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PROCEEDINGS

The Second National Solar Radiation Data Workshop

The ERDA Division of Solar Energy
and
The State Energy Offices
Skyland, Virginia; September 26-28, 1977

November 1977

Co-Sponsored By:
THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION AND THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Prepared under contract NOAA 03-7-022-35210
by

The Kenneth E. Johnson Environmental and Energy Center
The University of Alabama in Huntsville
P. O. Box 1247
Huntsville, Alabama 35807

Mn only

DISCLAIMER

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PREFACE

The Second National Solar Radiation Data Workshop was held at Skyland, Virginia, September 26-28, 1977, sixteen months after the first workshop held in Huntsville, Alabama.

This Second Workshop was co-hosted by the Energy Research and Development Administration (which became part of the Department of Energy on October 1, 1977) and the National Oceanic and Atmospheric Administration. Proceedings of the workshop were prepared by the Kenneth E. Johnson Environmental and Energy Center (JEEC) at the University of Alabama in Huntsville. The proceedings consist of an executive summary and a reproduction of all available papers presented at the workshop.

The executive summary consists of the opening remarks, the complete reports of the workshops, and concluding remarks by Fred Koomanoff and Dr. Lester Machta. It was published in November, 1977, and sent as a separate document to all attendees.

David L. Christensen
University of Alabama in Huntsville

NOTICE

ACRONYMS

ASRC	Atmospheric Sciences Research Center (SUNYA)
BNL	Brookhaven National Laboratory
CEDDA	Center for Experimental Design and Data Analysis (NOAA)
CWS	Canadian Weather Service
DOE	Department of Energy
EDS	Environmental Data Service (NOAA)
ERDA	Energy Research and Development Administration
FAA	Federal Aviation Agency
HUD	US Department of Housing and Urban Development
JEEC	Johnson Environmental and Energy Center (UAH)
LST	Local Standard Time
MSFC	Marshall Space Flight Center
NCC	National Climatic Center (Asheville NC)
NOAA	National Oceanic and Atmospheric Administration
NWRC	National Weather Records Center
SCE	Southern California Edison
SUNYA	State University of New York, Albany
TST	True Solar Time
UAH	University of Alabama, Huntsville
UD	University of Delaware
UNM	University of New Mexico
WEST	Western Energy Supply and Transmission Associates
WMO	World Meteorological Organization

OPENING REMARKS

Frederick Koomanoff, DOE (ERDA)

It is a pleasure to meet with many of you again and to see new faces as well for the Second National Solar Radiation Data Workshop. I would like to set the background as to where we have been, where we are going, and what we hope to accomplish in the next two days of discussions. First, I would like to give you my version of how people look at solar energy. Second, I would like to discuss as best I can the concept of the new organization of the Department of Energy (DOE). The Energy Research and Development Administration (ERDA), my former organization will be discontinued at the end of this week, and next week all of our functions will be undertaken by DOE. However, I must report that our organizational future is not clear at this time. And third, I would like to review what happened in our first solar radiation data conference in Huntsville in May, 1976, and to recap the actions taken, the actions that were left over, and those which are facing us today.

We are approaching a momentous decision for the future of solar energy and perhaps mankind. For the first time since our pioneering days, we have an opportunity to decentralize a major energy source. We also have the opportunity to capture that energy source in a massive satellite program. Confronting DOE and the American people today is the decision of whether to place major emphasis on satellite power stations in orbit about Earth or whether to put it on decentralized use of solar energy on Earth's surface. Perhaps the best, or at least a third, approach is some combination of these two approaches. Millions of dollars have already been spent on these concepts; at this point, of course, there is no such satellite and only a very, very limited amount of decentralized solar energy.

Solar energy has a much wider potential and application than providing just heating and cooling. It can be used in fish culture; for drying cement slabs, lumber, or tobacco; in the food-processing industry; and in many other ways including the direct production of electricity. The global energy can be gathered by flat-plate collectors, or the direct solar radiation can be converted using concentrating collectors. It is the challenge to all of us to develop the most economical procedures for using solar energy to meet all of our needs to the greatest extent possible. It is interesting to realize that for the first time, it may be technically and economically feasible to have small communities with their own energy source--that is the sun.

The Environmental Resource Assessment Branch (ERAB) concerns itself with four different types of assessments. They are resource, materials, ecology, and social, political and institutional factors. All of these are interrelated, and all of them must be kept in mind in the projects we undertake.

We have three sub-program elements. First is data collection through NOAA and non-NOAA sources. The second is data management and processing to produce useful information for solar-energy applications. And the third is the research and analysis functions. All of these programs require awareness and cooperation, not only at the federal level but also at the state and local levels.

The new Department of Energy has its own symbol. (The DOE symbol is reproduced on the inside front cover of this summary.) Secretary Schlesinger has been confirmed to fill the top position in the DOE. The DOE is much larger and more complex than the ERDA was. There are three Assistant Secretaries. One supervises the four DOE field laboratories located in Oregon, in Oak Ridge, the Pacific Northwest Laboratories, and the Solar Energy Research Institute in Colorado. The other two are an Assistant Secretary for Energy Technology and the Assistant Secretary for Conservation and Solar Applications.

The Solar Division will operate with some functions under each of these Assistant Secretaries. The Secretary for Energy Technology (ET) will be responsible for mid- and long-term energy technology research and development, emphasizing the other than immediate problems. He will be responsible for R&D for solar, geothermal, fossil, nuclear and fusion programs. The Secretary for Conservation and Solar Applications will start immediately with massive conservation programs in the fields of transportation, building, community systems, industry, commerce, utilities and others. This will help to maintain current solar commercialization studies, perform the solar heating and cooling of buildings program, and conduct the solar-agricultural/industrial-heat process program.

When an energy technology reaches the point of commercialization, functions will then be assumed by the Assistant Secretary for Conservation and Solar Applications. He will launch massive demonstration programs towards that end which will help to bring the technology into the marketplace. Established interfaces with society will be used by this unique organizational structure which had not previously been anticipated for DOE.

We do not know how all the 10 billion dollar budget of DOE will be allocated, but we do know how some of it will be spent. Conservation and solar applications will have 4% of the budget; energy technology, 25%; and environmental, 3%. That is about all of the information that is now available.

The primary responsibilities for Resource Applications are to develop and implement voluntary and incentive programs for increasing domestic supplies of petroleum, natural gas, coal and uranium, and to perform production and marketing of energy resources. The department also manages DOE aspects of federal energy resource leasing procedures, including promulgation of regulation as far as leasings are concerned. It also administers assigned regulatory programs and conducts energy supply commercialization activities.

To summarize within the DOE as it is now conceived, programs will start with research and development, proceed in the development stages to commercialization, and then move on to the regulatory stages.

Now, to review some of the items which transpired at the first solar radiation data meeting in Huntsville in May, 1976: action items at the federal level which have been accomplished as of this date include the establishment of a 35-station network, which was commissioned in January of this year. Two additional stations have now been added for a total of 37. The stations are undergoing growing pains and are being expanded to include pyrheliometers, but it will be a very good basic network. To supplement it, we have identified about 25 more stations and may increase them to 60 or more in order to improve on the density of the network.

We also have selected 6 meteorological research and training sites within the contiguous United States, in addition to one each in Alaska and Hawaii. More information about these will be presented during these meetings.

A catalog of data locations has been published encompassing those data which are archived at Asheville, NC, as well as identifying locations where data are available but not archived at Asheville. A catalog of solar radiation measuring instruments has also been printed, and the Network Design Handbook and related guidelines is in preparation. Criteria for solar radiation data collection have been established and published by the National Climatic Center (NCC). They have been separated into three classes for acceptance. A calibration center has been established and is in operation at Boulder, CO, operated by Ed Flowers who is here today and who will describe it more fully.

Now for the state actions which were identified a year and a half ago. First was the development of state guidelines for state user developments. To my knowledge, no action has been accomplished on this. Second was the development of state resource assessment services. Again, I have no report on this, although some work has been done and we hope to hear more about that in the next two days. Third, the states have helped to identify where their solar radiation data have been taken in the past and where they are being collected at this time.

So this is where we stand on the threshold of this meeting. We hope that the next two days will inform us of what action is being taken to further these goals and to establish new ones.

NETWORK RATIONALE FOR SOLAR ENERGY NEEDS

David Christensen, Gene Carter, UAH-JEEC

The Center for Environmental and Energy Studies (CEES) of The University of Alabama in Huntsville (UAH) was renamed the Kenneth E. Johnson Environmental and Energy Center (JEEC) in March of this year in memory of the late Dr. Kenneth E. Johnson, the first Director of the Center. Some of you may recall that Dr. Johnson participated in the First National Solar Radiation Data Workshop in Huntsville in May, 1976.

Our topic this morning is Network Rationale for Solar Energy Needs. However, there may be times during this discussion that we appear to be far afield from network rationale. This is a necessary deviation because before one can consider networks seriously he must have a good background, and as much information as possible about solar radiation and solar energy, particularly users and solar-energy needs.

This morning we will briefly cover the JEEC activities since the May, 1976, workshop. We will then go into some detail on the highlights of the Network Design Handbook. Dave Christensen will address the user needs and methods of analyzing user needs. Then, we will address two subjects which we have identified that may be possible subjects for discussion and perhaps resolution at this workshop. Reports of JEEC since the last workshop include "An Executive Summary and the Complete Proceedings of the First Workshop". The executive summary number is listed as TID-21337 in the September, 1977, bibliographies from Oak Ridge. However, we are quite certain that it is not a good TID number; and we suggest calling for it by TID-27563, but a copy may have to be xeroxed for you. Copies of the proceedings to be put in the notebooks for the workshop were distributed to all participants almost a year ago. "A Listing of Solar Radiation Measuring Equipment and A Glossary" is ERDA DSE 1024-1, dated July, 1976. It is similar to the one that was passed out at the May, 1976, workshop. A glossary was added that is receiving quite a bit of attention and use. A "Catalog of Solar Radiation Measuring Equipment" was published by UAH in April, 1977. And we understand this is in the process of being prepared as a DOE document, although as yet does not have a DOE number. We have a limited number of copies with us. The catalog identifies some 130 different models or types of equipment produced by approximately 33 manufacturers. Since this document was published, three additional pieces of equipment and three additional manufacuters have been identified, and we have learned that three of the manufacturers in the catalog no longer make solar-radiation measuring equipment. Solar-radiation observation stations, including the NCC archived data and data not currently archived, were also published by UAH. We have a limited number of copies of this publication. We understand it, too, is in the process of being republished as a DOE document.

A report of digitizing solar-radiation strip-chart data was prepared. It hasn't been published and is an internal UAH report only. A brief description of what we have learned about digitizing strip-chart data is in order. Fig. 1 is a copy of a digitized strip-chart produced by computer. It is actually the computer reproduction of a strip-chart. Obviously, there is hardly any way of telling that this is any different from the original strip-chart. In the computer, time can be reversed, it can be expanded, or portions of it can be expanded to look at any portion of the trace. Data can easily be digitized by computing the area under the curve either in local standard time (LST) or true solar time (TST) and they become a versatile plot. We have identified three different methods of digitizing the strip-chart. Fig. 2 shows a precise trace and is similar to the previous chart. This trace would be as close as possible to an exact reproduction of the strip-chart. It would then be stored on tape and be available for use as required. Also, data from the strip chart would be placed in SOLMET format. The second method is called a stream mode and is a quick line representing the general

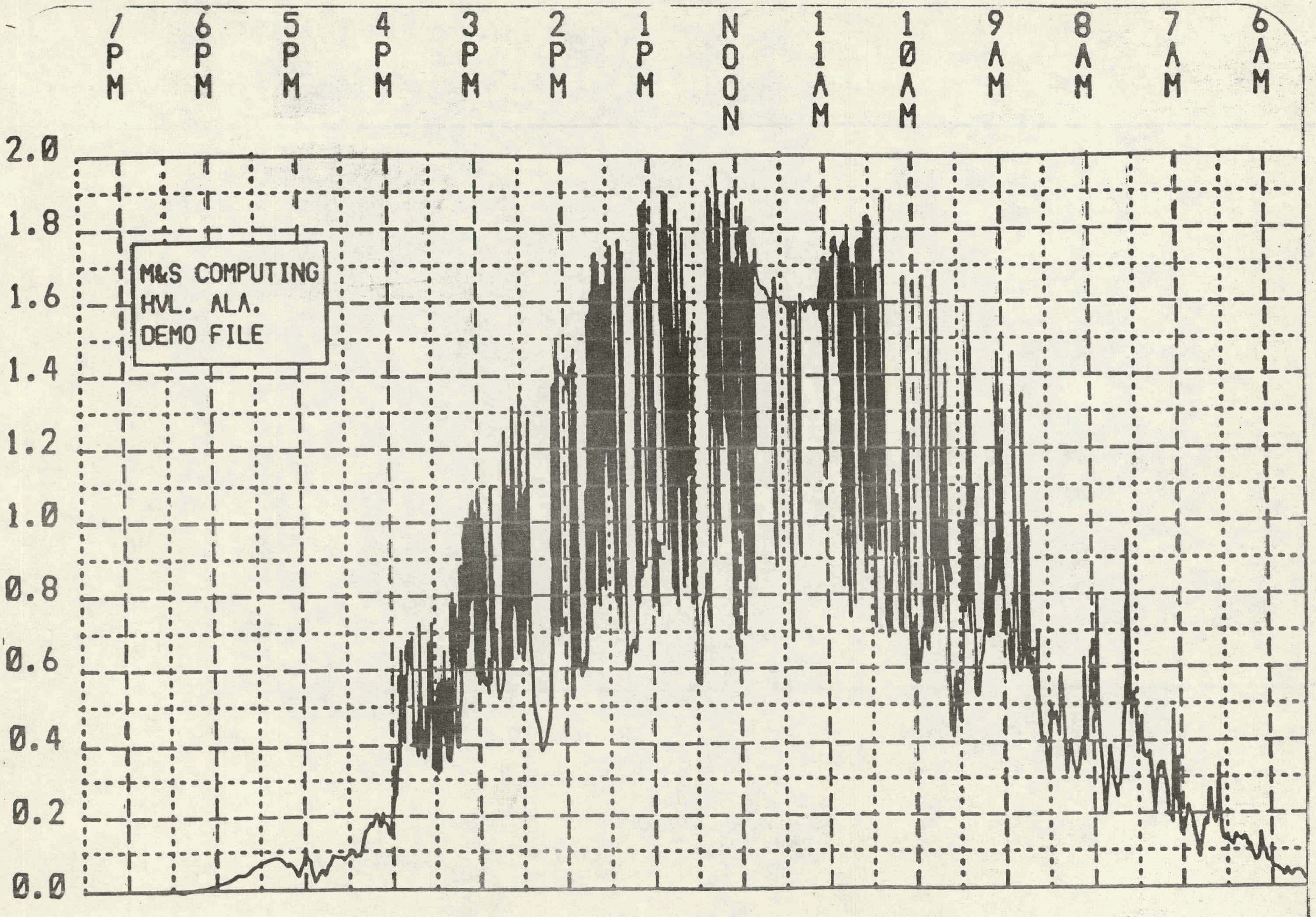


Fig. 1 19 APRIL 1973

PRECISE CHART TRACE

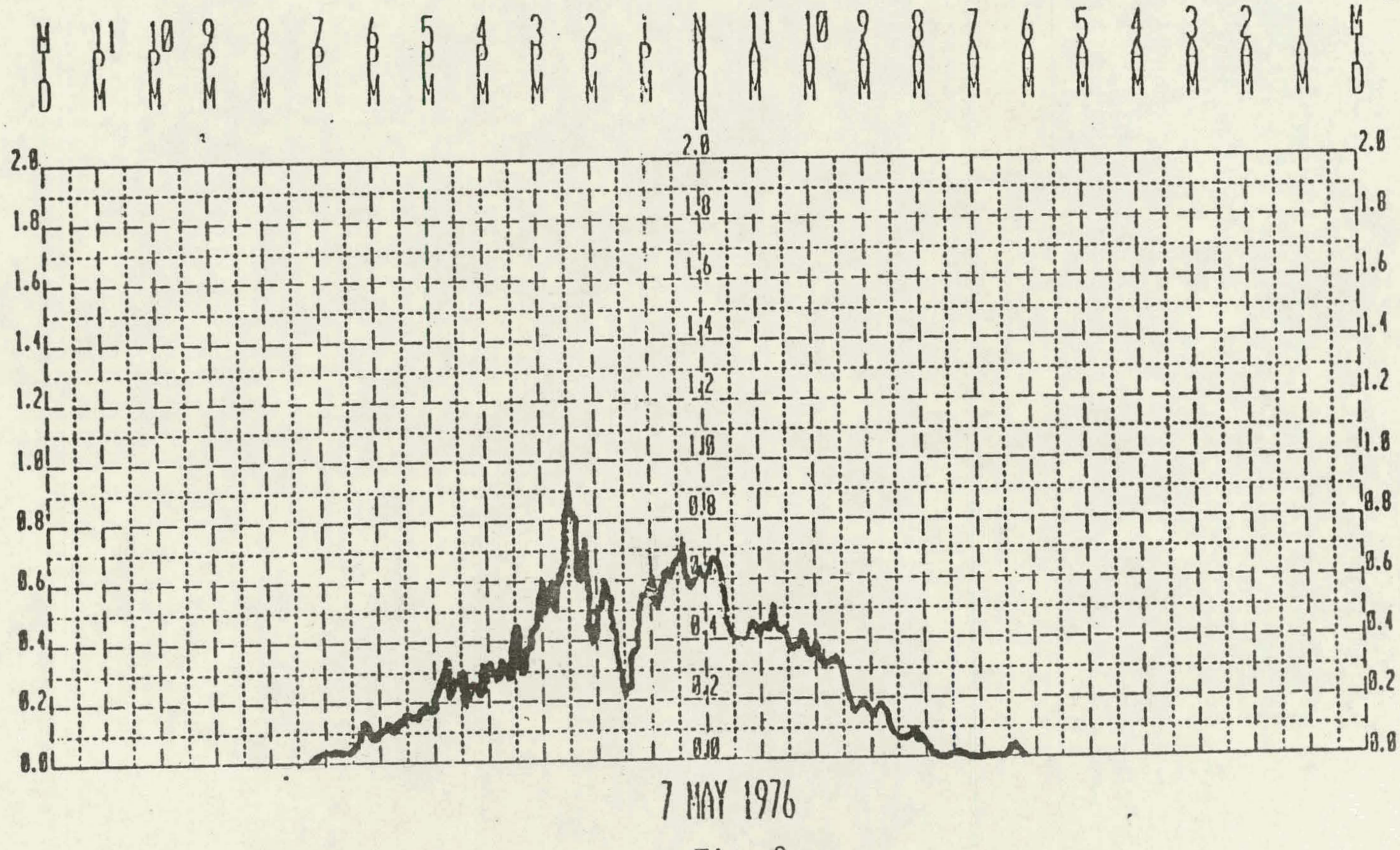


Fig. 2

M&S COMPUTING, INC.

4

features of the original strip-chart. The third method is a step mode which is similar to the manual process where each 30-min period is given a horizontal line representing the mean value for that period. Comparison of the various methods using three different days with differing amounts of radiation is shown in Fig. 3: the low-radiation day, a moderate radiation and another one which is not a clear day but a fairly good radiation day. The data are expressed in Btu/ft^2 for the day columns and in dollars for the cost column. There is very little difference in total daily values in either of the three methods. The largest variation is about 5 percent between the day-three digitized trace and the manual data. Of course, we do not know that the manual data process is accurate in itself, so we have no base line to use. We have developed certain criteria by which each method may be used to advantage. Further information about this is available from us.

The network-design handbook is in the final stages of editing, but a brief description of it is in order. It has an extensive introduction to provide the background and some of the information required before one considers a network. Also, it briefly discusses the atmospheric effects, the spectral distribution, the types of solar radiation, and the equation of time with a simple procedure for determining (TST) from sunrise and sunset tables . Additionally, the introduction includes a description of the NOAA programs with rehabilitation of the hourly data and the daily data, the new 35-station network and, as near as can be determined, additional plans that NOAA has for their data. There is also a discussion of related atmospheric data and its value and application with solar-radiation data. There is a description of solar-energy applications, including national, state and regional, power companies and private companies, which may have extensive applications for solar energy. Then, there is a description of the international data sources which are primarily the WMO and United Nations Environment Program, which has international and environmental referral

Method	Daily Radiation (Btu/ft^2)			Process Cost
	Day 1	Day 2	Day 3	
Manual Data Take-off	844	2020	2273	Not Available
Digitize: Precise Trace	837	2051	2402	10.50
Digitize: Stream Mode	859	2048	2317	5.25
Digitize: Step Mode	844	2055	2339	6.71

Fig. 3

centers throughout the world. The costs versus the number of stations is also addressed in the introduction.

Other highlights of the document are procedures for recording and collecting data network, data formats, data storage and retrieval, data summaries, and dissemination. There are references to various types of summaries which may be used as models for data utilization. There is also a discussion of economic factors, and a requirement for sustained operation of any network established.

Implementing the network requires detailed attention to subjects such as locating sites, equipment selection, installation and operation, quality control, training requirements, and costs. There is a network plan worksheet in an appendix in the document, reproduced here as Fig. 4. A description of the columns and suggested coding for the columns are included with the network plan worksheet.

We have found that there are many factors which are really not part of a network design but are valuable additional information. To avoid having the planner seek out a number of references, several appendices from them are in this document. Appendix A covers the SOLMET form and instructions and is a copy of the NCC SOLMET instructions. If SOLDAY instructions are available before publication, they also will be included in this appendix. Appendix B is an approach for evaluating the value of interpolated data between stations so that a rough determination can be made of the optimum distance between stations. Appendix C is a worksheet of instructions and a matrix of the user requirements. Appendix D offers a network plan worksheet and instructions as described earlier. Appendix E provides for instrument calibration and maintenance procedures. Appendix F covers the environmental measurements for standard solar-radiation data. Finally, Appendix G is a list of the NOAA-DOE requirements for standard solar-radiation measurements from stations other than those agencies if their data are to be archived at NCC. There probably will be an additional appendix which will list the sources of world-wide data. Dave Christensen will now address data user

NETWORK PLAN WORKSHEET

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

Fig 4.

SUGGESTED CODES FOR NETWORK PLAN WORKSHEET

Column

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

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

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

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

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

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

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

Code: H - Hourly total radiation

D - Daily total radiation

M - Monthly total radiation

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

O - Other

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

A_1 - Recorded on site

A_2 - Secured from nearby recording site (NWS)

A_3 - Other

Type of Measurements:

W_{sd} - Wind speed and direction

T - Temperature

T_H - Some humidity measurement

P - Pressure

O - Other

Fig. 4 (Cont'd)

Column

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

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

E_d - Electronic transmission daily; h - hourly.

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

Starting date and estimated ending date in month/year.

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

Indicate source of funds and periods funds are available.

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

Indicate the initial and continuing training requirements for sustained operation.

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

S_m - Coded in SOLMET format and stored at NCC.

S_d - Coded in SOLDAY format and stored at NCC.

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

C_n - Consolidated as network data.

O - Other

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

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

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

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

Fig. 4 (Cont'd)

requirements and then offer a summary of apparent needs, which may be a challenge to this workshop.

First, let me describe the needs of data managers and users, in general, and then move along into a rationale for developing solar-radiation data networks based on a systematic procedure for evaluating and meeting the needs of users.

Data managers need to identify their program management and user requirements; then, they need a definition of overall systems criteria to assure that all program factors are carefully evaluated. Standardization of terms, the formats and the definitions for the data are likewise necessary for the effective development of the overall system. Users generally require rapid gathering, processing, and dissemination of data as well as the identification of required funds and types of expertise required to realize maximum benefits.

An in-depth evaluation of the user requirements of solar-radiation data identifies the following needs, particularly during the initial design phases:

> First, is the location and classification of both data and users. The users must be identified and procedures established to meet their requirements—though not necessarily through the use of a new network program, but possibly the application of alternate methods. If a new network is required, it should be evaluated on considerations such as: a clear solar path at all seasons, availability of facilities and trained personnel, prospects for continuous operation, assessibility for routine maintenance, and, most importantly, cost effectiveness.

