574	13.0
35	223.749	25.3	35	1.573	12.9
40	226.311	25.5	40	1.591	13.1
45	233.490	26.4	45	1.643	13.5
50	234.783	26.5	50	1.786	14.7

SOLAR DATA PROCESSING AT THE NATIONAL CLIMATIC CENTER

Vincent Cinquemani and Jackson L. Pellett
NOAA/EDIS/National Climatic Center

1. BACKGROUND

1.1 Purpose. In January 1980, stations in the new NOAA network began sending their observed solar radiation data directly to the National Climatic Center (NCC). The Center for Environmental Assessment Services (CEAS) continued to send its processed 1979 data to the NCC for further processing leading to publication in Monthly Summary, Solar Radiation Data. Issues containing 1979 data will continue to be published until the backlog is eliminated. They will generally alternate with the more current data publications, although higher priority will be given to the latter.

1.2 Status. CEAS has provided the NCC solar radiation data for the period January 1977 through August 1979. These data are recorded on magnetic tape and as hour-versus-day listings on paper and microfilm.

The NCC has published solar radiation data observed by stations in the 39-station NOAA network from January 1977 through May 1979 (data pre-processed by CEAS) and from January 1980 through March 1980 (data entirely processed by the NCC). These data are available in the Monthly Summary or on 9-track, 1600 bpi SOLMET tapes. In addition, data from April 1980 to the present are available in various stages of processing.

Transmittal of solar radiation data to World Data Center-B in Leningrad, USSR, continued for data through the first quarters of calendar years 1979 and 1980. These data are provided in a format suited for publication in the WMO sponsored, Solar Radiation and Radiation Balance Data (The World Network).

2. DESCRIPTION

2.1 NCC Current Data Edit Processing System. The purpose of the Edit Processing System (see flow diagram in figure 1) is to parallel CEAS' pre-1980 data processing, beginning with 1-minute data cassettes and ending with the production of a CEAS format solar radiation data tape. The CEAS tape is the primary input to the NCC SOLMET/Solar Radiation Publication System.

The cassette editor reads NOVA copies of the solar radiation data cassettes. Each cassette record of 1-minute solar radiation is scanned for proper format, character content, and complete and proper accumulation of minutes and radiation values. The editor also performs a gross range check on the data. The outputs are a file of hourly radiation data and an edit/exception report. A microfiche dump of 1-minute cassette data is produced as a separate job.

After the hourly data tape, containing 1-, 2-, and 3-channel data, is produced, the remainder of the computer processing system is controlled by the SOLDRIVER program. It regulates the sequence of the following modules, each of which performs specific functions:

1. The FILGEN module generates a serially complete, direct access radiation data file with station identification, date-time groups, and dummy radiation values.

2. The LOAD module loads the hourly output radiation data from the cassette editor into the dummy radiation file produced by FILGEN.

3. The KEYENT module enters keyed hourly radiation data to the direct access radiation data file. The data may be keyed by NCC's Data Entry Section from printed paper tape, or entered via terminals by the NCC Solar Group, or entered by means of punch cards containing strip chart data extracted by the Air Resources Laboratory in Boulder, Colorado.

4. The TSHIFT module allows shifting of radiation time series forward or backward in time to compensate for faulty recorded time due to power interruptions, equipment malfunctions, etc.

5. The RESCAL module permits rescaling of, and updating to, the direct access radiation data file. Radiation and flag values may be changed, added, or deleted. This module alters only the edited data fields of the direct access file.

6. The MODCOM module compares edited global radiation values with the Machta clear sky global modeled values and, according to established criteria, flags those global values which exceed modeled values. It produces an hour-versus-day listing of percent differences between edited and modeled global radiation.

7. The NIGHT module flags or sets to zero - according to which option is selected - all nighttime radiation values.

8. The SHADOW module makes shadow band corrections (Latimer, 1972) to diffuse radiation data. It also compares shadow band corrected diffuse radiation with global radiation values and flags, according to established criteria, those diffuse values which exceed the global. A protect feature prevents double shadow band correction.

9. The LISTER module produces an hour-versus-day listing of edited global, direct, and diffuse solar radiation complete with flags.

10. The CEASTP module produces a CEAS format output tape from the direct access radiation data file.

Other modules (i.e., Research-Cooperator format tape data entry) can be brought into the system.

2.2 Problem Areas. A major concern is the continuing deterioration of the solar radiation data recording equipment (see table 1 for latest known status of system). Hopefully, recently acquired contract maintenance by the National Weather Service will soon repair out of service recorders, and site moves will alleviate data problems at the NOAA stations. The main impact of the many integrator-recorder malfunctions on the radiation data processing is loss of efficiency. Rapid computer processing of cassette data is replaced by the much slower keying of hourly values on printed paper tape and extraction of strip chart data. Moreover, minute data are not available. The bar graph in the figure 2 gives the source of data used in producing the monthly publication tables, and depicts the status of the NOAA network at the end of March 1980.

An interesting problem surfaced when the new 1980 data processing system tested the shadow band correction routine. Corrections were significantly greater than the results obtained with the pre-1980 program. This latter program contained an error causing upward of an 8.8 percent lower shadow band correction. This discrepancy (hidden prior to 1980) manifested itself in the solar radiation data time series plots (see figure 3, Brownsville, Station No. 12919, January 28-30, 1980). On totally cloudy days, the diffuse radiation values exceeded the corresponding global ones, at which time they should have been the same.

Several people have suggested that differences between global and diffuse radiation measurements on cloudy days are probably due to uncertainties in calibration. Normally, sensor calibration takes place during sunny days. During cloudy days, depending on the diffuse-global sensor pair, differences in either direction may occur. No one contacted could advise corrective action. Because of the uncertainty, the flagging criteria for diffuse exceeding global radiation were relaxed.

3. RESEARCH-COOPERATOR SOLAR DATA PROCESSING

Results of the NCC Research-Cooperator Format tape readability/element inventory program appear in the accompanying table 2 for each of 10 participating stations for about the past 12 months. (Two other cooperators - SERI and the University of Oregon - plan to submit data in the RC format.) NCC-station cooperation has been excellent toward minimizing deviation from the RC format.

4. MILESTONES (FY81)

Because complete future funding is not absolutely certain, a specific task schedule is not possible. The following outlines broad tasks that the NCC plans to accomplish in FY 1981:

Task I. Process and publish current global, diffuse, and direct solar radiation data from 39 NOAA stations.

Task II. Process and publish the remaining six months of 1979 backlog data.

Task III. Process and publish global, diffuse, and direct data from eight DOE research cooperators for 12 months.

Task IV. Continue support of the University of Alabama in Huntsville in its efforts to collect, summarize, and publish solar radiation data from cooperative sites.

The order of tasks is the priority in which NCC will undertake them in case of only partial funding.

5. ACKNOWLEDGMENTS

Special thanks are extended to Marc Plantico for his invaluable programming assistance, especially for his development of the hour-versus-day significant weather listing, solar time series plots, and monthly graphical and tabular reports. Gratitude is expressed to everyone in the NCC Solar Group for continued suggestions for improvement of the solar radiation data processing system.

Reference

Latimer, J.R., 1972: Radiation Measurement. International Field Year for the Great Lakes, Tech. Manual Series No. 2, Atmospheric Environment Service, Environment Canada, 53 pp.

Table 1 STATUS OF NOAA SOLAR RADIATION SYSTEM (As of 9/30/80)

A. ML 5130 Integrator Recorder Data Unusable(both cassette and PPT)

	STATION	STATUS*	AS OF DATE
1.	Blue Hill, MA	RFI	before 1980
2.	Boulder, CO	ONL	5/9/80
3.	Burlington, VT	OTS	4/4/80
4.	Desert Rock, NV	OTS	before 1980
5.	Ely, NV	OTS	2/25/80
6.	Fairbanks, AK	OTS	2/15/80
7.	Grand Junction, CO	OTS	7/5/80
8.	Guam, PI	OTS	8/1/80
9.	Lander, WY	OTS	9/23/80
10.	Madison, WI	OTS	2/5/80
11.	Nashville, TN	OTS	5/6/80
12.	Tallahassee, FL	OTS	7/12/80

B. Stations With Only Printed Paper Tape Data**

1. Albuquerque, NM
2. Brownsville, TX
3. Dodge City, KS
4. Lake Charles, LA
5. Los Angeles, CA

C. Stations Without Strip Chart Data

1. Fairbanks, AK
2. Las Vegas, NV
3. Miami, FL
4. Raleigh, NC
5. San Juan, PR

* Legend: RFI = radio frequency interference.
ONL = on loan to Fresno whose ML5130 is OTS; Boulder has backup data logger.
OTS = out of service.

** Cassette data unusable - no minute data retrievable.

Table 2 NCC RESEARCH-COOPERATOR DATA PROCESSING

SITE	POR	DATE RECEIVED	INVENTORIED/ ACCEPTED	DISPOSITION
Ga. Tech (Shen.)	12/78-4/79	11/20/79	Yes/Yes	archived
Ga. Tech (Atl.)	4/79-7/79	7/16/80	No/No	work in progress
NC (Bach)	1978	4/16/80	Yes/No	returned for remake
Oregon St. Univ.	12/79	3/03/80	Yes/Yes	archived
Oregon St. Univ.	1/80	4/80	Yes/Yes	archived
SUNY	2/79	6/01/79	No/No	returned for remake
Trinity Univ.	11/79	4/24/80	No/No	update requested
UAH Alabama	10/79-12/79	5/80	Yes/Yes	archived
UAH Alabama	1/80-6/80	9/80	No	
U. of Alaska	4/79	11/79	Yes/Yes	archived
U. of Alaska	5/79	-	Yes/Yes	archived
U. of Alaska	6/79	3/30/80	Yes/Yes	archived
U. of Alaska	7/79	5/05/80	Yes/Yes	archived
U. of Alaska	8/79	5/14/80	Yes/Yes	archived
U. of Alaska	9/79	5/23/80	Yes/Yes	archived
U. of Alaska	10/79	6/13/80	Yes/Yes	archived
U. of Alaska	11/79	6/13/80	Yes/Yes	archived
U. of Alaska	12/79	6/20/80	Yes/Yes	archived
U. of Alaska	1/80	6/27/80	Yes/Yes	archived
U. of Alaska	2/80-3/80	7/30/80	Yes/Yes	archived
U. of Alaska	4/80	9/10/80	Yes/Yes	archived
U. of California	1/79	7/12/79	No/No	update requested
U. of Hawaii	10/78-3/79	4/80	Yes/Yes	archived
U. of Hawaii	4/79-12/79	7/30/80	Yes/Yes	archived
U. of Michigan	9/79	5/80	Yes/Yes	archived

Figure 1. - NCC CURRENT DATA EDIT PROCESSING SYSTEM

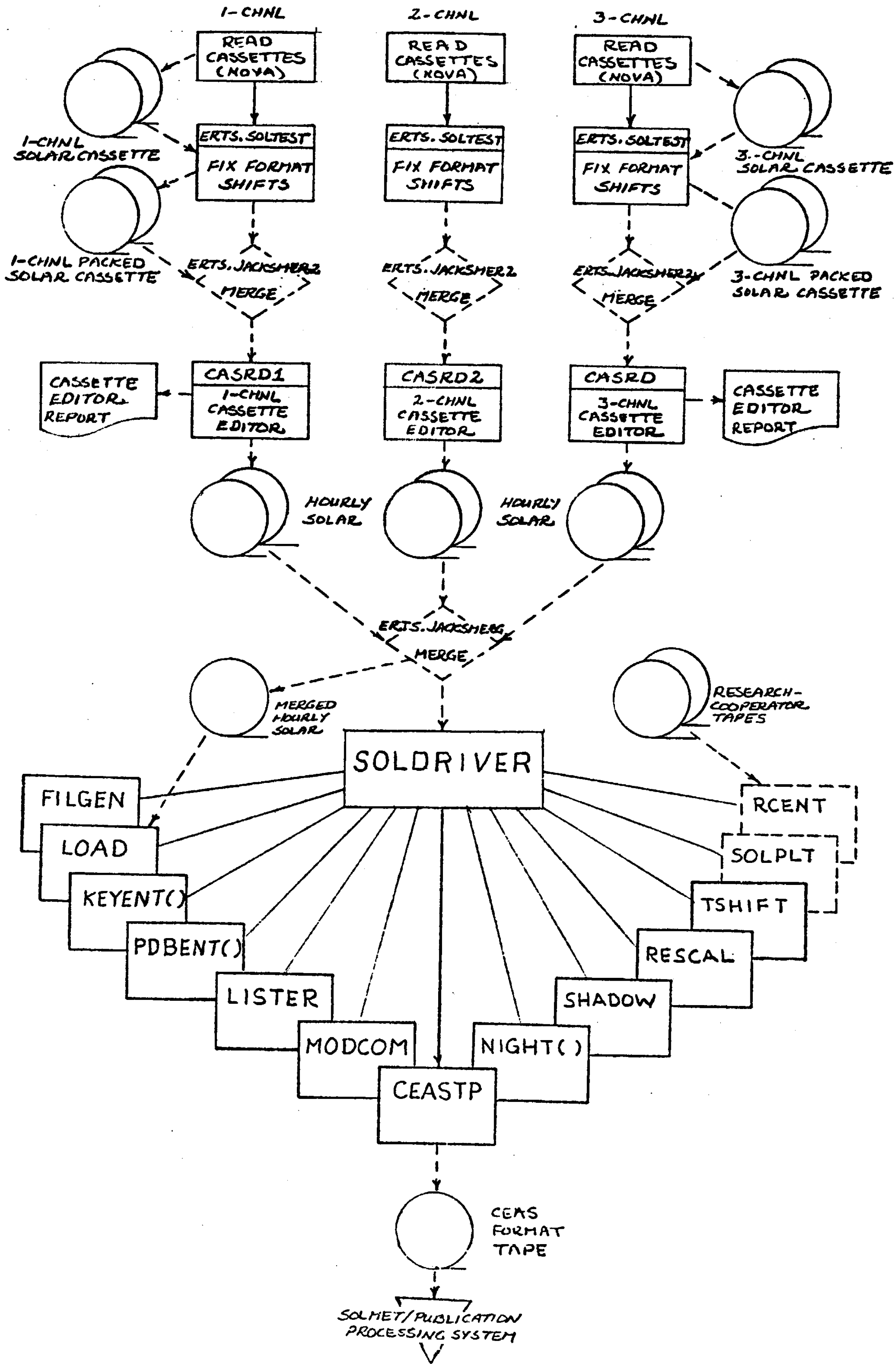


Figure 2. - NOAA SOLAR RADIATION DATA
MARCH 1980

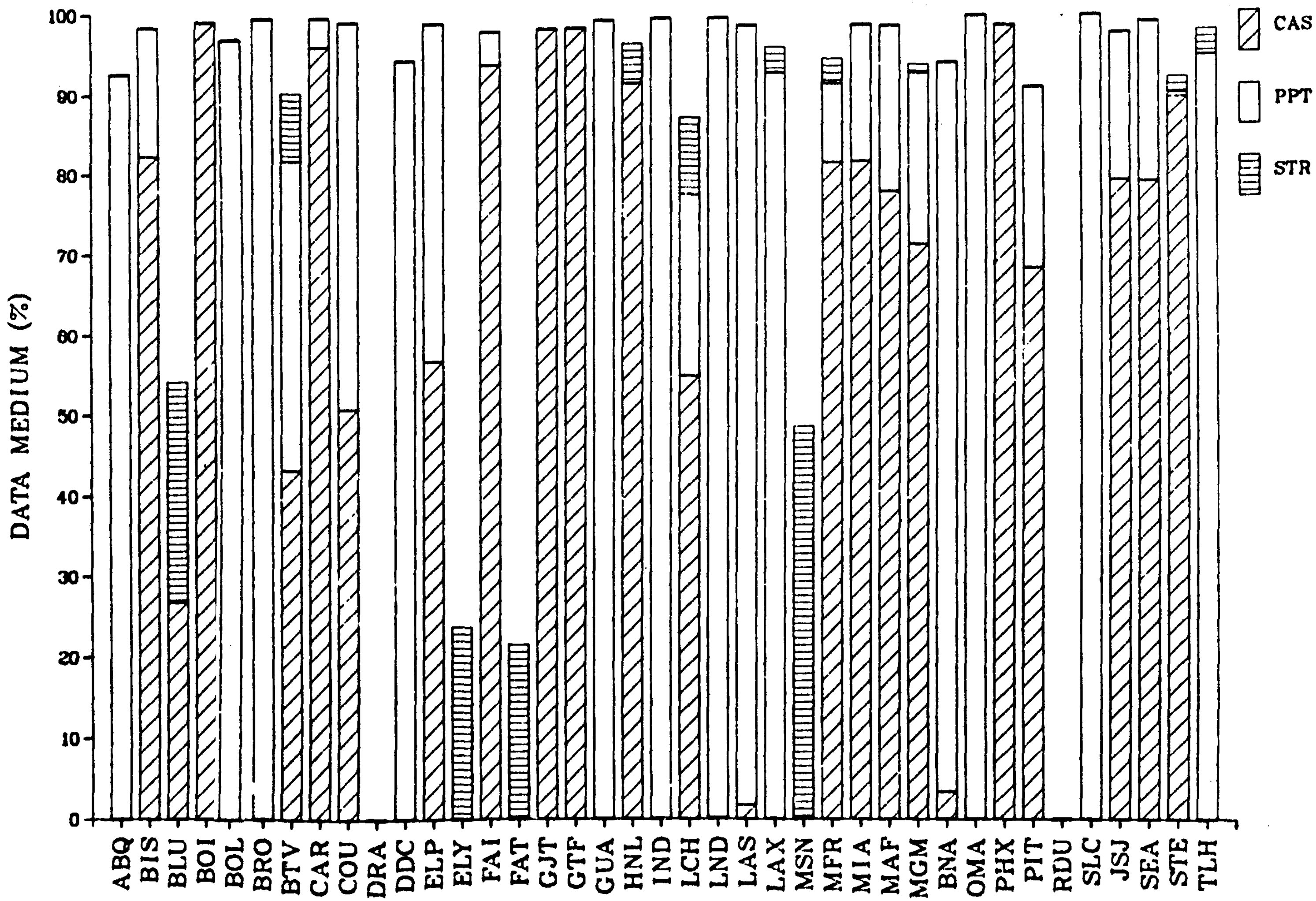
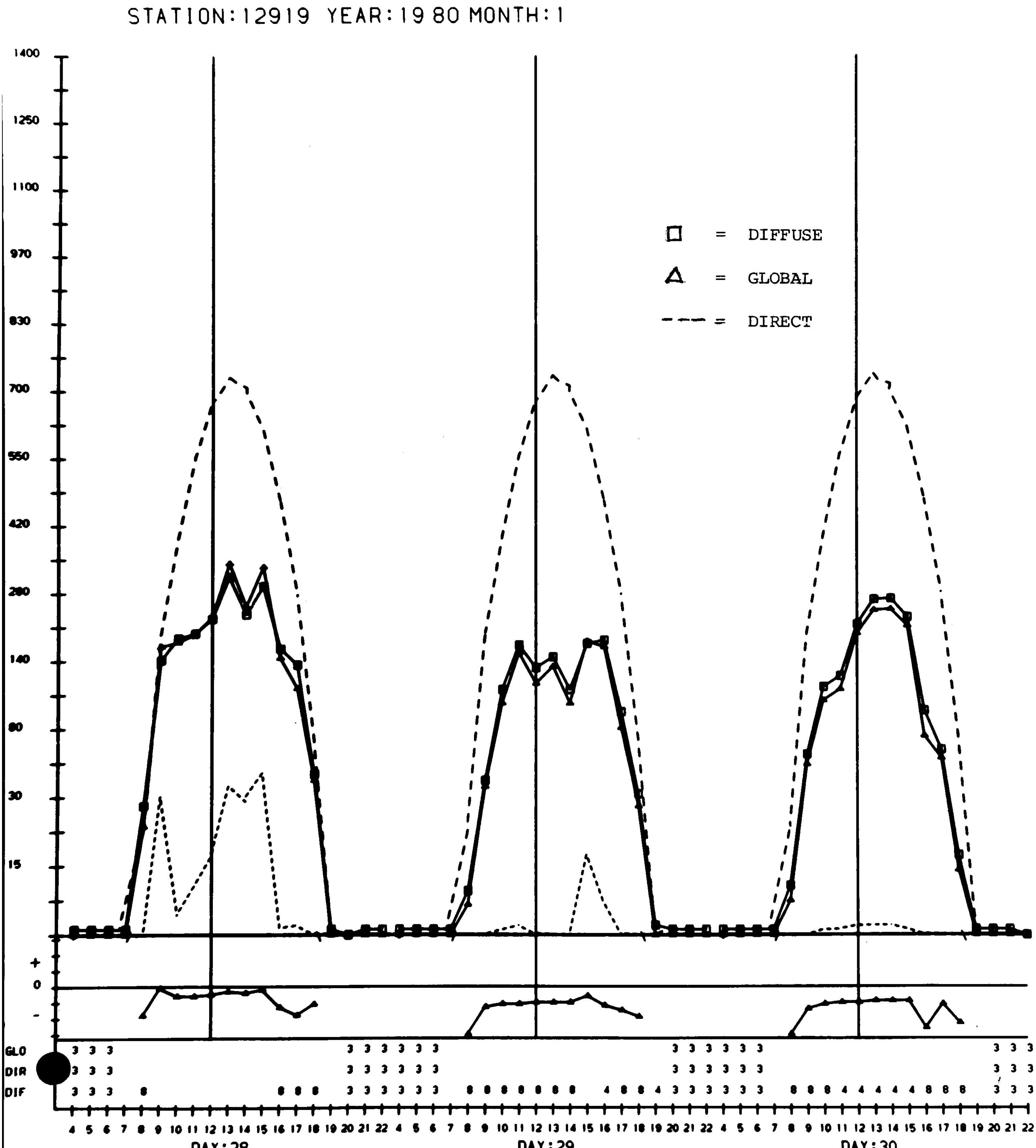


Figure 3. - SOLAR RADIATION DATA PLOT FOR BROWNSVILLE, TEXAS



NCC SOLAR DATA PROJECT AND SERI WORLD INSOLATION DATA

Eugene A. Carter and David L. Christensen
The University of Alabama in Huntsville/The K.E. Johnson Environmental and Energy Center
Huntsville, Alabama 35899

INTRODUCTION:

The two projects in this report describe products now available resulting from policies established several years ago. These should provide useful information for research, engineers and designers. Suggestions you have to make them more useful would be welcome.