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

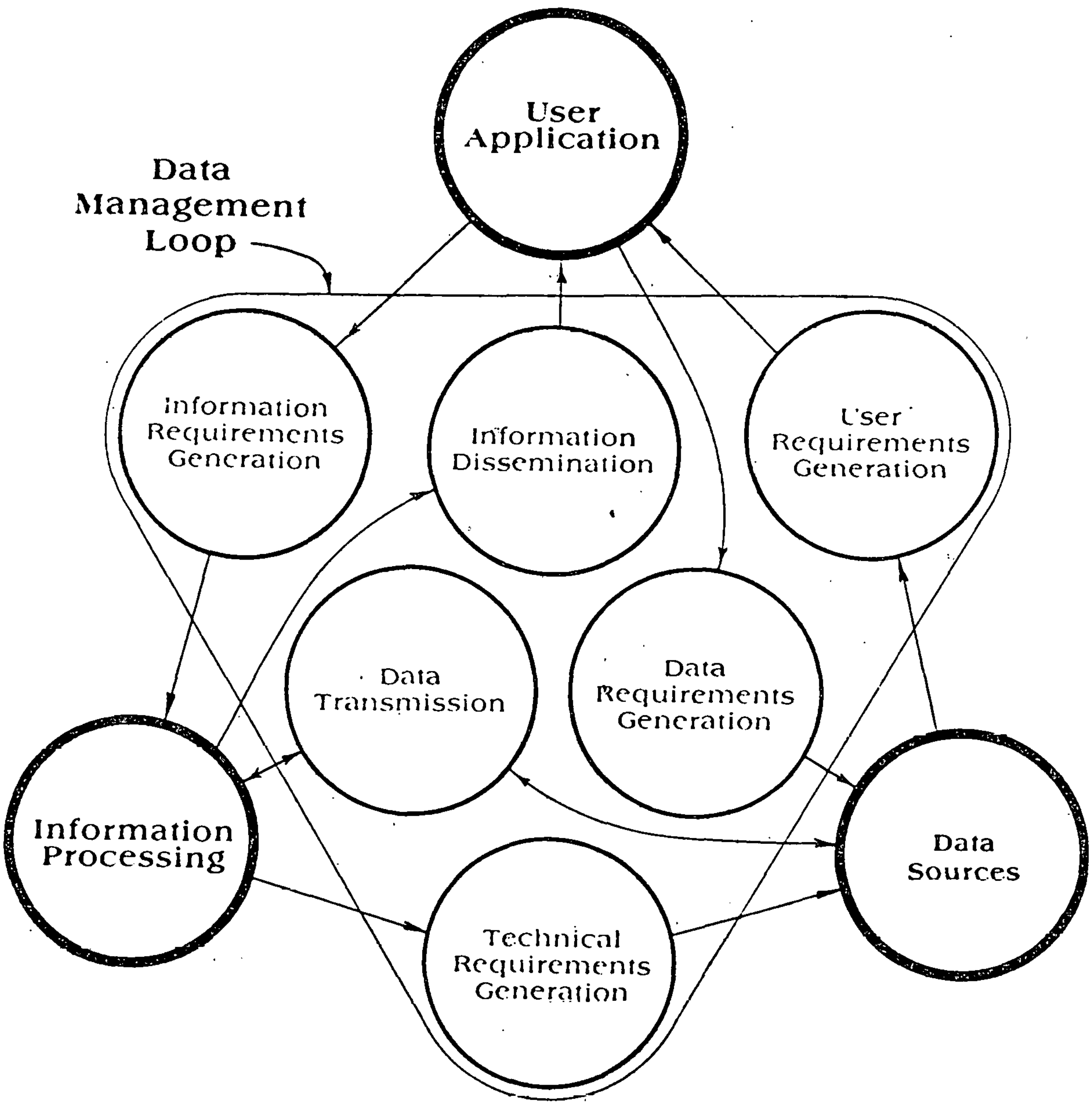
Analytical techniques to evaluate the user community should be developed and applied. Factors include, amoung others, direct contact through meetings, telephone surveys, etc; questionnaires and surveys; categorization of the data requirements; publication of available data sources and currently available data for review and further refinement.

Various methods and associated costs should be considered in the means of disseminating the potential results of the network program. Handbooks, data users' guides, computerized data bases, and various other data storage and retrieval techniques typically should be compared before proceeding with the final network design.

It is also desirable that a systems analysis approach be made before undertaking the final network design. Several discrete steps are indicated in this analysis. A statement of the need should be made as well as a clear statement of the goals and objectives of the program. Performance specifications should be established to meet the expected system output and to insure system reliability. Related design specifications should likewise be developed to meet the proposed hardware and software requirements, the estimated cost of the system, and the proposed developmental schedule. Then, the general feasibility of the network can be evaluated, including the technical, economic, and institutional factors which relate to user acceptance. Throughout the process, various changes and alternatives should be considered and, if possible, fed back into a modified statement of goals, objectives, and performance specifications. In this way the overall systems analysis can be refined and, hopefully, the final output will closely match the user's requirements.

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

A competent network manager is a necessity. He needs, at a minimum, a broad background in solar-radiation measuring instruments, and an awareness of data presently available; data recording, processing, storing and retrieval techniques; formats for summarizing data; techniques of cost management; and dedication to operating the network on a sustained basis. Finally, he must continuously review the costs and the potential results, as well as actual results, to assure that the network always meets the user requirements.



ALTERNATIVE SOLAR RADIATION NETWORKS

SATELLITE DATA

Dan Tarpley, NOAA

Insolation is the rate at which direct and scattered solar radiation is incident upon a unit horizontal surface. It is measured in units of energy/second·area. Insolation at Earth's surface in the visible region of the solar spectrum is one of the most important meteorological variables determining the growth rate of crops. An experiment was planned for the summer of 1977 to investigate methods for determining visible surface insolation from satellite and ground-based meteorological data. This experiment entailed collecting coincident satellite, meteorological, and pyranometer measurements over that portion of the Great Plains bounded by by the 29°N and 49°N parallels of latitude and the 95°W and 105°W meridians. The area is illustrated in Fig. 1.

Visible solar radiation incident on Earth is either reflected to space, absorbed in the atmosphere, or absorbed by Earth's surface (Fig. 2). Surface insolation, the quantity of interest, is a function of incident solar radiation and the amounts of energy reflected to space and absorbed by the atmosphere.

The fraction of incoming radiation that is reflected to space is primarily controlled by cloud amount and cloud thickness, both of which can be estimated from satellite data. Cloud amount in an area is computed by the two-threshold method (Shenk and Salomonson, 1972) in which the number of pixels in clear, partly cloudy, and cloudy classes are weighted to yield fractional cloud cover.

If the partly cloudy class is assumed to be 50 percent cloud covered, then the cloud fraction, C, is expressed by

$$C = \frac{0.5N_2 + N_3}{N_1+N_2+N_3}$$

or

$$C = \frac{N_2 + 2N_3}{2N}$$

where N is the total number of pixels in the target area, and N_1, N_2, and N_3 are the numbers of pixels in the clear, partly cloudy, and cloudy classes, respectively.

The brightness of a clear scene changes continually over the course of a day because of changing angles of illumination. The clear threshold is also a function of the illumination angles and will be obtained by regression. The variables in the regression equation are local solar zenith angle and the local azimuth angle between sun and satellite.

Another cloud parameter that can be calculated is mean cloud brightness. This is determined by averaging all pixels equal to or brighter than the cloud threshold. Mean target brightness is also computed as another measure of reflected radiation.

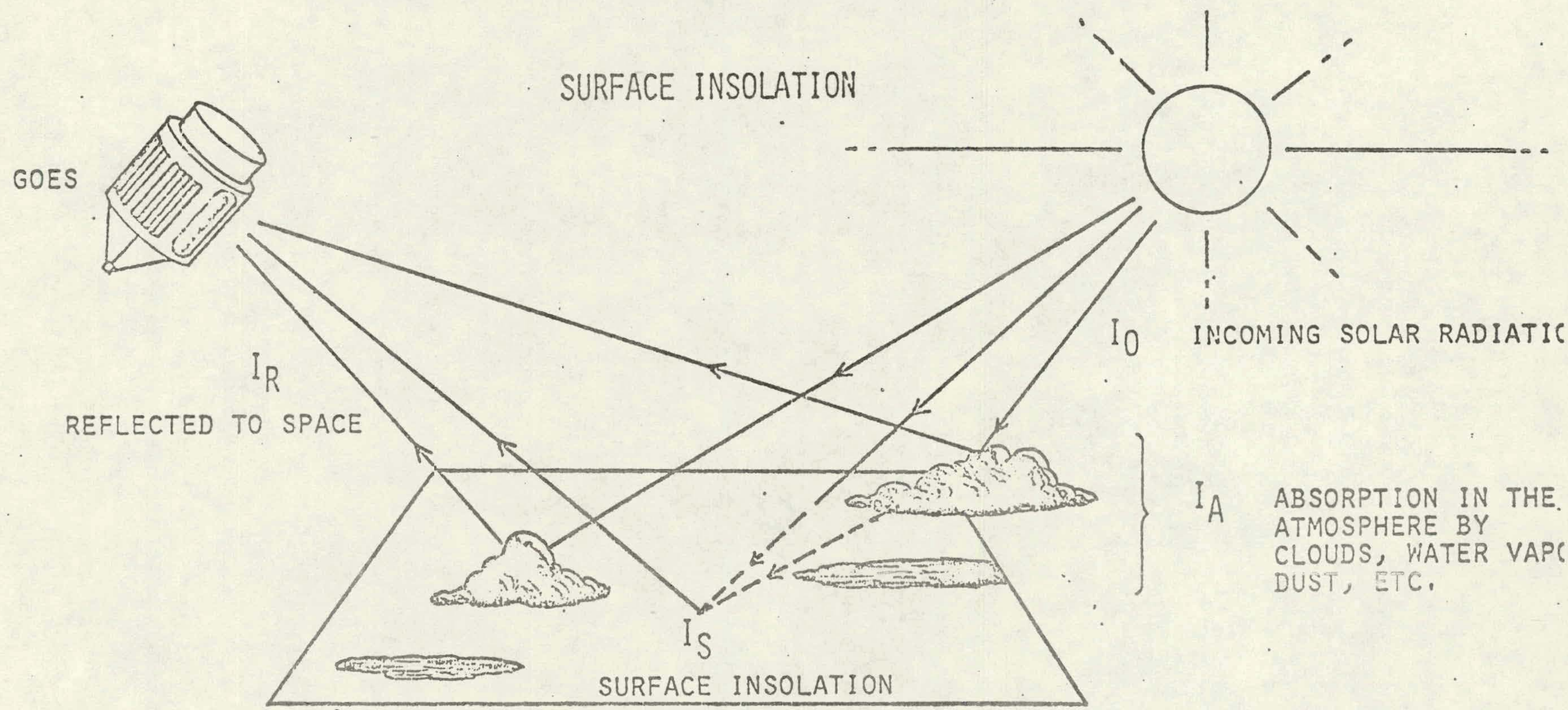
The amount of incoming radiation that is absorbed in the atmosphere is controlled by cloud cover, atmospheric moisture, dust, and the atmospheric mass traversed by the beam. Precipitable water and surface pressure are available from the NCC; these two quantities, together with the satellite-derived cloud characteristics, should provide enough information to account for radiation absorbed by the atmosphere. The precipitable water and surface pressure is accessed from NCC fields, whose resolution is about four deg at mid-latitudes, lower than the one-half deg grid used for the

Great Plains.

The data collection procedure is illustrated in Fig. 3. The Great Plains are divided into targets 0.5 latitude and longitude on a side (about 50-km square) and data collected for each target. A minimum of six to eight observations distributed over daylight hours will be made each day. The data are collected for 60 days, although the days are not necessarily consecutive. The quantities described above, along with local solar zenith and azimuth angles, are written on computer compatible tape (Fig. 4). Copies of the tape will be available for the price of the tape.

Further information on this project can be obtained by writing to Dr. Dan Tarpley, NESS, Computer Techniques Branch, FB-4, S1124, Stop E, Washington, D. C. 20233, or by calling (301) 763-2700.

Fig. 1 AREA COVERED BY SURFACE INSOLATION EXPERIMENT



$$I_S \sim I_O - I_A - I_R$$

SURFACE INSOLATION

GROUND TRUTH FROM PYRANOMETERS

INCIDENT SOLAR RADIATION

KNOWN

RADIATION ABSORBED IN THE ATMOSPHERE

INFORMATION FROM NMC DATA AND SATELLITE CLOUD COVER ESTIMATES

RADIATION REFLECTED TO SPACE

MEASURED BY SATELLITE

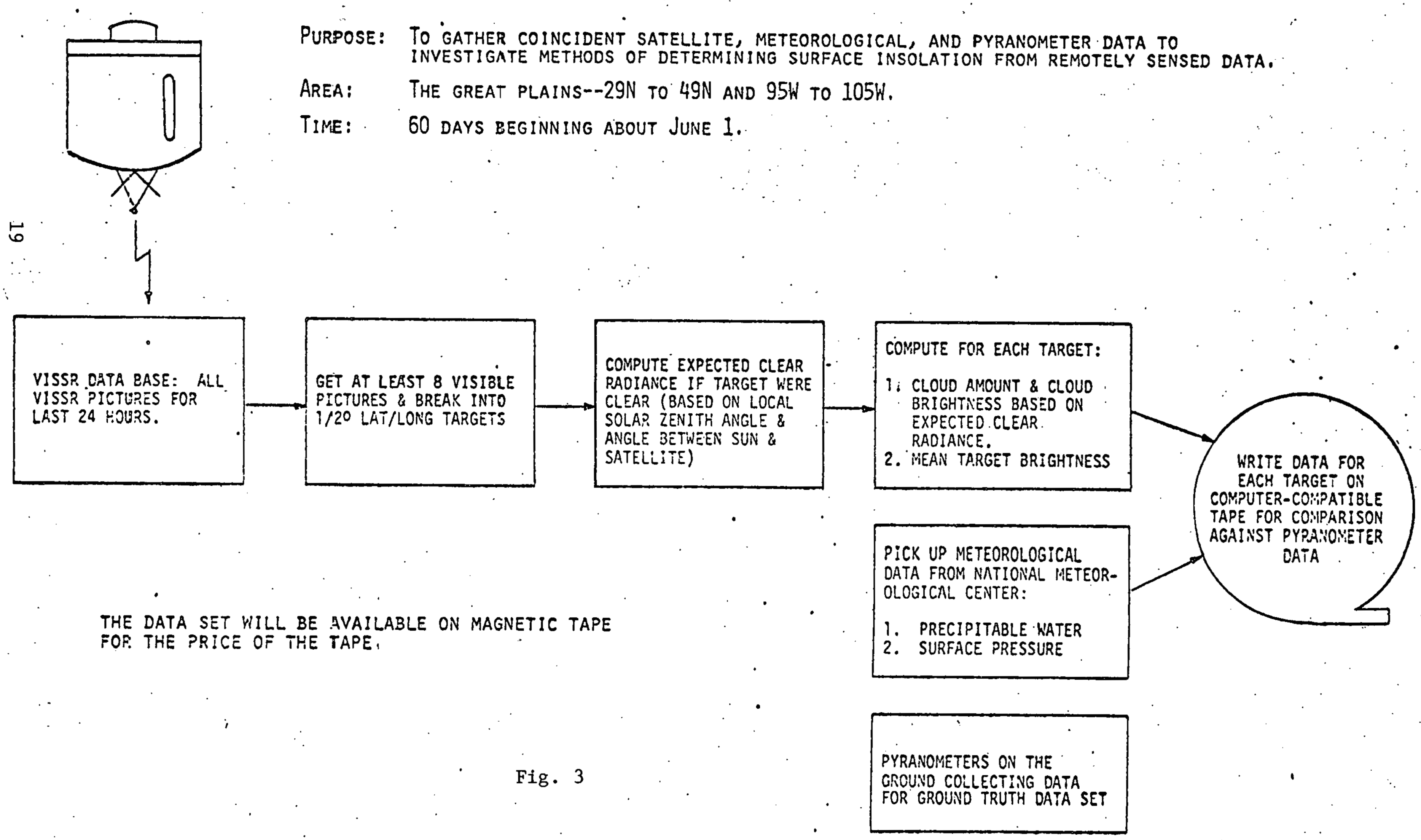
Fig. 2

AN INSOLATION DATA GATHERING EXPERIMENT PLANNED FOR SUMMER 1977

PURPOSE: TO GATHER COINCIDENT SATELLITE, METEOROLOGICAL, AND PYRANOMETER DATA TO INVESTIGATE METHODS OF DETERMINING SURFACE INSOLATION FROM REMOTELY SENSED DATA.

AREA: THE GREAT PLAINS--29N TO 49N AND 95W TO 105W.

TIME: 60 DAYS BEGINNING ABOUT JUNE 1.



THE DATA SET WILL BE AVAILABLE ON MAGNETIC TAPE FOR THE PRICE OF THE TAPE.

Fig. 3

QUANTITIES TO BE MEASURED FOR EACH TARGET AND WRITTEN TO TAPE:

1.	MEAN TARGET BRIGHTNESS	DERIVED FROM SATELLITE DATA
2.	CLOUD FRACTION	DERIVED FROM SATELLITE DATA
3.	MEAN CLOUD BRIGHTNESS	DERIVED FROM SATELLITE DATA
4.	PRECIPITABLE WATER (CM)	FROM NATIONAL METEOROLOGICAL CENTER
5.	SURFACE PRESSURE (MB)	FROM NATIONAL METEOROLOGICAL CENTER

ADDITIONAL QUANTITIES TO BE WRITTEN TO TAPE:

1. LOCAL SOLAR ZENITH ANGLE
2. LOCAL SOLAR AZIMUTH ANGLE

Fig. 4

Alternates to a Ground-based Solar-radiation Monitoring Network

L. Machta and G. Cotton, NOAA

There are two methods, aside from the possible use of earth-orbiting satellites, which may provide solar-radiation data in the absence of network measurements. First, one might interpolate or extrapolate from existing station information. While it has been shown generally that interpolation is reasonable over distances of a few hundreds of kilometers, there are difficulties. They arise from unusual gradients which occur between urban and non urban locations and costal or mountainous areas. The DOE has programs designed to generalize the interpolation or extrapolation methods between these three areas of gradients of sharper than normal. Two items may be added. First, surveys of urban-non-urban differences indicate smaller values than reported in popular rather than technical or scientific publications. But, it is likely difficulties will appear in generalizing the gradients in mountainous areas; and much of the far west may not lend itself to easy interpolation.

This presentation treats the second alternative to networks (and satellites): the use of sunshine and/or cloudiness data to derive global (direct plus diffuse) solar radiation. There exists a body of studies relating solar radiation to sunshine (daily or monthly values) and a smaller quantity of literature on cloudiness. This report uses the hourly SOLMET cloudiness data to predict solar radiation. The reason for emphasizing clouds rather than sunshine follows from the greater number of stations reporting clouds compared to sunshine and because no hourly sunshine data are available beyond that from 26 rehabilitated stations.

As a result of a great deal of trial and error using opaque clouds, sky cover, precipitation, temperature, etc., regression equations were developed to achieve the best fit with the fewest parameters. More complex relationships were very little better and were likely to be less valid when applied to an independent set of data. The relationship of solar radiation (SR) to cloudiness involves two steps. The first is the derivation of a regression equation between solar radiation with clear skies (SR_{CS}) and the sun's zenith angle (ZA) as shown in the upper part of Fig. 1. The ZA is a function of time of day, day of year, and latitude. The coefficients were derived independently for each month and separately for morning and afternoon.

The SR_{CS} is multiplied by a factor which is a function of the number of tenths of opaque cloudiness (OPQ) as reported subjectively by the weather observer during the sun hour (but at a specific point in time) over which the hourly integrated, global solar radiation was observed. The lower part of the Fig. 1 shows the relationship using OPQ, OPQ^2 and OPQ^3. In addition, the occurrence of precipitation at the time of the cloud information is designated by RN. RN = 0 if no precipitation occurs, and RN = 1 if there is precipitation. The introduction of precipitation was found to improve the relationship between solar radiation and clouds for those cases when the sky was almost or actually overcast; e.g., OPQ = 0.8, 0.9, 1.0. The same values of B_0, B_1. . . B_5 apply to all hours of the day and all days of the year.

A few examples of the numerical values of the regression coefficients also appear on Fig. 1.

There is nothing unusual about the above analysis. The leading question is what the predictive skill might be. A few typical examples are given to illustrate the errors in the regression equation predictions.

Fig. 2 provides two examples of the errors found when the equations in Fig. 1 predict the observed data. In part, but not entirely, the Fig. 2 is a measure of how well the data can be fit by the equations in Fig. 1. The qualifying phrase "but not entirely" reflects the fact that the "B" coefficients in Fig. 2 were derived from data for all 12 months, not just June and December.

Fig. 2 presents data for two "rehabilitated" stations, El Paso, TX, and Dodge City, KS. The first line beneath the station identification is the standard deviation of the differences between SOLMET values and the predicted values for the sun hours above the numbers (8, 10, 12, 15, 17 hours solar time at the station). The second line, labelled "MEAN", gives the average solar radiation in the SOLMET tapes for all days in all of 24 years in the months of June or December at the indicated hour. The final line divides the standard deviation by the mean and expresses the ratio as a percentage. Thus, the errors (so expressed) are generally in the 10-15 percent range for the important 10-15 hours of the day. Other stations provided both smaller and larger errors. Some of the worse cases were as large as 35 percent. The larger errors were associated with smaller mean amounts of solar radiation (smaller denominators).

Thus, the regression equations using clouds cannot consistently predict solar radiation to 10 percent (as the standard deviation over the mean) and in some cases may be much above 10 percent. In some cases, the predictions can approach 5 percent. Though not shown, the same statistic (standard deviation over mean) for hours with clear skies are a half or smaller than the statistic for all weather.

Fig. 3 is a plot comparing the integrated daily values of solar radiation for Dodge City derived from the regression equations, the crosses, with the SOLMET values. The fit for daily predictions is clearly better than the hourly values (about 15 percent in Fig. 2).

Fig. 4 makes a similar comparison for integrated monthly values. The fit in it is clearly better than for hourly or daily values.

The conclusion, therefore, is that the capability of regression equations such as those in Fig. 1 is not particularly adaptable to matching the SOLMET (observed) data hour by hour. It is fairly good when the hours are summed to days and the daily predictions compared with SOLMET values. The use of clouds can yield surprisingly excellent fits to monthly values when hourly values are summed into monthly totals.

The regression equations illustrated in Fig. 1 will be applied to weather stations adjacent to the 26 rehabilitated stations as shown in Fig. 5. The 26 rehabilitated stations appear as open circles. The dots show the locations of 139 other NWS stations while the crosses are FAA or military stations. All provide at least 25 years of cloudiness data which will be converted to "ersatz" solar-radiation data by regression equations from the 26 stations and formatted as SOLMET. The 175 new "ersatz" global solar radiation stations will be so converted on or about November 1, 1977. The accuracy will, of course, be somewhat lower than the statistics in Fig. 2, 3, and 4. In the eastern US, the deterioration accuracy in going from the 26 stations to nearby other stations is likely to be small. The same assurance cannot be given for the western mountainous states. It will be possible to estimate the loss of accuracy by using one of the 26 stations to predict via its regression equation, the values for an adjacent rehabilitated station.

Currently it appears that the use of cloudiness information may possibly provide a substitute means for actual observations. Even more important than savings in dollars and manpower is the possibility of providing solar-radiation statistics without waiting for the network to collect new data.

FIGURE 1

REGRESSION EQUATIONS IN MODEL CALCULATIONS

CLEAR SKIES (BY MONTH, AM AND PM)

$$SR_{CS}\ (KJ/M^2/HR) = A_0 + A_1 \cos ZA + A_2 \cos^2 ZA + A_3 \cos^3 ZA$$

ZA = ZENITH ANGLE

EXAMPLE, <u>CARIBOU, ME</u>, JANUARY, AM

$$SR_{CS} = 33 + 2140 \cos ZA + 4000 \cos^2 ZA - 2470 \cos^3 ZA$$

OPAQUE CLOUD ONLY (SINGLE ANNUAL COEFFICIENTS)

$$SR = SR_{CS}\ (B_0 + B_2\ OPQ + B_3\ OPQ^2 + B_4\ OPQ^3 + B_5\ RN)$$

RN = 0, 1 FOR PRECIPITATION

EXAMPLE, <u>BOSTON, MA,</u> JANUARY

$$SR = SR_{CS}\ (1.010 - 0.734\ OPQ + 1.236\ OPQ^2 + 1.230\ OPQ^3 - 0.165\ RN)$$

FIGURE 2

ERRORS IN USE OF REGRESSION EQUATION BY HOUR AND MONTH

OPAQUE CLOUDS

	JUNE					DEC				
SUN TIME	8	10	12	15	17	8	10	12	15	17
EL PASO										
σ (KJ/M²/HR)	167	220	272	303	290	61	181	229	183	56
MEAN (KJ/M²/HR)	1671	3126	3788	3056	1553	216	1295	1935	1315	205
σ/MEAN, %	10.0	7.0	7.2	9.9	18.7	28.1	14.0	11.8	12.5	27.1
DODGE CITY										
σ	231	350	462	412	299	--	172	215	156	--
MEAN	1403	2552	3173	2600	1457	--	921	1428	929	--
σ/MEAN	16.4	13.7	14.7	15.9	20.5	--	18.7	15.1	16.8	--

FIGURE 3

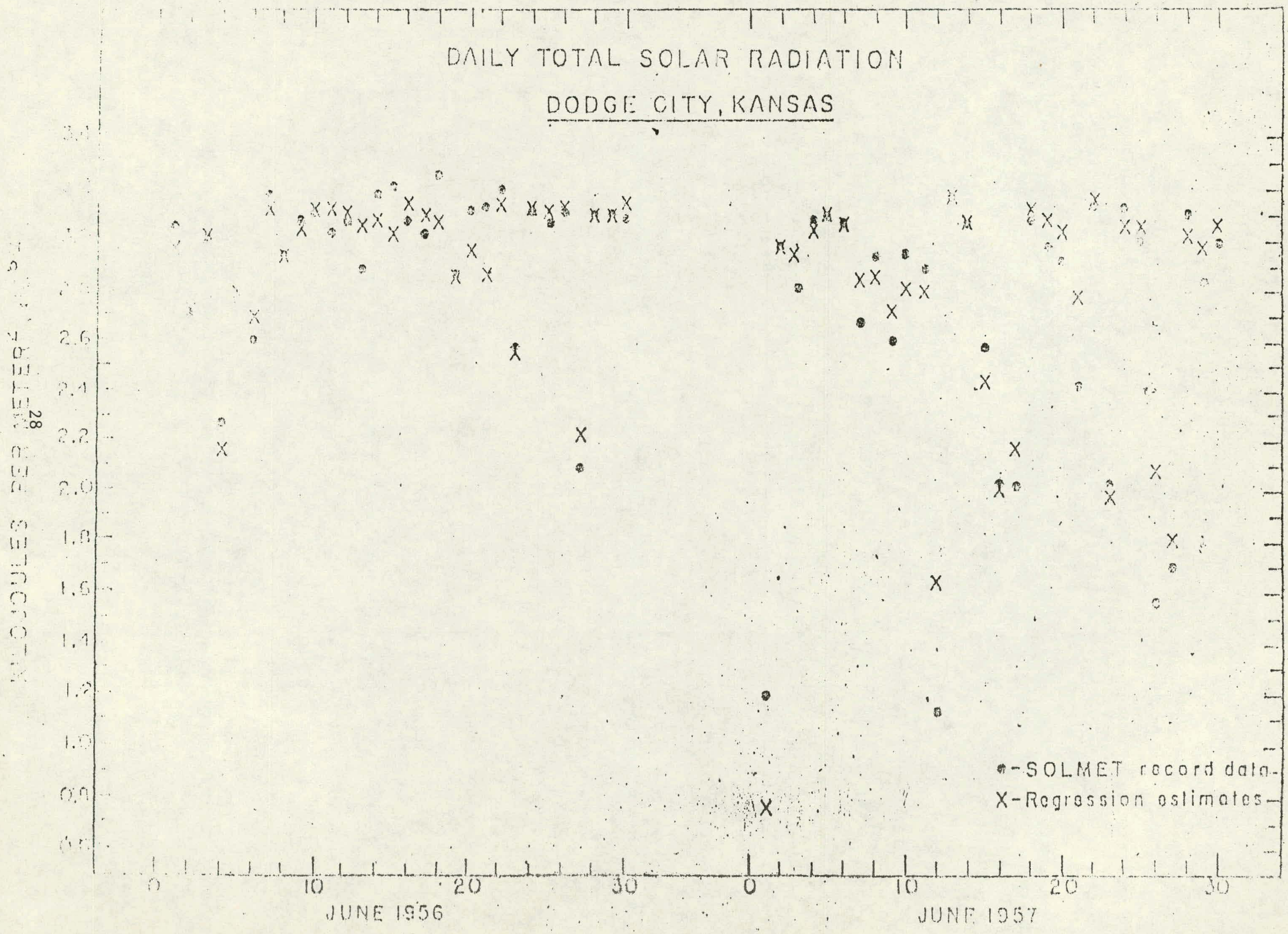

DAILY TOTAL SOLAR RADIATION
DODGE CITY, KANSAS
•-SOLMET record data
X-Regression estimates
JUNE 1956
JUNE 1957

FIGURE 4

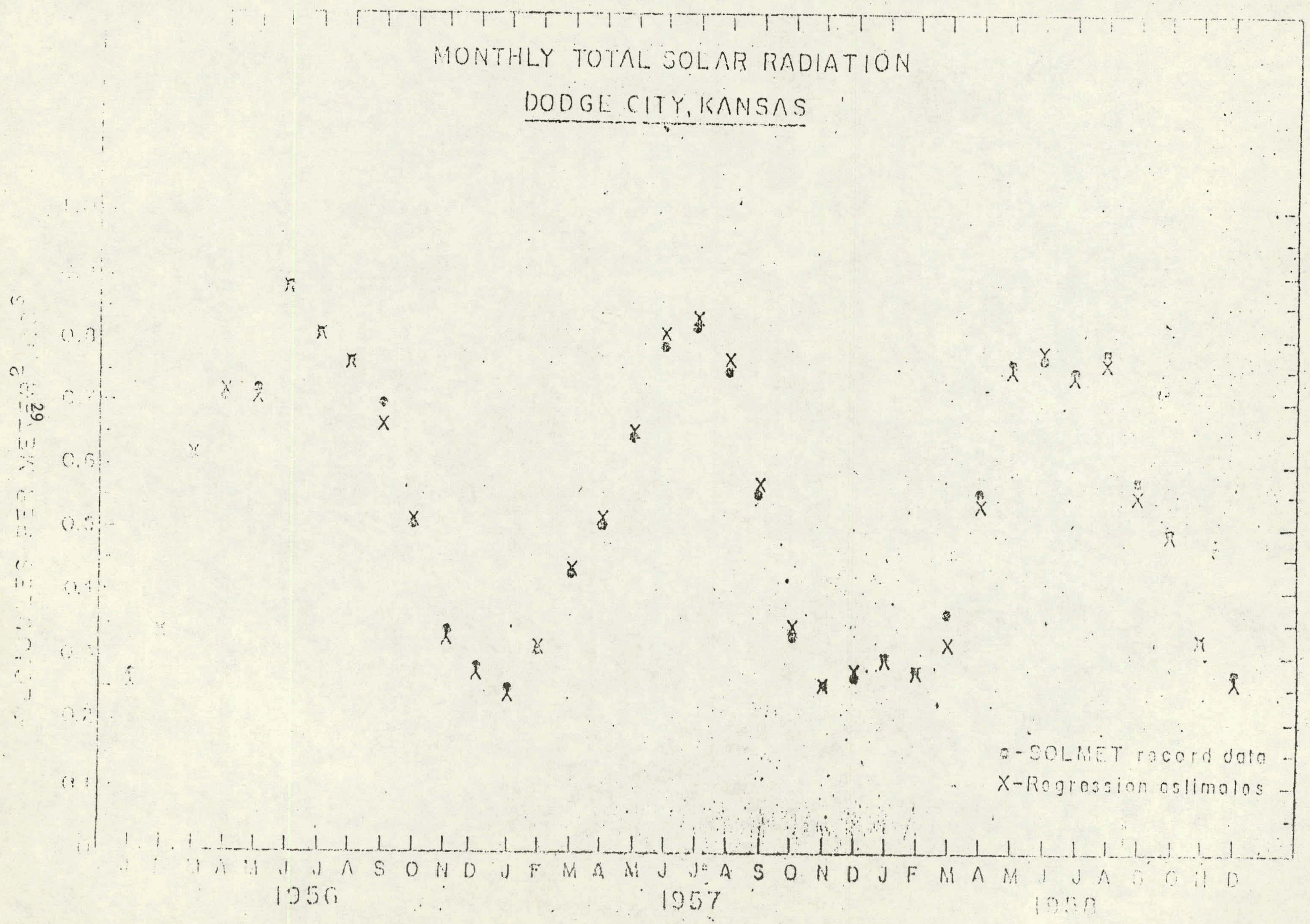
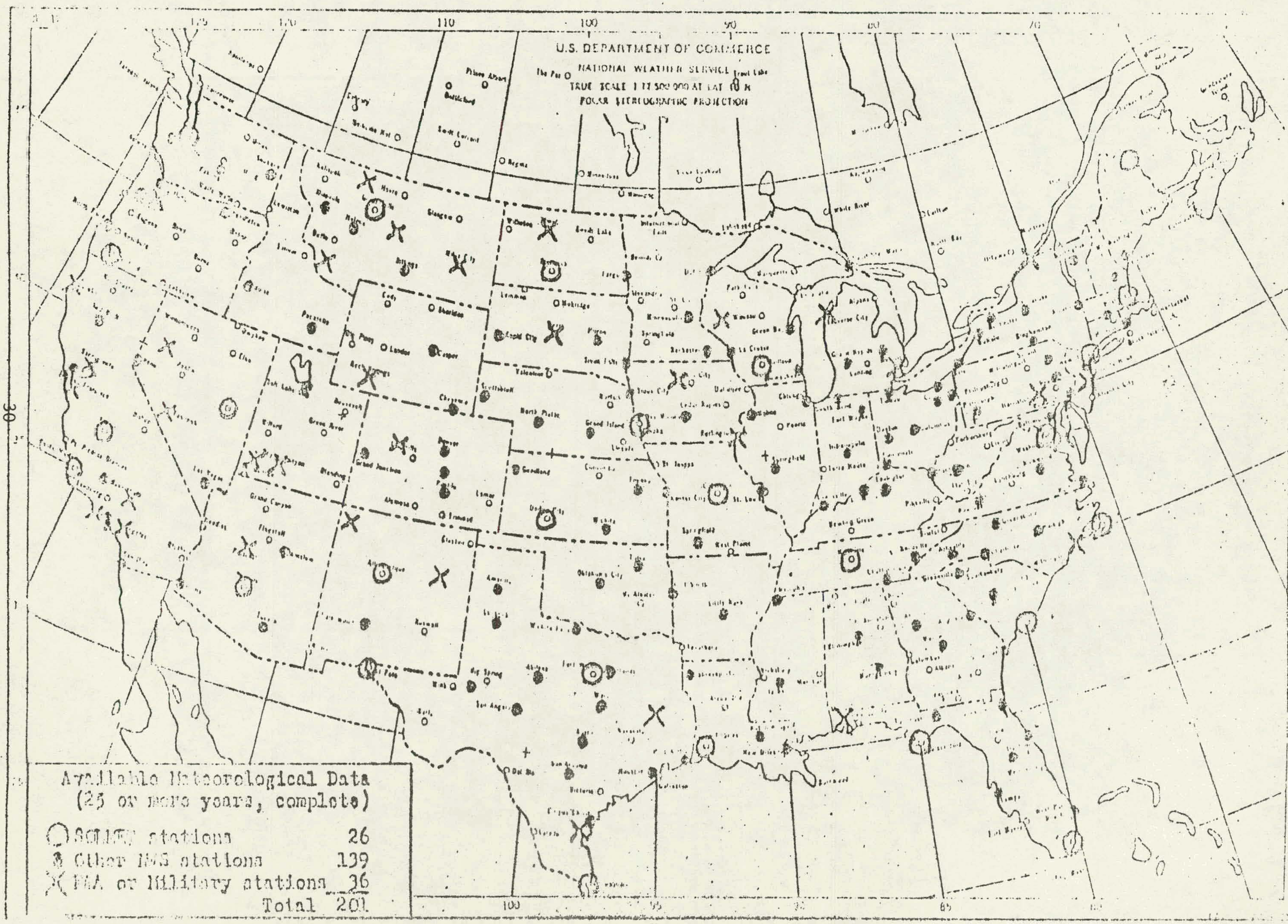

MONTHLY TOTAL SOLAR RADIATION
DODGE CITY, KANSAS
●-SOLMET record data
X-Regression estimates
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1956
1957
1958

FIGURE 5


U.S. DEPARTMENT OF COMMERCE
NATIONAL WEATHER SERVICE
POLAR STEREOGRAPHIC PROJECTION
Available Meteorological Data
(25 or more years, complete)
SOLMET stations 26
Other NWS stations 139
FAA or Military stations 36
Total 201

The State of New Mexico

Solar Radiation resource Assessment Project

by Raymond J. Bahm, UNM

Preface

New Mexico, because of its arid climate, ranks among the best areas for sloar-energy availability. However objective information on the amount of solar radiation available around the state has been difficult to obtain. A much better data base is needed before the establishment of large-scale, solar-electric, power-generating sites. This project is the logical first step in the establishment of a high quality solar-radiation monitoring network in the state.

This project is sponsored by the state of New Mexico through the New Mexico Energy Resources Board, Mr. Fred O'Chesky, Chairman, and through the New Mexico Energy Institute for Solar, Dr. Robert L. San Martin, Director. The work is being performed at the University of New Mexico, Bureau of Engineering Research, in Albuquerque, NM.

This report was prepared for the 2nd National Solar Radiation Data Workshop held at Skyland, Virginia, September, 1977.

The State of New Mexico

Solar Radiation Resource Assessment Project

September, 1977 by Raymond J. Bahm

The Bureau of Engineering Research at The University of New Mexico is engaged in a project to evaluate the solar energy available within the State of New Mexico. This project is part of an effort to stimulate the development of solar related and other clean industries within the state, and to develop energy conserving technologies to benefit all the citizens of New Mexico.

This project is focusing on three task areas: a) assessment of the data required by the various solar programs and other users of solar data, b) a survey of past, present and planned solar radiation monitoring programs to be carried out within the State of New Mexico, and c) an attempt to formulate a program to coordinate local, state and regional solar radiation data collection into a network which would benefit all.

The kind, amount and precision of data required by the various users is being determined, as well as the most useful formats for presenting the data.

The survey of monitoring programs includes all the data such as that collected by pyranometer, pyrheliometer and cloud observations. The available data has been obtained, cataloged and is being analyzed for its quality. That data judged to be of useful quality will be published in formats which are appropriate.

All groups known to have instrumentation for the measurement of solar radiation were contacted in an attempt to formulate a program of data collection and coordination into a network. An effort will be made to coordinate data collection within the State of New Mexico with those regional and national programs which are currently being organized.

The task of assessing the needs of various users for different types and precision of data has used a number of different methods in an attempt to formulate specific answers. Experts in the fields using solar radiation data were interviewed to determine their current and future needs for data. Resource assessment programs in other states were analyzed and their perceptions of data needs were obtained. A draft handbook of solar radiation data was published for comment with currently available solar radiation data for the state. The data in that handbook appeared in a wide variety of forms in an attempt to determine the utility of each. The literature on solar radiation was surveyed for different data display methods and forms, and those judged to be useful were selected. The methods of data presentation used by those projects currently collecting and utilizing the data were examined. A solar data user workshop was sponsored to aid in defining the data requirements.

One of the major conclusions from this effort is that it is not practical at the current stage of development of many of the solar users to ask for a complete and precise definition of their needs for solar radiation data. They simply do not know all of their needs yet. The definition of these needs is an iterative process, starting primarily with whatever information is available, and then refining their requirements as better or more precise data becomes available, or as the lack of data with certain characteristics becomes a barrier to further progress.

Another major conclusion is that each user would like to have data available in a form which applies directly to his needs. The wide variety of users means a wide variety of formats. As new uses for solar energy develop still different formats will be required for the presentation of the data.

Most of the users felt that data on the amount of solar radiation available around the state except for Albuquerque has been difficult or impossible to obtain, and that there was little or no information on how well the Albuquerque data would apply elsewhere. It was felt by many that a network of 5 to 10 stations around the state is justified.

Examination of the increasing cost of a data collection station as we increase the quality of the data and the variety of data collected leads to a curve, shaped something like that shown in figure 1. One would therefore want to design for that data quality at the knee of the curve.

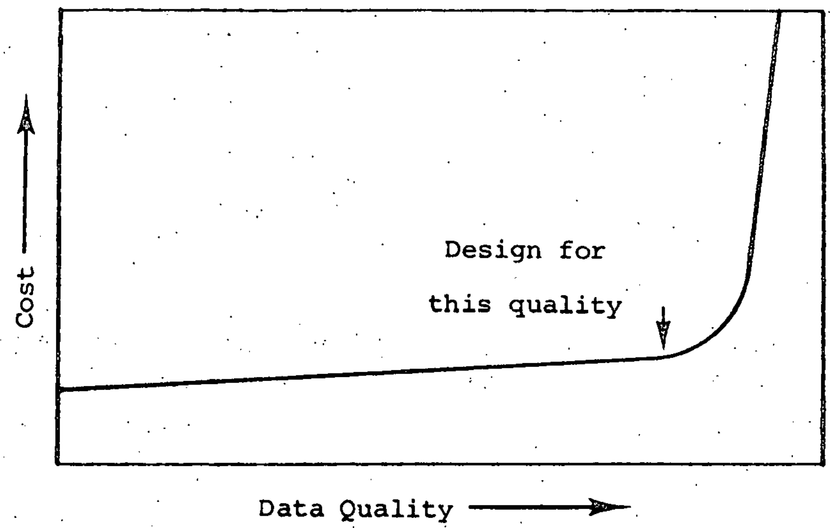


Figure 1. Station Cost vs Data Quality

The geographic density required for a group of network stations depends on the variation of the climate with geography and the accuracy of data required. A brief study was done with the data for two locations with similar climates, separated by 300 miles, to see how well the data from one location could be used to predict solar radiation at the other. The curve in figure 2 indicates that one would find errors of more than 10% in daily or weekly means, but that means computed over monthly or longer intervals would have smaller errors.

The survey of users identified 14 different locations where solar radiation data had been or was currently being collected within the state. A listing of these stations and the approximate time periods which the data covers is given in table 1. Data from nearby monitoring stations in other states were also included in the data base. These data were collected and placed into a

Figure 2. Standard Deviation of Solar Radiation Daily Total Estimates Between Two Location: Albuquerque, NM and El Paso, Tx

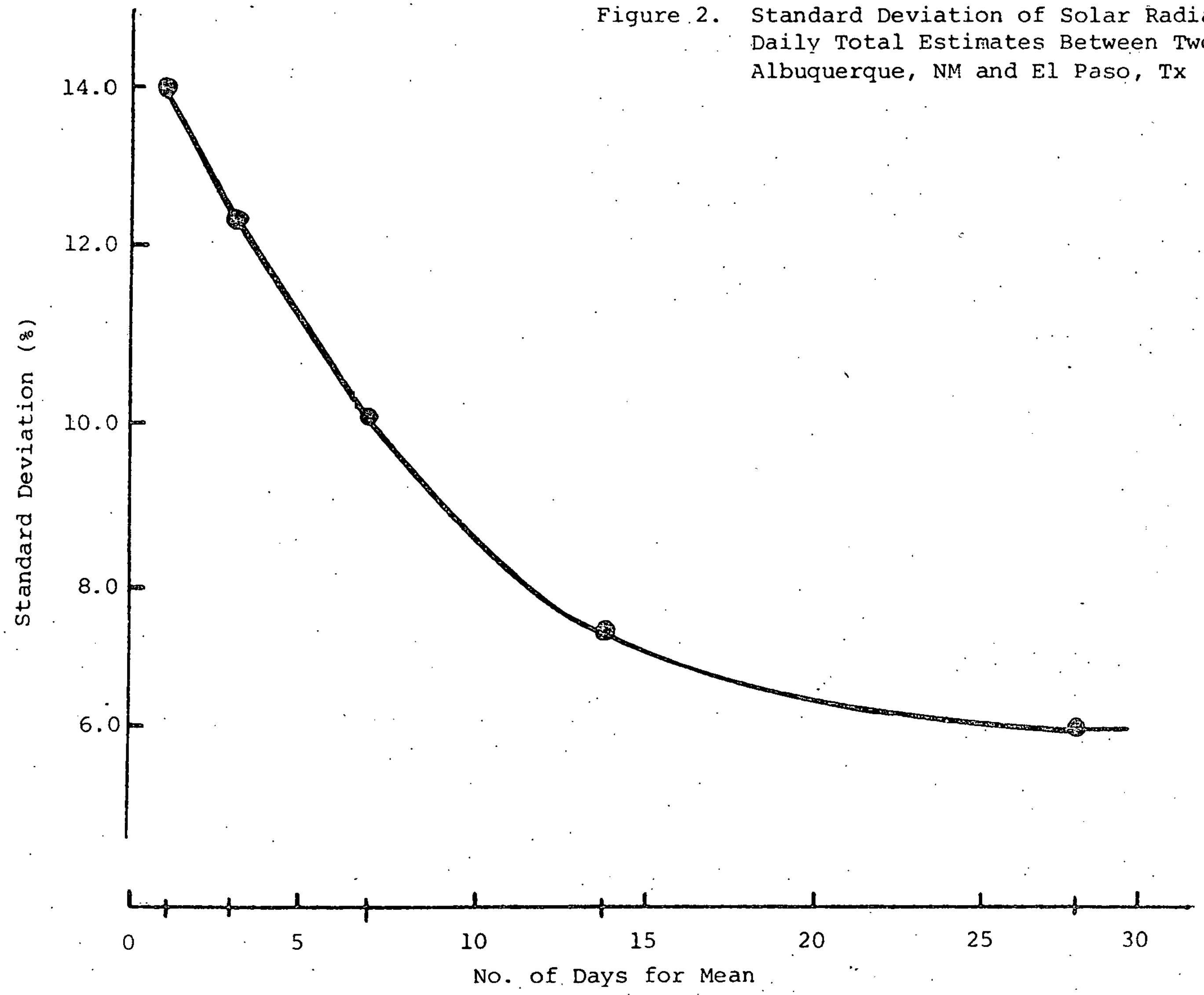


Table 1. Solar Data for New Mexico

Site	Dates Available
Albuquerque (NWS)	1952 - 1976*
El Paso (NWS)	1952 - 1976*
Santa Fe (NWS)	1910X
Los Alamos	9/72-8/73, 1/74-12/74
Langmuir Lab	1964 - 1969
Portales	3/72 - 4/75
BIBO	9/74 - 3/76
Albuquerque (B+P Bldg)	- 12/76
" (Embudo Station)	7/75 - 12/76
" (Solar Pond)	8/76 - 12/76
Las Cruces (Plant Science Farm)	1/75 - 12/76
Las Cruces (Dept. of Ag. Engineering)	this network just installed in spring of 1976
Artesia "	this network just installed in spring of 1976
Clovis "	this network just installed in spring of 1976
Farmington "	this network just installed in spring of 1976
Los Lunas "	this network just installed in spring of 1976
WIPP Site	1/76 - 12/76

* - Earlier data also available from NWS but not gathered for this project.

X - Earliest NWS measurements in New Mexico. Limited data is available. The primary value of this data is to show changes in atmospheric transmission over many years. Probably the first NWS solar measures west of the Washington, D. C. area.

computerized data base. Where other compatible meteorological data was available along with the solar radiation data it also was included in the data base. All data was converted to daily values to provide a uniform and comparable data set.

The record format of the data base is shown in table 2. All programs for manipulating the data base are written in FORTRAN. The data base displays were prepared in two formats. Table 3 shows only the solar radiation data, but an entire year's data is on one page. Table 4 shows one month of solar data and the corresponding meteorological data. Zeroes indicate that there was no data available for that parameter, except for precipitation where 0.0 means no measureable precipitation.

A variety of techniques were developed or adopted to evaluate the quality of the solar radiation data, to detect errors or changes in calibration and for correcting the data. All of these are interactive man-computer methods which allow combining the flexibility of human judgement with the speed and precision of the computer.

The first is the automated clear day plot described in reference [1] which is similar to the manual technique currently being used by the National Weather Service for the rehabilitation of the historical solar radiation data for the U. S.[2] This method highlights instrument or system calibration drift and allows a correction factor to be computed.

A second method is shown in figure 3. This displays the difference between the mean of the clearest days of one or more nearby locations and the clearest days at one specific location, allowing the identification of discontinuities in the data at that specific location.

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1. R. Bahm, "Instrument Errors in the National Weather Service Solar Radiation Data," presented at 1977 ISES Conference in in Orlando, Florida.