PART I – NCC SOLAR DATA PROJECT

BACKGROUND:

At the National Science Foundation-sponsored Solar Energy Data Workshop in November 1973 it was recommended that non-NOAA solar radiation data be collected and evaluated. About 1975 when the new 33-station (now 39) NOAA Solar Radiation Network was designed, it was intended that the network be supplemented with cooperative non-NOAA data. Some of the people who formulated this policy were Fred Koomanoff, Mike Riches, Lester Machta, Ed Flowers and Frank Quinlan.

In 1975 when no one else was contacting the non-NOAA stations, UAH independently sought to catalogue the non-NOAA stations. An April 1979 report (DoE/ET/20175-1) is the third and most recent catalogue of NOAA and non-NOAA stations, prepared jointly with UAH and NCC information.

The NOAA Network became operational in 1977. NCC is currently processing that data into monthly reports of which all of you are aware. NCC contracted with UAH to process the non-NOAA data to supplement the NOAA data to implement the policy envisioned 5 to 6 years ago. It is my pleasure to report today that the work of many people has finally produced the planned results.

CURRENT WORK DESCRIPTION:

The UAH portion of this project consists of three tasks (Figure 1). Task I is to maintain a list of the non-NOAA solar radiation measuring stations. You who have been at previous meetings know that we started this list about four years ago. The present task is to prepare a supplement to the 1979 lists by August 1980. The supplement is currently being finalized with new stations and indicating stations which are no longer in operation. Next spring we are planning to prepare a revised report of the entire document or those stations which are active at that time.

Task I – Maintain a List of Non-NOAA Solar Radiation Measuring Stations

- **Prepare a Supplement to the Current List** — **August 1980**
- **Prepare a Revised Report** — **April 1981**

Task II – Maintain Record of Operation for Stations Providing Data

- **Update Station Forms from Stations Providing Data**
- **Publish These Forms when Requested by NCC**
- **Prepare Test File for Computerizing the Station Lists**

Task III – Collect Data From Non-NOAA Stations

- **Mean Daily Solar Radiation by Months**
- **Goal of 50 Supplemental Reporting Stations for 1980**
- **Evaluate the Non-NOAA Data**
- **Prepare Monthly Tabulated Data**
- **Prepare Monthly Maps of NOAA and Non-NOAA Data**

Figure 1 NCC Solar Data Project Tasks

Task II is to maintain an operating record for those stations which provide data for evaluation. We are presently updating station forms from the stations who are sending monthly data to us routinely. We plan to publish the station forms when requested by NCC. We also will test putting the data from these stations in a computerized format to maintain the station lists.

Task III is the real payoff of the project but requires the first two tasks to do Task III. We are collecting mean daily solar radiation for each month starting with January 1980. Our goal is to add fifty supplemental recording stations by the end of this year. We will evaluate the non-NOAA data, prepare monthly tabulated data and finally, prepare maps by combining the NOAA and the non-NOAA data. We have today for handout the first set of maps and the report for January 1980. We hope that you will make any comments or suggestions which will make this more useful. In these reports there is a comparison of the solar radiation data and a percent of possible sunshine map produced by NOAA. We have not examined these carefully but hope that when the atlas monthly maps of solar radiation are available we may be able to make some comparison between each month's map and the atlas map for that month. Since January 1980 was provided at the meeting, the February 1980 data is provided as an enclosure to this report.

FUTURE WORK:

It is planned to produce monthly maps, we hope with only 2-3 month's lag time. We will also maintain coordination with non-NOAA stations, collect and evaluate the data.

PART II – SERI WORLD INSOLATION DATA

BACKGROUND:

In January 1979, UAH began contacting foreign countries through the International Referral System of the United Nations to collect worldwide solar radiation data. At a joint DoE/DoC-sponsored meeting with solar industries to promote export of solar technology and equipment in August 1979, it was apparent that better information of the worldwide solar resource is necessary.

The reports and data collected by UAH, the WMO reports of data, the Budyko worldwide maps, the University of Wisconsin maps produced by Löf *et al* and new data are on hand at UAH. I have spoken with Jack Duffie, co-author of the University of Wisconsin report, and he agreed that a new report is needed.

CURRENT WORK DESCRIPTION:

This task is primarily work being performed for SERI but includes a small task for Marshall Space Flight Center to investigate activities in collecting or processing worldwide solar radiation data. The UAH-SERI contractual activities (Figure 2) require locating world insolation measuring stations and data. The first portion is to locate the measuring stations. We have designed a questionnaire in conjunction with SERI for solar radiation stations. Some of you have received copies of that to complete for your stations. These are primarily for worldwide locations but do fit the requirements for U. S. stations. About fifty of these questionnaires have been mailed and last week I handed out another fifty to representatives of developing countries. Many of these questionnaires are being completed from data which are in our files. SERI has established a list of priority countries. An announcement was sent to the "WMO Bulletin" that we are conducting such a survey and asking stations who do not routinely report through WMO to inform us of their operation and we will coordinate further with them. That announcement should be in the "WMO Bulletin" within the next month or two. We are currently preparing a publication format as to the type of final report which will be prepared. The final report of stations is due by March of 1981.

The second portion of the task was to collect solar radiation data. Maps of world solar radiation data are in the Budyko report for 1963 and the Löf *et al* University of Wisconsin report (referred to as Report 21), (July 1966). In this search for radiation data we have discovered several individual country maps. The

Locate World Insolation Measuring Stations and Data

- **Locate Solar Radiation Measuring Stations**
  - **Design Questionnaire for Solar Radiation Stations**
  - **Mail Questionnaires for Solar Radiation Stations**
  - **Prepare Results of the Questionnaires for Publication and/or Computerized Data Bank, by Country**
  - **Announce the Survey in the WMO Bulletin**
  - **Coordinate Publication Format**
  - **Final Report – March 1981**
    Publish Station List by Countries
- **Collect Solar Radiation Data**
  - **World Maps of Solar Radiation**
    Budyko (Russian, Monthly & Annual)
    Löf (University of Wisconsin, Monthly & Annual)
- **Individual Country Maps**
- **WMO Data Reports**

  Hourly Data in Monthly Reports
  Monthly Data in 5-year Reports (1964-68, 1969-73)
- **Other Sources and Technologies**

Figure 2 UAH/SERI Contractual Activities

hourly WMO data is in monthly report documents and the monthly data are in 5-year reports. The first report was 1964-68 and the second report 1969-73. The subsequent 5-year report is not yet available. Other sources are reports in solar energy magazines, meteorological magazines, Library of Congress, NOAA libraries, etc. The data collection is growing quite rapidly.

Figure 3 is a diagram of procedure that we follow to determine the solar radiation most any place in the world. It shows where the data come from and how it may be collated to get preliminary results of the solar resource. The surrogate climate technique has been used by Löf *et al* and there are equations with certain empirical coefficients to be used with certain climates. This is not a new technique and has been used in lieu of other data or to substantiate other data. Figure 4 lists the various techniques to get daily average global solar radiation by months and annual at all locations throughout the world. We determine the value from the world maps of Budyko, compare this with maps by Löf and any data from those countries. In addition, at any location we find a surrogate climate that does have solar radiation measurements. The better the data, the more confidence in the results. The climate classifications have developed over the past sixty years and are accepted by climatologists. Also from worldwide cloud data the solar radiation is calculated using techniques of Ångström, as others have done. There is better cloud data now than was used earlier. There are WMO reports at over 600 locations with up to ten years of data. A literature survey has revealed reports from many other countries. Direct contact is continuing through the International Referral System and more stations are located each day.

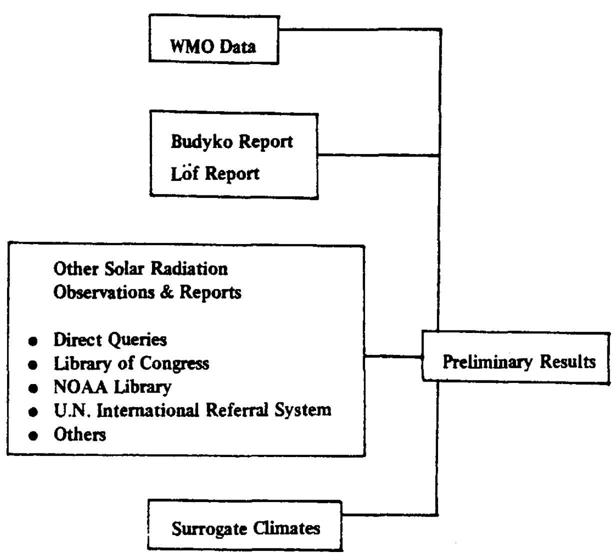


Figure 3 Procedure to Determine Solar Radiation

The last three techniques in Figure 4 show that after you have values for the global horizontal radiation, there are techniques for computing direct radiation, diffuse radiation and the radiation on inclined surfaces or other special requirements. The final technique is the use of a worldwide cloud data base. Marshall Space Flight Center has had such a data base for some years. They are presently improving their data base with recent U. S. Air Force cloud data which combines surface reports, aircraft reports and satellite data. There are many other projects and I show this as a follow-on. Others who are doing work in this field indicate they need the best surface data available in developing the best techniques for using satellite data.

(Daily Average Global Solar Radiation by Months and Annual)

All Locations

- **Determine the value from world maps by Budyko (compare with maps by Löf and others)**
- **Determine one or more surrogate climate regions with quality data (climate classifications of Köeppen [1918], Trewartha and Thornthwaite [1948])**
- **From worldwide cloud data calculate solar radiation (techniques of Ångström, Prescott, Löf et al)**

Most Locations

- **WMO reports have up to 10 years of data for over 600 locations**
- **Literature survey has revealed reports for many countries**
- **Direct contact through the International Referral System**

Additional Techniques

- **Computations for direct radiation, diffuse radiation, radiation on inclined surfaces and other special requirements**
- **Contacts are leading to additional data and reports**
- **Use of MSFC and USAF worldwide "Cloud Data Base" from satellite data**

Figure 4 Available Techniques for Determining the Solar Resource Worldwide

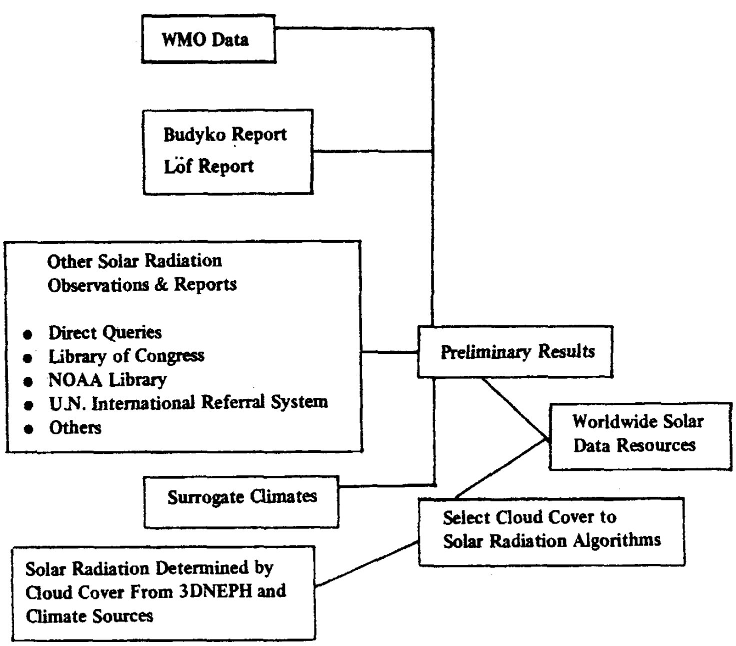


Figure 5 Procedure to Determine Solar Radiation With Cloud Cover and Satellite Techniques Added

FUTURE WORK:

Figure 5 shows the preliminary results with the cloud cover and satellite techniques added. The preliminary results of the solar resource at the surface is needed to be sure that calculations from cloud cover and satellite data are in the ball park, and are referred to as "ground truth" for their calculations. After the preliminary results, the addition of techniques currently being developed will provide the worldwide solar data resource.

Figure 6 lists some organizations and their prime interest. Most of these have contacted us to exchange information.

The samples of solar resource charts have not been evaluated for accuracy nor compared with data from adjacent countries, but that needs to be done. The Mexican data (Figure 7) will be compared with U.S. data. Extending this with data from Canada will provide complete North American charts for each month.

The three maps of Japanese data are examples of data received from Japan. Figure 8 is an annual solar radiation chart for the islands. Figure 9 shows the July solar radiation and Figure 10 is unique in that it shows the percent deviation of the monthly global radiation from the 30-year mean. The deviation charts are available for four months out of the year plus an annual and yield the maximum and minimum solar radiation expected. The final chart, Figure 11, is a listing of the solar radiation from Italy. This is a sample of stations with the global radiation values for each month, the calculations for various inclined angles and the average daily sunshine for each month in hours.

I believe this project is proceeding fine and that we can currently provide monthly solar radiation data for any point on the earth within 15-20% confidence. Of course, doing the entire world is going to take some time, but it is needed to improve the confidence of the solar radiation monthly values throughout the world.

NASA	Space Technology Applications
MSFC	Solar Terrestrial Projects
DOE	World Marketing
SERI	Data Bank
DOD	Conservation, World Deployment
DOC	International Trade
NOAA	Research Data Bank
DOS	Public Relations, Balance of Trade
AID	Developing Countries
U. S. Industry	International Markets
United Nations	International Relations, Use of International Referral System, World Data Bank
WMO	Improve International Data Bases
World Countries	Develop Their Solar Resources

Figure 6 List of Organizations and Their Prime Interest in the Worldwide Solar Data Base

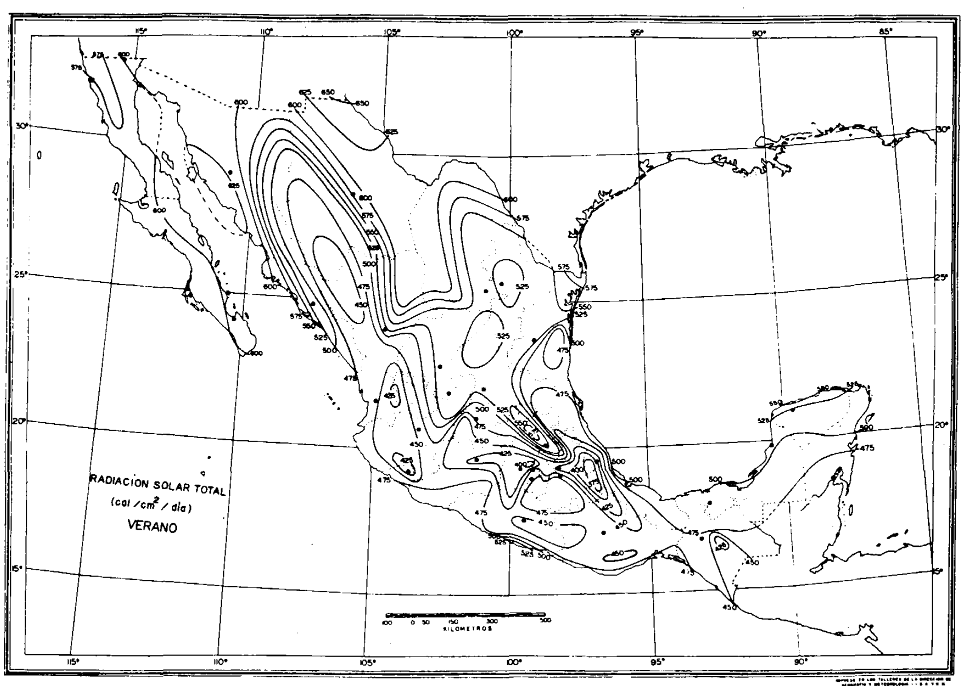


Figure 7 Total Solar Radiation for Mexico – Summer

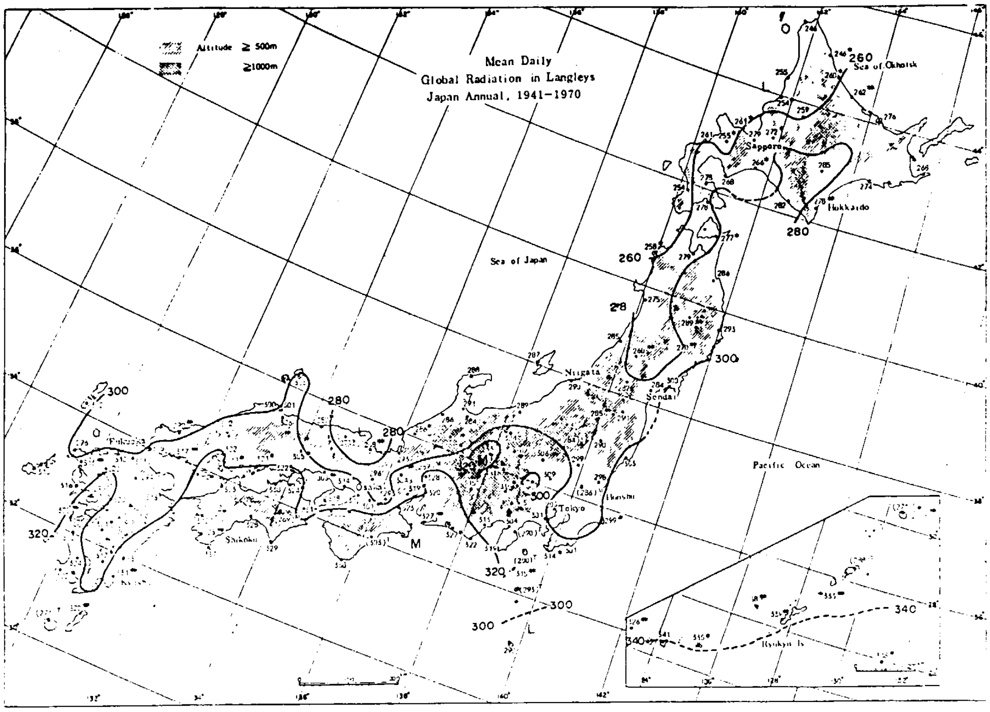


Figure 8 Japan – Annual Solar Radiation (1941-1970)

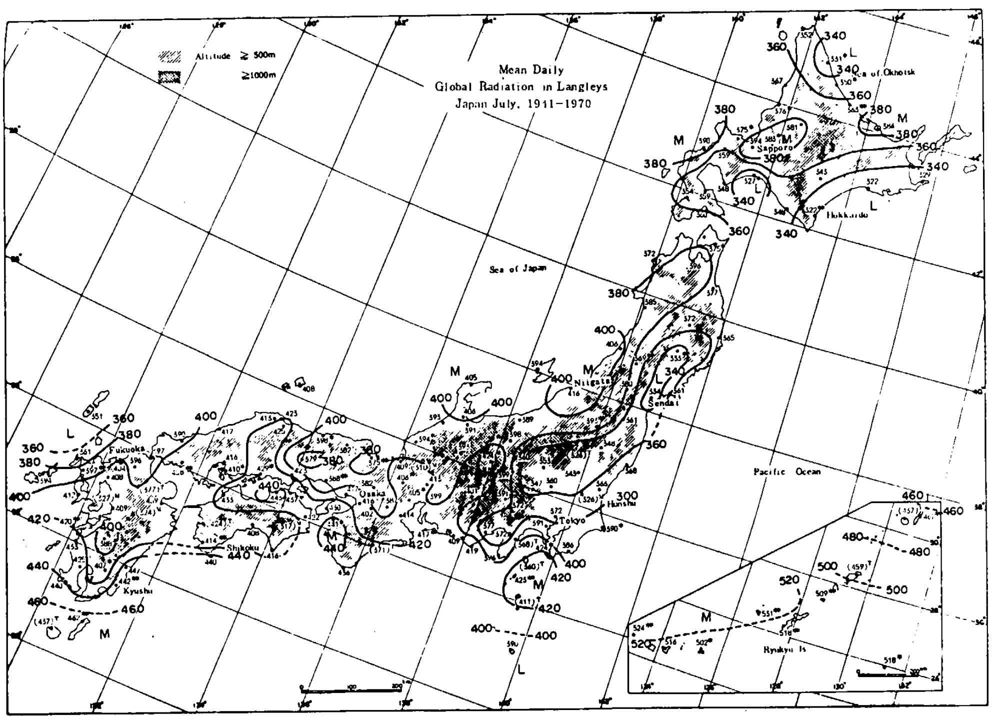


Figure 9 Japan – July Mean Daily Global Radiation (1941-1970)