2. F. Quinlan, Personal Communication, 1977.

Table 2. Format for Solar Data Base

Field Number	Field Name	FORTRAN Character Format	Units
1	Site Number	I6	None
2	Date	3I2	MM DD YY
3	Daily Total Radiation	I5	Langleys x 10
4	Daily Mean Temperature	I3	F°
5	Daily Max. Temperature	I3	F°
6	Daily Min. Temperature	I3	F°
7	Daily Mean Dew Point	I3	F°
8	Daily Mean Wind Speed	I3	MPH
9	Daily Max. Wind Speed	I3	MPH
10	Daily Total Precipitation	I4	Inches x 100
11	(Unused Field)	A6	Optional Data
		45 characters	

DAILY TOTALS OF SOLAR RADIATION FOR NEW MEXICO AND SURROUNDING AREAS

STATION NUMBER:100010 STATION NAME: LAS CRUCES N.M (AGE) LAT: 32.28 LONG: 106.75 ELEV: 3807

1975 MONTH..............

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	54.2	415.0	504.0	0.0	655.6	679.6	0.0	323.2	454.0	255.1	413.6	301.3
2	340.5	355.0	444.0	0.0	635.6	608.3	0.0	610.0	418.6	488.5	310.5	295.7
3	360.0	94.3	372.8	0.0	352.0	623.8	0.0	609.7	529.6	477.5	372.3	342.3
4	332.0	280.7	557.2	0.0	414.5	619.3	0.0	593.0	471.5	510.2	359.3	294.0
5	359.3	306.2	519.7	0.0	428.0	627.0	0.0	616.5	156.3	490.7	358.6	270.3
6	0.0	411.5	447.0	589.8	514.1	622.5	0.0	612.1	422.5	504.0	349.5	297.6
7	362.7	400.7	477.1	675.7	630.8	672.3	612.0	531.5	524.2	494.0	355.5	294.6
8	357.1	189.5	531.0	556.1	632.0	650.0	643.0	575.7	427.5	0.0	354.6	284.7
9	338.8	109.8	553.5	536.0	637.5	663.5	641.2	547.1	146.0	436.1	340.3	252.8
10	330.5	297.7	359.8	618.1	647.8	684.0	611.1	542.5	482.0	456.3	346.3	252.5
11	359.7	300.3	567.1	592.5	575.5	687.5	525.5	577.8	499.5	462.5	300.7	221.5
12	360.6	344.2	575.0	564.8	595.6	712.2	505.1	541.5	544.2	431.5	57.3	236.8
13	361.1	463.6	559.5	260.0	674.0	616.5	505.1	576.1	490.1	147.0	173.6	274.8
14	358.1	469.1	583.5	404.3	661.5	686.8	596.8	533.7	429.7	330.7	195.7	288.7
15	366.2	456.0	0.0	495.5	622.3	703.8	419.8	538.3	491.0	372.6	134.7	303.7
16	361.3	467.3	532.2	608.5	624.7	687.3	526.1	454.5	434.0	418.1	268.1	292.2
17	363.1	466.0	479.3	591.8	597.7	685.5	573.2	496.6	462.5	385.8	159.5	91.3
18	357.5	480.5	574.5	600.5	610.1	690.3	624.0	500.7	558.5	377.7	155.8	177.1
19	233.1	493.5	552.8	642.0	404.0	670.0	423.5	540.5	491.7	426.5	217.7	165.2
20	283.0	500.7	620.0	614.6	486.7	629.0	339.0	521.3	508.6	371.5	283.5	265.5
21	306.3	513.2	0.0	547.3	631.2	586.3	478.2	585.5	502.8	242.5	342.5	247.7
22	360.0	515.1	0.0	586.0	665.2	548.6	602.5	551.5	486.0	295.0	316.5	303.3
23	170.1	501.3	412.5	586.0	662.1	717.0	480.3	526.5	416.1	339.0	274.0	280.1
24	307.5	501.3	0.0	600.1	614.7	715.5	539.5	569.8	275.0	368.2	262.0	277.0
25	389.0	520.0	0.0	595.0	673.5	684.5	546.5	552.3	397.2	397.6	285.8	300.2
26	0.0	518.3	0.0	649.3	673.2	701.5	551.0	544.6	409.0	383.1	302.8	21.1
27	332.0	435.5	0.0	598.2	654.7	692.7	563.3	315.5	490.2	56.0	169.1	293.5
28	402.5	402.0	0.0	590.6	660.2	648.6	535.8	420.2	520.3	61.5	312.0	243.8
29	405.8	519.5	0.0	519.3	677.2	659.7	547.7	574.5	512.8	336.7	322.8	158.7
30	396.0	0.0	0.0	607.3	693.2	0.0	430.8	542.5	489.8	397.5	307.8	260.0
31	401.0	0.0	0.0	0.0	672.0	0.0	592.5	460.6	0.0	376.5	0.0	0.0
AVG	335.5	404.4	513.6	569.2	602.5	661.2	536.7	531.8	448.0	369.7	280.1	252.9

NOTE: ZEROES INDICATE THERE IS NO DATA FOR THAT DAY.
VALUES ARE IN LANGLEYS. (GRAM CALORIES PER SQUARE CENTIMETER PER DAY.)

Table 3. One Year of Solar Radiation Data from One Site

SITE: LOS LUNAS N.M (AGE) DAILY TOTALS FOR: AUGUST 1976 PAGE 6

DATE	DAY	RAD	MET	MAT	MIT	MCP	MEWS	MAWS	PRCP
1	SUN	422.1	71	83	59	0	1	0	0.02
2	MON	445.0	71	85	57	0	1	0	0.0
3	TUE	470.2	75	87	62	0	1	0	0.0
4	WED	533.0	72	88	55	0	1	0	0.01
5	THU	567.1	70	90	50	0	2	0	0.0
6	FRI	558.1	70	90	49	0	2	0	0.0
7	SAT	572.5	73	89	56	0	2	0	0.0
8	SUN	191.2	67	82	51	0	1	0	0.0
9	MON	308.6	75	85	64	0	1	0	0.0
10	TUE	425.1	75	89	60	0	1	0	0.0
11	WED	520.0	74	90	58	0	1	0	0.0
12	THU	485.0	75	92	58	0	2	0	0.05
13	FRI	551.3	73	90	56	0	2	0	0.0
14	SAT	499.6	71	90	51	0	2	0	0.0
15	SUN	417.3	70	89	51	0	1	0	0.0
16	MON	498.8	69	87	51	0	2	0	0.0
17	TUE	476.5	73	86	59	0	1	0	0.0
18	WED	348.5	71	83	58	0	2	0	0.0
19	THU	437.2	73	83	63	0	1	0	0.0
20	FRI	568.8	71	84	58	0	1	0	0.01
21	SAT	504.0	73	90	56	0	1	0	0.0
22	SUN	422.0	73	88	57	0	1	0	0.0
23	MON	447.7	72	87	57	0	1	0	0.0
24	TUE	445.8	71	85	57	0	2	0	0.05
25	WED	501.3	72	89	55	0	1	0	0.0
26	THU	369.2	72	89	55	0	2	0	0.0
27	FRI	489.8	72	85	59	0	2	0	0.0
28	SAT	565.7	72	86	58	0	1	0	0.0
29	SUN	414.5	68	83	53	0	1	0	0.0
30	MON	499.0	69	85	52	0	2	0	0.0
31	TUE	437.6	67	82	51	0	3	0	0.0
MONTHLY TOTALS:		14392.5	2220	2691	1736	0	45	0	0.14
MONTHLY AVERAGES:		464.3	71.6	86.8	56.0	0.0	1.5	0.0	0.00

Table 4. Solar Radiation and Meteorological Data from One Site

A = (B - C) * GAIN + OFFSET

B = 23050 ALBUQUERQUE, N. MEX. MUN AP LAT: 35.05 LONG: 106.62 ELEV: 5327

C = THE MEAN OF THE FOLLOWING STATIONS:

ONLY DAYS WHICH HAVE GREATER THAN 0.0 OF ETR ARE INCLUDED IN THIS ANALYSIS.

-6180	PAGE, ARIZONA	LAT: 36.93	LONG: 111.450	ELEV: 4280	NUMBER OF
-6815	TUCSON, ARIZONA (STATE UNIV.)	LAT: 32.23	LONG: 110.950	ELEV: 2440	NUMBER OF
23023	MIDLAND, TEXAS (SLOAN FIELD)	LAT: 31.93	LONG: 102.200	ELEV: 2885	NUMBER OF
23044	EL PASO, TEXAS WBAS	LAT: 31.80	LONG: 106.400	ELEV: 3954	NUMBER OF
23066	GRAND JUNCTION, COLO. WBO	LAT: 39.12	LONG: 108.530	ELEV: 4832	NUMBER OF
23183	PHOENIX, ARIZONA WBAS	LAT: 33.43	LONG: 112.020	ELEV: 1139	NUMBER OF

PERCENT OF ETR FOR "A" GAIN OF 5.00 AND OFFSET OF + 50.00

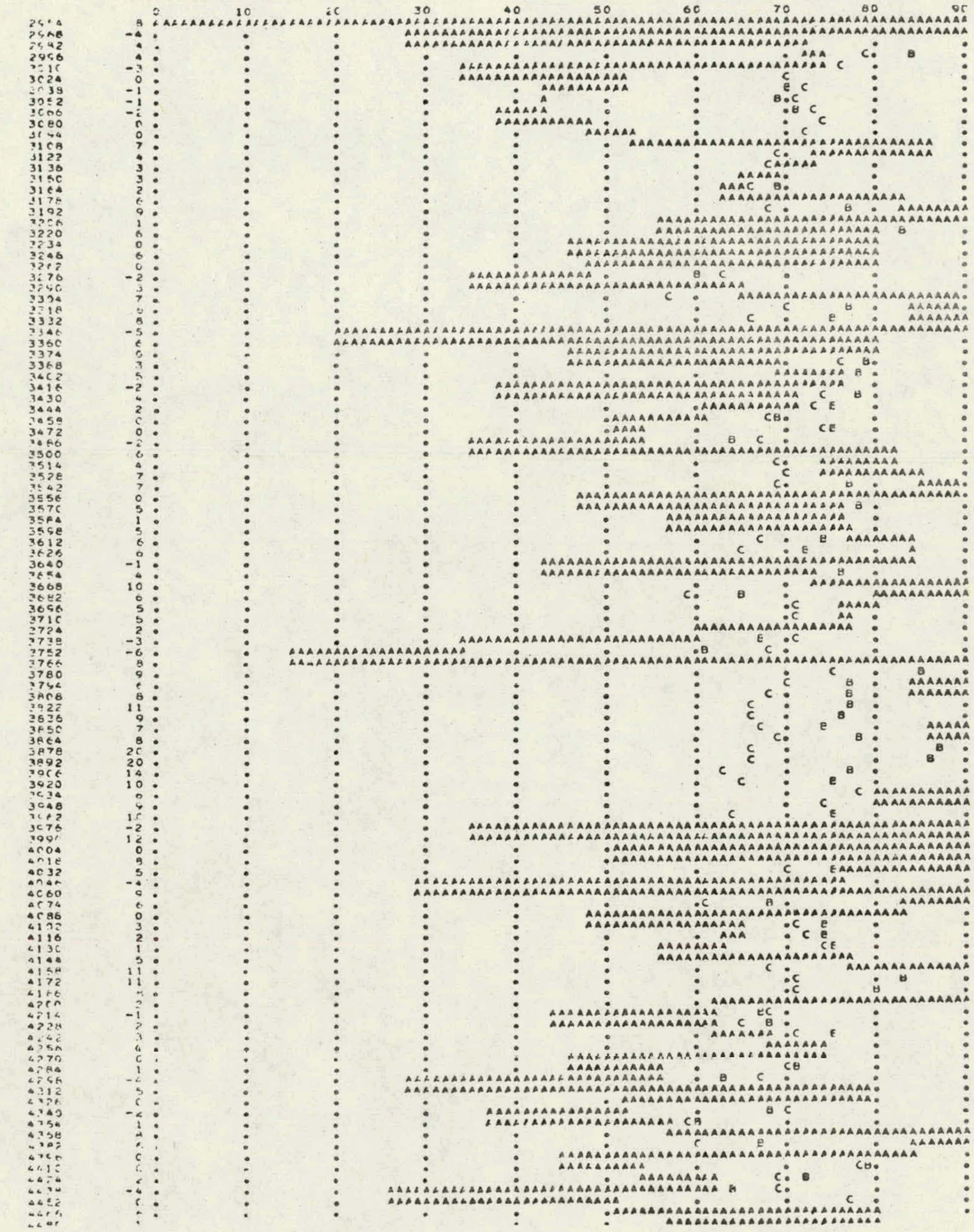


Figure 3. Plot of Difference Between Solar Radiation at One Site and Regional Average

A third method uses the histogram of data as described in [1]. Figure 4 illustrates how this has allowed the identification of two data errors. Data from three different instruments are displayed in figures 4a, b and c.

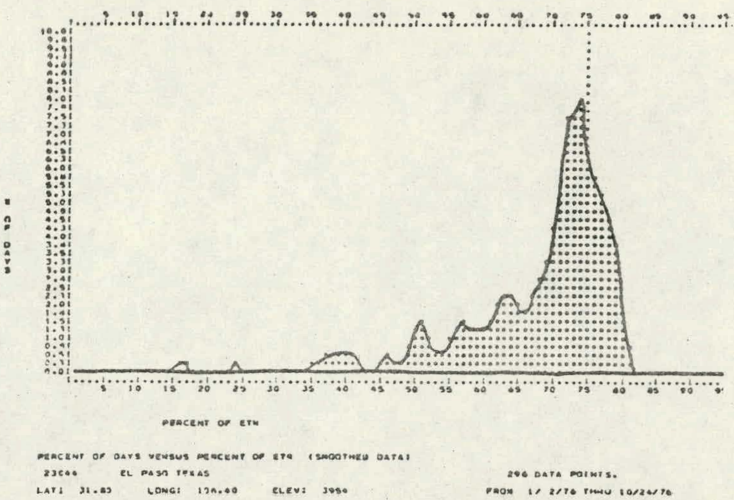
A 7% difference due to differing calibration constants caused the difference in the positions of the modes of curves 4a and 4b. In figure 4c part of the data was improperly processed giving values which were 13% too high, causing the bimodal shape.

A fourth method was developed to highlight the variability between two locations for different statistics, in hopes that it would be valuable both in identifying instrument calibration errors and in planning for placement of stations in a statewide network. An example of this display is shown in figure 5.

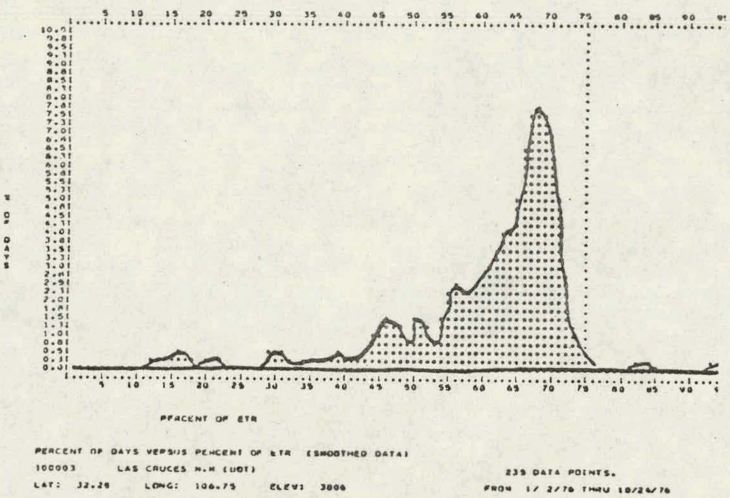
The evaluation of the data which has been collected is currently underway. Completion of the project is expected in December, 1977. It is expected that a corrected (or rehabilitated) data base will be available at that time.

Due to the considerable interest in rapid solar energy development within the state and the demand for design data, a preliminary release of the project results was made in the form of a monograph giving design data for solar systems. A copy of that monograph is the appendix to this paper.

a)



b)



c)

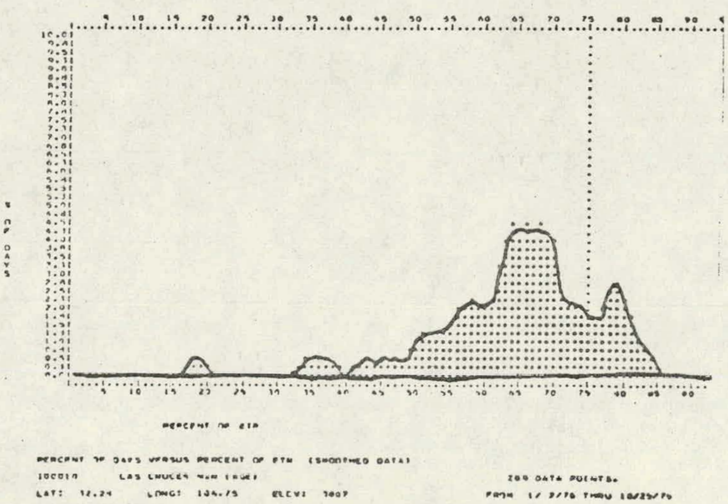
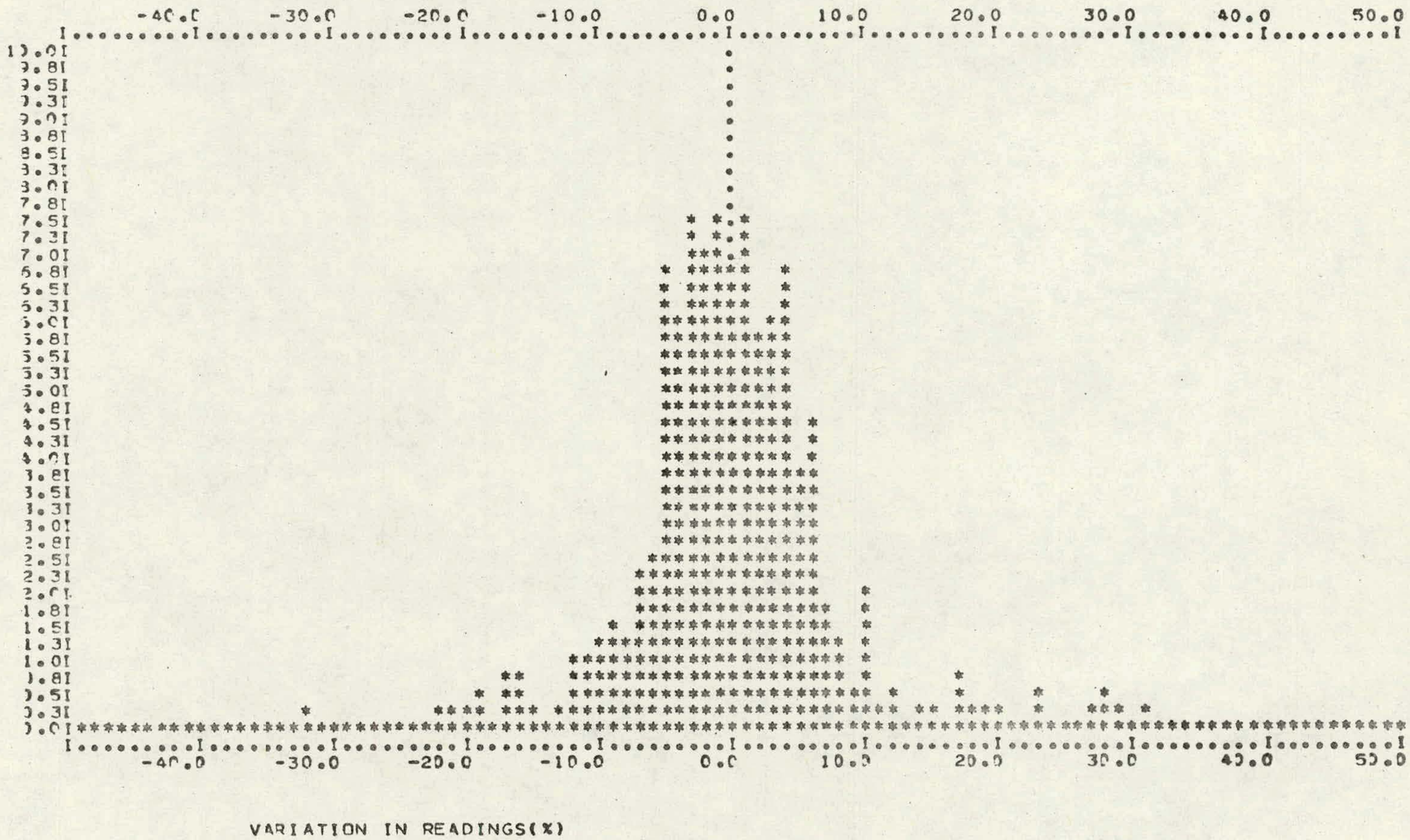


Figure 4. Comparison of Histograms of Solar Data from Three Sites



DISTRIBUTION OF DIFFERENCE BETWEEN TWO STATIONS 411 DATAPOINTS.

23044 EL PASO TEXAS ELEV: 3954 LAT: 31.80 LONG: 106.40

23050 ALBUQUERQUE N.M (NWS) ELEV: 5327 LAT: 35.13 LONG: 106.40

MEAN DIFFERENCE: 0.4 STD.DEV.: 7.2 % 3 DAYS PER POINT. FIRST DAY: 7/ 1/73

Figure 5. Distribution of the Difference of Solar Radiation Values Measured at Two Locations

the New Mexico SOLAR ENERGY RESOURCE

by

Raymond J. Bahm

September 1977

New Mexico is one of the best places in the nation for the application of solar energy systems, yet measured data on the amount of solar energy available has been difficult to obtain. This monograph presents the best estimates currently available on the amount of solar radiation available around the state. The errors in these estimates are judged to be small enough that the data may be used for design of solar heating systems over most of the state.

These estimates are based on over 20 years of solar radiation data measured at Albuquerque, New Mexico, El Paso, Texas, and Midland, Texas, and on shorter periods of data measured at Farmington, Los Alamos, Clovis, Portales, Artesia, Los Lunas, Las Cruces and at Langmuir Laboratory (a mountaintop site near Socorro). The New Mexico Solar Resource Assessment Project[1] has gathered together these data which were originally collected by others[2], and analyzed that data to obtain better information on the amount of solar radiation available in the state.

The early conclusions from this project are:

a) One may expect less solar radiation in mountainous areas than in the relatively flat areas. This may be as much as 20% less and possibly more as there are no measures of solar radiation in most of these areas. (These are the shaded areas on the map.)

b) The data in the table should be adequate for design of solar heating systems in locations represented by unshaded areas of the map. The variation of long term averages of most of these values is probably less than 10% over the unshaded areas of the map. (Exceptions to these would be those collector geometries TH, TNSH, and TT(15) where the seasonal effects at the Northern and Southern state borders would be just over 10%.)

c) The extreme years and extreme months show a much greater variation from the long term averages as presented in the table, than the variation of the solar radiation values measured at different locations within the state.

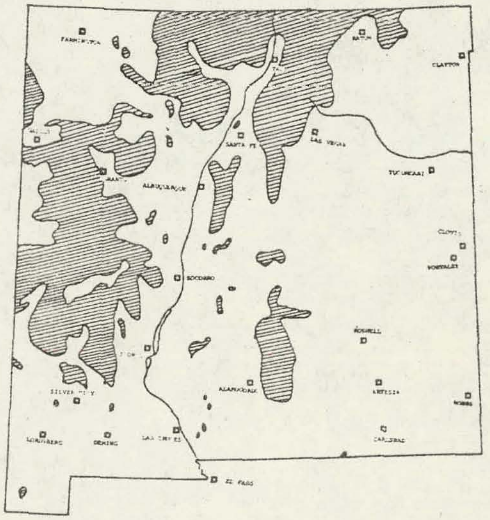
The table contains information on the typical amounts of solar energy available to solar collectors per day. This information does not refer to the design or construction of the collector; rather, it is the amount of radiation available to that type of collector. These data do not include adjustments for collector efficiency.

The top section of the table lists availabilities of direct radiation available to tracking, focusing collectors. These are average daily amounts, expressed in kilowatt hours per square meter (followed by Btu per square foot in parentheses) of collector aperture. The collector-radiation type designations are:

DN - direct-normal (full tracking on two axes).
DNSP - direct on surface rotating about a polar axis (an axis parallel to earth's axis).
DNSH - direct on a surface rotating about an N-S horizontal axis.
DEW - direct on a surface rotating about an E-W horizontal axis.
DVL - direct on a surface tilted upward latitude degrees and rotating about a vertical axis.

The middle section of the table gives average daily amounts of total radiation (direct + diffuse) available to a tracking flat plate collector, which tracks the sun according to these same schemes.

The last section of the table lists average daily values of solar radiation incident upon various fixed surfaces. The values are in kilowatt hours per square meter (Btu per square foot). The designation TH refers to total radiation on a horizontal surface. TT(N) refers to a surface tilted up N degrees from horizontal toward the South. The notation TT(45, ± N) refers to a surface tilted 45 degrees from horizontal and turned N degrees from due South toward either the East or the West. There may be differences in the amounts of radiation available to surfaces depending on whether they face East or West of South. Such differences would be caused by prevalence of clouds in the morning or evening. These differences are small on the average, and are ignored in this table.



The values given in this table are based upon data recorded in Albuquerque. Values for other locations in New Mexico will be generally within about 10% of these. Larger differences may exist for locations which are in the shaded area of the map, or which are significantly more cloudy.

An important fact to keep in mind concerning the values in the table is that these are <u>average</u> values. On particular days the <u>actual</u> values which occur may be as low as 1/5 of these, or they may be 20% more than these numbers, depending on whether that day is exceptionally cloudy or especially clear.

The long term records show that extreme years may have annual average values of daily total solar radiation which vary as much as ± 10% from the values given. The extreme monthly averages can vary as much as ± 25% from the long term average.