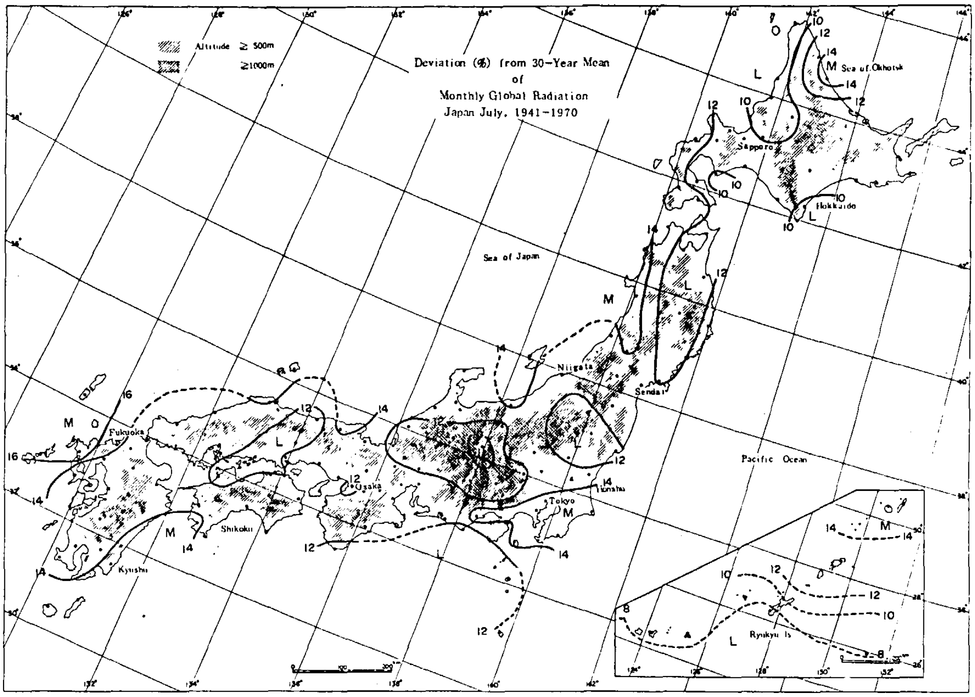


Figure 10 Japan – Deviation (%) from 30-year Mean of Monthly Global Radiation July (1941-1970)

Figure 11 Monthly Solar Radiation Totals at Various Angles for Ten Italian Sites

LATITUDINE LOCALITA	α / s - Ore di soleggiamento effettivo	INSOLAZIONE GIORNALIERA MEDIA MENSILE SU SUPERFICI PIANE ORIENTATE A SUD DIVERSAMENTE INCLINATE (Kcal/mq²g)											
		Gen.	Feb.	Mar.	Apr.	Mag.	Giu.	Lug.	Ago.	Sett.	Ott.	Nov.	Dic.
PESCARA 42° 26′	α = 0°	1120	1750	2510	3570	4330	4550	4750	4160	3160	2180	1290	960
	30°	1669	2320	2909	3684	4099	4176	4488	4311	3726	2925	1969	1540
	45°	1822	2436	2890	3498	3766	3795	4118	4096	3733	3164	2159	1676
	60°	1880	2427	2750	3130	3202	3164	3486	3660	3550	3174	2236	1751
	90°	1645	2025	2076	1966	1561	1354	1642	2267	2678	2669	1965	1548
	s = n°	3.2	4.3	4.8	6.6	8.2	8.7	10.2	9.5	7.4	5.7	3.6	2.7
ROMA 41° 48′	α = 0°	1430	1980	2860	3870	4770	5170	5320	4650	3550	2520	1490	1140
	30°	2257	2665	3351	3995	4502	4720	5011	4828	4221	3516	2330	1856
	45°	2498	2810	3348	3786	4118	4262	4575	4579	4234	3743	2572	2076
	60°	2600	2805	3177	3376	3471	3506	3834	4076	4026	3764	2674	2180
	90°	2268	2332	2385	2087	1614	1371	1704	2471	3018	3155	2330	1906
	s n°	4.3	4.7	6.6	7.0	8.6	9.4	10.8	9.9	8.1	6.4	4.1	3.3
OLBIA 40° 56′	α 0°	1320	1920	2750	3700	4610	4950	5230	4470	3380	2280	1490	1120
	30°	1976	2521	3166	3765	4340	4522	4922	4578	3951	3090	2256	1744
	45°	2159	2636	3144	3546	3957	4073	4480	4315	3939	3263	2471	1927
	60°	2225	2615	2967	3141	3325	3347	3745	3815	3727	3263	2551	2007
	90°	1896	2147	2206	1913	1563	1355	1682	2277	2769	2704	2178	1710
	s n°	4.4	5.2	6.2	7.7	9.8	9.1	12.1	10.6	8.5	6.3	4.3	3.6
NAPOLI 40° 51′	α 0°	1180	1660	2260	3150	3970	4410	4470	3920	3020	2190	1310	972
	30°	1700	2108	2536	3196	3736	4030	4198	4010	3481	2914	1908	1434
	45°	1837	2184	2501	3014	3412	3636	3826	3785	3458	3060	2070	1565
	60°	1880	2152	2350	2690	2890	3007	3219	3362	3265	3046	2123	1615
	90°	1591	1756	1753	1638	1443	1294	1536	2072	2430	2509	1800	1364
	s = n°	3.8	4.5	5.2	6.6	8.2	9.3	10.4	9.9	8.1	6.4	4.1	3.0
ALGHERO 40° 38′	α 0°	1520	2060	3090	4040	5100	5390	5730	4970	3860	2630	1530	1170
	30°	2360	2742	3616	4152	4792	4897	5370	5143	4587	3630	2332	1845
	45°	2600	2878	3607	3922	4356	4393	4871	4861	4594	3849	2559	2046
	60°	2696	2862	3415	3481	3635	3577	4037	4303	4359	3857	2645	2135
	90°	2303	2353	2541	2122	1623	1338	1704	2559	3237	3194	2253	1814
	s = n°	4.5	4.9	6.2	7.4	9.4	10.1	11.6	10.5	8.6	6.5	4.3	3.4
BRINDISI 40° 39′	α 0°	1240	1830	2500	3540	4320	4650	4700	4240	3240	2270	1400	1040
	30°	1807	2372	2843	3613	4062	4241	4410	4352	3765	3037	2076	1571
	45°	1960	2472	2814	3409	3703	3819	4014	4108	3748	3194	2262	1724
	60°	2010	2446	2651	3031	3119	3144	3366	3645	3543	3182	2327	1786
	90°	1700	2001	1974	1883	1502	1305	1567	2218	2633	2621	1974	1510
	s = n°	4.2	5.1	5.5	7.1	9.1	10.0	11.2	10.4	8.3	6.6	4.4	3.5
CAPO PALINURO 40° 1′	α 0°	1560	2210	2970	3870	4700	5700	5270	4780	3770	2750	1680	1290
	30°	2407	2962	3443	3968	4411	5164	4934	4925	4434	3801	2600	2070
	45°	2647	3115	3424	3746	4009	4616	4474	4647	4425	4036	2862	2304
	60°	2741	3101	3234	3326	3354	3729	3718	4109	4184	4038	2965	2411
	90°	2324	2543	2400	2044	1550	1327	1633	2450	3088	3333	2514	2035
	s n°	4.2	5.0	5.5	6.9	8.7	9.9	10.9	10.6	8.5	6.8	4.7	3.6
CAGLIARI 39° 15′	α 0°	1560	2120	3020	3840	4670	4840	5180	4580	3560	2530	1610	1210
	30°	2343	2768	3465	3880	4369	4389	4843	4653	4125	3412	2389	1854
	45°	2558	2887	3432	3636	3955	3922	4377	4362	4096	3594	2400	2036
	60°	2633	2855	3227	3200	3293	3188	3626	3830	3857	3583	2670	2107
	90°	2185	2309	2369	1917	1517	1269	1607	2246	2829	2923	2213	1731
	s n°	4.5	4.7	6.2	7.2	9.0	9.5	10.7	10.2	8.3	6.3	4.3	3.6
CROTONE 39° 4′	α 0°	1460	2180	2800	3790	4640	5080	5250	4710	3560	2480	1580	1290
	30°	2150	2867	3190	3852	4338	4601	4895	4820	4131	3302	2339	2005
	45°	2336	2996	3155	3621	3927	4105	4419	4532	4105	3464	2545	2214
	60°	2396	2967	2966	3200	3270	3324	3651	3992	3868	3442	2614	2301
	90°	1985	2405	2186	1950	1507	1278	1588	2364	2842	2798	2165	1893
	s n°	4.2	5.3	5.3	6.6	8.2	9.2	10.2	9.4	7.4	6.2	4.5	3.8
MESSINA 38° 12′	α 0°	1320	1980	2610	3580	4280	4860	4650	4150	3160	2250	1460	1140
	30°	1840	2515	2922	3611	3990	4392	4325	4178	3579	2916	2053	1642
	45°	1970	2600	2873	3383	3605	3907	3899	3903	3528	3035	2202	1777
	60°	1998	2555	2688	2983	3001	3155	3228	3422	3305	2999	2237	1821
	90°	1617	2043	1970	1822	1425	1239	1479	2027	2411	2411	1813	1458
	s n°	3.7	4.9	5.5	7.0	8.3	9.5	10.6	10.0	7.9	6.1	4.3	3.3

The University Of Alabama In Huntsville

Kenneth E. Johnson Environmental and Energy Center

Huntsville, Alabama 35899
Phone: (205) 895-6331

FEBRUARY 1980

NATIONAL CLIMATIC CENTER SOLAR DATA PROJECT

The solar radiation measurements in the United States for February 1980 have been collected and presented here in tabular and map form. Isolines have been drawn on the map for each megajoule per square meter. Of course, there will be variations in mountainous regions and due to local effects, but for an optimum exposure location one would expect solar radiation near the values shown on the chart.

The number in parentheses beside each radiation value in the tables is the number of days with missing data at that location during the month. A map of the percent of possible sunshine for February 1980 is also reproduced here.

NOAA and non-NOAA data were used. The NOAA network was established in January 1977 to provide a basic network of data to be supplemented with non-NOAA data to determine the solar resource. This work was performed for the National Climatic Center which provided us with the NOAA data.

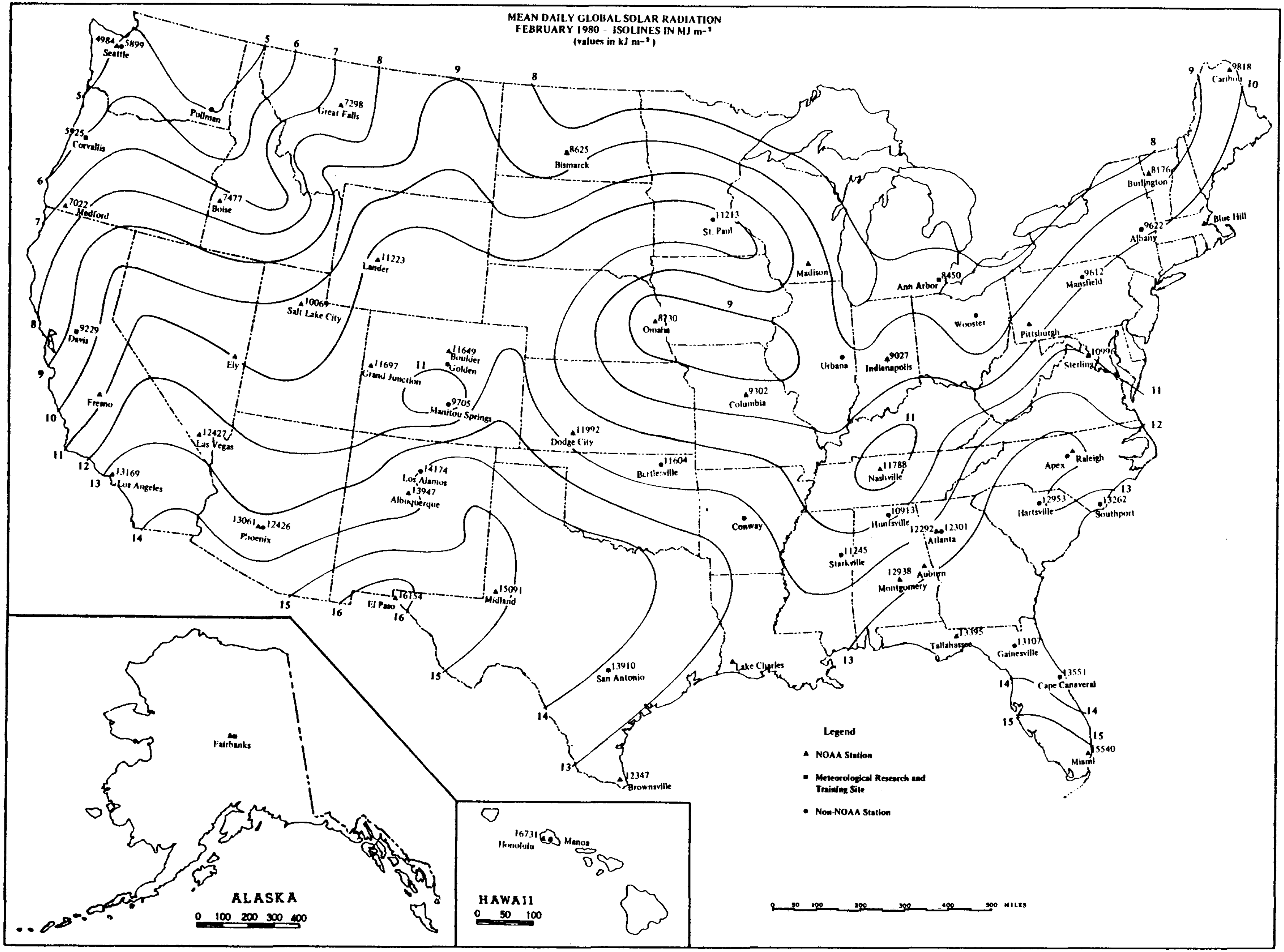
Additional non-NOAA station locations are being sought to improve the quality of the charts. If you know of additional locations not shown here, please let us know and we will try to evaluate their data so that it may be included in subsequent monthly reports. (Contact E. A. Carter at the above address.)

We gratefully acknowledge the assistance of those persons who are providing data and hope this report is helpful in their work and rewarding to know that others are using their data.

Reference:

Monthly Solar Radiation Data. February 1980, Vol. 4, No. 2, National Climatic Center, Asheville, NC 28801.

An Affirmative Action/Equal Opportunity Institution


MEAN DAILY GLOBAL SOLAR RADIATION
FEBRUARY 1980 - ISOLINES IN MJ m⁻²
(values in kJ m⁻²)
4984 Seattle 5899
Pullman
7298 Great Falls
5925 Corvallis
7477 Boise
7022 Medford
8625 Bismarck
11213 St. Paul
Madison
Ann Arbor 8450
Wooster
Pittsburgh
9612 Mansfield
9622 Albany
8176 Burlington
Blue Hill
9818 Caribou
11223 Lander
10069 Salt Lake City
9229 Davis
Ely
Fresno
11697 Grand Junction
11649 Boulder
Golden
9705 Manitou Springs
8730 Omaha
Urbana
9027 Indianapolis
9302 Columbia
10996 Sterling
12427 Las Vegas
13169 Los Angeles
11992 Dodge City
11604 Bartlesville
11788 Nashville
Apex
Raleigh
14174 Los Alamos
13947 Albuquerque
13061 12426 Phoenix
Conway
10913 Huntsville
12292 12301 Atlanta
12953 Hartsville
13262 Southport
11245 Starkville
12938 Montgomery
Auburn
16154 El Paso
15091 Midland
13395 Tallahassee
13107 Gainesville
13551 Cape Canaveral
15540 Miami
13910 San Antonio
Lake Charles
12347 Brownsville
Legend
▲ NOAA Station
■ Meteorological Research and Training Site
● Non-NOAA Station
Fairbanks
ALASKA
0 100 200 300 400
16731 Honolulu
Manoa
HAWAII
0 50 100
0 50 100 200 300 400 500 MILES

National Weather Service Stations

Station-Name	Stn. Number	Lat. (Deg.Min)	Long. (Deg.Min)	Elev. (M)	Solar-Radiation-Data-Types Gbl	Dir	Dif	Net	Tlt	Net	Tlt	Uv	Ir	Otr	Mean Daily Global Solar Radiation (kj/m^2) February 1980
Fairbanks, AK	26411	64.49N	147.52W	143											m
Montgomery, AL	13895	32.18N	86.24W	68	x	x									12938 (3)
Phoenix, AZ	23183	33.26N	112.01W	339	x	x									13061 (4)
Fresno, CA	93193	36.46N	119.43W	102	x	x									m
Los Angeles, CA	23174	33.56N	118.24W	37											13169 (2)
Boulder, CO	94018	40.01N	105.15W	1634	x	x	x								11649
Grand Junction, CO	23066	39.07N	108.32W	1473	x	x									11697
Miami, FL	12839	25.49N	80.17W	8	x	x									15540 (5)
Tallahassee, FL	93805	30.23N	84.22W	18	x	x	x								13395
Honolulu, HI	22521	21.20N	157.56W	5											16731
Boise, ID	24131	43.34N	116.13W	873	x	x									7477 (2)
Indianapolis, IN	93819	39.44N	86.16W	244	x										9027
Dodge City, KS	13985	37.46N	99.58W	795	x	x									11992
Lake Charles, LA	03937	30.07N	93.13W	19	x										m
Blue Hill, MA	14753	42.13N	71.07W	200											m
Caribou, ME	14607	46.52N	68.01W	195											9818 (1)
Columbia, MO	03945	38.49N	92.13W	277	x	x									9302 (4)
Great Falls, MT	24143	47.29N	111.22W	1118	x	x									7298 (2)
Raleigh, NC	13722	35.52N	78.47W	137											m
Bismarck, ND	24011	46.46N	100.46W	511	x	x	x								8625 (1)
Omaha, NE	94918	41.22N	96.01W	404	x	x									8730
Albuquerque, NM	23050	35.02N	106.37W	1623	x	x	x								13947 (3)
Ely, NV	23154	39.17N	114.51W	1912	x	x									m
Las Vegas, NV	23169	36.05N	115.10W	670	x	x									12427 (3)
Medford, OR	24225	42.22N	122.52W	412	x	x									7022 (1)
Pittsburgh, PA	94823	40.30N	80.13W	371		x									m
Guam, PI	41415	13.33N	144.50E	112	x	x									m
San Juan, PR	11641	18.26N	66.00W	19	x	x									m
Nashville, TN	13897	36.07N	86.41W	186	x	x									11788 (1)
Brownsville, TX	12919	25.54N	97.26W	12	x	x	x								12347 (4)
El Paso, TX	23044	31.48N	106.24W	1206	x	x									16154 (1)
Midland, TX	23023	31.57N	102.11W	872	x										15091
Salt Lake City, UT	24127	40.46N	111.58W	1288	x	x									10069 (1)
Sterling, VA	93734	38.59N	77.28W	87	x	x									10996 (2)
Burlington, VT	14742	44.28N	73.09W	112		x									8176 (2)
Seattle-Tacoma, WA	24233	47.27N	122.18W	143	x	x	x								4984 (1)
Madison, WI	14837	43.08N	89.20W	271	x	x									m
Lander, WY	24021	42.49N	108.44W	1699	x	x									11223 (3)

The data from the NOAA Solar Radiation Network were obtained from the publication, Monthly Summary Solar Radiation, NCC, EDIS, NOAA, and the quality control of the data is explained in this publication.

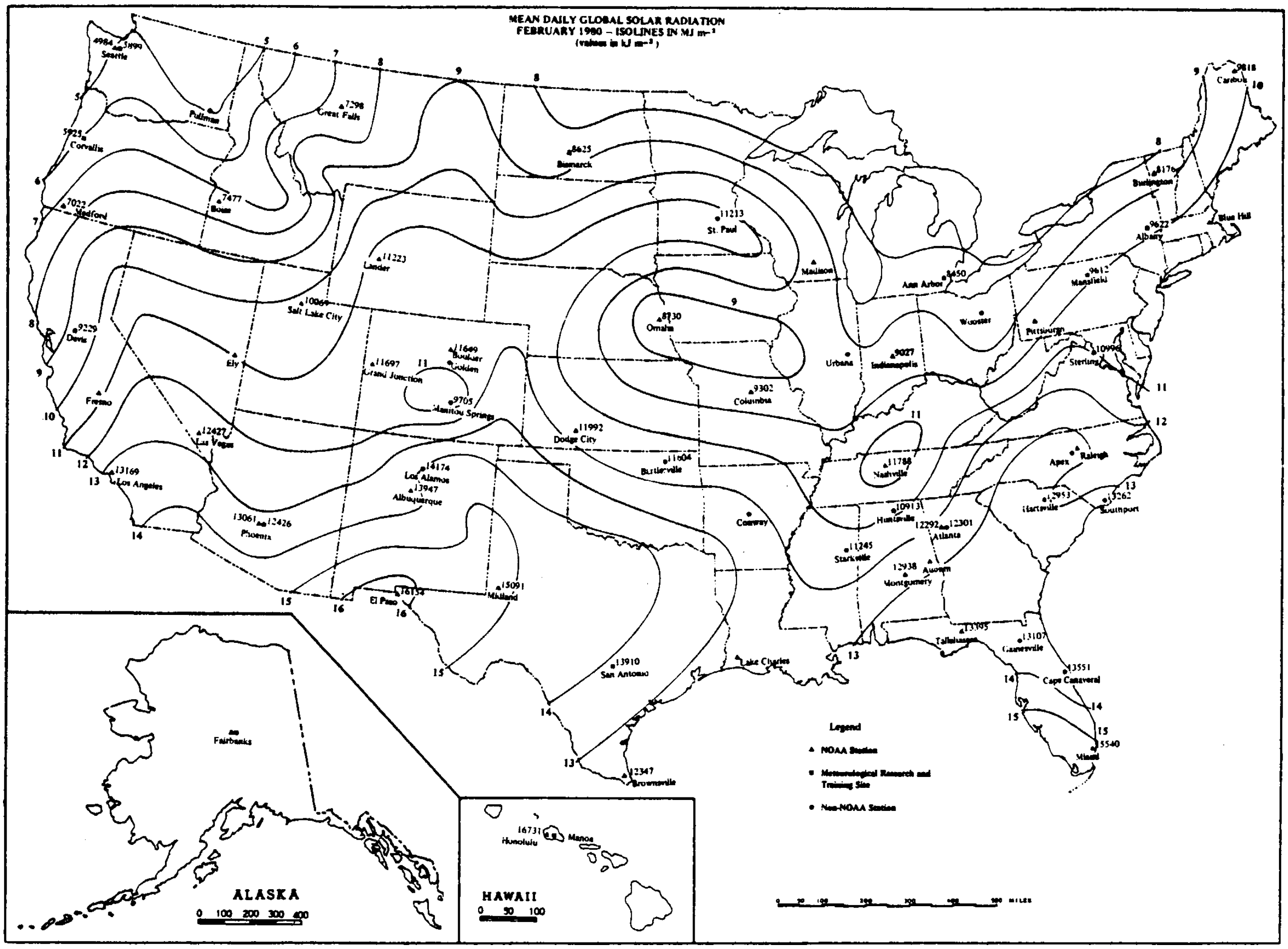
The number in parentheses indicates the number of days with questionable or missing data. If an hourly value is questionable or missing, the daily total is considered questionable or missing.

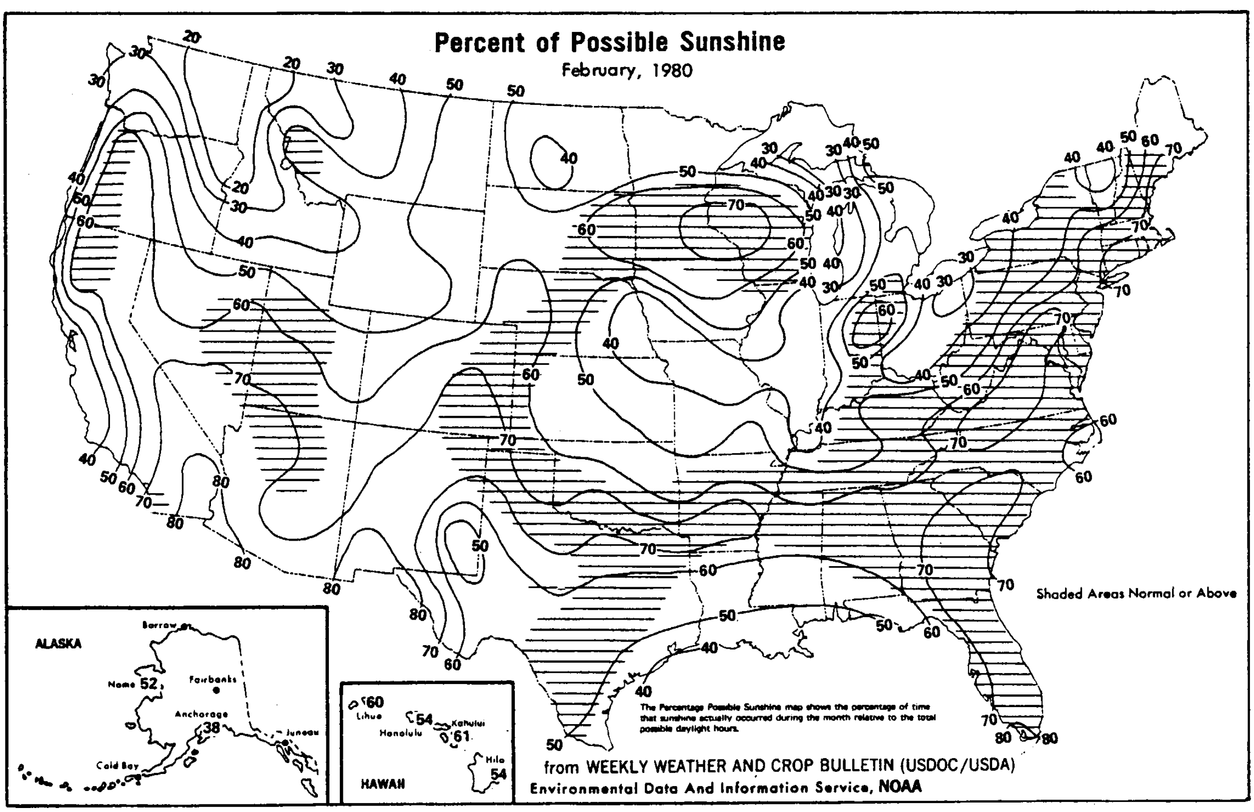
METEOROLOGICAL RESEARCH AND TRAINING SITES

Station Name	Station Number	Lat.	Long.	Elev.	Observer	Mean Daily Global Solar Radiation (kJ/m^2) February 1980
Fairbanks, AK		64°49'N	147°43'W	138m	University of Alaska	
Davis, CA		38°32'N	121°45'W	15m	University of California	9229
Atlanta, GA		33°46'N	84°25'W	335m	Georgia Institute of Technology	12292
Manoa, HI					University of HI – Manoa	
Ann Arbor, MI		42°18'N	83°42'W	290m	University of Michigan	8450
Albany, NY		42°42'N	73°50'W	79m	State University of NY – Albany	9622
Corvallis, OR		44°36'N	123°13'W	91m	Oregon State University	5925 (4)
San Antonio, TX		29°27'N	98°29'W		Trinity University	13910

NON–NOAA STATIONS

Station Name	Station Number	Lat.	Long.	Elev.	Observer	Mean Daily Global Solar Radiation (kJ/m²) February 1980
Auburn, AL		32°15′N	85°30′W	199m	Auburn University	10334
Huntsville, AL		34°44′N	86°40′W	201m	University of AL in Huntsville	10913 (8)
Conway, AR		35°04′N	92°27′W	91m	University of Central Arkansas	
Phoenix, AZ		33°50′N	112°10′W	610m	DSET Labs.	12426
Golden, CO		39°53′N	105°12′W	1841m	SERI	
Manitou Springs, CO		38°49′N	194°50′W	1935m	Pikes Peak – GM Vehicle Test Site	9705
Cape Canaveral, FL		28°24′N	80°36′W	2.7m	Florida Solar Energy Center	13551
Gainesville, FL		29°41′N	82°16′W	47m	University of Florida	13107
Atlanta, GA		33°45′N	84°23′W	362m	Georgia State University	12301 (1)
Hilo Cpo, HI		19°42′N	155°05′W	61m	University of Hawaii at Manoa Network	13112
HCPC, HI		19°50′N	155°05′W	30m	University of Hawaii at Manoa Network	16501 (6)
Kulani, HI		19°33′N	155°18′W	157m	University of Hawaii at Manoa Network	12769
Palaau, HI		21°07′N	156°59′W	23m	University of Hawaii at Manoa Network	18254 (5)
Holmes Hall, HI		21°18′N	157°49′W	23m	University of Hawaii at Manoa Network	15359
Maunawili, HI		21°21′N	157°46′W	125m	University of Hawaii at Manoa Network	11389
Waikiki Sheraton, HI		21°16′N	157°49′W	3m	University of Hawaii at Manoa Network	16995 (2)
Huelani, HI		21°19′N	157°48′W	98m	University of Hawaii at Manoa Network	15221
Maui CC, HI		20°53′N	156°28′W	3m	University of Hawaii at Manoa Network	15962
Kaunakakai, HI		21°05′N	157°01′W	3m	University of Hawaii at Manoa Network	15853 (26)
Kealakehua, HI		19°29′N	155°53′W	640m	University of Hawaii at Manoa Network	17840 (6)
Urbana, IL		40°06′N	88°14′W	266m	Illinois State Water Division	10592 (8)
St. Paul, MN		44°59′N	93°11′W	295m	University of Minnesota	11213
Starkville, MS		33°28′N	88°48′W	122m	Mississippi State University	11245 (4)
Apex, NC		35°38′N	78°00′W		Carolina Power & Light	12746
Southport, NC		33°57′N	78°00′W		Carolina Power & Light	13262
Los Alamos, NM					LASL	14174
Wooster, OH					Ohio Agricultural Research & Dev. Cen.	
Bartlesville, OK		36°45′N	95°59′W	222m	Energy Technology Center – DoE	11604
Mansfield, PA		41°49′N	77°04′W	414m	Mansfield State College	9612
Hartsville, SC		34°24′N	80°09′W		Carolina Power & Light	12953
Pullman, WA		46°42′N	117°12′W	776m	Washington State University	
Seattle, WA		47°39′N	122°18′W	62m	University of Washington	5899


MEAN DAILY GLOBAL SOLAR RADIATION
FEBRUARY 1980 – ISOLINES IN MJ m⁻²
(values in kJ m⁻²)
ALASKA
HAWAII
Legend
NOAA Station
Meteorological Research and Training Site
Non-NOAA Station


Percent of Possible Sunshine
February, 1980
Shaded Areas Normal or Above
The Percentage Possible Sunshine map shows the percentage of time that sunshine actually occurred during the month relative to the total possible daylight hours.
from WEEKLY WEATHER AND CROP BULLETIN (USDOC/USDA)
Environmental Data And Information Service, NOAA
ALASKA
HAWAII

SESSION III
NATIONAL LABS AND CONTRACTOR INSOLATION ASSESSMENT AND RESEARCH PROJECTS

MEASUREMENT AND ANALYSIS OF CIRCUMSOLAR RADIATION

Donald Grether, David Evans, Arlon Hunt and Michael Wahlig

Lawrence Berkeley Laboratory
University of California
Berkeley CA 94720

BACKGROUND

Purpose

The purpose of this project is to provide measurements and analyses of the solar and circumsolar radiation for application to solar energy systems that employ lenses or mirrors to concentrate the incident sunlight. Circumsolar radiation results from the scattering of direct sunlight through small angles by atmospheric aerosols (e.g., dust, water droplets or ice crystals in thin clouds).

Concentrating solar energy systems will typically collect all of the direct solar radiation (that originating from the disk of the sun) plus some fraction of the circumsolar radiation. The exact fraction depends upon many factors, but primarily upon the angular size (field-of-view) of the receiver. A knowledge of the circumsolar radiation is then one factor in predicting or evaluating the performance of concentrating systems.

The project employs unique instrument systems (called Circumsolar Telescopes) that were designed and fabricated at LBL. The basic measurements are (1) the "circumsolar scan", the brightness of the sun and circumsolar region as a function of angular distance from the center of the sun and (2) the usual "normal incidence" measurement of a pyrheliometer. Both measurements are made for the entire solar spectrum, and (via colored filters) for eight essentially contiguous wavelength bands. Thus the measurements are applicable to systems in which the receiver is essentially wavelength-insensitive (e.g., central receiver) and to wavelength-sensitive systems (e.g., concentrating photovoltaics).

A secondary purpose of the project is to relate the data to the atmospheric processes that attenuate the solar radiation available to terrestrial solar energy systems.

Organization

The project was initiated in May, 1974; with the initial deployment of telescopes about two years later. The instruments have been operated since then at a variety of locations of relevance to concentrating solar energy systems. Arrangements are made for site personnel to provide routine maintenance of the instruments. LBL provides the technical and engineering effort and the spare parts inventory necessary to maintain the instruments in working order; monitors the data for quality control; and processes the data to the analysis stage. LBL undertakes a variety of analyses of the data for application to concentrating systems, and prepares the data in forms suitable for use at other DOE supported institutions.

Relationship to Other Projects

In conjunction with operating the telescopes, LBL has worked with the following DOE-supported projects: Solar 1, the Barstow 10 Mw_e Central Receiver pilot plant; the Advanced Components Test Facility at Georgia Tech; the Central Receiver Test Facility at Sandia, Albuquerque; the CPC project at Argonne National Laboratory; and the JPL Parabolic Dish Test Site at Edwards, California. Discussions are currently underway with McDonnell-Douglas regarding telescope operation (as of June 1, 1981) at Solar 1, and interfacing of the telescope to the facility's data acquisition system.

Institutions that have been provided data include: Sandia, Livermore (Central Recevier sensitivity analysis and quasi-minute-by-minute data for cloud transient studies); Sandia, Albuquerque (input to performance calculation program Helios); SERI (analysis of effect of circumsolar radiation on point-focusing systems); Watt Engineering (climatological-oriented study of circumsolar); JPL, Boeing, Georgia Tech, McDonnell-Douglas and Sanders Associates (analyses of concentrating systems).

Previous Results

Early results from the telescopes showed that there were clear-sky conditions for which the levels of circumsolar radiation were of negligible importance to concentrating systems. However, during less-clear sky conditions the circumsolar radiation could become tens of percent of the direct solar radiation. Under these conditions the circumsolar radiation would have to be taken into account in evaluating the performance of a solar plant.

Subsequent to these early results, the project has proceeded to establish in more detail the effect of the circumsolar radiation. Several approaches have been taken to establishing the average effect over time (e.g., months or years) on the performance of concentrating systems (1). In a generic approach, the system is described in terms of two simplified parameters, the operating threshold and the effective field-of-view of the receiver. Summaries have been presented, for example, of the fraction of the energy content of the solar plus circumsolar radiation that is "lost" (misses the receiver). The monthly average loss for a highly concentrating system (effective field-of-view of 0.75°) can range from a few percent to as much as 8%, depending on the telescope location and time of year. In a second approach (in conjunction with Sandia, Livermore) the loss for two specific central receiver designs for the Barstow pilot plant was determined. Monthly average losses ranged from 1% to as much as 6%, depending upon the location, season, and design.

Analyses have been made of the systematics of the circumsolar radiation. The objective is to develop quantitative relationships between the circumsolar radiation and atmospheric and solar parameters; relationships that can be used to estimate the circumsolar level when actual measurements are not available. One approach has been to examine empirical correlations of the circumsolar radiation with other parameters such as the pyrheliometer reading, air mass, season, etc. One result, for example, is that a plot of the circumsolar level vs. pyrheliometer reading shows distinct patterns, with the different parts of the plot corresponding to different types of atmospheric conditions. In another approach, calculations have been performed to relate the data to the atmospheric scattering processes. For example, the angular distribution of the circumsolar radiation has been compared to the predictions of the Mie theory of light scattering from small particles.

DESCRIPTION

Instrumentation, Measurements, and Data Logging

Each instrument system consists of a scanning telescope mounted on a precision solar tracker, an electronic controller, and various pieces of auxiliary equipment. The latter include a pyrheliometer to provide the usual "normal incidence" measurement as well as the calibration for the telescope scan, and two pyranometers (one tracking the sun and one mounted in the usual horizontal position). The telescope scans thru a total angle of six degrees, with the sun at the center of the scan. A digitization of the brightness of the solar or circumsolar region is taken every 1.5 minutes of arc. One scan takes about one minute of time. The telescope and pyrheliometer have matched ten position filter wheels: one clear (or open) filter, eight colored filters, and one opaque filter used to monitor detector noise. The data are recorded on magnetic tape using a Kennedy incremental-digital tape drive.

A sunphotometer, on loan from NOAA, was recently mounted on one of the telescopes (Scope 3). To allow for automated operation, the photometer was placed in an environmentally sealed and temperature controlled housing, and the output connected to the data acquisition system.

Support facilities at LBL include the Solar Energy Program's electronics laboratory; the mechanical, electronic, and optical shops of the Special Projects group (which fabricated the instruments and provides maintenance and development support); a roof-top area for instrument calibration and testing; and the Laboratory's computer facilities for data processing and analysis.

Measurement Sites

The budget for FY80 was not sufficient for LBL to support all four telescopes. Sandia, Albuquerque agreed to operate one, but only in conjunction with tests at the Central Receiver Test Facility (thus concluding the long-term data base for this location). LBL continues to support the instrument at Atlanta, and a recently-upgraded instrument that was installed at the beginning of the fiscal year at the JPL Parabolic dish test facility at Edwards. The instrument at Barstow was returned to

LBL. The following table summarizes the telescope locations to date.

Scope	Site	Motivation	Dates
1	Boardman, OR	Boeing heliostat test	2/77 - 5/77
	Colstrip, MT	NOAA Atmospheric tests	5/77
	Atlanta	ACTF (a), humid climate	6/77-present
2	Albuquerque	CRTF (b), high-desert climate	5/76 - 10/79
	Albuquerque	CRTF tests	11/79-present
3	Ft. Hood, TX	TES (c), warm cloudy climate	7/76 - 8/77
	Argonne, IL	Cool cloudy climate	8/77 - 10/78
	Berkeley, CA	Rehabilitate & upgrade	11/78 - 10/79
	Edwards, CA	JPL PDTF (d), Mojave climate	11/79-present
4	China Lake,CA	Mojave desert climate	7/76 - 5/77
	Barstow, CA	Mojave, 10 Mw_e pilot plant	5/77 - 10/79
	Berkeley, CA	Storage	11/79-present

(a) Advanced Component Test Facility at Georgia Tech
(b) Central Receiver Test Facility at Sandia Laboratories
(c) Total Energy System (proposed)
(d) Jet Propulsion Laboratory Parabolic Dish Test Facility

Quality Control, Data Processing, and Data Availability

Data tapes are shipped to LBL from the various sites at the end of each week. At LBL, the data undergo an initial computer processing to determine if the telescope is experiencing any difficulties. If so, corrective actions are first attempted by contacting site personnel. Should the problem prove intractable by this approach, then an LBL staff member travels to the site and undertakes the necessary repairs.

At the time of the initial processing, the data are transferred as-is from the original, low density magnetic tapes to high density ones called RAW tapes. Later, the information from the RAW tapes, with various organizational problems (e.g., incorrect dates) fixed, is rewritten onto so-called FIX tapes. At this point calibration factors are applied, and the data are condensed and written onto a preliminary version of the Reduced Data Base (RDB). Various statistical methods are then employed to look for and, when necessary, devise correction factors for faulty data. A revised RDB is then produced, and the data are ready for analysis.

The RDB, which contains one record for each ten minute measurement cycle of the telescope, is available. However, for many applications hourly average data are sufficient or preferable. Thus a Hourly Data Base is also available, variations of which have been the means of providing data to SERI, Watt Engineering, and Sandia, Albuquerque. For specific time periods (e.g., tests of concentrating systems) data are available in the form of graphs and computer printout of individual scans of the telescope, as well as magnetic tape.

Research Tasks, Data Applications and Models

An on-going task is the summarizing of the data along the lines described above (BACKGROUND). These approaches have established a baseline for identifying any changing conditions at long-term sites, and for comparing different climate regions. In addition, the approaches themselves continue to be developed.

A second area is the analysis of the systematics of the circumsolar radiation (also above). One aspect involves developing a model that could be used to estimate the circumsolar radiation given other, more readily measured, parameters. Work in this area has been at a low level this fiscal year.

A major effort this fiscal year has been the analysis of the spectral (filtered) data, for application to wave-length sensitive systems. Extensive use is made of a model of the solar spectrum (referred to as SSM for Solar Spectral Model) that combines the atmospheric transmission computer code LOWTRAN (2) with an extraterrestrial solar spectrum (3).

SUMMARY OF RESULTS (FY 1980)

Data Collected/Processed

Data were obtained from the two telescopes (Atlanta and Edwards) supported this fiscal year by LBL. The data were processed to the preliminary RDB stage up thru June, 1980 and to the revised stage up thru December, 1979.

Presentation and Discussion of Results

Summaries of the type discussed under BACKGROUND were prepared for the data up thru December, 1979. Sample results are shown in Fig. 1 for the Mojave desert area (the small, vertical arrows indicate the changes from one location to the next). Displayed in Fig. 1(a) is the monthly average circumsolar ratio; defined as the monthly total circumsolar (from the edge of the sun out to 3^o) radiation, divided by the direct solar (coming from the disk of the sun) plus circumsolar radiation. This quantity is approximately the same as the overestimate that a pyrheliometer would make in estimating the monthly total direct solar (from the disk of the sun) radiation. Fig. 1(b) shows the ratio of the monthly total direct solar radiation to the extraterrestrial value. This quantity (which is similiar to the commonly-used K_t of Ref. 4) compensates for the seasonal changes in the length of the day and the varying earth-sun distance, and hence can be taken as an indicator of "cloudiness." The circumsolar ratio shows a distinct seasonal dependence, with a winter peak of as much as 7% and summer minima of about 2%. There is also a noticable correlation with the total/extraterrestrial parameter; with a tendency for cloudy months to have high circumsolar levels. Comparable data for Albuquerque (not shown) do not have any obvious seasonal dependence. Rather, the circumsolar ratio shows a trend of increasing values from 2-3% in May-June, 1976 to 4-5% in February-March, 1977, and then, with considerable fluctuations, a more or less steady value thereafter.