AVERAGE DAILY TOTALS OF SOLAR ENERGY AVAILABLE TO VARIOUS COLLECTORS BY SEASONS[3]

Collector - Radiation Types	Direct Radiation Available to Tracking Collectors			
	Spring (Mar., Apr., May)	Summer (June, July, Aug.)	Fall (Sept., Oct., Nov.)	Winter (Dec., Jan., Feb.)
DN	8.9 (2820)	9.5 (3010)	7.4 (2350)	6.5 (2060)
DNSP	8.6 (2730)	8.9 (2820)	7.3 (2310)	6.1 (1930)
DNSH	8.3 (2630)	9.3 (2950)	6.1 (1930)	4.5 (1430)
DEW	6.3 (2000)	7.0 (2220)	5.7 (1810)	5.4 (1710)
DVL	8.2 (2600)	8.9 (2820)	6.7 (2120)	5.6 (1780)
	Total Radiation Available to Tracking Collectors			
	Spring (Mar., Apr., May)	Summer (June, July, Aug.)	Fall (Sept., Oct., Nov.)	Winter (Dec., Jan., Feb.)
TN	10.2 (3230)	10.8 (3420)	8.4 (2660)	7.3 (2310)
TNSP	10.0 (3170)	10.3 (3260)	8.3 (2630)	6.9 (2190)
TNSH	9.7 (3070)	10.7 (3390)	7.1 (2450)	5.4 (1710)
TEW	7.8 (2470)	8.5 (2690)	6.7 (2120)	6.2 (1970)
TVL	9.6 (3040)	10.3 (3260)	7.8 (2470)	6.5 (2060)
	Total Radiation Available to Fixed Collectors			
	Spring (Mar., Apr., May)	Summer (June, July, Aug.)	Fall (Sept., Oct., Nov.)	Winter (Dec., Jan., Feb.)
TH	7.1 (2450)	8.2 (2600)	5.1 (1620)	3.8 (1200)
TT (15)	7.5 (2380)	8.1 (2570)	5.9 (1870)	4.8 (1520)
TT (30)	7.4 (2350)	7.6 (2410)	6.5 (2060)	5.6 (1770)
TT (45)	6.9 (2190)	6.7 (2120)	6.6 (2090)	6.1 (1930)
TT (60)	6.0 (1900)	5.4 (1710)	6.3 (2000)	6.1 (1930)
TT (75)	4.8 (1520)	3.9 (1240)	5.7 (1810)	5.9 (1870)
TT (90)=TV	3.4 (1080)	2.3 (729)	4.8 (1520)	5.2 (1650)
TT (45,±15)	6.9 (2190)	6.7 (2120)	6.5 (2060)	6.0 (1900)
TT (45,±30)	6.9 (2190)	6.8 (2150)	6.3 (2000)	5.7 (1810)
TT (45,±45)	6.8 (2150)	6.8 (2150)	5.9 (1870)	5.2 (1650)
TT (45,±90)	6.0 (1900)	6.7 (2120)	4.4 (1390)	3.3 (1050)
TT (90,±15)	3.6 (1140)	2.5 (792)	4.7 (1490)	5.1 (1620)
TT (90,±30)	3.7 (1170)	3.0 (951)	4.5 (1430)	4.7 (1490)
TT (90,±45)	3.9 (1240)	3.4 (1080)	4.1 (1300)	4.1 (1300)
TT (90,±90)	3.7 (1170)	3.8 (1200)	2.8 (887)	2.2 (697)

[1]The data analysis and preparation of this report was part of the New Mexico Solar Resource Assessment Project, and was sponsored by the State of New Mexico through the New Mexico Energy Resources Board and The New Mexico Energy Institute for Solar Energy at New Mexico State University. The work was performed at The University of New Mexico.

[2]These organizations are: The National Weather Service of the U.S. Government, The Department of Agricultural Engineering at New Mexico State University, The New Mexico Institute of Mining and Technology, The Department of Physics at Eastern New Mexico University, and Los Alamos Scientific Laboratories.

[3]These data from a report entitled "Solar Radiation Availability for New Mexico," by Eldon Boes of Sandia Laboratories, Sandia Report No. SAND-77-0004.

NEW YORK STATE SOLAR NETWORK

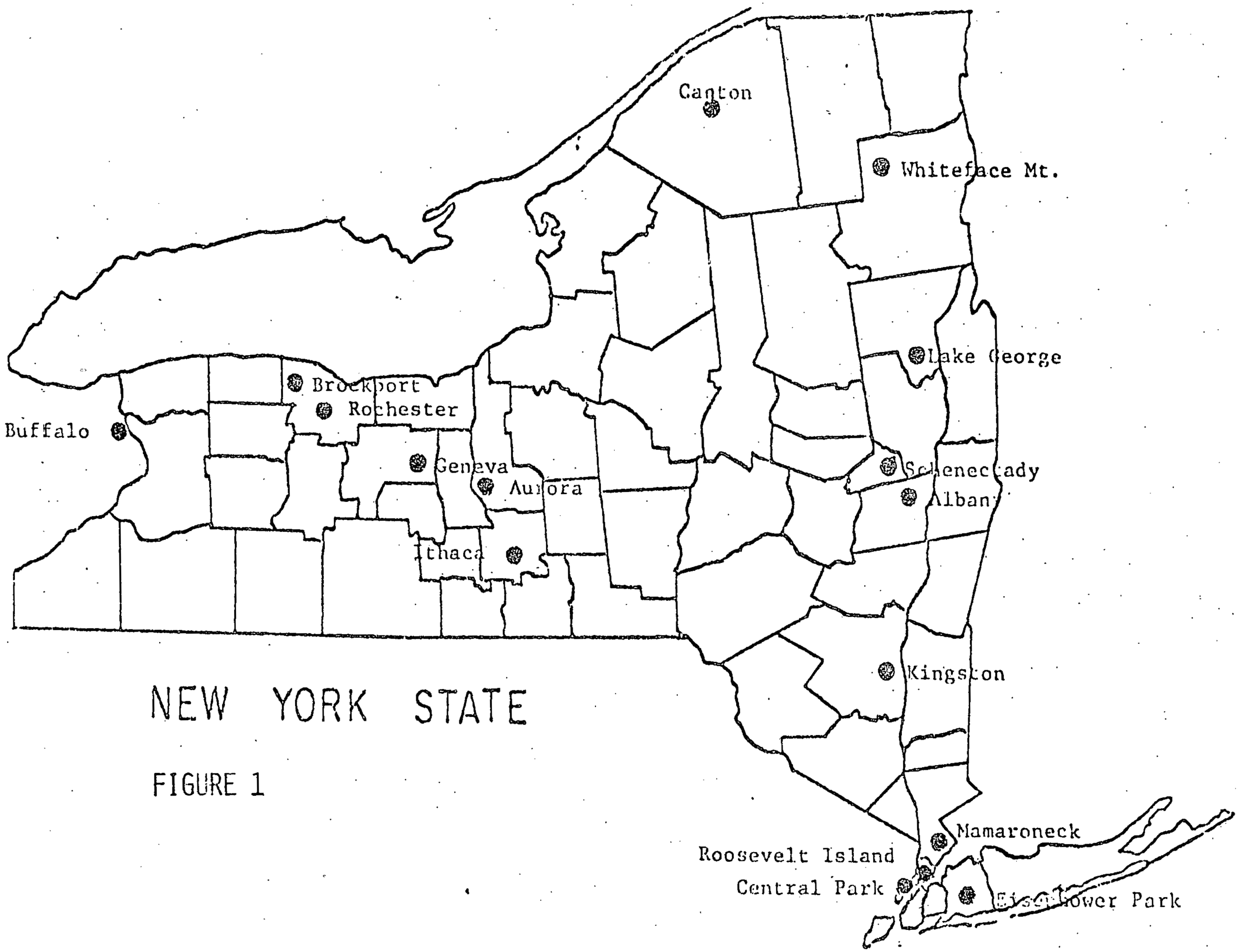
Ronald Stewart
Atmospheric Sciences Research Center, SUNYA

The New York state (NYS) network of solar-radiation stations (Fig. 1) represents a composite effort by several agencies. The majority of the stations were set up by the Department of Environmental Conservation as an integral part of the air and water pollution network. Two other stations have been operated for over 30 years. The Department of Agronomy at Cornell University has operated a station at Ithaca, NY and the NWS has operated a station at Central Park, New York City.

The Atmospheric Sciences Research Center (ASRC) began taking measurements for research purposes in 1962. Since that time a series of stations has been established for specific purposes, such as the Whiteface Mountain and the Albany stations. Recently the NYS Energy Research & Development Authority supported the development of three total incoming and diffuse measurement stations. These were established at Buffalo, Saratoga, and Farmingdale, NY. Since 1974 the ASRC has been processing data from these various sources and has published Solar Atlas for New York State I, II and III. (Healey, Nelson & Stewart 1975; Bailey, Healey & Stewart 1976; Bailey, Spencer & Stewart 1977.)

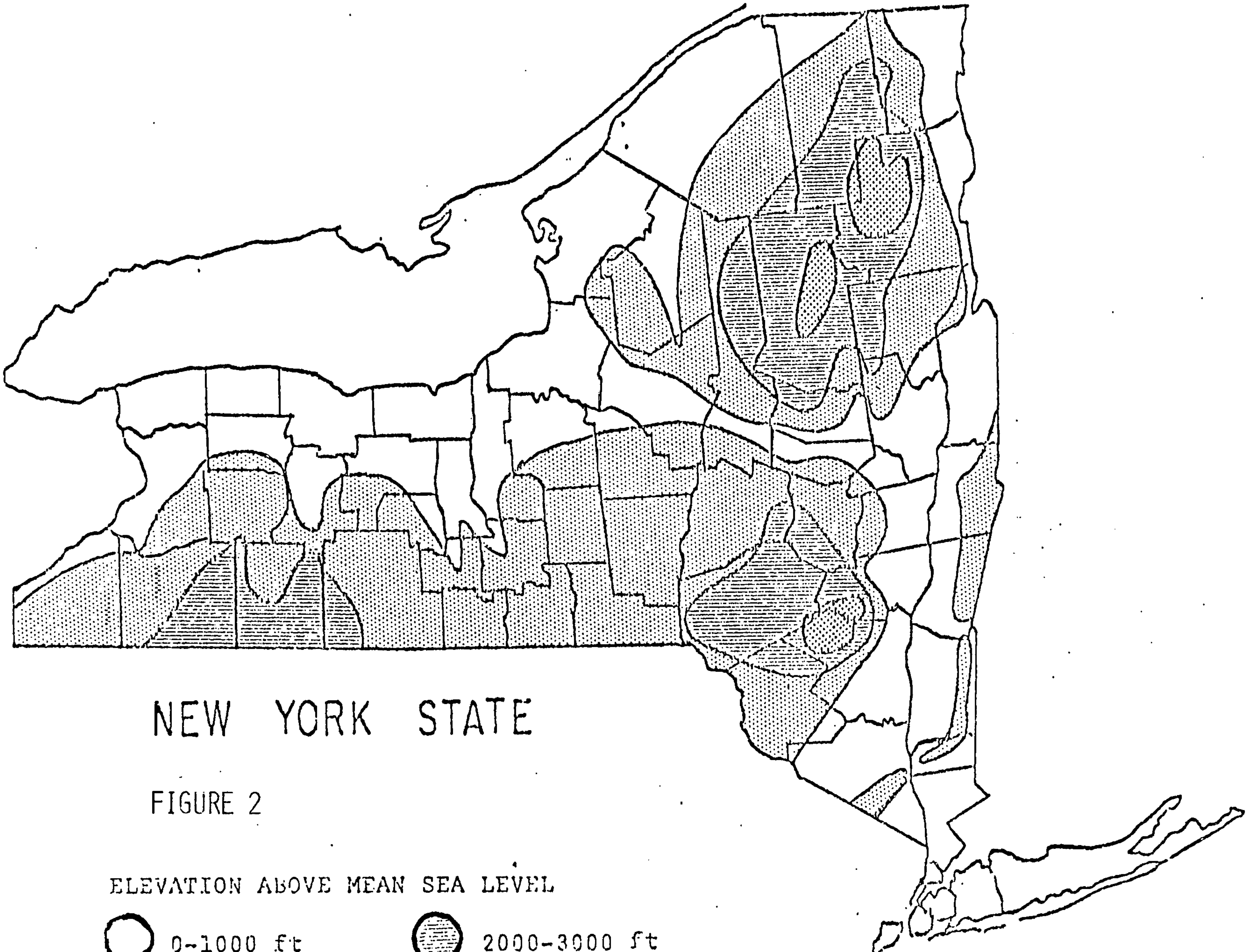
The rationale behind the location of the solar stations in NYS is not directly applicable to other solar networks. The placement was dictated by specific research and monitoring needs of several organizations, but by a single, statistical analysis based on a monitoring program. However, the data from the NYS network may be useful in developing the spatial distribution of future networks.

The topography of NYS is varied (Fig.2) but does not affect the January monthly means analysis presented in Fig.3. The July data (Fig. 4) show somewhat more spatial variation but still no more ±5 percent of a statewide mean. The annual spatial variation is just over ±3 percent of the statewide mean. (Fig.5) If total monthly means of incoming solar radiation on the horizontal were the only data required for the solar program, then few stations would be necessary. However, if one plots the incoming diffuse radiation day by day the state-wide variations begin to become more evident (Fig.5, 6 and 7). For instance the number of days in Buffalo in June with total diffuse radiation measurements of 150-200 ly was 14, while 300 mil to the east Saratoga only 6 days fell into this category. These differences have definite impact on the installation of flat plate and concentrating collectors, or on spectrally selective surfaces. Thus the distribution of solar-radiation stations will be affected greatly by the perceived need for the quantity and quality data.



NEW YORK STATE

FIGURE 1



NEW YORK STATE

FIGURE 2

ELEVATION ABOVE MEAN SEA LEVEL

0-1000 ft
2000-3000 ft
1000-2000 ft
3000-5000 ft

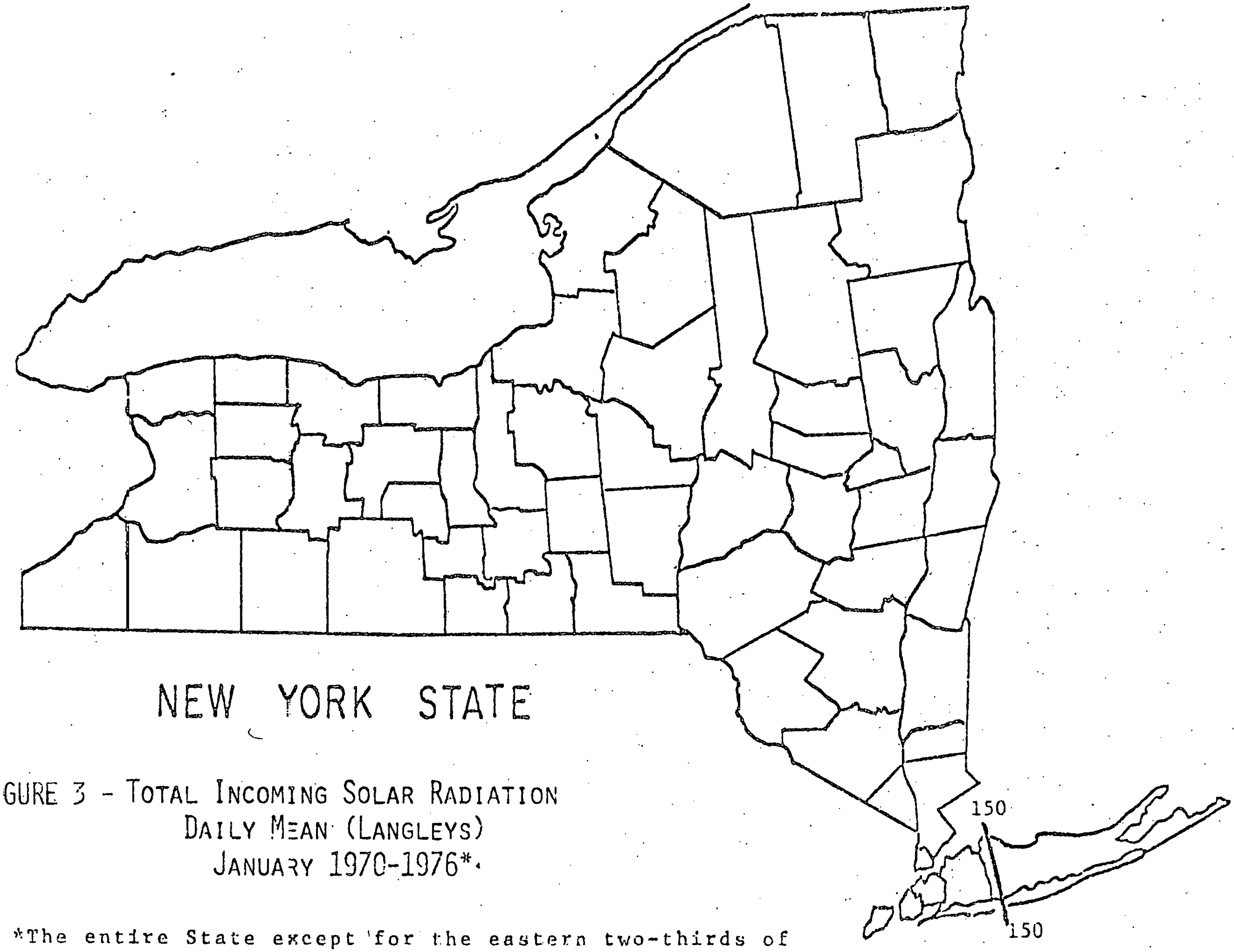
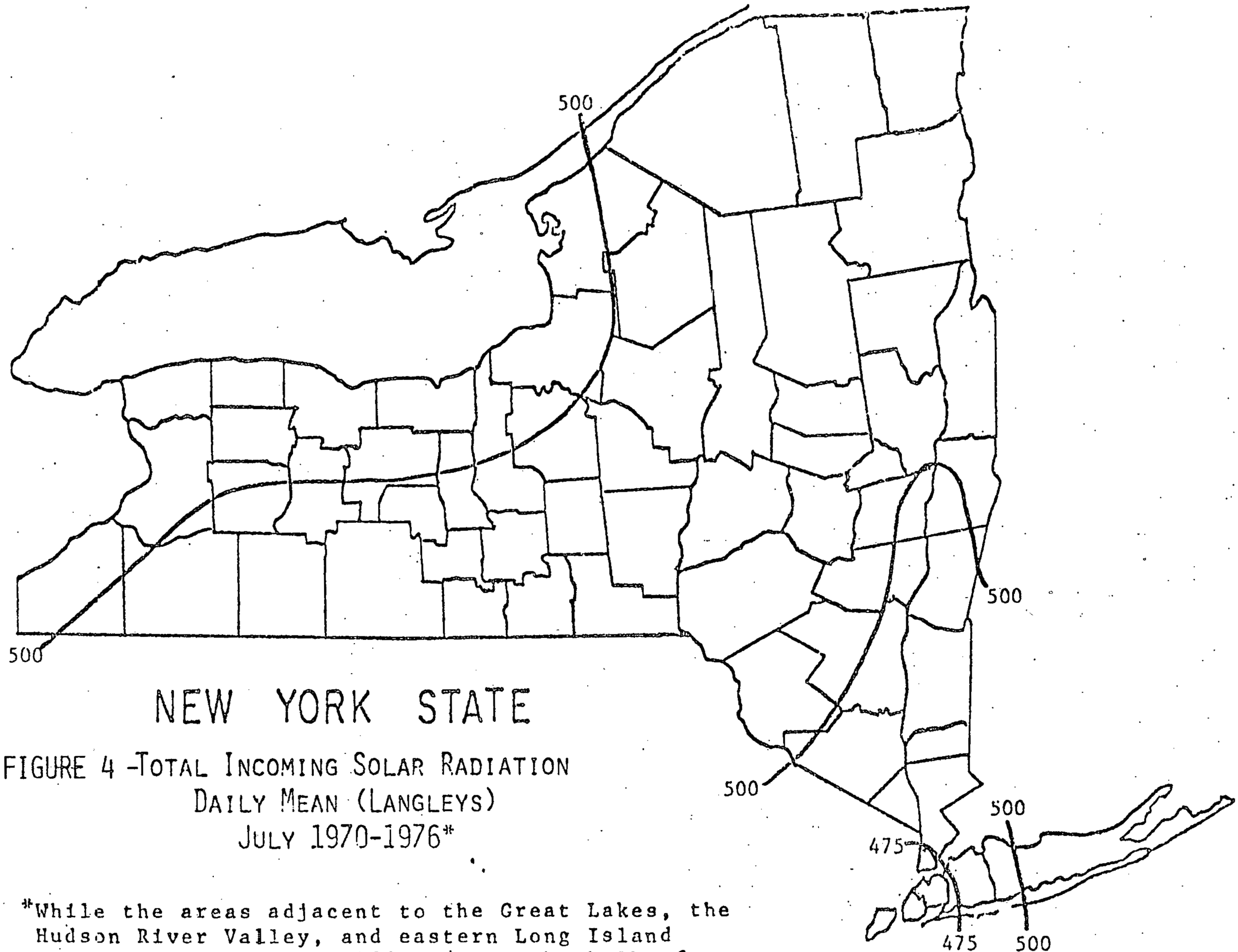


FIGURE 3 - TOTAL INCOMING SOLAR RADIATION
DAILY MEAN (LANGLEYS)
JANUARY 1970-1976*

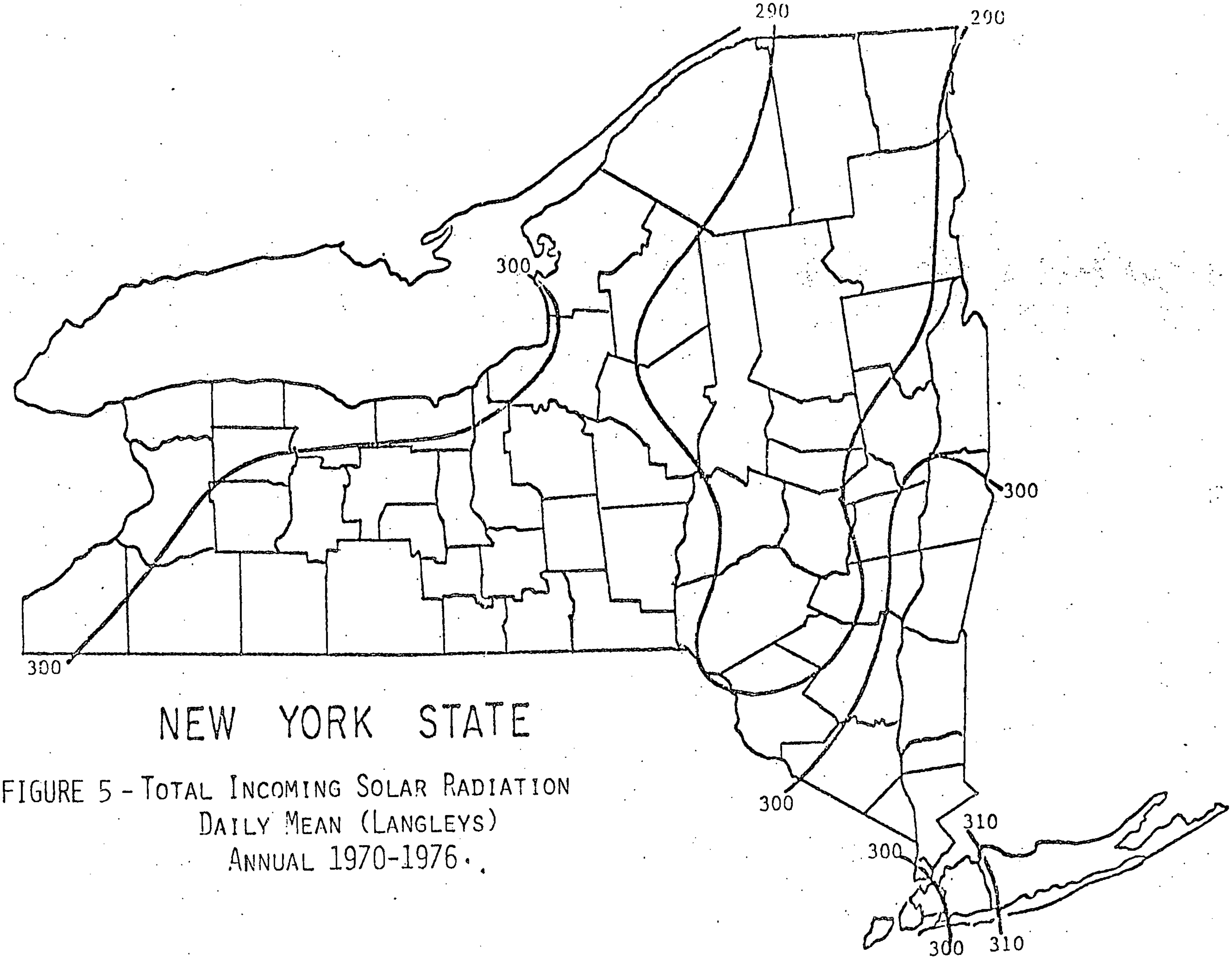
*The entire State except for the eastern two-thirds of Long Island averages between 125 and 150 ly/day. The bulk of Long Island averages between 150 and 175 ly/day.



NEW YORK STATE

FIGURE 4 - TOTAL INCOMING SOLAR RADIATION
DAILY MEAN (LANGLEYS)
JULY 1970-1976*

*While the areas adjacent to the Great Lakes, the Hudson River Valley, and eastern Long Island average greater than 500 ly/day, the bulk of upstate New York and west-central Long Island experience between 475 and 500 ly/day. The New York City area receives under 475 ly/day.



NEW YORK STATE

FIGURE 5 - TOTAL INCOMING SOLAR RADIATION
DAILY MEAN (LANGLEYS)
ANNUAL 1970-1976.

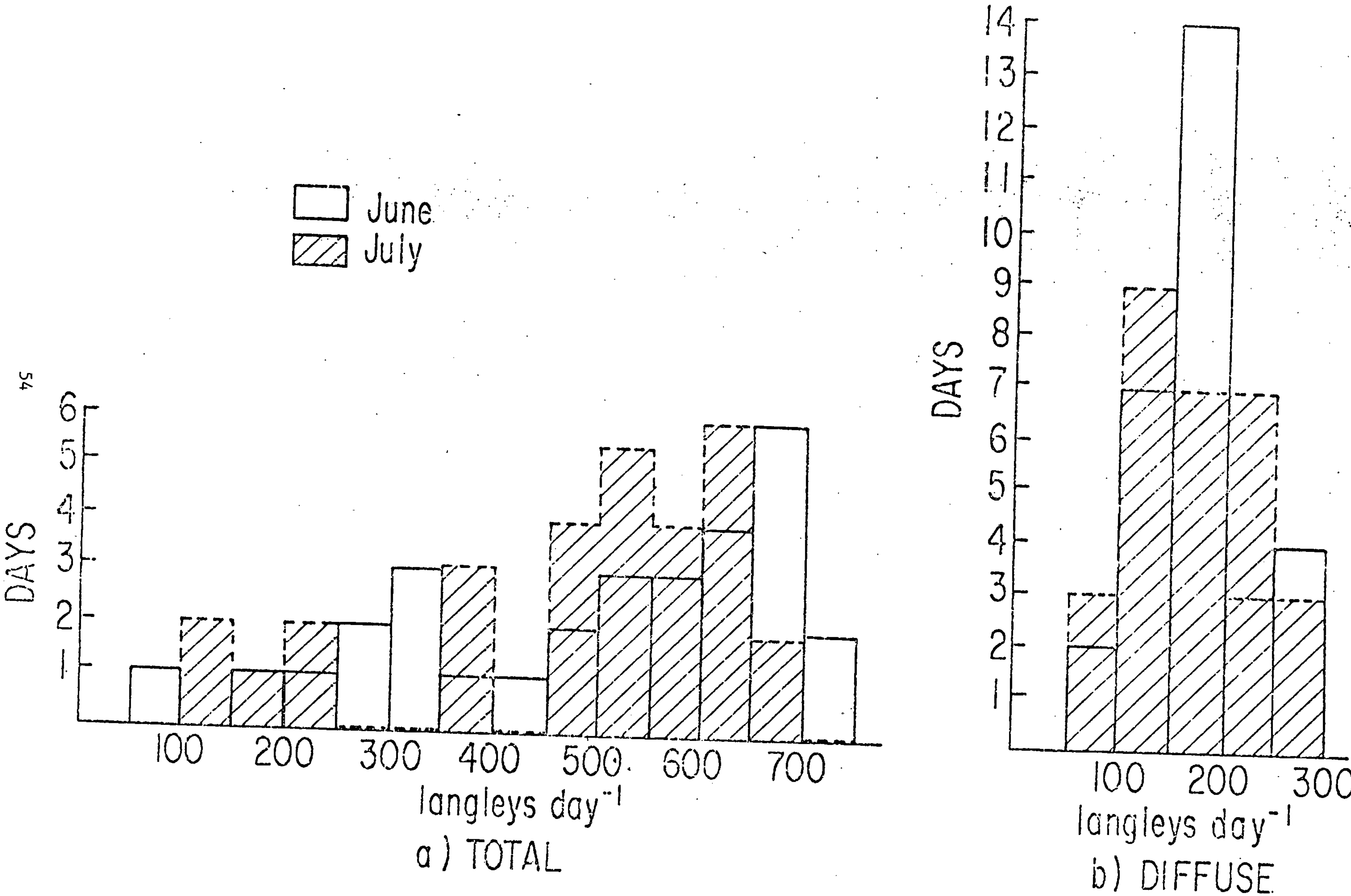


Fig. 6- Distribution of daily irradiation totals at Buffalo

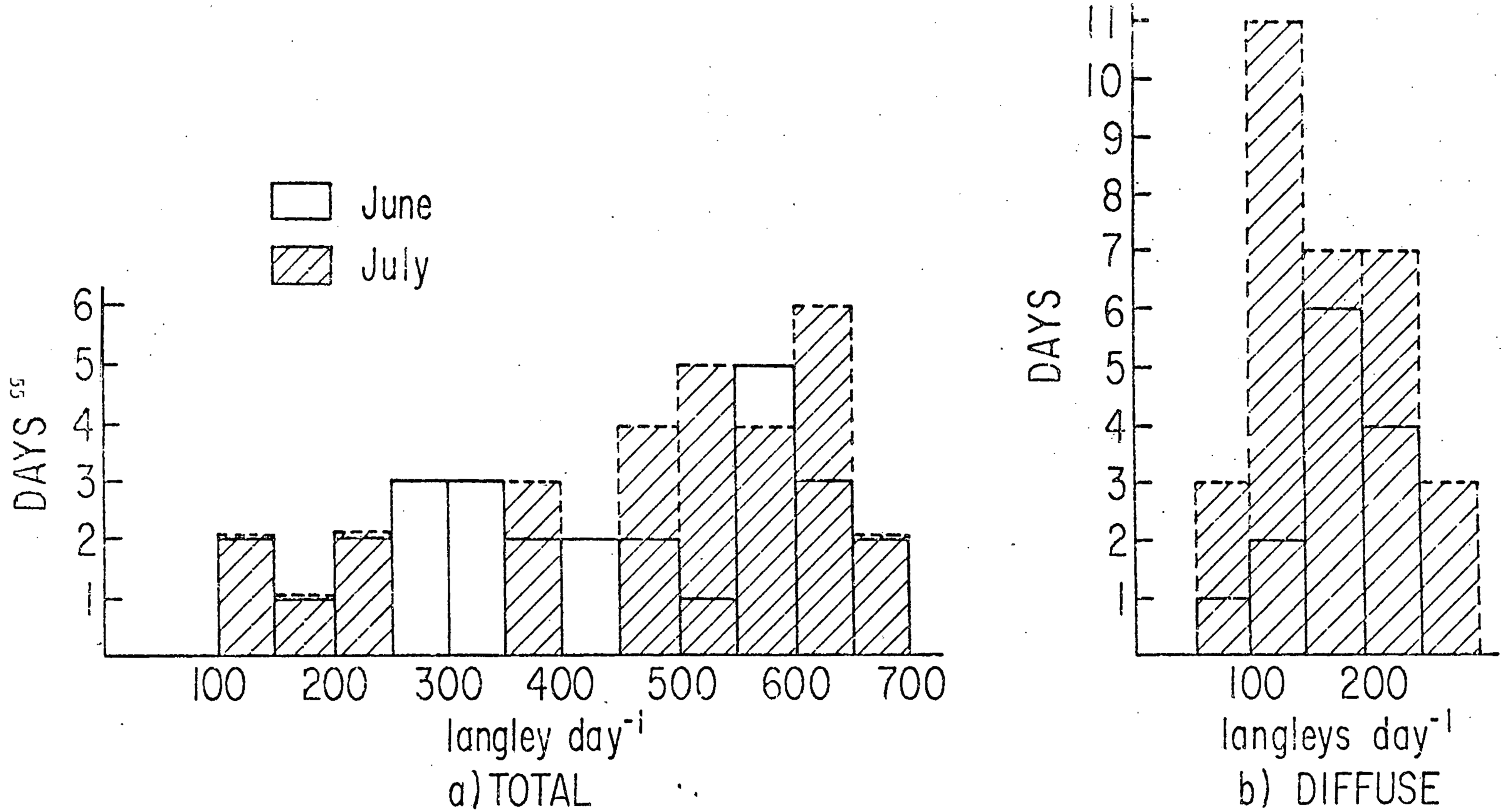


Fig.7 - Distribution of daily irradiation totals at Saratoga

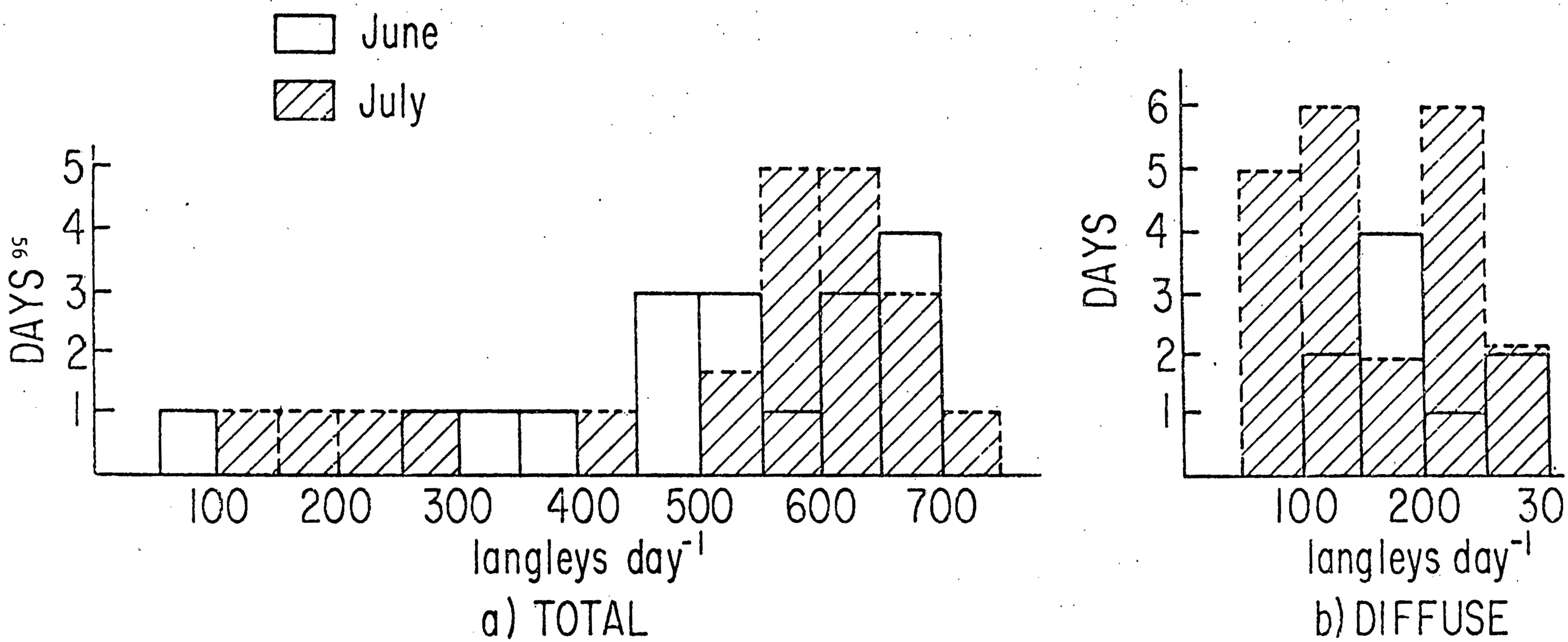


Fig. 8 - Distribution of daily irradiation totals at Farmingdale

The WEST Associates

Solar Resource Evaluation Project

Nick W. Patapoff, Southern California Edison

Western Energy Supply and Transmission Associates (WEST), a group of utilities, is funding the Solar Resource Evaluation Project with Southern California Edison, (SCE) as project manager. The objective of the project is to establish a regional data base for use by utilities in evaluations of solar technology. Nearly 40 stations monitoring total insolation and air temperature are now operating. At 14 of these stations, measurements are also being made of direct radiation.

During initial assessments of the impact of solar-energy technology, SCE recognized the need to have accurate insolation (incident solar radiation) information for their design and evaluation. The existing data base was, however, discovered to be inadequate in several ways. Poor instrument calibration and maintenance procedures had resulted in data inaccuracies of up to 15 percent. There had not been enough data stations to properly characterize solar-radiation variations nor were the stations in areas with potential for future solar-energy applications. In addition, the available solar data had not been taken at close enough time intervals to properly characterize short-term variations.

In 1975, SCE launched a multiyear effort to create the needed data base of solar information. By January, 1976, a network of 13 stations "monitoring" the solar resource had been deployed at selected points throughout the SCE service territory. By August, 1977, 21 stations were recording solar radiation and air temperature data.

SCE located solar-monitoring stations in various geographic areas in order that representative data would be available from coastal, inland, desert, and mountain areas. The current operating system and the planned stations are shown on Fig. 1 and Fig. 2.

Coverage of the Southwest beyond the borders of the SCE service territory became possible through funding by WEST. SCE, as program manager, contracted with WEST to develop computer software, to design station instrumentation, to maintain system calibration, and to translate, store, and verify all collected data. Participating utilities in Arizona, Colorado, Nevada, and New Mexico are operating 18 monitoring stations. These stations are owned and operated by the utilities. The system and participants are shown in Fig. 3. Data from the over 40 stations in the WEST network will be stored in the computer files at SCE.

All WEST solar-monitoring stations record air temperature and total insolation on a horizontal surface. Eppley black and white pyranometers are used in the SCE network for measuring total insolation. Eppley normal incidence pyrheliometers are used for measuring direct insolation. Participants in the WEST Solar Resource Evaluation Project have the option of using Eppley black and white, Eppley precision, or Spectrolab SR-75 Pyranometers for total insolation measurements. Six non-SCE stations also monitor direct insolation with the Eppley normal incidence pyrheliometer.

The accuracy of the instruments and the quality of the routine maintenance program are key elements in the integrity of the solar network and the value of its data. In an effort to minimize the difficulties experienced by past, large-scale, solar-monitoring efforts, SCE has instituted a rigorous program of maintenance and calibration. Maintenance procedures are performed at least weekly at SCE solar-monitoring stations. On a weekly basis at stations monitoring only total insolation and air temperature, the pyranometer dome is cleaned, the temperature checked, and the signal conditioning equipment inspected. Where direct insolation is also being measured, sites are visited three times a week to make declination and azimuth adjustments on the tracking equipment.

Instruments are currently calibrated to the International Pyrheliometric Scale, 1956. Provision exists for modification of the data should a new scale be adopted.

SCE calibrates all instruments on the network twice a year. It also has obtained a TMI Mark VI cavity radiometer for use in calibrating the Eppley normal incidence pyrheliometers. Normal incidence pyrheliometers are calibrated side by side in sunlight, near noon, under clear-sky conditions and only after waiting a suitable length of time for temperature stabilization. Pyranometers undergo three tests to assure a valid calibration: the Sun and shade method, comparison with reference pyranometers, and a SCE version of the collimation tube method. The instruments also are checked for cosine and azimuth response. Pyranometers similar to field units are used as reference standards and are kept at the SCE Laboratory when not in use.

Insolation and temperature data are recorded at all stations in the WEST network. The recording system for the data stations was designed to make use of four-channel recorders and the existing SCE load survey translator/computer facilities. With the recording system now being used, solar intensity and air temperature are simultaneously recorded as averages over a 15-min interval. Each day of the year is divided into 96 15-min intervals. All intervals are described in standard time and no adjustment is made for Daylight Saving Time.

In spite of efforts to maintain high levels of instrument reliability, there have been occasional failures. They cause loss of data for periods ranging from a couple of hours to a few weeks. In some cases, noise in the system may be recorded as data. Efforts have been made to reconstruct missing data where possible and to eliminate as many extraneous data points as can be discovered (though care is taken not to disturb normal extremes).

Instrument and hardware outages resulted in loss of about 3 percent of the nearly 800,000 data points possible from the 13 stations. Temperature data are irretrievable when lost due to an instrument outage. Missing total insolation data also are considered lost. On days when direct insolation data were missing, estimates were made only for those days that were clear according to pyranometer measurements of total insolation. The direct component of total insolation was estimated by one of two methods, depending upon the length of time the data are missing. Data missing for a short period, one or two 15-min intervals, are estimated by taking an appropriate average between available levels of adjacent intervals. Periods of missing data of greater length are estimated by means of a comparison of ratios of direct/total insolation of immediately adjacent clear sky days to the total insolation level on the missing day. The method typically results in an estimated error of ± 3 percent from actual values of direct insolation levels.

The data collected on the WEST solar monitoring network is available in three formats: summaries for use in building applications; detailed statistical summaries for a detailed analysis; and unreduced data on magnetic tape. These formats are described in detail in "The WEST Associates Solar Resource Evaluation Project—Solar Energy Measurement During 1976." This report is available from the Research and Development Division of Southern California Edison.

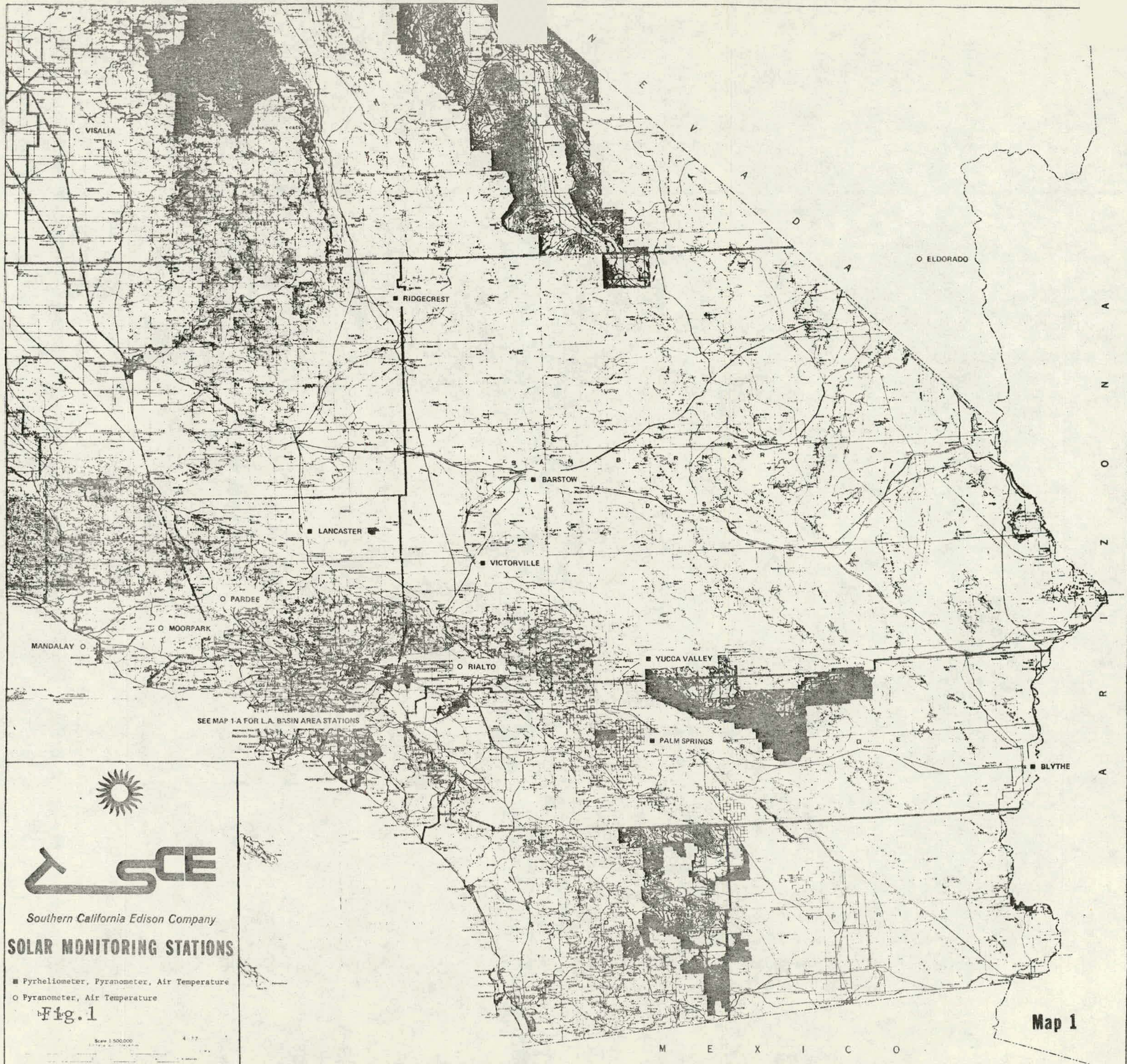
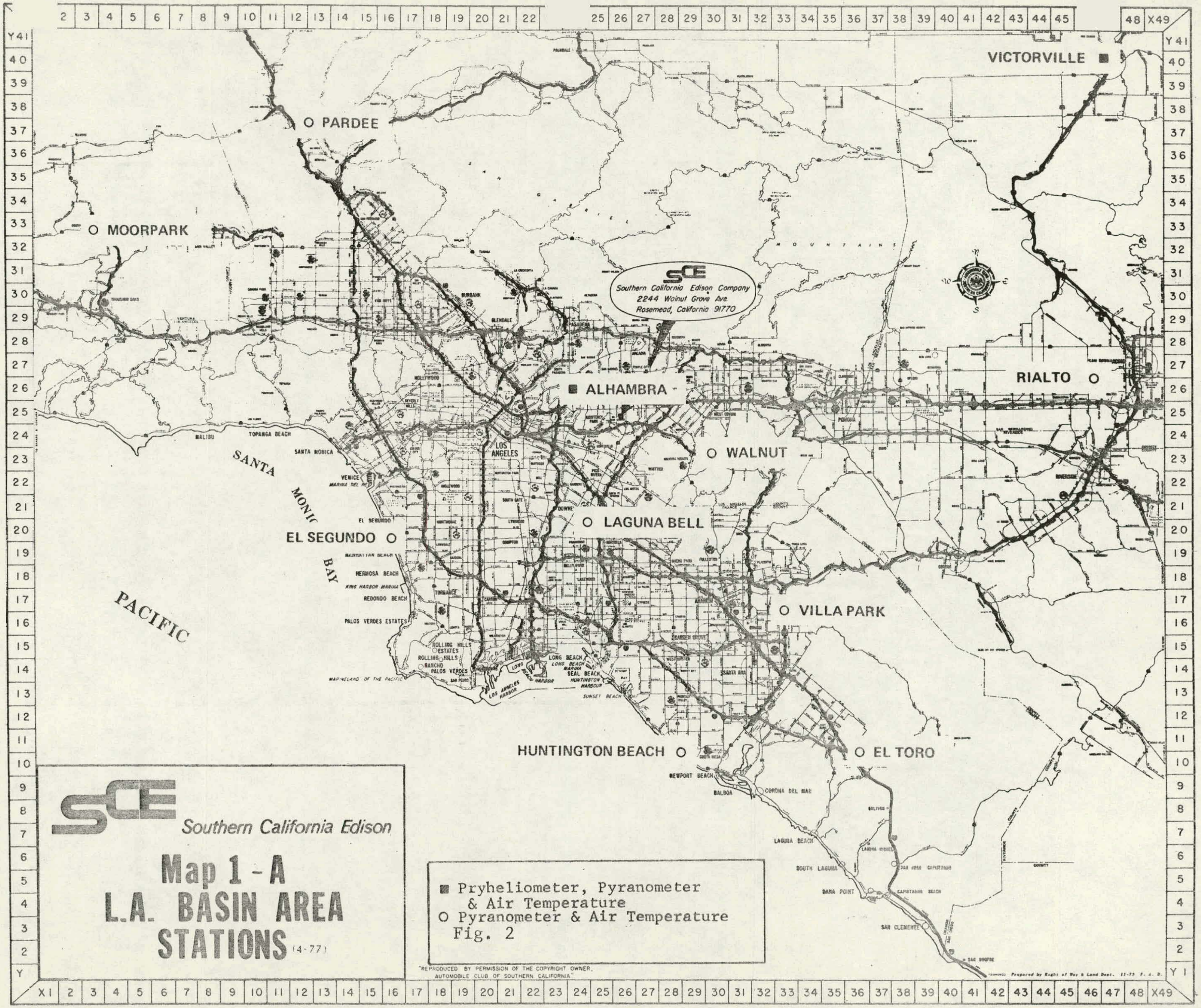

NEVADA
ARIZONA
MEXICO
VISALIA
ELDORADO
RIDGECREST
BARSTOW
LANCASTER
VICTORVILLE
PARDEE
MOORPARK
MANDALAY
RIALTO
YUCCA VALLEY
PALM SPRINGS
BLYTHE
SEE MAP 1-A FOR L.A. BASIN AREA STATIONS
SCE
Southern California Edison Company
SOLAR MONITORING STATIONS
■ Pyrheliometer, Pyranometer, Air Temperature
○ Pyranometer, Air Temperature
Map 1

Fig. 1



SCE Southern California Edison

Map 1 - A
L.A. BASIN AREA STATIONS (4-77)

■ Pryheliometer, Pyranometer & Air Temperature
O Pyranometer & Air Temperature
Fig. 2