A considerable effort this fiscal year was devoted to analyzing the colored filter pyrheliometer data. The work will be briefly discussed here based on the data from Scope 4 (China Lake and Barstow). The first step was to characterize the transmission function (transmission vs wavelength) of each filter during the period of operation of the telescope (July, 1976 thru October, 1979). Spectrophotometer measurements of the transmission of the filters were made at LBL this fiscal year. Comparisons to measurements provided by the manufacturer when the filters were new suggested that many of the filters had experienced a change in overall transmission. A method was then developed to use the pyrheliometer data to track the change. Using a modified "Langely Plot" approach, the ratios of colored-filter to clear-filter pyrheliometer values for each month of clear-sky data were extrapolated to zero air mass (no atmosphere). The extrapolated value, C, is expected to be relatively independent of actual atmospheric conditions but quite sensitive to changes in filter characteristics. Figure 2 shows C (the small squares) plotted from July, 1976 thru October, 1979 for two of the filters. The filter for Fig. 2(a) is observed to have experienced an abrupt reduction in transmission in November, 1976. Fig. 2(b) shows more typical behavior; a steady decrease in transmission over time. To account for such effects ad-hoc "aging" factors were adapted, with a linear dependence generally adequate to describe the data. The LBL spectrophotometer measurements, together with the aging factors, are then taken as specifying the filter transmission functions. As a consistency check, the SSM (Solar Spectral Model, see above) was used to generate nominal clear-sky solar spectra, which were convolved with the transmission functions to produce modeled pyrheliometer readings. These were then extrapolated to zero air mass in the same manner as for the actual data. The modeled values, shown as solid curves in Figure 2, are in quite good agreement with the data. [The apparent seasonal variations, which appear in both the real and modeled data, are artifacts of the extrapolation process.]

Given a knowledge of the filter transmission functions, the second step was to invert the pyrheliometer readings to obtain the (spectral) distribution of energy in the solar spectrum. Since the transmission functions are non-ideal in shape (as is the case for all physically realizable filters) the inversion cannot be carried out exactly and an estimation method must be used. The method developed here, described in detail in Ref. 5, involved calculating an effective transmission over a nominal pass band for each filter. The calculation uses an SSM solar spectrum so as to take into account in an approximate way the shape (but not the magnitude) of the actual solar spectrum in the region of the filter. The results have been shown to be insensitive to the details of the model. The energy content of the solar spectrum within the nominal pass band is obtained by (i.e., the inversion is carried out by) dividing the pyrheliometer reading by the effective transmission.

Fig. 3 displays in bar graph form inverted values for two sequences of colored-filter clear-sky pyrhelimeter readings. Superposed on the data is an SSM modeled solar spectrum for nominal clear-sky conditions. For ease of comparison, the average of the modeled spectrum over each pass band has been plotted as a square at the center of the band. The two data sequences and the modeled spectrum are for the same air mass value and have nearly the same clear-filter pyrheliometer readings (about 940 w/m^2). Of note is the variation in spectral composition of the data, with one sequence in quite good agreement with the model, and the other having a relative depletion in the wavelength region around 1.0 microns.

Recommendations and Future Plans

For FY 1981 plans are to continue the operation of the instruments at Atlanta and in the Mojave area, with the telescope at Edwards to be moved to the Barstow Pilot Plant by June, 1981. In addition, the telescope currently at LBL would be rehabilitated & upgraded and located at SERI. Work would continue on the analysis of the clear-filter data, with an increased emphasis on modeling the systematic behavior of circumsolar radiation. The effort on the colored-filter pyrheliometer data will be concluded on the data available to date, with summaries produced of the energy content of the solar spectrum for various locations, atmospheric conditions, etc. Some attention will be given to the colored-filter scan data.

It is proposed that a new instrument be designed as part of the FY 1981 program. The design would incorporate our knowledge of the character of circumsolar radiation as obtained with the current instruments, and a control system based on modern micro-processor devices. The instrument would be simplier to operate and maintain, and would take fewer data points but over a somewhat increased range of parameters. Actual construction would be deferred until FY 1982.

ACKNOWLEDGEMENTS

This work has been supported by the Division of Distributed Solar Technology, Office of Conservation and Solar Energy, U.S. Department of Energy under contract No. W-7405-ENG-48.

REFERENCES

1. Grether, D.F., Evans, D., Hunt, A., and Wahlig, M., 1979. Application of Circumsolar Radiation Measurements to Concentrating Collectors. Proceedings of the 1979 International Congress of the International Solar Energy Society, Atlanta, and Lawrence Berkeley Laboratory Report No. LBL 9412.

2. Selby, J.E.A., et. al., 1975. Atmospheric Transmittance from 0.25 to 28.5 microns: Computer Code Lowtran 3. Air Force Cambridge Research Laboratory.

3. Thekaekara, M.P., June, 1975. The Total and Spectral Solar Irradiance and Its Possible Variations. Preprint X-912-75-155, Goddard Space Flight Center, Greenbelt, Maryland.

4. Liu, B.Y.H. and Jordan, R.D., 1960. The Interrelationship and Characteristic Distribution of Direct, Diffuse, and Total Solar Radiation. Solar Energy 4, No. 3, p.1.

5. Evans, D.B., Grether, D.F., Hunt, A.J., and Wahlig, M., May, 1980. The Spectral Character of Solar and Circumsolar Radiation. Proceedings of the Annual Meeting of the American Section of the International Solar Energy Society, Phoenix, and LBL-10802.

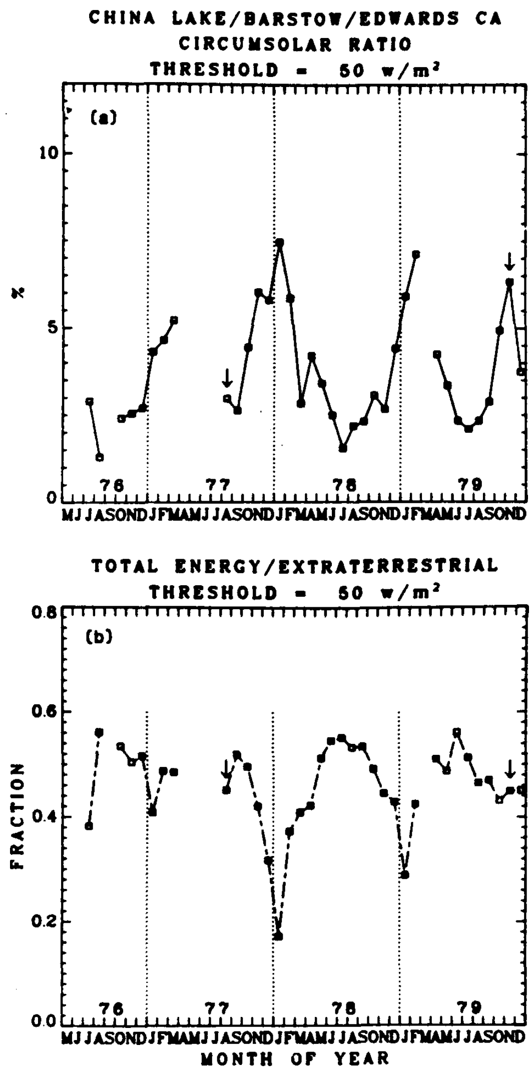


Figure 1

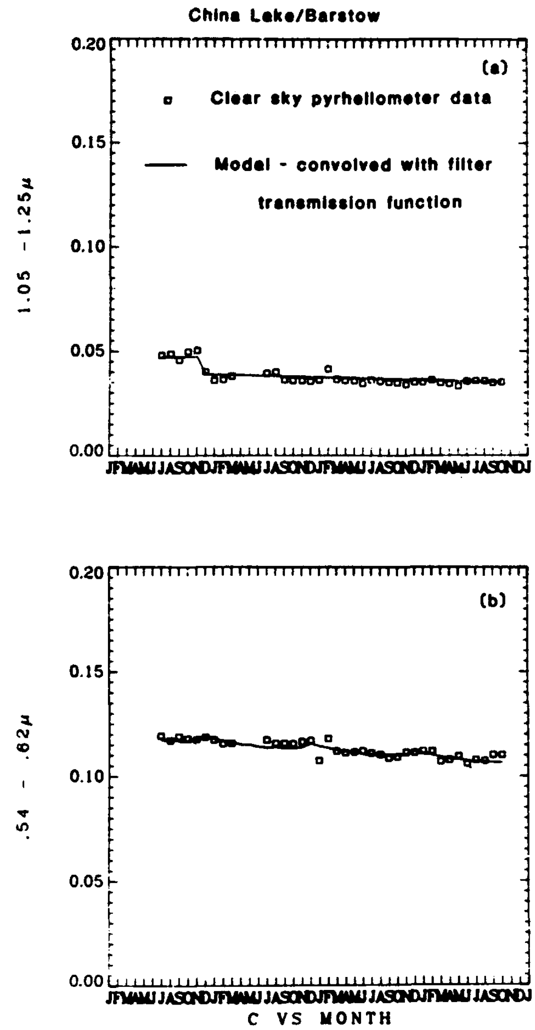


Figure 2

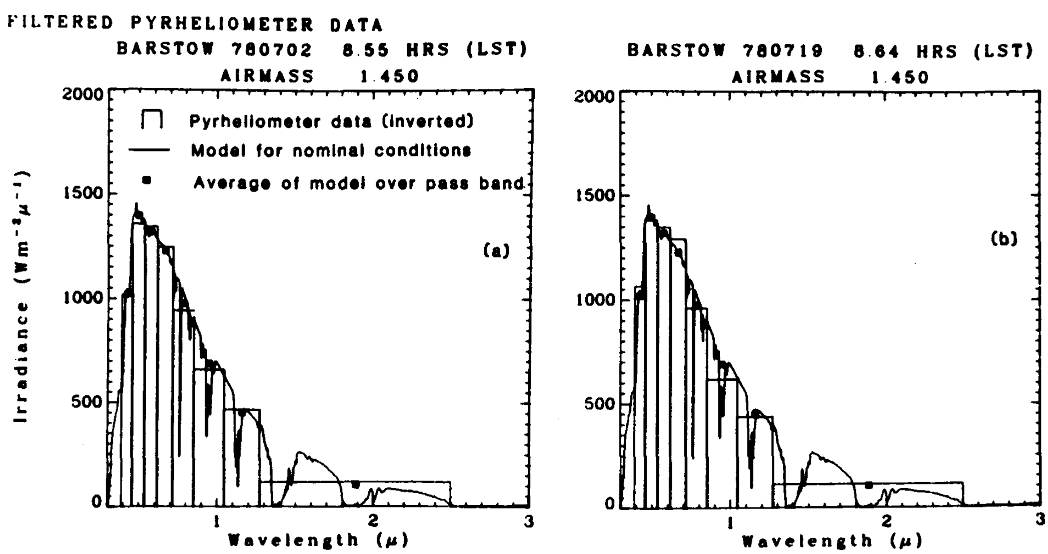


Figure 3

GROUND-BASED INSOLATION MEASUREMENTS AT SELECTED FIELD SITES

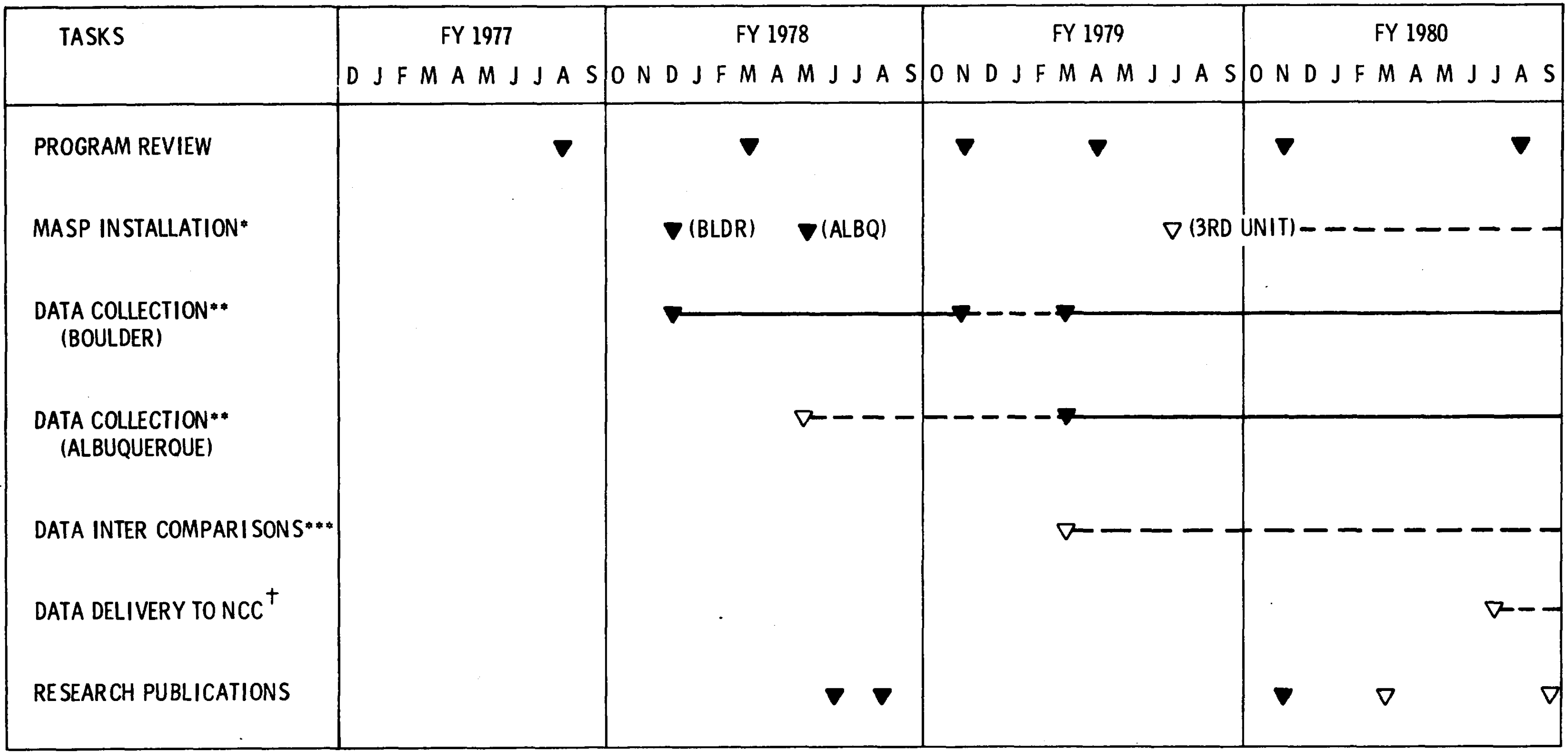
Joseph J. Michalsky and Edward W. Kleckner
Battelle, Pacific Northwest Laboratory
P. O. Box 999, Richland, WA 99352

I. BACKGROUND

The National Weather Service operates a network of 39 stations which acquire data from horizontally mounted pyranometers and shadow-band pyranometers and sun-tracking pyrheliometers. The pyranometers have a 2Π steradian field of view and the pyrheliometers have a 5° diameter field of view centered on the sun. All three types of instrumentation accept radiation in the wavelength range from 0.3 to 2.8μm. In contrast, the present program uses a computer-controlled scanning photometer to acquire high accuracy, spectrally and spatially resolved insolation data. These data are important to programs, such as photovoltaics and biomass, that are developing practical solar energy conversion devices. The data are also useful to programs which model the effects of the atmosphere on solar radiation.

The objective of this program is to build and site two to three of these photometers for the routine collection of the type of data described above. Not only are the data to be published, but a program of calibration and analysis which ensures and maximizes their utility is to be pursued. In particular the output of the units sited at Boulder, Colorado, and Albuquerque, New Mexico, is to be compared with data acquired by others at those two locations. These data are to be provided to the National Climatic Center (NCC) in Asheville, North Carolina, for use by others.

The program was begun in December 1976 at the Pacific Northwest Laboratory operated by Battelle Memorial Institute for the Department of Energy. The milestone schedule in figure 1 represents the major goals and achievements of the program since its inception. There exist about 2½ years of useful data from the Boulder site and 1½ years of useful data from the Albuquerque site as of the end of FY 1980. Boulder began taking data with a prototype unit built for another program, but which obtained data useful to both programs. In November 1978 the first Boulder unit was replaced by a photometer of the same type as had been installed in May 1978 at Albuquerque. A problem with the objective lens, discovered in January 1979, was corrected at both units by March 1979. There has been some exchange of data and other exchanges



* SOUTHEASTERN SITE UNIT NOT FUNDED AS YET
** LENS PROBLEM RESULTED IN NO USEFUL DATA
*** MINOR ACTIVITY THUS FAR
† UNDERFUNDED BY ~60%

initiated at the two sites, but thus far this effort has been minor. Data from the sites were to be delivered to the NCC in July 1980. Underfunding by about 60% in FY 1980 precluded this task being accomplished. Five research publications have been published or submitted due to work funded in part or entirely by this program. They include two instrument papers (Kleckner, Michalsky and Smith 1978; and Kleckner et al. 1980), two papers on turbidity differences in the first kilometer of the troposphere in semi-arid regions (Laulainen, Kleckner and Michalsky 1978; and Michalsky et al. 1980), and one paper on practical techniques for estimating the solar spectrum based on the discrete output of a small set of filters (Michalsky and Kleckner 1980).

This program is most nearly related to DOE AK-01-04-03, "Development and Operation of DOE Insolation-Aeronomy Observatory," and makes use of the instrument developed in this program. The scope of the present research, however, is complementary to AK-01-04-03 and allows needed intercomparison of instruments and valuable on-site data to be gathered at the Boulder and Albuquerque sites. Although there is some emphasis on insolation in AK-01-04-03, the major thrust of that program is aeronomy; and siting of these programs' units is dictated by aeronomical considerations, i.e., the units are north of the major solar resource area within the United States. The program is related to NSF ATM78-12313, "A Photometric Study of the Mid-Latitude Auroral Region during the IMS," in that it uses the same instrument, but, as is clear from the title, the program goals differ. NSF ATM79-19447, "Simultaneous Photometric and Polarimetric Studies of Ice-Crystal Clouds," also uses the same instrument, but with a specific activity as indicated in the title. The units in the other programs collect solar data which will also be archived at the NCC for the cost of processing the data. The network of photometers collecting spectral direct and diffuse data is listed in table 1.

Table 1. Mobile Automatic Scanning Photometer Locations and Sponsors

Location	Sponsor
Albuquerque, NM	DDST-DOE
Boulder, CO	DDST-DOE
Richland, WA	BES-DOE
Hinsdale, MT	BES-DOE
Iron Mountain, MI	NSF
Albany, NY	NSF
Leduc, ALB, CAN	NSF
Fort Providence, NWT, CAN	BES-DOE

Besides the work on spectral estimation of the solar spectrum using the discrete output of the seven basic solar filters, some progress has been made in the previous FY on two other studies intended for publication. Superimposed on plots of the direct solar radiation versus time from each of seven filters, which are used to sample the direct insolation each 5-minute period, is noise which exceeds that expected from the instrument. The magnitude of the noise can vary throughout the day. A correlation analysis from filter to filter and one using colocated MASPs are being conducted to examine the reality of the atmosphere-induced changes. These changes have been suggested to result from sub-visual cirrus or possibly nonhomogeneous aerosol layers.

The other study involves an analysis of the all-sky data which is collected every 30 minutes in a broad blue and broad red filter. Methods for displaying and working further with the all-sky data have been developed, and it appears that based on the theoretical work of Yamamoto and Tanaka (1973) that maps of this type may be extremely sensitive to the physical parameters which are input to generate matching theoretical results.

II. DESCRIPTION

The instrument which acquires the spectral data is briefly described in Kleckner, Michalsky and Smith (1978) and is more fully described in a paper recently submitted to *Applied Optics* (Kleckner et al. 1980). Briefly, the instrument is an altazimuth telescope with 6-inch optics and a 1.5° diameter field of view. The focussing optics are actually fixed and light from any part of the 2Π steradian field accessible to the telescope is acquired using a system of two rotating mirrors mounted at 45° to each other and to the focal plane of the objective lens. The filter wheel consists of 12 filters with effective wavelengths and bandpasses given in table 2. The detector is a silicon PIN photodiode. As much of the decision-making as practical has been incorporated within

Table 2. Mobile Automatic Scanning Photometer Filters, Bandwidths and Functions

Central λ(nm)	FWHM(nm)	Use
630.0	1	Night, Day
557.7	1	Night, Day
486.1	2	Night, Day
427.8	2	Night, Day
535.0	3	Night, Day
395.0	60	Day
470.0	100	Day
570.0	100	Day
680.0	120	Day
785.0	20	Day
900.0	160	Day
1010.0	30	Day

the software of the computer-controlled device to allow flexibility in the choice of observing programs. Recording is on magnetic cassette tapes. The present solar observing sequence is used in all instruments. At every 5-minute mark a direct solar measurement is made in seven filters. Once each half hour azimuth scans at the solar elevation angle are made with sampling every 5° in azimuth from 5° to 180° from the sun. Once each half hour scans in the solar-zenith plane are made beginning 5° above the sun and sampling every 5° to the opposite horizon. Twice each half hour all-sky scans are made with roughly 10° between samples. One scan is in a broad blue filter (470nm) and one scan is in a broad near-infrared filter (900nm). Observations are made from sunrise to sunset. All measurements are made relative to the solar position which is calculated each minute using the universal time and the latitude and longitude of the site. Positioning is accurate to about $\frac{1}{2}^{\circ}$ due to the accumulation of errors in approximating declination and hour angle and due to the mechanical resolution and absolute mechanical alignment of the photometer.