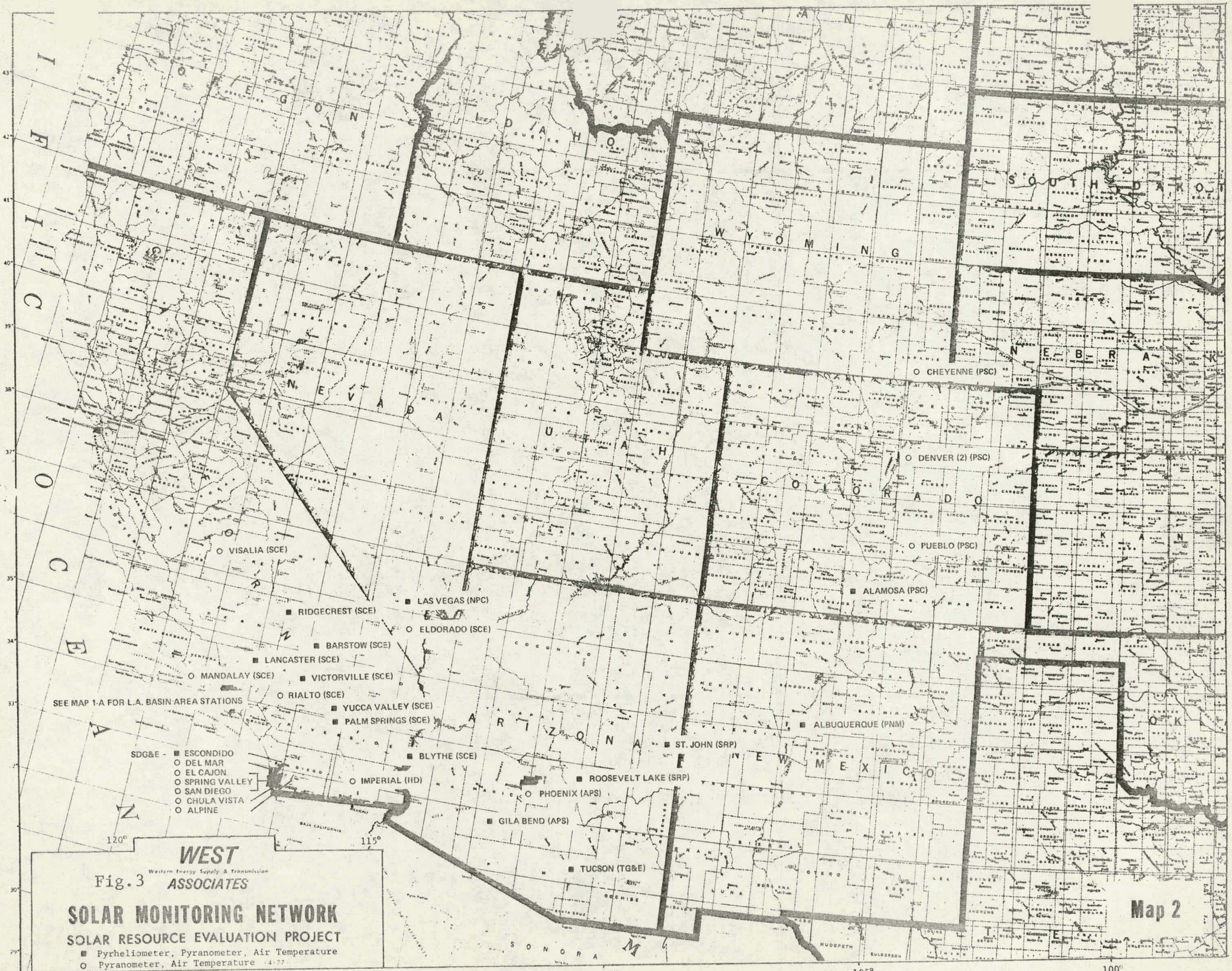


Fig.3

WEST
Western Energy Supply & Transmission
ASSOCIATES

SOLAR MONITORING NETWORK

SOLAR RESOURCE EVALUATION PROJECT

■ Pyrheliometer, Pyranometer, Air Temperature
O Pyranometer, Air Temperature (4-77)

63

SOLAR RADIATION ENERGY SOURCE COMPARISON USING SOLMET DATA

E. S. Terry and R. A. Schlagheck, MSFC

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME:
EL12	SOLAR RADIATION ENERGY SOURCE COMPARISON USING SOLMET DATA	R. SCHLAGHECK
		DATE: SEPT 1977

BACKGROUND OF STUDY

WHAT WAS ANALYZED

A COMPREHENSIVE COMPARISON OF MONTHLY AVERAGE RADIATION VALUES OF 2 DIFFERENT DATA SOURCES AND 2 MATHEMATICAL PREDICTOR METHODS COVERING 26 U.S. SITES

- SOLMET DATA - AS SUMMARIZED FROM PRERELEASE SOLMET (NON-GAP FILLED) TAPES
- F CHART DATA - AS SUMMARIZED FROM THE CURRENT DATA BASE USED IN THE F CHART II VERSION ANALYSIS PROGRAM
- ASHRAE CLOUD COVER MODEL - AS CALCULATED USING THE ASHRAE ALGORITHMS FOR BUILDING HEAT TRANSFER SUBROUTINES
- ASHRAE % SUNSHINE MODEL - AS CALCULATED BY A % SUNSHINE MODIFIER OF THEORETICAL CLEAR DAY DATA

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME:
EL12	SOLAR RADIATION ENERGY SOURCE COMPARISON USING SOLMET DATA	R. SCHLAGHECK
		DATE: SEPT 1977

BACKGROUND

WHY PERFORM THE STUDY?

SOLMET IS THE STANDARD FOR SOLAR RADIATION INPUT TO SHAC PERFORMANCE ANALYSIS

HOW DO OTHER DATA BASES (SUCH AS F CHART) COMPARE AGAINST 23 YEAR AVERAGES OBTAINED FROM SOLMET DATA?

HOW DO VARIOUS LONG TERM PREDICTOR TECHNIQUES (SUCH AS % SUNSHINE AND ASHRAE CLOUD COVER) COMPARE AGAINST GOOD INSOLATION DATA AS SOLMET?

WHAT TECHNIQUE CAN BE RECOMMENDED FOR GENERATING INSOLATION VALUES FOR NON SOLMET SITES?

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME: R. SCHLAGHECK
EL12	DATA SOURCES	DATE: SEPT 1977

SOLMET --- RADIATION VALUES OF REHABILITATED INSOLATION DATA ON A HORIZONTAL SURFACE WAS OBTAINED BY COMPUTING THE AVERAGE DAILY FLUX PER MONTH FOR EACH OF THE 26 SOLMET SITES

AVERAGES ONLY INCLUDED REHABILITATED HOURLY OBSERVATIONS IN WHICH DATA WAS RECORDED. THOSE TIME PERIODS WITH MISSING DATA WAS NOT INCLUDED IN THE CALCULATIONS

DATA USED IN ANALYSIS WERE PRELIMINARY NON-GAP FILLED SOLMET TAPES FOR THE 26 STATION HISTORICAL NETWORK

F CHART -- THE AVERAGE DAILY INSOLATION VALUES PER MONTH FOR THE 26 HISTORICAL SOLMET SITES WERE OBTAINED FROM THE F CHART 2 DATA BASE

THESE VALUES WERE COLLECTED FROM A VARIETY OF VARIOUS SOURCES SUCH AS THE WEATHER BUREAU, BENNETT MAPS AND RESEARCH SITES

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME: R. SCHLAGHECK
EL12	ANALYTICAL TECHNIQUES	DATE: SEPT 1977

ASHRAE CLOUD COVER - RADIATION VALUES CALCULATED FROM THEORETICAL CLEAR DAY VALUES MODIFIED BY A CLOUD COVER FACTOR

$$I_{CLOUD} = I_{CLEAR} * CCF$$

$$I_{CLEAR} = f\ (LAT,\ SEASON,\ TIME)$$

CCF = f (C. TYPE, C. AMOUNT, SEASON)
C. TYPE AND C. AMOUNT OBTAINED FROM SOLMET TAPE

REFERENCE - KIMURA AND STEPHENSON ASHRAE TRANSACTIONS PAPER 2106, PAGES 227-233, 1969

- PROCEDURE FOR DETERMINING HEATING AND COOLING LOADS FOR COMPUTERIZING ENERGY CALCULATIONS, ASHRAE 1975

% SUNSHINE - RADIATION VALUES CALCULATED FROM ASHRAE THEORETICAL CLEAR DAY VALUES MODIFIED BY PERCENT OF POSSIBLE SUNSHINE

REFERENCE - ASHRAE FUNDAMENTALS HANDBOOK CHAPTER 22

- MORRIS AND LAWRENCE ASHRAE TRANSACTIONS PAPER 2110 PAGES 34-42, 1969

ORGANIZATION: EL12	MARSHALL SPACE FLIGHT CENTER TABLE 1 SOLMET RECONDITIONED DATA SITES	NAME: R. SCHLAGHECK DATE: SEPT 1977

Site Name	Printout Abbreviation	WBAN #
Albuquerque, New Mexico	ALB, NM	23050
Apalachicola, Florida	APA, FL	12832
Bismark, North Dakota	BIS, ND	24011
Boston, Massachusetts	BOS, MS	94701
Brownsville, Texas	BRO, TX	12919
Cape Hatteras, North Carolina	HAT, NC	93729
Caribou, Maine	CAR, ME	14607
Charleston, South Carolina	CHA, SC	13880
Columbia, Missouri	COL, MO	03945
Dodge City, Kansas	DCT, KA	13985
El Paso, Texas	ELP, TX	23044
Ely, Nevada	ELY, NV	23154
Fort Worth	FTW, TX	03927
Fresno, California	FRE, CA	93193
Great Falls, Montana	GRF, MT	24143
Lake Charles, Louisiana	LCH, LA	03937
Madison, Wisconsin	MAD, WI	14837
Medford, Oregon	MED, OR	24225
Miami, Florida	MIA, FL	12839
Nashville, Tennessee	NAS, TN	13897
New York, New York	NWY, NY	94728
Omaha, Nebraska (North Omaha)	OMH, NE	94918
Phoenix, Arizona	PHO, AR	23183
Santa Maria, California	SMA, CA	23273
Seattle, Washington	SEA, WS	24233
Washington, D. C.	WAS, DC	93734

ORGANIZATION: EL12

MARSHALL SPACE FLIGHT CENTER

PERCENT OF SOLMET DATA BASE (23 YEARS) HAVING ACTUAL (NON FILLED) REHABILITATED INSOLATION VALUES

NAME: R. SCHLAGHECK

DATE: SEPT 1977

	CITY, STATE	MINIMUM-MONTH	MEAN
1.	ALB, NM	93% - AUG	97%
2.	APA, FL	86% - AUG	91%
3.	BIS, ND	96% - AUG	98%
4.	BOS, MS	50% - DEC	74%
5.	BRO, TX	44% - JUL	75%
6.	HAT, NC	90% - JUL	97%
7.	CAR, ME	80% - NOV	92%
8.	CHA, SC	12% - JUL	69%
9.	COL, MO	92% - MAY	97%
10.	DCT, KA	88% - JUN	92%
11.	ELP, TX	98% - FEB	99%
12.	ELY, NV	57% - NOV	64%
13.	FTW, TX	96% - NOV	99%
14.	FRE, CA	61% - OCT	63%
15.	GRF, MT	58% - SEP	62%
16.	LCH, LA	45% - JUL	78%
17.	MAD, WI	61% - JUL	76%
18.	MED, OR	52% - DEC	64%
19.	MIA, FL	3% - AUG	52%
20.	NAS, TN	61% - AUG	87%
21.	NWY, NY	59% - JUL	78%
22.	OMH, NE*	77% - JUN	90%
23.	PHO, AR	60% - JUL	62%
24.	SMA, CA*	89% - JUN	94%
25.	SEA, WS	32% - FEB	54%
26.	WAS, DC	71% - JUL	88%

AVERAGE DAILY TOTALS -- KJ/M^2 - DAY

SUMMARY OF SOLAR RADIATION USING ACTUAL SOLMET DATA

SITE	WBAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG MO
ALB,NM	23050	11625	15235	20032	25392	28844	30605	28275	25974	22404	17501	12918	10536	20778
APA,FL	12832	9669	12695	16650	21339	23681	22905	20423	19186	17390	15527	11807	9192	16705
BIS,ND	24011	5276	8841	13332	16590	21012	23414	24727	21329	15440	10268	5751	4219	14183
BOS,MS	94701	5421	7987	11966	15051	19310	20262	19719	16853	14835	10277	5805	4761	12687
BRO,TX	12919	10373	12827	16634	19540	21696	24475	25630	23140	19462	16434	12169	9784	17680
HAT,NC	93729	7759	10802	15098	20114	22236	23119	21968	19299	16651	12911	9934	7547	15619
CAR,ME	14607	4822	8320	12845	16053	17832	19835	19647	16799	12468	7786	4193	3648	12020
CHA,SC	13880	6944	9902	13411	17153	21296	23810	24040	21335	16381	12386	7997	5945	15050
COL,MO	13983	8449	11312	15104	19637	21533	21454	21348	19560	16042	13539	10603	8169	15562
DCT,KA	13985	9480	12722	16871	21506	23842	26652	26082	23435	18921	14684	10166	8360	17726
ELP,TX	23044	13390	16973	20556	26279	30090	31394	28990	26705	24361	18904	15503	12585	22144
ELY,NV	23154	9424	13183	18383	22895	26085	28941	27922	25413	21840	16265	10703	8423	19123
FTW,TX	3927	9623	12079	16081	18474	21568	24591	24677	22434	18385	14416	10949	9107	16865
FRE,CA	93193	10000	11825	18511	22152	28024	29124	29623	25621	22048	15438	11452	6094	19159
GRF,MT	24143	4919	8267	13760	17247	21107	24066	26736	22329	15629	10203	5610	4012	14490
LCH,LA	3937	8219	11491	14846	17853	21225	23476	20302	18639	16754	14631	10446	7930	15484
MAD,WI	14837	6003	9167	13138	15768	19516	22383	22316	19745	14876	10346	5770	4401	13619
MED,OR	24225	4421	8433	12790	19354	22821	25897	27997	24048	18069	11321	5875	3711	15394
MIA,FL	12839	12027	14941	18141	21473	21888	20190	21258	21616	17218	14915	12704	11561	17327
NAS,TN	13897	6490	9327	12848	17564	20808	22263	21281	19721	15716	12387	8021	5801	14352
NWY,NY	94706	5702	8241	11765	15342	18384	20099	19773	17258	13741	10134	6003	4550	12582
OMH,NE	94918	7179	10097	13996	17598	21297	24047	24046	21159	15540	12193	7531	5796	15039
PHO,AR	23183	11491	15658	20628	26702	30280	31441	28267	25877	22938	18011	13141	10564	21249
SMA,CA	23236	9983	12941	18213	21755	24523	26956	27195	23947	19964	15669	11297	9161	18467
SEA,WS	24233	2978	5436	9892	14888	19455	20422	22187	17988	12855	7269	3773	2324	11622
WAS,DC	93722	6495	9143	12773	16579	19759	21890	20618	18762	15219	11256	7383	5416	13774

AVERAGE DAILY TOTALS -- KJ/M^2 - DAY

SUMMARY OF SOLAR RADIATION USING THE FCHART DATABASE

SITE	WBAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG MO
ALB,NM	23050	12895	16328	21436	26376	28804	30939	28888	26628	23697	18714	14151	11764	21718
APA,FL	12832	12267	15239	18463	23026	25497	24743	22650	21226	19259	17500	13942	11053	18738
BIS,ND	24011	6615	10509	14695	18799	23068	24576	25622	21687	15993	11430	6741	5192	15410
BOS,MS	94701	5820	8290	12267	15239	19762	20892	20766	17793	14276	9964	6071	4982	13010
BRO,TX	12919	12016	14067	16830	19175	23278	25288	25916	23237	19468	16998	11891	10592	18229
HAT,NC	93729	10216	13272	18087	23906	26585	27004	26334	23320	19762	15114	11891	9043	18711
CAR,ME	14607	5736	9629	15366	16747	19845	20096	21310	18841	13942	8792	4605	4438	13278
CHA,SC	13880	10592	12686	16412	21562	23026	23446	21896	20766	17082	14360	11932	9043	16900
COL,MO	13983	7536	10467	14403	18129	22231	23906	24032	22022	18757	13565	9295	7075	15951
DCT,KA	13985	10843	13691	18087	22608	23571	27591	27213	24408	20641	15909	11722	9713	18833
ELP,TX	23044	13858	18087	22985	27422	29935	30563	28051	26753	24074	19342	15366	13104	22461
ELY,NV	23154	9964	13942	19426	23613	26125	29642	27130	25455	21729	16454	12016	9211	19558
FTW,TX	3927	10550	13439	17793	20641	23487	26879	25622	24618	20933	16496	12476	10216	18595
FRE,CA	93193	7787	12392	18338	22817	26670	29181	27967	25371	21059	15700	10090	6699	18672
GRF,MT	24143	5778	9588	15155	17961	21938	24743	26585	22147	16914	10970	6447	4689	15242
LCH,LA	3937	10006	12728	16579	20222	23195	24367	21813	21185	18757	16830	12392	9713	17315
MAD,WI	14837	6412	9224	13992	16527	19821	23073	23241	19762	16397	11277	6311	5632	14305
MED,OR	24225	4941	8876	13900	20263	24659	27339	29265	25204	18799	11639	6363	3851	16258
MIA,FL	12839	14360	17417	20557	22776	23110	22231	22483	21268	18714	16287	14821	13355	18948
NAS,TN	13897	6824	10049	13774	18841	21645	23738	23153	20683	17920	13691	9085	6741	15512
NWY,NY	94706	5443	8332	12142	15449	18087	19678	19217	16287	13858	10132	6155	4815	12466
OMH,NE	94918	8546	11598	14905	19385	21479	23572	23782	21814	16580	12310	8290	6950	15767
PHO,AR	23183	12434	17082	21813	26921	30312	30982	27297	25622	23780	18924	14193	11722	21756
SMA,CA	23236	11095	14654	20347	23446	26670	29139	28512	25622	21928	17500	13021	10592	20210
SEA,WS	24233	3266	5694	11053	16579	20975	21813	23738	19134	13733	7913	4438	2679	12584
WAS,DC	93722	6657	9629	13397	16272	18714	23362	22147	19342	15366	11764	8834	6154	14353

AVERAGE DAILY TOTALS -- KJ/M^2 - DAY

SUMMARY OF SOLAR RADIATION USING ASHRAE THEOR. * SOLMET CCF

SITE	WBAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG MO
ALB,NM	23050	13805	18694	22154	26679	31597	30146	28518	25965	21399	15757	11742	12059	21542
APA,FL	12832	11280	14697	16951	20244	23167	21122	18803	17906	15185	13239	10004	10208	16067
BIS,ND	24011	7188	11940	16854	22110	26334	25329	25122	21379	14905	10250	5764	5359	16044
BOS,MS	94701	8473	12711	16526	20158	24176	23083	21787	19001	14424	10360	6659	6768	15343
BRO,TX	12919	14677	17838	19521	22187	25194	23913	24454	22901	19035	15588	12219	13159	19223
HAT,NC	93729	9877	13672	16999	21742	26406	21991	21497	19343	16975	13901	10432	10071	16908
CAR,ME	14607	6810	11710	16577	21246	25013	23505	22406	19357	13582	9063	5152	5125	14962
CHA,SC	13880	12468	16597	19398	22922	25700	24111	23783	22251	17727	12128	8176	10852	18009
COL,MO	13983	8594	12764	16655	21188	23202	21716	20688	18457	13767	11214	8046	7577	15322
DCT,KA	13985	11868	16315	19938	24632	26977	26432	25484	22863	17730	13840	9746	9948	18814
ELP,TX	23044	15943	21137	23815	27905	30367	28675	27734	25550	21638	17510	13680	14103	22338
ELY,NV	23154	12243	17087	21393	26326	31449	30440	29424	26223	20988	14798	10150	10172	20891
FTW,TX	3927	12858	16926	20022	22802	25812	25440	25043	22864	18266	14443	10605	11243	18860
FRE,CA	93193	8180	13177	18352	24285	30410	29553	28413	25324	20718	14726	9808	8892	19319
GRF,MT	24143	6949	11618	16393	21155	26962	26639	26821	22408	15381	10034	5667	5337	16280
LCH,LA	3937	12642	16174	18740	21528	25356	23917	22864	21399	18161	13398	9453	11421	17921
MAD,WI	14837	8552	13233	17422	18724	21563	22278	23911	20506	12573	8808	4794	5005	14780
MED,OR	24225	5050	9427	13252	18308	23950	23937	26511	22756	16477	10523	6060	3965	15018
MIA,FL	12839	13325	16189	18581	21100	22400	19906	20832	20053	15895	13380	11493	12516	17139
NAS,TN	13897	8538	15459	15052	19331	22622	22141	20960	19306	14242	11468	7219	7323	15305
NWY,NY	94706	7361	10611	13890	20991	24038	22545	18616	17941	15279	11419	7249	7391	14777
OMH,NE	94918	10299	15176	18942	23995	27259	26351	25470	22247	16649	12929	8428	8391	18011
PHO,AR	23183	14251	19142	22380	26547	31106	29289	27337	25117	21489	16069	12199	12652	21464
SMA,CA	23236	11205	15205	18476	21329	25992	23823	23295	20445	16989	13322	10316	10713	17592
SEA,WS	24233	3881	7324	11175	15151	20459	17978	19938	16101	10941	6499	3570	3002	11334
WAS,DC	93722	8551	12379	15579	19418	21924	21688	20811	18558	13899	11323	7655	7029	14901

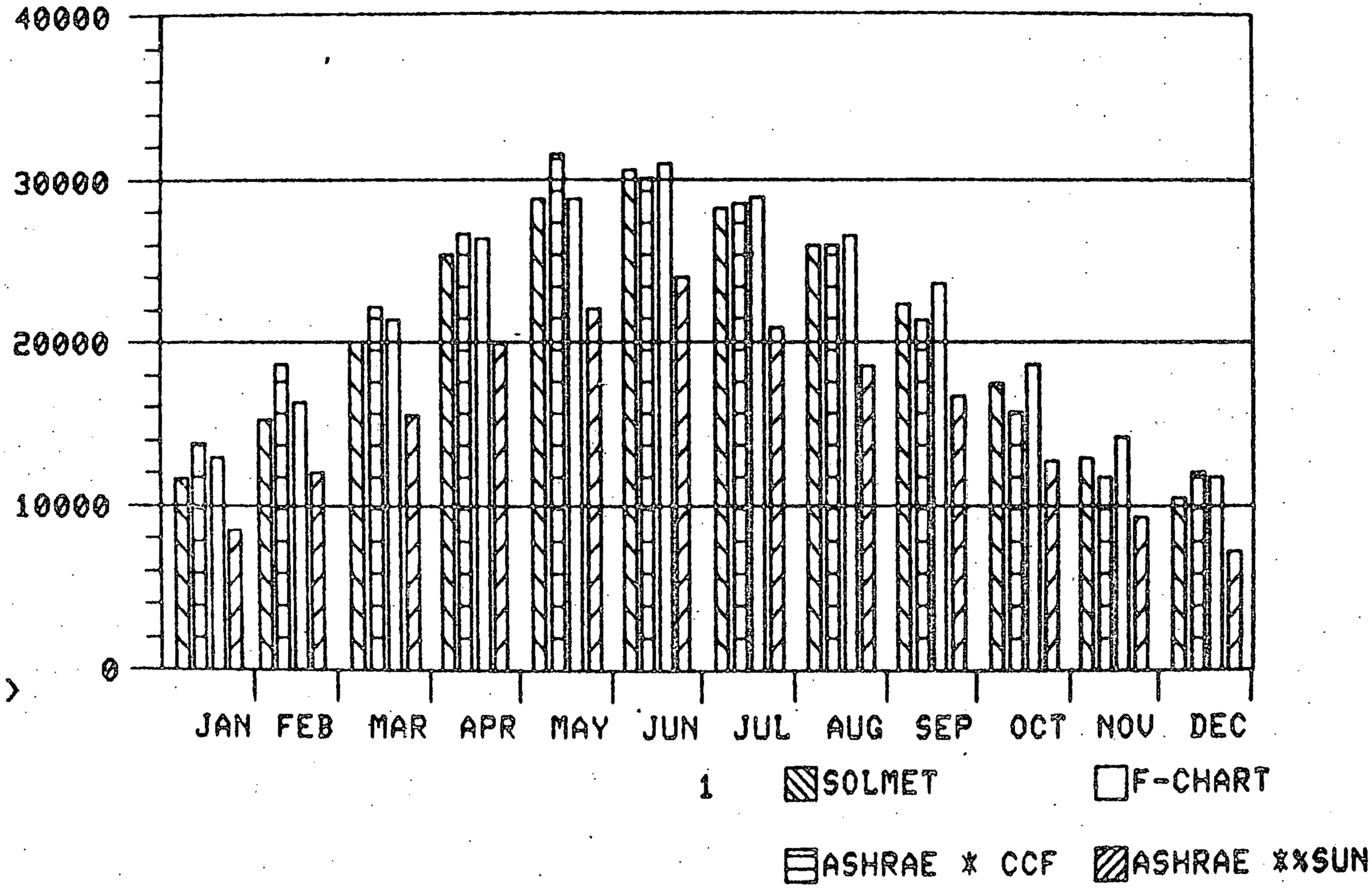
AVERAGE DAILY TOTALS -- KJ/M^2 - DAY

SUMMARY OF SOLAR RADIATION USING ASHRAE THEOR. * % SUNSHINE

SITE	WBAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG MO
ALB,NM	23050	8530	12036	15528	19966	22089	24002	20939	18568	16779	12747	9357	7298	15653
APA,FL	12832	8623	11723	14364	18723	21617	19882	17691	21162	18271	13379	9399	6855	15140
BIS,ND	24011	3307	6455	9514	13024	15532	17146	19292	15218	10069	6184	2999	2278	10084
BOS,MS	94701	4104	7549	10836	13527	16168	17631	17298	14703	11112	7410	4061	3358	10646
BRO,TX	12919	7260	10066	12389	15277	18174	20502	21464	20206	20324	13785	8708	6556	14559
HAT,NC	93729	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR,ME	14607	0	0	0	0	0	0	0	0	0	0	0	0	0
CHA,SC	13880	7647	10575	14454	18676	20477	19986	18236	16565	14320	11437	8726	6531	13969
COL,MO	13983	5640	8493	11900	14902	17727	19986	20758	18735	13538	9488	5869	4411	12620
DCT,KA	13985	7190	10134	13955	17028	18889	21144	21357	18886	14966	10953	7290	5996	13982
ELP,TX	23044	10127	13921	18278	22183	24424	24820	21579	19701	17362	14164	10666	8754	17164
ELY,NV	23154	6255	9536	13715	16144	18558	22555	21577	19456	15666	10338	6665	5259	13810
FTW,TX	3927	7383	10046	14454	17119	18794	20842	21552	19577	15816	11773	8085	6646	14340
FRE,CA	93193	5156	9959	15029	20945	24784	26859	26626	23674	18631	13091	7950	4435	16428
GPF,MT	24143	2989	6232	10024	13938	16603	17989	20349	16320	10231	5975	2938	2088	10473
LCH,LA	3937	7162	9643	13205	16349	18809	19882	19350	17847	15597	13017	8687	6597	13845
MAD,WI	14837	3622	6371	9679	12670	15828	18163	18841	15238	10691	6887	3264	2472	10310
MED,OR	24225	2096	4313	7604	12319	15620	16778	21353	17970	12387	5366	2369	1259	9952
MIA,FL	12839	10891	14792	17733	19565	19013	17413	17886	17356	14484	12209	10482	9685	15125
NAS,TN	13897	4908	7643	11462	15250	18137	19724	18979	16719	14058	9759	6252	4168	12254
NWY,NY	94706	4535	7822	11063	14392	17061	18514	17907	15089	11905	8077	4755	3747	11238
OMH,NE	94918	5275	8241	11645	14636	17336	19653	20620	16739	12463	8739	5293	4122	12063
PHO,AP	23183	10020	13924	18456	22826	26088	26838	23210	21083	19022	14801	10780	8823	17989
SMA,CA	23236	8286	11200	14665	17407	19013	20001	21490	19311	16157	11950	9002	7298	14648
SEA,WS	24233	1717	3784	7135	10968	14193	13492	16385	12350	8607	3983	1713	1139	7955
WAS,DC	93722	4717	7897	11295	14157	16896	18272	17480	14892	11991	8638	5372	3987	11299