The data are to be supplied to the NCC in Asheville, North Carolina, and will be available on request. As yet no data have been shipped to the NCC. At present it is planned that all direct solar data will be archived at the NCC and only a representative collection of the other types of data collected will be archived. For example, clear all-sky data with a variety of aerosol loading conditions and all-sky data with various cloud types present will be archived. Each station will be represented. Specific data will be made available to individual users for a particular set of observations on request and to the limits imposed by available resources. To the extent that they do not alter the goals of the fundamental observing program, requests for minor short-term changes in the observing program may be accommodated.

III. SUMMARY OF RESULTS (FY 1980)

At the outset of FY 1980, the main goals for the year were to deliver data to the NCC from all stations collecting solar data and to complete three-five research publications. The largest task was to develop software to convert our raw compacted data to data in the research format designed by the NCC. Care in delivering calibrated data was our utmost concern, especially in the case of the diffuse data which probably is a unique data collection. The research publications anticipated included the basic paper on the mobile automatic scanning photometer, the paper on estimating the solar spectrum using discrete output from a small filter set, a paper on sub-visual attenuation of the direct solar radiation and its possible causes and a paper on shadow-band corrections for shadow-band pyranometers.

After one quarter of FY 1980, i.e., after 25% of expected funds were spent, it was discovered that funding for the year would be $\simeq$40% of that expected. Based on this information, it was decided to delay the delivery of data to the NCC until the following FY, to concentrate on finishing the paper on spectral estimation if possible, and to continue the photometer operations in Boulder and Albuquerque. Most of the funds remaining were spent on that paper and in preparing for and attending the August program review. Some money was spent on a turbidity analysis of Mt. St. Helens-related aerosols. These two research efforts are discussed in the remainder of this document.

A. Spectral Estimation

The problem of interest here is to make the best possible estimate of the continuous solar flux as a function of wavelength over the sensitivity of the detector used in the photometer using the output of a small number of filters which sample that sensitivity range. One possible approach is that of Wiener estimation as outlined in a paper by Pratt and Mancill (1976). Suppose we have a series of measurements of the form

$$V_i = \int I(\lambda)T_i(\lambda)d\lambda + n_i \quad , \tag{1}$$

where $T_i(\lambda)$ is the spectral sensitivity of the measurement system for the ith filter, $I(\lambda)$ is the input spectrum, V_i is the output as a result of sampling through the ith filter and n_i represents an additive noise contribution. Discretizing (1), we form a vector equation

$$V_i = \vec{T}_i\vec{I} + n_i \quad , \tag{2}$$

where $\vec{T}_i$ and $\vec{I}$ are vectors with components which are quadrature samples of $\vec{T}_i(\lambda)$ and $\vec{I}(\lambda)$. The number is arbitrary but is chosen to provide a reasonable low spectral resolution. The set of observations can then be arranged to form the vector equation

$$\vec{V} = T\vec{I} + \vec{n} \quad , \tag{3}$$

where the vector $\vec{T}_i$ occupies the ith row of the matrix T. This set of equations is highly underdetermined, i.e., there are generally many more quadrature samples than sampled points.

A minimum mean-square error estimate $\hat{\vec{I}}$ of the true spectral energy distribution $\vec{I}$ is given by the generalized inverse estimate

$$\hat{\vec{I}} = T^t(TT^t)^{-1}\vec{V} \quad , \tag{4}$$

but, because of the ill conditioning of T, $\hat{\vec{I}}$ is an oscillatory estimate. It is reasonable, knowing the nature of $I(\lambda)$ to apply some smoothing constraints on the solution. The Wiener estimate of $\vec{I}$ is given by

$$\hat{\vec{I}} = K_I T^t(TK_I T^t + K_n)^{-1}\vec{V} \quad , \tag{5}$$

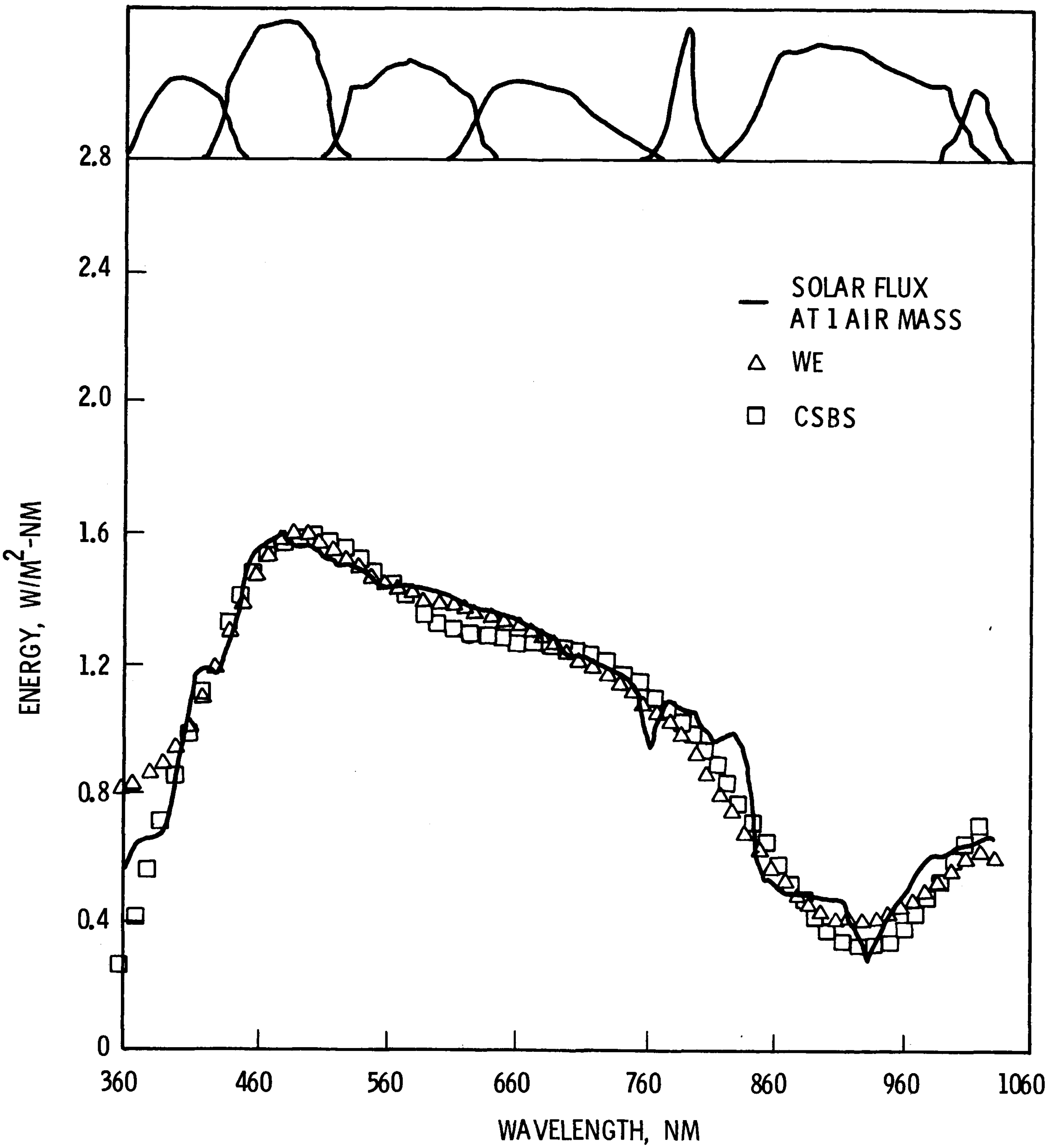
where K_I is the covariance matrix for $\vec{I}$ and K_n is the covariance matrix of the noise. In practice both matrices are modeled. If the noise is white, then

$$K_n = \frac{\sigma_n^{\ 2}}{N} I_0 \quad , \tag{6}$$

where $\sigma_n^{\ 2}$ is the noise energy, N is the number of quadrature points, and I_0 the identity matrix. The covariance matrix is assumed to be that for a first-order Markov process and is given by

$$(K_I)_{ij} = \frac{\sigma_I^{\ 2}}{N} \rho^{|i-j|} \quad , \tag{7}$$

where $\sigma_I^{\ 2}$ is the energy of $\vec{I}$ and ρ is the adjacent element correlation coefficient. What is assumed here is that if one part of the spectrum changes, adjacent parts of the spectrum are likely to change in the same direction and the correlation is highest for the nearest parts of the spectrum. This is reasonable except near absorption features, and it is expected that features much narrower than the widths of the quadrature samples will be missed altogether in this scheme. Figure 2 contains a


2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
ENERGY, W/M2-NM
SOLAR FLUX
AT 1 AIR MASS
WE
CSBS
360
460
560
660
760
860
960
1060
WAVELENGTH, NM

one air mass solar spectrum from Thekaekara (1975) and the estimate of it using the Wiener technique. As can be seen, the fit is fair except near absorption features and at the uv spectral end. The latter results from the fact that the uv filter does not actually sample part of this spectral regime. A very low resolution spectrum is fairly well reproduced by this method and the estimated total energy is within 1% of the input spectrum's energy.

An alternate method of estimation uses a basis set of cubic spline functions (Park and Huck 1977). Again we are looking for an estimate of the spectral energy $\hat{I}(\lambda)$. Let us suppose we expand the estimate in a set of basis functions

$$\hat{I}(\lambda) = \vec{X}\,\vec{h}\,(\lambda) \quad , \tag{8}$$

where $\vec{X}$ is a set of constant coefficients and $\vec{h}(\lambda)$ is a linearly independent basis set. $\vec{X}$ is chosen such that we minimize

$$\varepsilon(\lambda) = I(\lambda) - \hat{I}(\lambda) \quad , \tag{9}$$

the difference between the estimate and the actual spectral energy. The error equation can be written as

$$\vec{e} = \vec{V} - A\,\vec{X} \quad , \quad \text{where} \tag{10}$$

$$A_{ij} = \int_0^\infty T_i(\lambda) h_j(\lambda) d\lambda \quad , \tag{11}$$

and $\vec{V}$ is the measurement set. A number of strategies exist for minimizing $\vec{e}$, perhaps the simplest of which is $\vec{e} = 0$. This is equivalent to requiring the estimate match the measurement at the measured points. Doing this results in the equation set

$$\vec{V} = A\,\vec{X} \quad . \tag{12}$$

The set $\vec{h}(\lambda)$ can be any linearly independent basis—for our purposes we choose $\vec{h}(\lambda)$ to be a set of cubic splines. The solution is then given by

$$\vec{X} = A^{-1}\,\vec{V} \quad , \tag{13}$$

where $\vec{X}$ is the coefficient set sought.

Figure 2 shows the result of applying this method. As can be seen, the agreement is similar to that obtained with the Wiener method.

B. Mt. St. Helens Aerosols

The eruption of Mount St. Helens provided the opportunity to engage in a topical and potentially important study of volcano-related aerosols. Located some 180 km from Mount St. Helens and often downwind of it, we have experienced many of its deleterious effects. This study uses the direct solar measurements and the Bouguer-Langley approach for measuring turbidity. If the atmosphere above the measuring station is homogeneous during a measurement period, the Bouguer law

$$I = I_0 \exp(-\tau m) \quad , \tag{14}$$

where I and I_0 are the terrestrial and extraterrestrial intensities, τ is the optical depth referred to one air mass, and m is the relative air mass, holds true. By plotting $\ln I$ versus m and extrapolating to zero air mass I_0 can be determined and thereafter used in equation (1) in the form

$$\tau = \frac{1}{m} \ln(I_0/I) \tag{15}$$

to determine τ for future measurements assuming instrument stability. This then gives the total optical depth for each filter of the photometer. Nine filters of the 12 used contain, at most, contributions to the measured optical depths from Rayleigh scattering and ozone absorption which can be subtracted straightforwardly to yield aerosol optical depths (τ_a) as a function of wavelength.

From the wavelength dependence of τ_a, we can assess whether the distribution is Junge (1973), i.e., whether it is a power law distribution. If it is, then the number size distribution will be given by

$$n(r) = Cr^{-\gamma-1} \quad , \tag{16}$$

in which case and under certain assumptions concerning the very largest and smallest particles of the distribution, namely their neglectibility, τ_a will depend on λ according to

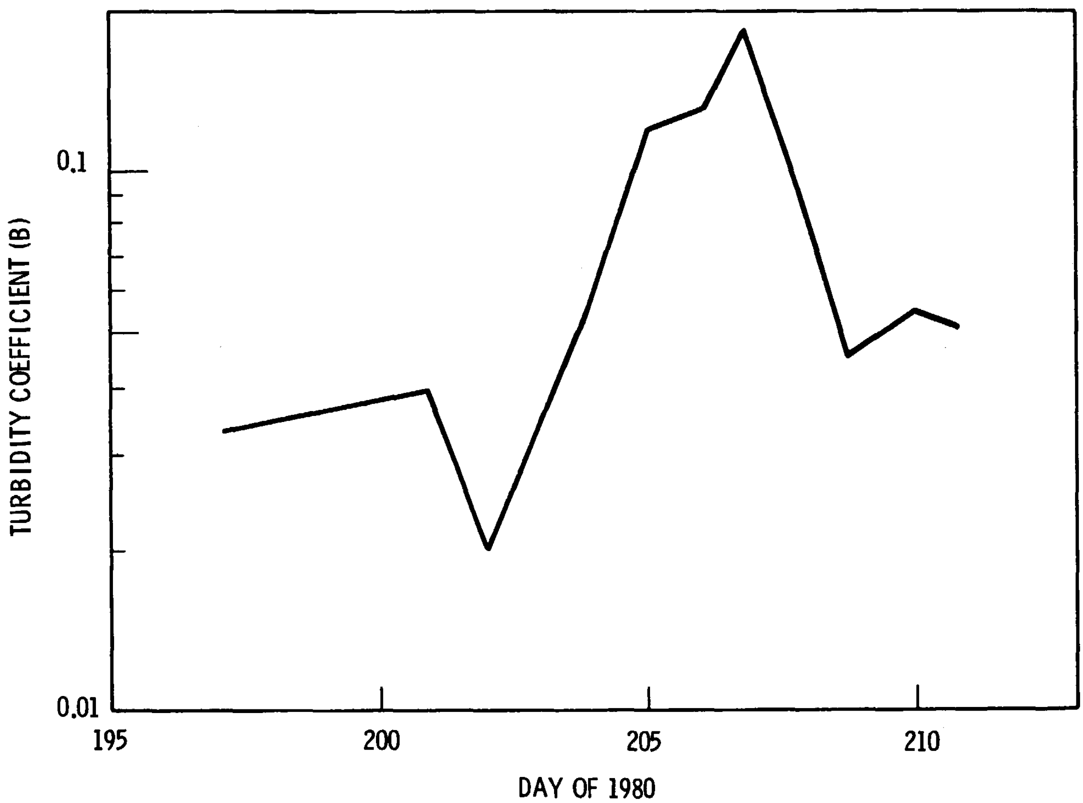
$$\tau_a = \beta \ \lambda^{-\gamma+2} \quad . \tag{17}$$

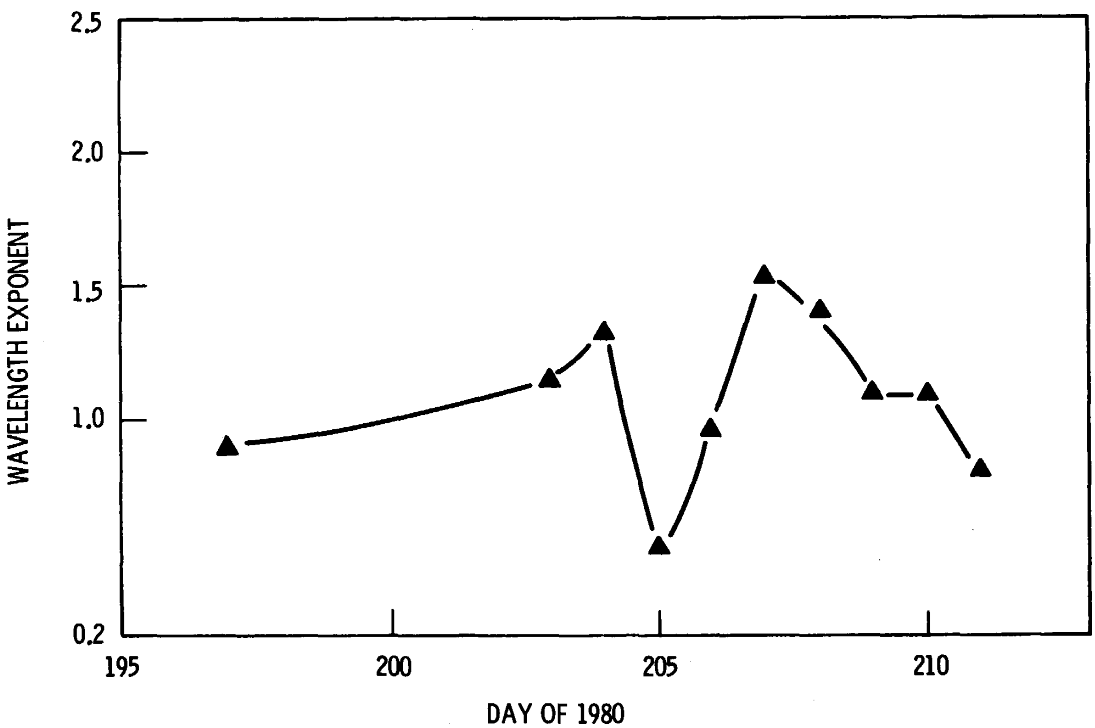
The period before and after the 22 July 1980 eruption of Mount St. Helens was particularly suited for turbidity study because of good weather. Figure 3a is a plot of the decadic turbidity coefficient at 500nm (i.e., $B = .4343\ \tau_a(500\text{nm})$) versus day of 1980 (204 is 22 July). The increase in optical depth on the several days following the eruption is apparent. In 3b the coefficient of the wavelength dependence of τ_a is plotted. Typical continental hazes have coefficients of ≈ 1.3. Smaller values imply larger particles than normal and larger values imply smaller particles. As is evident, on the day following the evening eruption of Mount St. Helens, the particles were very large as expected of ash. However, on the following days the coefficient was quite large implying a preponderance of small particles. It is suspected that following the settling of the ash that sulfates in the accumulation mode were the prime contributor to turbidity which seems reasonable in light of the enormous amount of sulfate precursors released during volcanic activity.

III. REFERENCES

Junge, C.E. 1963. *Air Chemistry and Radioactivity.* Academic Press, New York.

Kleckner, E.W., Michalsky, J.J., and Smith, L.L. 1978. In *Proceedings of the 1978 Annual Meeting: American Section of the International Solar*


0.1
0.01
TURBIDITY COEFFICIENT (B)
195
200
205
210
DAY OF 1980


2.5
2.0
1.5
1.0
0.2
WAVELENGTH EXPONENT
195
200
205
210
DAY OF 1980

Energy Society, Inc., Eds. K.W. Böer and G.E. Franta, 2.2, pp. 676-680. Publishing Office of the American Section of the International Solar Energy Society, Inc., Newark, Delaware.

Kleckner, E.W., Michalsky, J.J., Smith, L.L., Schmelzer, J.R., Severtsen, R.H., and Berndt, J.L. 1980. Submitted to *Applied Optics*.

Laulainen, N.S., Kleckner, E.W., and Michalsky, J.J. 1978. In *Third Conference on Atmospheric Radiation*, pp. 130-133. American Meteorological Society, Boston, Massachusetts.

Michalsky, J.J., Laulainen, N.S., Stokes, G.M., and Kleckner, E.W. 1979. In *Atmospheric Aerosols: Their Formation, Optical Properties and Effects*, in press. Institute for Atmospheric Optics and Remote Sensing, Hampton, Virginia.

Park, S.K. and Huck, F.O. 1977. *Appl. Opt.* 16, 3107.

Pratt, W.K. and Mancill, C.E. 1976. *Appl. Opt.* 15, 73.

Thekaekara, M.P. 1975. In a report to *Solarimetry Workshop, Energy Task Group, Financiadora de Estudos e Projetos* - FINEP, Brazilian National Academy of Sciences, Rio de Janeiro.

Yamamoto, G. and Tanaka, M. 1973. In *Proceedings, the UCLA International Conference on Radiation and Remote Probing of the Atmosphere*, Ed. J.G. Kuriyan, pp. 74-134. Western Periodicals Company, North Hollywood, California.

OVERVIEW AND SUMMARY:
INSOLATION ACTIVITIES AT JPL

J.R. Huning, M.S. Reid, J.H. Smith

BACKGROUND

The Jet Propulsion Laboratory, California Institute of Technology, is involved in a number of projects related to insolation assessments. The majority of these projects support various solar energy conversion technologies, but there is additional research in extra-terrestrial applications for space related projects.

Primary activities of the laboratory during the fiscal year ending 30 September 1980 dealt with measurement programs, calibration programs for major solar energy experiments, several specific research programs, and publication of technical reports. Program plans for the 1980-81 fiscal year have been formulated, and budgetary action upon them pending. The following pages summarize the primary activities related to insolation at JPL.

DESCRIPTION AND RESULTS

Measurement Program

JPL has two major insolation measurement programs in operation. These are at the Edwards Test Facility in the western Mojave Desert, north of Los Angeles, and at the Goldstone Deep Space Network (Venus Site) north of Barstow, CA. In addition, there are special measurement activities that occur on an ad hoc basis (e.g., photovoltaic test field on the lab, Table Mountain, spectral measurements at various sites).

At the Edwards Test Facility insolation and meteorological data are collected to support the testing of parabolic dish collectors for the solar thermal electric program. Instruments at Edwards are located on a rooftop and include an Eppley NIP, Eppley pyranometer, all weather PACRAD, and an MRI weather instrument package. The data are collected at one minute intervals and stored on magnetic tape. Data are reduced monthly and stored at JPL. During actual test of a parabolic dish a second Eppley NIP monitors and records insolation data at the specific site of the dish. Instruments are periodically calibrated against the lab's Mark VI, a more recent version of the PACRAD, cavity pyrheliometer. Several problems hinder the operation at Edwards. These focus on instability of the relative humidity instrument and intermittent power failures. The current insolation measurement activity at Edwards is planned to continue for several years.

At the Venus site of the Goldstone Deep Space Network insolation data have been recorded on magnetic tape since the mid-1970's. The program became part of the MASDAS (Microwave and Solar Data Acquisition System) activity. The Venus site is located about 30 miles north of Barstow, CA in the central Mojave Desert. The instrument package includes two all weather PACRAD pyrheliometers (each with a quartz window); two

Spectrolab pyranometers mounted horizontally; and one Spectrolab pyranometer tilted at 45 degrees. Additional meteorological data are also routinely collected. The system operates 24 hours a day and data are recorded as two minute averages. Numerous problems continue to hinder the operation of the insolation measurement program at Goldstone. Primary among these problems is malfunction of the data logger, which is similar in design to the SOLMET network data loggers. Interruptions in the measurement program and periods of inoperability are frequent. Data that have been recorded at Goldstone have only recently been reduced and very small amounts of them analyzed.

Periodically insolation data are collected at Table Mountain, a high elevation site in southern California, for use in calibration programs and atmospheric model verification. Insolation data are also collected at the main lab in Pasadena during tests of photovoltaic cell output performance.

Calibration Activities

In the late 1960's, an absolute cavity radiometer was conceived, designed, and built at JPL by James M. Kendall, Sr. This instrument, a primary standard for measurement of solar irradiance, was used for simulated solar testing of spacecraft and for measurement of normal incident solar irradiance. This work was sponsored and funded by NASA.

A version of this instrument, known as the Primary Absolute Cavity Radiometer, or PACRAD, was built specifically for measuring normal incident solar irradiance. It was intercompared with several existing standards on Table Mountain, CA and on NASA Ames 990 high altitude flights. Two PACRAD instruments were taken to the World Radiation Center of the World Meteorological Organization (WMO) in Davos, Switzerland, in 1970 to be compared with the Angstrom International Pyrheliometric Scale (IPS). International comparisons are held once every five years. As established at the World Radiation Center in 1975, the PACRAD revealed a two percent difference with the 1956 IPS.

JPL placed one of the two PACRAD instruments, the PACRAD III, at the disposal of WMO, at their request, and it is now maintained by them in Davos as the International Reference Standard of absolute irradiance for the IPS.

The other instrument, the PACRAD II, is maintained and used by JPL as a reference instrument for traceability to the IPS. In 1973/4, JPL developed an all-weather version of the PACRAD for use at Goldstone in the Deep Space Network (DSN) energy conservation project. Two of these instruments are still collecting data daily at Goldstone. In addition, two other all-weather instruments are being used at the JPL Edwards solar test facility.

A more recent version of the PACRAD, the Mark VI, is used at JPL as a standard for calibration of all instruments used by JPL for solar irradiance measurements. A Mark VI is used by the National Oceanic and Atmospheric Administration (NOAA)/ National Weather Service (NWS) as the U.S. standard. A Mark VI instrument was represented in Davos at the

1975 intercomparisons.

JPL will take the PACRAD II to the 1980 intercomparisons for historical continuity of traceability, and the Mark VI for direct traceability to the IPS.

In addition to the PACRAD and Mark VI instruments, JPL has developed a cavity pyranometer based on the same design principles. This is an absolute instrument which shows promise of becoming the first calibration standard for total (global) radiation. Completion of the development of this cavity pyranometer has been held up pending additional funding.

For many years, JPL has been involved in the design and development of precision radiometric instrumentation both for spacecraft flight projects and ground-base measurements. In addition to instrument development, JPL has also played a major role in developing techniques for instrument calibration and testing. JPL's large optical laboratory played a key role in some of these developments. Methods of calibration and intercomparison of pyrheliometers and pyranometers have been prominent in these developments. Southern California Edison, for example, consulted with JPL on setting up and developing methods for calibration of the WEST network.

Data systems, data acquisition and recording, and techniques of maintenance, automation, etc., are also part of JPL's strength, derived from years of experience in aerospace and energy programs.

<u>Small Community Solar Experiment Data Acquisition System</u>

The Small Community Solar Experiment (EE1) is designed to examine the operation of a solar thermal electric plant in a small community electric grid network. The experimental plant will consist of units that concentrate solar energy and drive an electric generator with an organic Rankine engine. Each unit consists of three main components: a parabolic focusing dish; a receiver, and an engine/generator. The design calls for replication of the units to yield a plant size in the one megawatt range (about 55 units). Although final site selection has not been made, six candidate sites were judged to be in the competitive range. The sites selected are in Arizona, Hawaii, Kansas, South Carolina, South Dakota, and Washington.

Since assessment of insolation at each site is crucial to performance evaluation and plant operation, an instrument data collection package was designed and will be fabricated at JPL, and then deployed at each site. The purpose will be to gain a greater understanding of the insolation resource at the prime site and the additional sites. Each package will consist of instruments to measure, at five minute intervals, direct normal and total horizontal radiation, ambient air temperature, dewpoint temperature, and wind speed. A reference cell may be added to the package to measure short circuit current. All instruments will be driven by a microprocessor that will turn the system on and off, collect data, and communicate with a central data acquisition system at JPL. The unit at JPL will consist of a microprocessor that will poll the sites at regular intervals, transmit the data via phone link and store the data on floppy disk. The central unit will also be able to monitor the data acquisition system in real time, and provide for monitoring at frequencies of 6 samples per minute. In addition to the microprocessor design currently underway, the feasibility of constructing a low cost mechanical automatic tracker is under evaluation.

Current program plans call for measurements to continue for a minimum of two years. Instrument packages will be maintained and cleaned each day by on-site personnel and instrument calibration will be performed by laboratory personnel during the period of observation.

Recent Publications

Several technical reports dealing directly with insolation assessments were published by JPL during FY'80. Summaries of the reports follow.

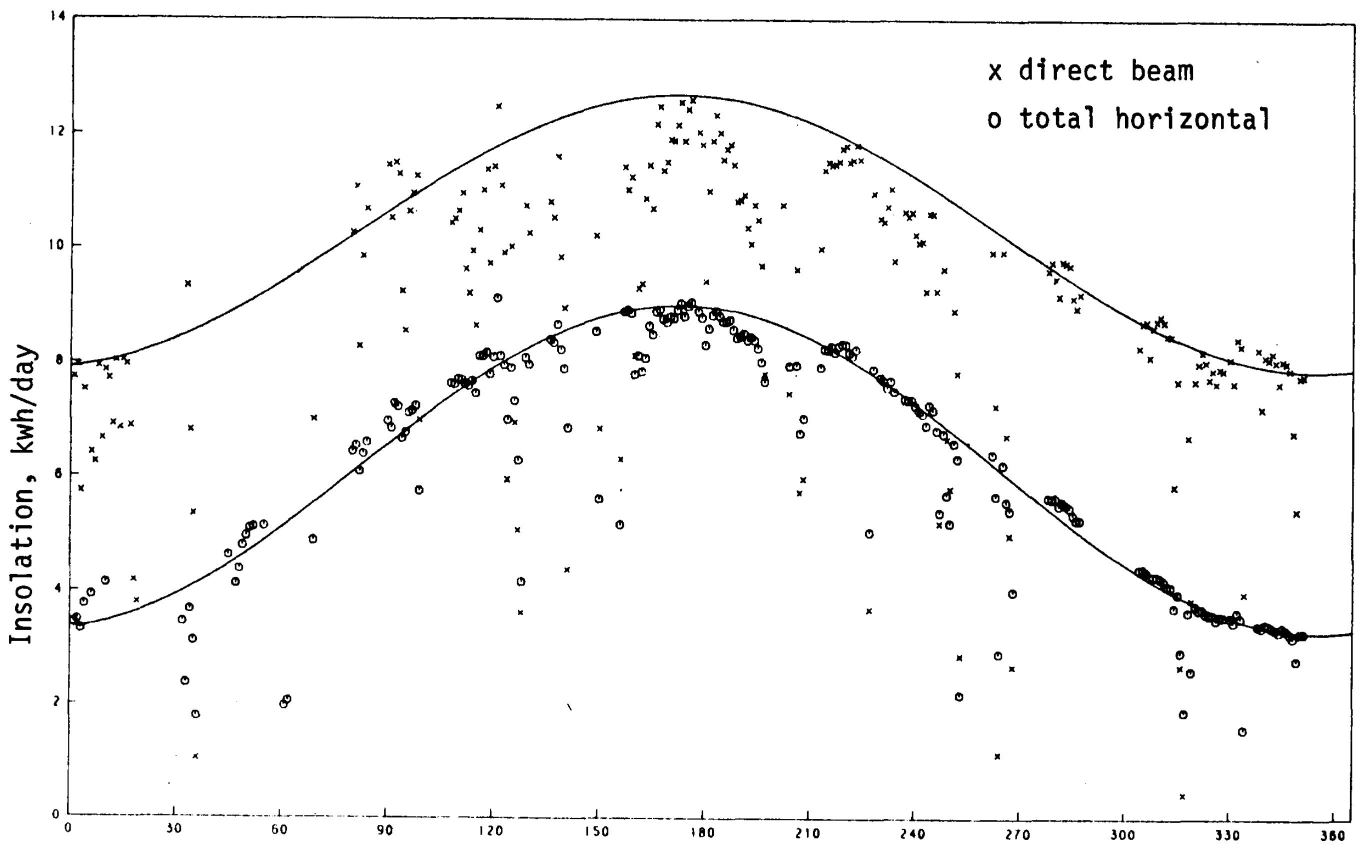
A Low Cost Solar Array project publication (LSA 510-153) discussed reduction and analysis of the 1976 insolation data recorded at the Goldstone site. The year 1976 was selected for initial data reduction and analysis because the 1976 Barstow (WEST Associates) data are being used in numerous solar energy system performance evaluations at the lab. To determine the sensitivity of a particular solar energy system performance model to insolation variations (the 1976 Barstow data are suspect because that year may be atypical), a comparison study of the Barstow data with Goldstone data was made. The two sites approximate the same climatic and weather province, although the Goldstone site is located at a slightly higher elevation and is not as susceptible to advection of polluted air from the Los Angeles basin as is the Barstow site (located along the Mojave River wash).

Data from two Kendall pyrheliometers and two Spectrolab pyranometers were reduced and analyzed. Data from each of the two instrument pairs were then averaged. Figure 1 shows the daily plots of total horizontal and direct normal insolation (each value is the average of two instruments). For those days on which good data were collected (i.e., no system failure or inclement weather) comparisons with the Barstow data were made.

Comparisons between Goldstone and Barstow data collected over an 18 day period in 1978 are shown in Table 1. As the data indicate, values from the two sites agree remarkably well. The closeness of the values is all the more remarkable when consideration is given to the fact that different instruments are used, calibration and operation, and maintenance protocol are not consistent with one another. Values from Goldstone are greater than those from Barstow because, in part, Goldstone is approximately 1,320 feet higher than the site in Barstow.

Unfortunately, the critical question about data quality can not be satisfactorily answered. The analysis only indicates that data from the two sites are in close agreement. Whether the data are all good, or whether they are all marginal, could not be determined.

A three volume Handbook of Solar Energy Data (DOE/JPL-1010-25; LSA 5101-



Daily Insolation, Goldstone, 1976

Figure 1

	Global			Direct		
Day No.	G'stone	Barstow	B/G	G'stone	Barstow	B/G
206	7.978	7.868	.986	9.650	9.459	.980
213	7.944	7.875	.991	10.011	9.721	.971
214	8.260	8.135	.985	11.384	11.103	.975
215	8.251	8.094	.981	11.523	10.954	.951
216	8.306	8.033	.967	11.476	10.486	.914
217	8.212	8.072	.983	11.486	11.036	.961
218	8.311	8.066	.971	11.535	10.863	.942
219	8.352	8.089	.969	11.758	11.092	.943
220	8.342	8.094	.970	11.808	11.110	.941
221	8.202	7.934	.967	11.526	10.651	.924
222	8.148	8.029	.985	11.563	11.170	.966
223	8.256	8.079	.979	11.820	11.166	.945
228	7.914	7.518	.950	10.978	10.096	.920
230	7.769	7.550	.972	10.544	9.987	.947
231	7.708	7.441	.965	10.479	9.248	.883
232	7.586	7.469	.985	10.745	9.949	.926
233	7.709	7.486	.971	11.058	10.575	.956
234	7.519	7.210	.959	9.800	9.289	.948

Daily Insolation at Goldstone and Barstow 1976 (kwh/m^2)

Table 1

91) was recently released for distribution. The handbook provides estimates of average available insolation to fixed, flat-plate, south-facing collector surfaces at various tilt angles for a variety of specific sites in the United States. The three volume set provides average daily, total insolation estimates, by month and annual totals, in addition to the daily profiles by hour that were used to compute the daily totals.

A model that estimates direct, diffuse, and reflected components of total insolation on an hourly, daily, and monthly basis is also given.

It is hoped that the data will be used in a variety of solar energy system performance evaluations.

Average Daily and Annual Direct Normal Insolation Estimates for the United States are published in JPL document 5105-42. The estimates were generated using a modified Liu and Jordan procedure and input data compiled from the Solmet base. A computer simulation program was used to estimate average hourly values; these values were then aggregated to average day totals. The data were calculated to support evaluation of proposals submitted for the Small Community Solar Experiment (EE1), the one megawatt solar thermal electric facility. Direct normal radiation resource was one of ten criteria used for technical evaluation of the proposals.

The publications are available from the Jet Propulsion Laboratory.

Insolation Special Interest Group

Because of the wide variety of insolation related activities at JPL, the Solar Energy Program Office has allocated funds to form an insolation Special Interest Group. The primary objectives of the group are to:

1) provide a forum for effective communication among individuals on lab who are engaged in some facet of insolation research or in the use of insolation data;
2) insure that information is freely and effectively exchanged;
3) provide timely and accurate recognition of insolation related technical issues that develop between different task areas at JPL;
4) to insure effective coordination of parallel research and a minimum of duplication.

To meet these goals the group sponsors periodic technical and programmatic seminars by individuals at the lab, and encourages participation by speakers from off-lab. A randomly published newsletter, Friends of Langley, is distributed at JPL and to several individuals off-lab.

Solar Energy System Performance and Air Pollution

A study to evaluate effects of air pollution on solar energy system performance has been initiated at JPL. The emphasis of the study is to identify those natural and anthropogenetic factors that can influence the siting of solar energy conversion systems, especially of concentrating options. Since pollution has temporal and spatial preferences in any specific region, one area within that region will be more or less favorable to siting of a system than another one within the same region.

To examine the potential effects of polluted air on system performance, 1979 data from Alhambra, CA, within the Los Angeles basin, were obtained from the WEST Associates (Southern California Edison Office). These data were then analyzed to assess the impact of the aggregate of photochemical smog, haze and smoke on the receipt of direct normal radiation. Comparisons of highly polluted days in September were compared to radiation values measured during extremely clear weather in February. The period in September that was evaluated was classified by the State Air Resources Board and local Air Quality Management District as the worst episode of ozone concentrations in 25 years.

Even allowing for the uncertainties in specific atmospheric conditions that existed between the control dates in February and the smog dates in September, the reduction in direct normal values was impressive, in excess of 20%. The effects of this reduction are significant in terms of solar energy system performance because, according to some system performance models (e.g., SES II solar thermal model), there is approximately a one-to-one correspondence between cost of energy output and insolation input, at least as evaluated from a specific base level (a stand alone plant with storage). In cases where there is no backup storage, and thus more sensitivity to insolation variation, the reductions in insolation levels cause plant unit energy costs to rise higher than a one-to-one rate. The Small Community EE1 project mentioned earlier has no external storage so implications for site selection activities are obvious.

Effects of air pollution on system performance are still under evaluation. As data from test sites in the Los Angeles Basin and Mojave Desert, and pollution data collected by state and local agencies become available, a more sophisticated analysis will be undertaken in which spectral irradiance variations on photovoltaic cells will be examined.

SOLAR ENERGY RESOURCE ATLAS

Donald Wright
EG&G
Los Alamos, N. M.

BACKGROUND

Since I last spoke to you, the Solar Energy Resource Atlas has been completed. All maps, graphs, and tables have been delivered to SERI for final review and I am delivering the final text today. The final microfiche will be delivered at a later date.

In October of 1978, EG&G/Los Alamos began to work on the Solar Energy Resource Atlas. The target date for completion was January 1, 1980. Errors in threshold parameters and the difficulty in producing the contour maps kept us from making final delivery until June 1980.

At the last contractors meeting, I showed the final list of parameters and presented some preliminary contour maps of the Solar parameters. These contour maps were not acceptable. We decided to try an experiment in which we changed three of our available options:
1) The number of stations from which data was used to produce the contours
2) The interval between contours
3) The grid size used for interpolation
We found that the most significant change was produced by varying the number of stations used. The "best" contours were produced using 118 stations. The distribution of the stations is such that we used more of the coastal and mountain stations than plains stations. An example is given below along with a contour map generated by NOAA (see Figures 1 and 2). We believe the areement is quite good.

We anticipate that the Solar Energy Resource Atlas will be of value to scientists, engineers, government and industry planners, and the concerned lay public. It will be a necessary and valuable tool in planing the Nation's response to its energy problem through the use of solar energy.

I would like to thank the many people, both at EG&G and other agencies, who contributed to this effort.

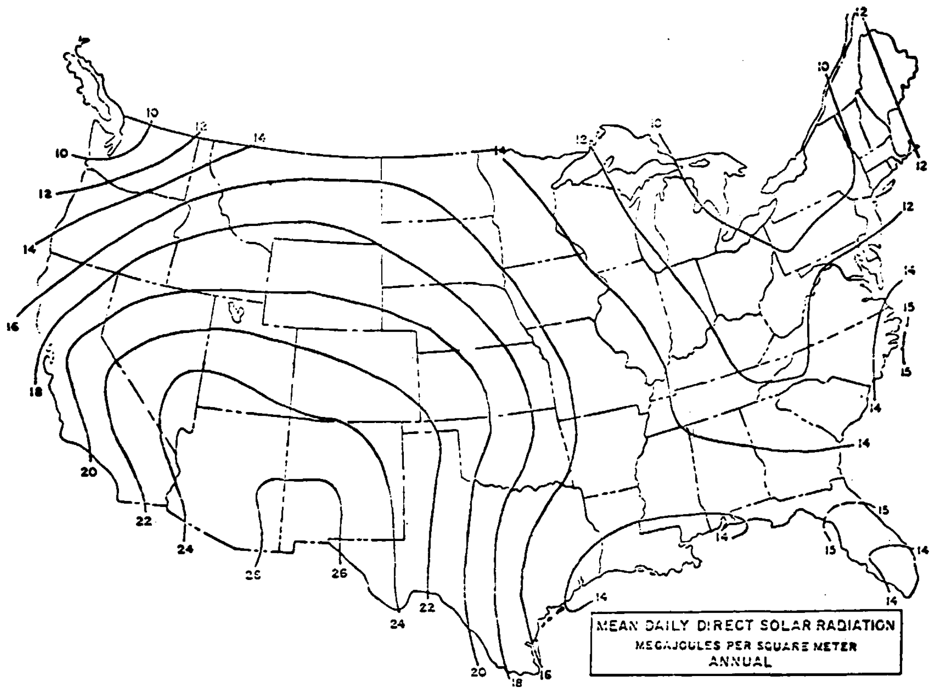


Figure 1. NOAA-Produced Contour Map.

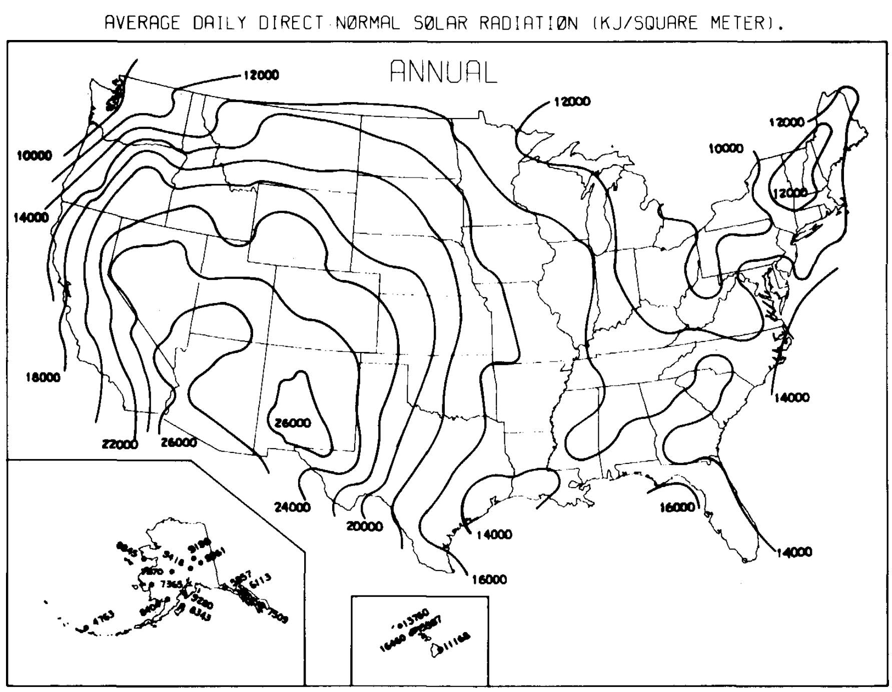


Figure 2. EG&G-Produced and Enhanced Contour Map

SITE INSOLATION AND WIND POWER CHARACTERISTICS

Roger E. Bray
Principal Investigator

Northrop Services, Inc.
Huntsville, Alabama
Contract No. DEAC01-77ET20160
Start Date: June, 1977
End Date: August, 1980

BACKGROUND

Design and operation of solar and wind energy conversion systems should be based, in part, on knowledge of expected solar and wind power trends at a proposed site. This study was initiated to provide empirical statistical information at certain selected sites on the occurrence and persistence of selected daily average solar and wind power conditions. An inference of the chance of having similar conditions in the future is provided from these type data.

Historic surface meteorological and solar radiation data, combined into a common format called SOLMET, are available from the National Oceanic and Atmospheric Administration (NOAA). Solar radiation data recorded at 26 sites for nearly 24 years were rehabilitated by the NOAA National Climatic Center and combined with surface meteorological data on magnetic tape. In addition to these, 75 sites were selected which had derived (regression modeled by NOAA) hourly solar radiation data included with surface meteorological data on tape. The total base then consisted of 101 sites for this analysis.

Empirical probabilities were constructed from the historic data to provide estimates of daily average insolation and daily average wind power, independently and jointly, occurring and persisting at or above specified thresholds for up to one week. Probabilities were also constructed for solar and wind power below the same thresholds. Diurnal wind power variations were also obtained. The basis of this effort was previous work by Carter and Graves (Ref.'s 2 and 3) in determining frequencies of occurrence of weather events. As in those studies, the term probability was also used here to mean the straightforward empirical probability obtained using the frequencies of occurrence of climatological variables. In addition, joint probability distribution tables were constructed to show the proportion of days that have wind and solar power within defined intervals. Finally, ratios were constructed for each station to relate global horizontal insolation to insolation on an inclined south-facing surface. Summary results were generated by combining into monthly averages data used in constructing the above mentioned empirical probabilities.

DESCRIPTION

Hourly solar radiation and wind speed data from the SOLMET tapes are used to derive daily average insolation and daily average wind power.

Wind data are considered on a daytime, nighttime and total day basis. Insolation data are global radiation data incident on a horizontal surface and are obtained from the Standard Year Corrected tape field (Ref.'s 4 and 5). Wind speed data from tape are ajusted to a common 10 meter height above the local terrain. The adjustment is made using the one-seventh power law due to the typically airport environment of the SOLMET stations. Sample calculations allow the basic comparison of the energy per unit area of wind perpendicular to the air flow and solar radiation on a unit area of horizontal surface. Both energy forms can be expressed in watts per square meter. The amount of wind power contained in the wind is obtained using the expression one-half the air density times the cube of the wind speed. Wind speeds below 1.6 m/s are considered to produce no wind power, and wind speeds above 14.2 m/s are set to 14.2 m/s to eliminate biasing daily averages when unusually high or gusty winds are observed. Thus, power contained in the wind is treated as a meteorological parameter and the problems of recovery, efficiency, etc., are left to the user.

Statistical data in the form of empirical probabilities are derived, essentially, by counting the number of occurrences of a specified insolation/wind event being satisfied and dividing by the total number of observations. The basic unit of time is the day. Empirical probabilities are constructed, by month, for daily average values of insolation and wind power, independently and jointly, equaling or exceeding each of several thresholds for successive days of up to one week. Probabilities below the thresholds are also obtained. Possibilities of occurrences are investigated into the next month to eliminate end-point problems and keep the sample size the same for each successive day string being considered. Persistence of an event for n days is taken to mean that an event continues to occur for n-1 days after it occurred the first day. It is constructed by dividing the probability of the event for n successive days by the probability of the event initially, meaning one day. These data are available from the successive day probabilities. Diurnal wind power statistics are derived using sunrise-sunset information based on the 15th of each month.

In addition, ratios are provided for relating global horizontal insolation (as recorded historically) to insolation on an inclined south-facing surface at each site. Joint probability distribution tables are also generated to show the proportion of days that have wind power and insolation within defined intervals. Finally, summary results are formed from the above data to provide monthly, seasonal and annual averages.

SUMMARY OF RESULTS

The study has been completed and is expected to be published by DOE in mid-October (Ref. 1). The study objective was threefold. One, to provide probability estimates of insolation and wind power, alone and in combination, occurring and persisting at or above (and below) specified thresholds for up to one week. Two, to provide probability distributions of the joint occurrence of wind power and insolation within selected intervals. And, three, to provide a means of relating horizontal insolation to insolation on an inclined surface. Specific results are delineated below using Dodge City, Kansas as the sample site.

Empirical probabilities were generated, by month, for daily average insolation, wind (day), wind (night) and wind (total day) each, independently, equaling or exceeding 5 thresholds. These probabilities were constructed for the chance of the events occurring at or above, and below, each threshold for 1, 3, 5 and 7 successive days at any time during each month. The thresholds selected for insolation are the same for each site. Wind power, however, varies considerably and three sets of wind power thresholds are selected by classifying a site as a high, moderate or low wind area. Shown in Table 1 are the successive day probabilities for insolation, independently, for the month of July. Note that there is a 90% probability of insolation being at or above 120 watts/m^2 for 5 successive days, and a 8% probability of having less than 300 watts/m^2 for any three-day period. Similar data are constructed for all months and arranged in a calendar type format. The same format is used for wind data, which are shown in Table 2. For the joint solar and wind probabilities different thresholds are selected since all permutations of three thresholds each are considered. Sample data for the joint combinations are shown in Table 3, for successive day occurrences, in a format similar to those above. Note, for example, that the probability for insolation at or above 150 watts/m^2 when wind power is at or above 100 watts/m^2 for 3 successive days is 28%.

Probabilities were generated, by month, for the insolation and wind variables each, independently, persisting for 2, 3, 5 and 7 days at or above, and below, each of five thresholds. These are the n-day probabilities for the chance, that once an event has satisfied a threshold during a month, it will continue to do so for n-1 additional days. Data were generated in formats similar to those shown above. An example for probabilities of persistence for insolation is shown in Table 4 for the month of July. Similar tables were again generated for wind power, and for the joint solar and wind persistence probabilities.

The distribution of joint solar and wind occurrences is of particular interest to hybrid system planning activities. Several values each for insolation and wind power are selected as interval boundaries for deriving joint occurrences. Shown in Table 5 are the proportion of days that have joint insolation and wind power within the defined intervals for the month of January at Dodge City. January was selected to show because of the large wind variability; similar data are generated for all months. The total number of historic January days available at each site is shown as total observations; days with either solar or wind missing were not counted. Note that there were 40 days where wind power was between 300 and 400 watts/m^2 when insolation was between 60 and 120 watts/m^2. Numbers of occurrences, as opposed to percentages, are given since this provides much more meaningful data to those interested in few or one-time only occurrences for certain design criteria.

A means of relating insolation to tilted surfaces was provided using the Becker and Boyd daily average data method (Ref. 6). Data were compiled in the form of ratios for multiplying historically recorded insolation values (which are related to the local horizontal) to obtain estimates of insolation available on south-facing inclined surfaces. Five different tilt angles were selected. The method is based on clear-sky conditions, and the ratios at each site for each month are secured for the 21st day of the month. Ratios for other tilt angles, or different days if desired, can be obtained from interpolation. An example of the tilt ratio data is shown in Table 6 for a few months.

Summary results of monthly average values of daily average insolation and daily average wind power are derived from the data used to construct the above discussed probabilities. Data are combined to show seasonal and annual trends in addition to monthly averages. Daily average data presented in this manner are consistent with publications by NOAA and others. Monthly and annual average solar and total wind power data are derived, by site, on maps of the U.S. as an overview of nationwide power variability. Maps are constructed by month to show daily average power in watts/m^2. Presented in Figure 1 is the map of annual average data at each of the SOLMET sites selected for the study reviewed here. At each site the upper number is insolation and the lower, in italics, is wind power. These data are also plotted, together with diurnal wind power, by month (and annual) at each site. A sample plot is shown in Figure 2 for Dodge City. At most sites daytime wind is greater than nighttime wind annually; however, nighttime winds are usually higher in the winter months. (Roman numeral XIII indicates the annual averages.) The sum of insolation and wind power is shown to indicate total available combined energy. Seasonal solar and wind data at each site were also prepared by combining the monthly data. After including diurnal wind power variations, seasonal and annual insolation and wind power data are presented as shown in Table 7 for all sites. Winter is defined as Dec, Jan, Feb, etc. Average wind power is generally lower in summer than for any other season.

REFERENCES

1. Site Insolation and Wind Power Characteristics, U.S. Department of Energy, Washington, D.C., to be published.

2. Carter, E. A., "Basic Relationships to Determine Wind Power and Solar Radiation Available from the Atmosphere", Proceedings of the Second Southeastern Conference on Applications of Solar Energy, Baton Rouge, Louisiana, ERDA CONF-760423, April 19-22, 1976, pp. 381-389.

3. Graves, M. E. and Carter, E. A., "A Procedure and Computer Program to Interrogate Weather Records and Infer the Probability that Combinations of Weather Criteria will be Satisfied", Northrop Services, Inc., Huntsville, Alabama, Technical Report, TR-230-1369, November 1974.

4. SOLMET, Volume I-User's Manual, "Hourly Solar Radiation-Surface Meteorological Observations", National Climatic Center (NOAA), TD-9724, December 1977.

REFERENCES (Continued)

5. SOLMET, Volume II - Final Report, "Hourly Solar Radiation-Surface Meteorological Observations", National Climatic Center (NOAA), TD-9724, February 1979.

6. Becker, C. F. and Boyd, J. S., "Solar Radiation Availability on Surfaces in the United States as Affected by Season, Orientation, Latitude, Altitude, and Cloudiness", Journal of Solar Engineering, Science & Engineering, VI, January 1957.

Table 1. Probability (%) of insolation being above, and below, selected thresholds for up to 7 successive days.

THRESHOLD	JULY							
	.GE. THRESH				.LT. THRESH			
	DAYS				DAYS			
	1	3	5	7	1	3	5	7
60	100	99	99	98	0	0	0	0
120	98	93	90	86	2	0	0	0
180	94	84	75	67	6	0	0	0
240	85	64	48	35	15	1	0	0
300	66	35	18	9	34	8	3	0

Table 2. Probability (%) of wind (total) being above, and below, selected thresholds for up to 7 successive days.

THRESHOLD	JULY							
	.GE. THRESH				.LT. THRESH			
	DAYS				DAYS			
	1	3	5	7	1	3	5	7
80	70	40	23	13	30	7	2	1
140	46	16	6	2	54	25	12	6
200	28	7	2	0	72	46	31	22
260	17	3	1	0	83	65	53	45
320	10	1	0	0	90	79	72	67

Table 3. Probability (%) of comb. insol-wind (total) being above, and below, selected thresholds for up to 7 successive days.

THRESHOLD	JULY							
	.GE. THRESH				.LT. THRESH			
	DAYS				DAYS			
I / W	1	3	5	7	1	3	5	7
50/100	62	30	15	8	0	0	0	0
50/200	28	6	2	0	0	0	0	0
50/300	12	1	0	0	0	0	0	0
150/100	60	28	15	8	2	0	0	0
150/200	28	6	1	0	4	0	0	0
150/300	11	1	0	0	4	0	0	0
250/100	53	21	10	4	8	0	0	0
250/200	24	4	1	0	12	1	0	0
250/300	10	1	0	0	15	1	0	0

Table 4. Probability (%) of insolation persisting above, and below, thresholds for up to one week.

THRESHOLD	JULY							
	.GE. THRESH				.LT. THRESH			
	DAYS				DAYS			
	2	3	5	7	2	3	5	7
60	100	99	99	98	0	0	0	0
120	98	96	92	88	5	0	0	0
180	94	89	79	70	7	1	0	0
240	86	75	56	41	22	3	0	0
300	72	51	27	13	46	21	7	1

Table 5. Joint probability distribution of insolation and wind power (total) — Dodge City, Kansas.

```
        JAN                      TOT OBS=712

>360-:---:---:---:---:---:---:---:---:
     :  0:  0:  0:  0:  0:  0:  0:  0:
I 360-:---:---:---:---:---:---:---:---:
     :  0:  0:  0:  0:  0:  0:  0:  0:
N 300-:---:---:---:---:---:---:---:---:
     :  0:  0:  0:  0:  0:  0:  0:  0:
S 240-:---:---:---:---:---:---:---:---:
     :  0:  0:  0:  0:  0:  0:  0:  0:
O 180-:---:---:---:---:---:---:---:---:
     : 95: 81: 37:  9:  9:  3:  2:  2:
L 120-:---:---:---:---:---:---:---:---:
     :124: 97: 61: 40: 18:  9:  6: 15:
   60-:---:---:---:---:---:---:---:---:
     : 30: 27: 18: 11:  3:  4:  2:  9:
    0-:---:---:---:---:---:---:---:---:
     0  100 200 300 400 500 600 700 >700

             WIND POWER-TOTAL
```

Table 6. Ratios to relate global horizontal insolation to insolation on a south-facing inclined surface.

DODGE CITY, KANSAS (LAT=37.77DEG)

TILT ANGLE	R A T I O					
	JAN	FEB	MAR	APR	MAY	JUN
10	1.26	1.18	1.10	1.04	1.01	.99
30	1.64	1.42	1.21	1.04	.94	.90
50	1.85	1.52	1.20	.94	.80	.75
70	1.86	1.45	1.08	.74	.59	.53
90	1.69	1.23	.83	.45	.30	.25

Table 7. Daily average insolation and wind power — seasonal and annual.

DODGE CITY, KANSAS

	WI	SP	SU	FA	AN
INSOL	110	232	289	165	199
WIND-DAY	89	165	113	105	118
WIND-NIGHT	121	110	60	88	95
WIND-TOTAL	210	275	173	193	213

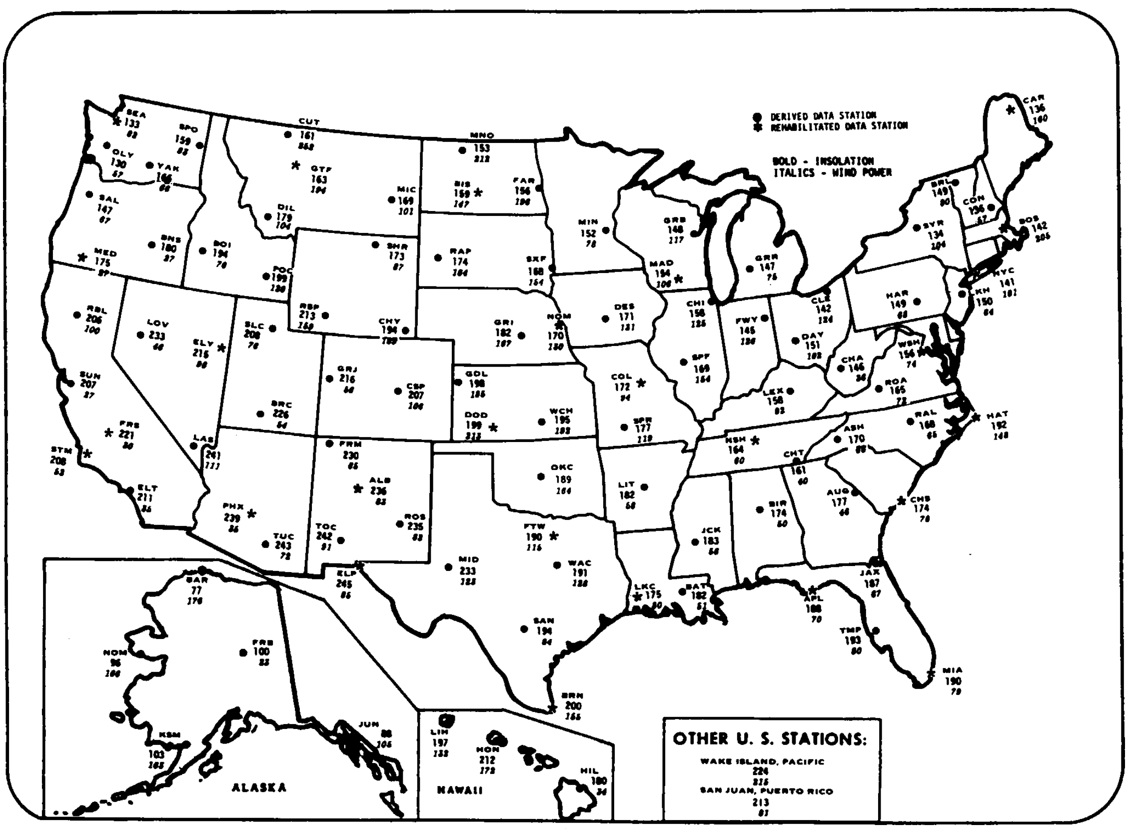


Figure 1. Available solar and wind power (watts/m^2) — annual average.

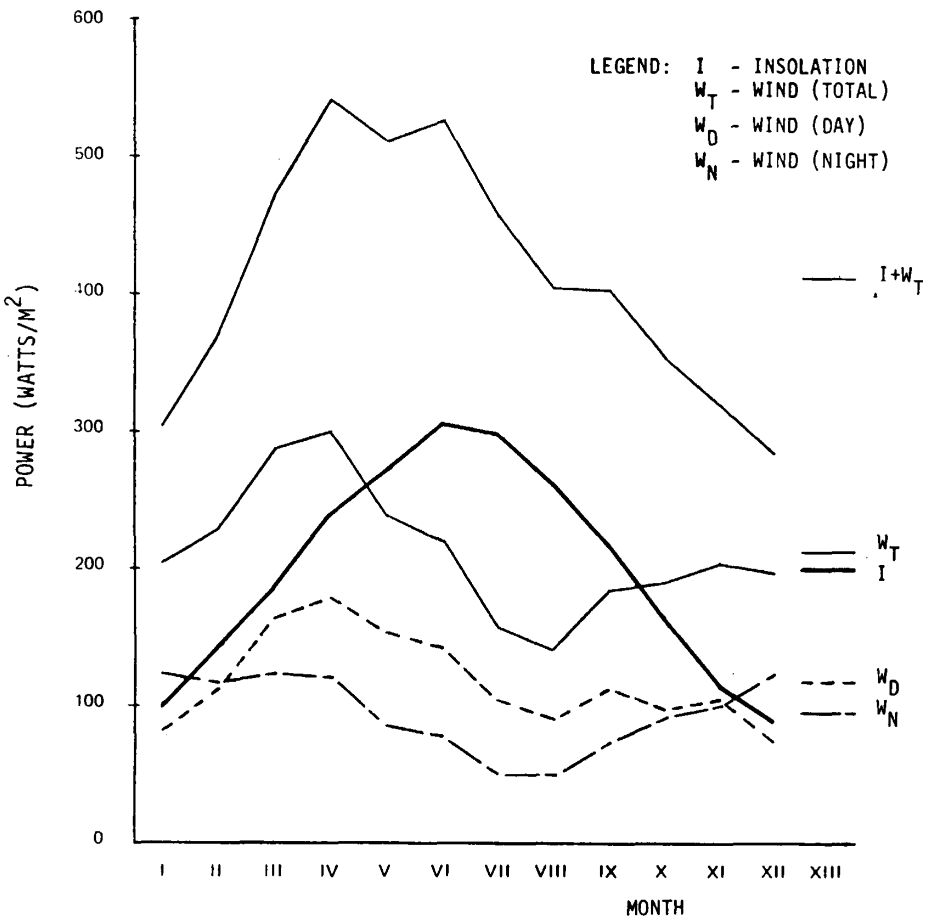


Figure 2. Daily average insolation and wind power, by month and annual— Dodge City, Kansas.