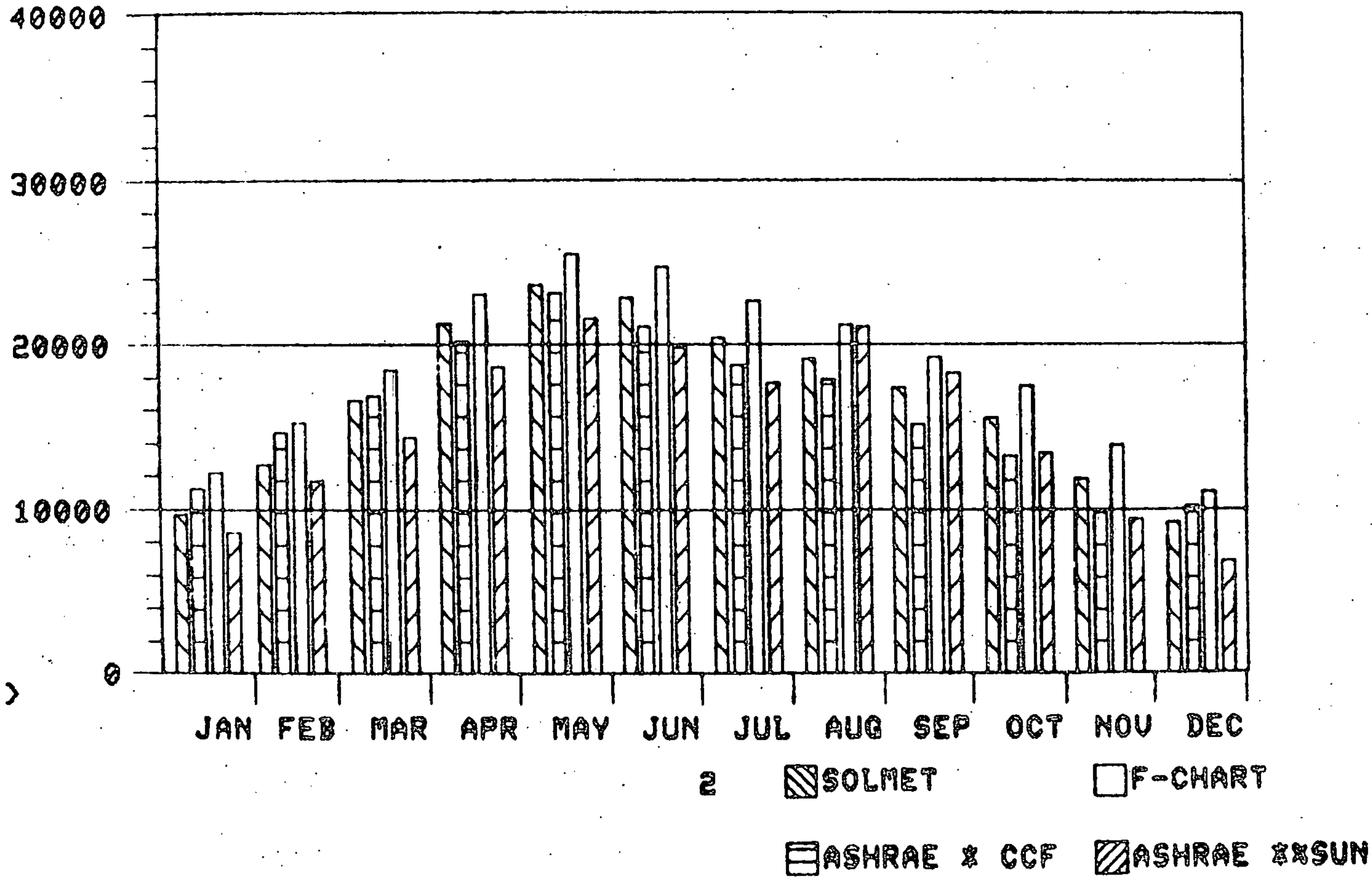
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: ALB,NM   WBAN NO: 23050



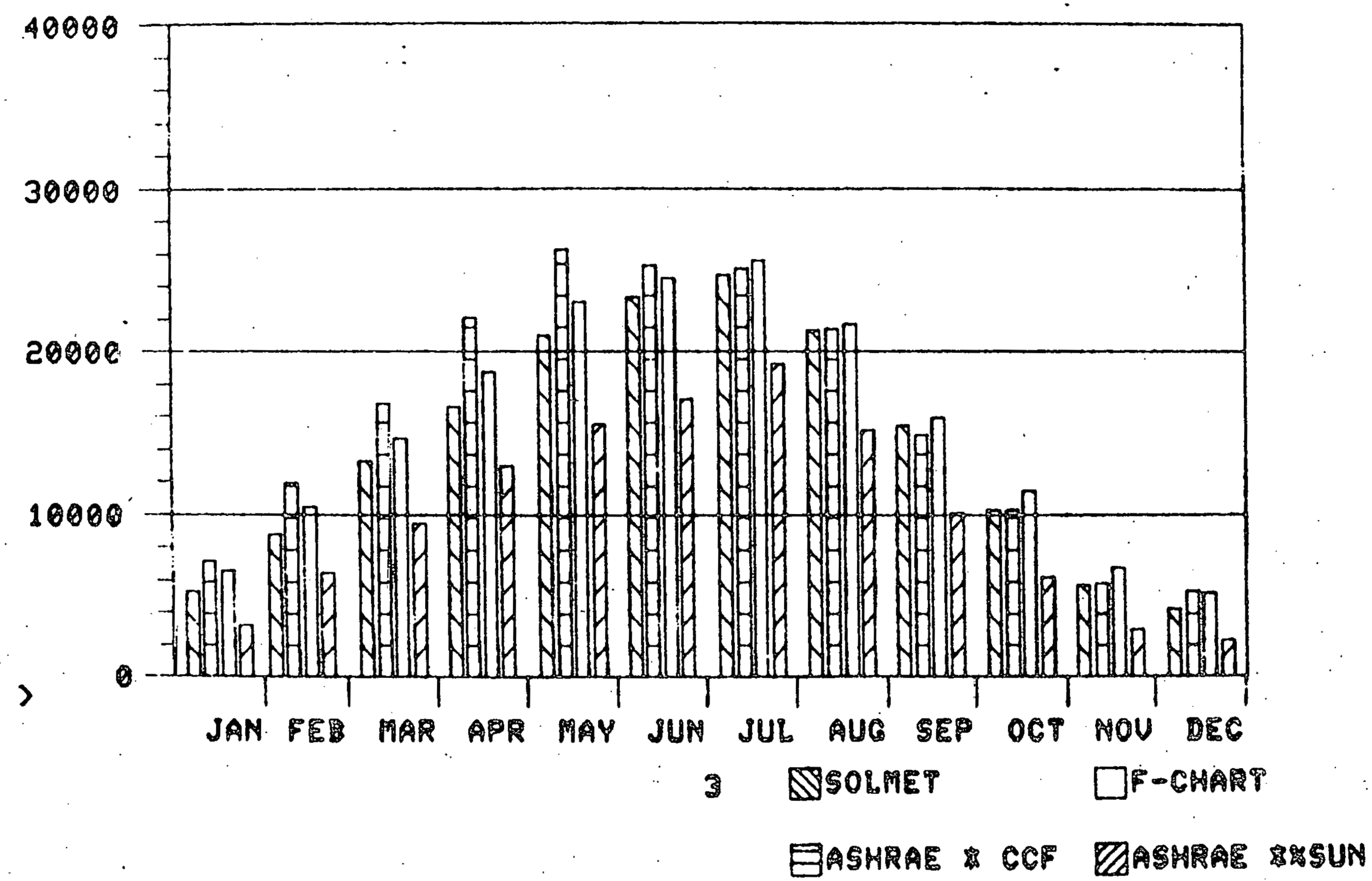
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: APA,FL   UBAN NO: 12832



SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: BIS,ND   WBAN NO: 24011



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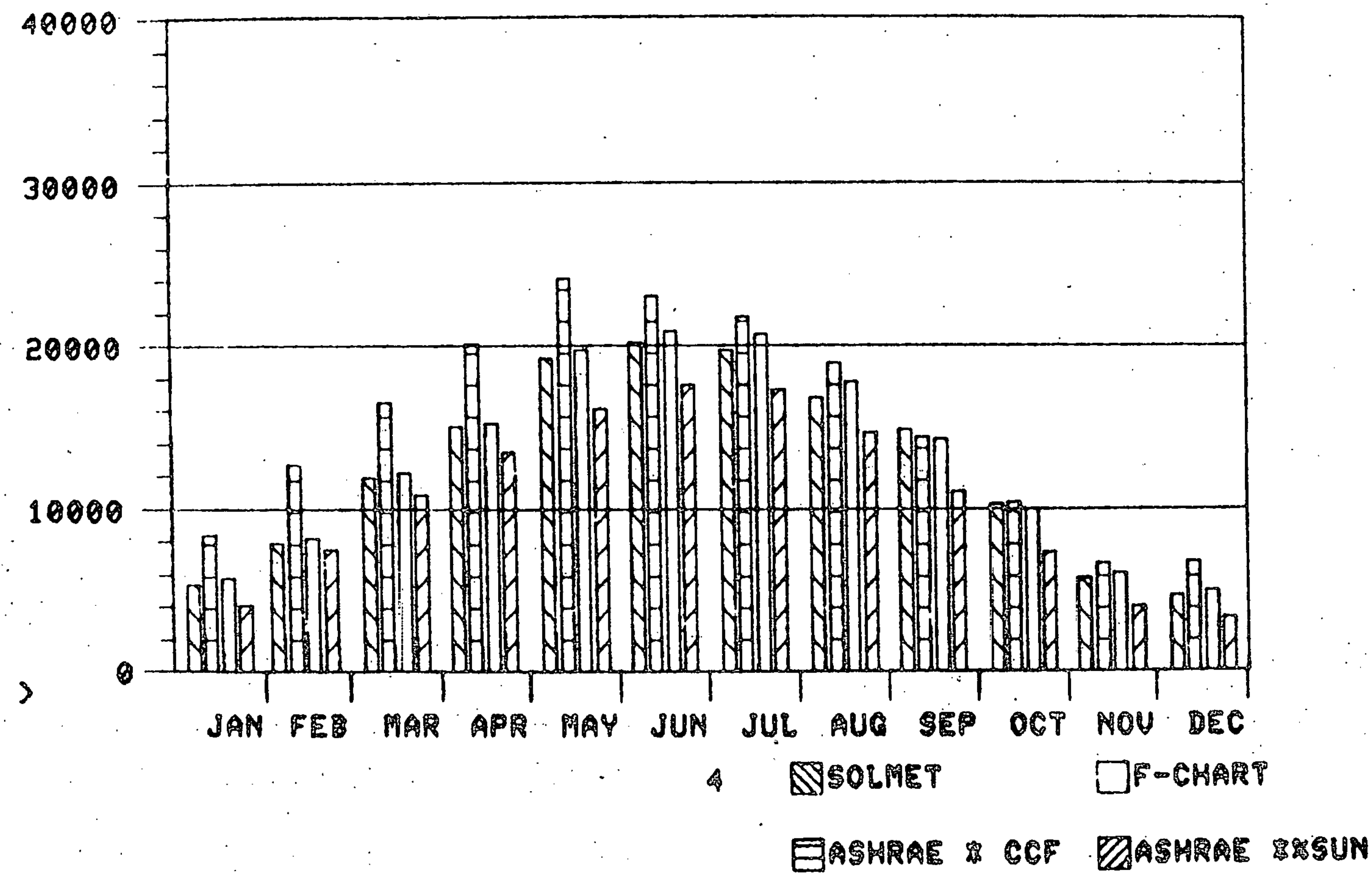
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: BOS,MS   WBAN NO: 94701



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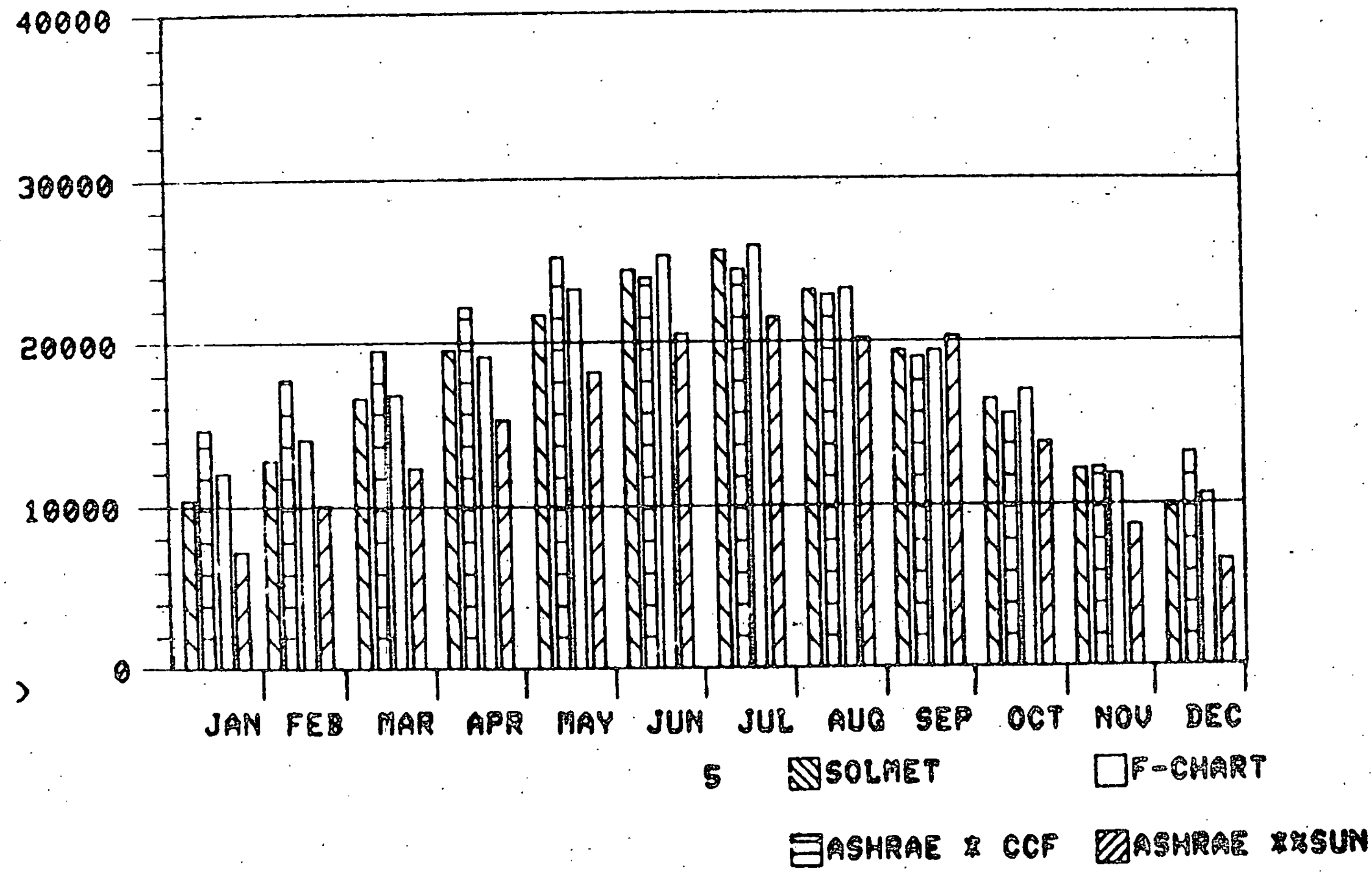
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: BRO,TX   WBAN NO: 12919



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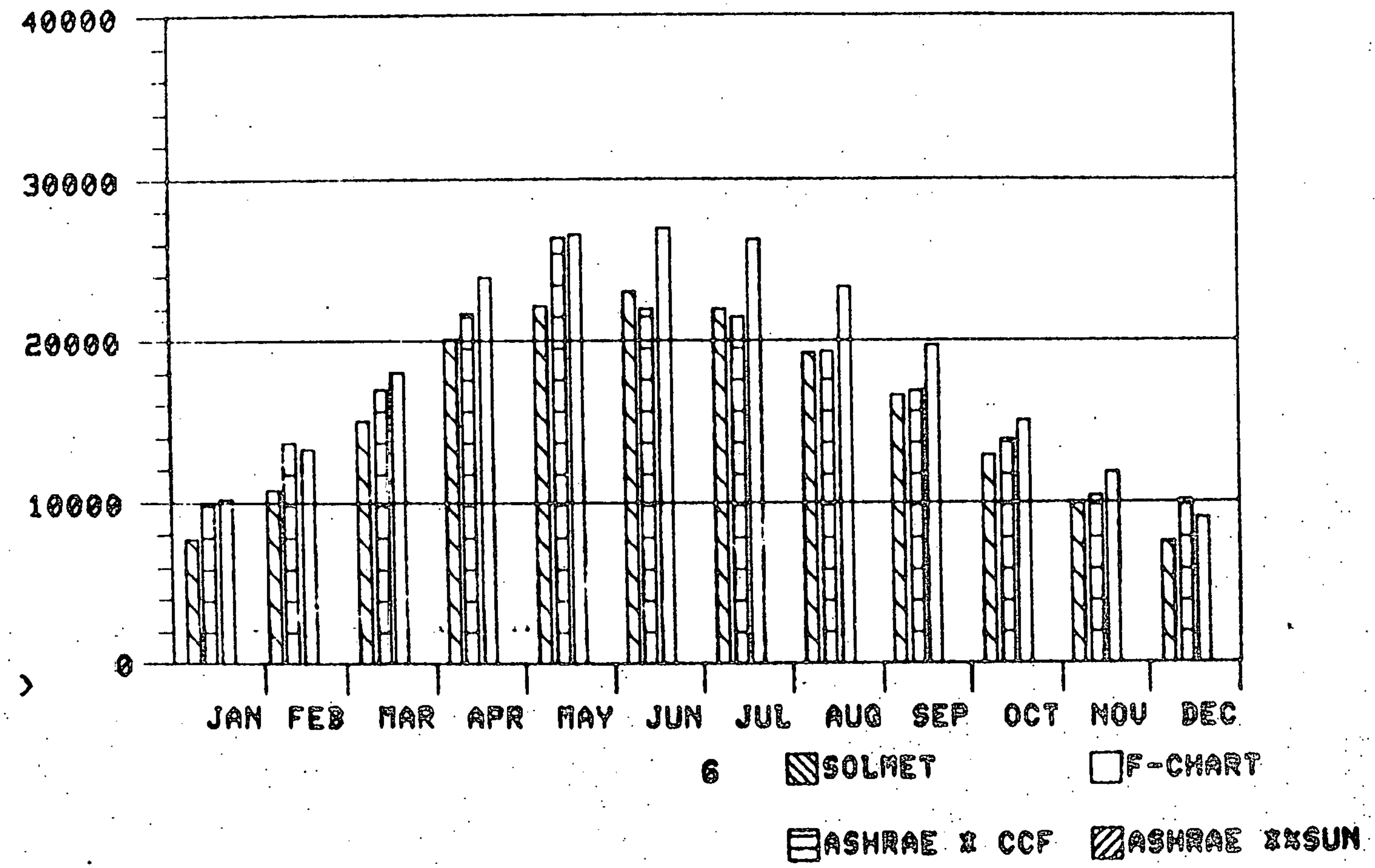
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: HAT,NC   WBAN NO: 93729



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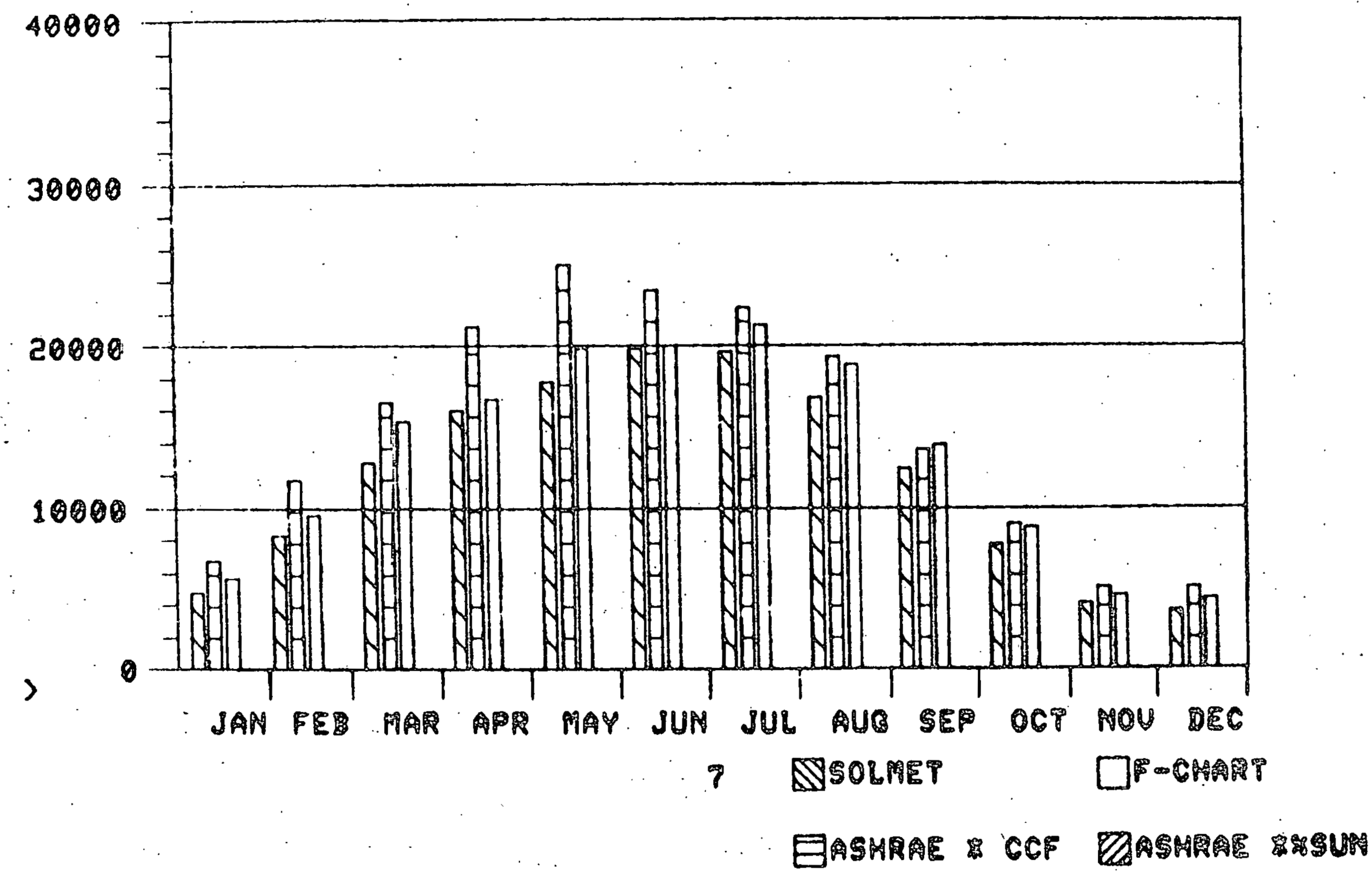
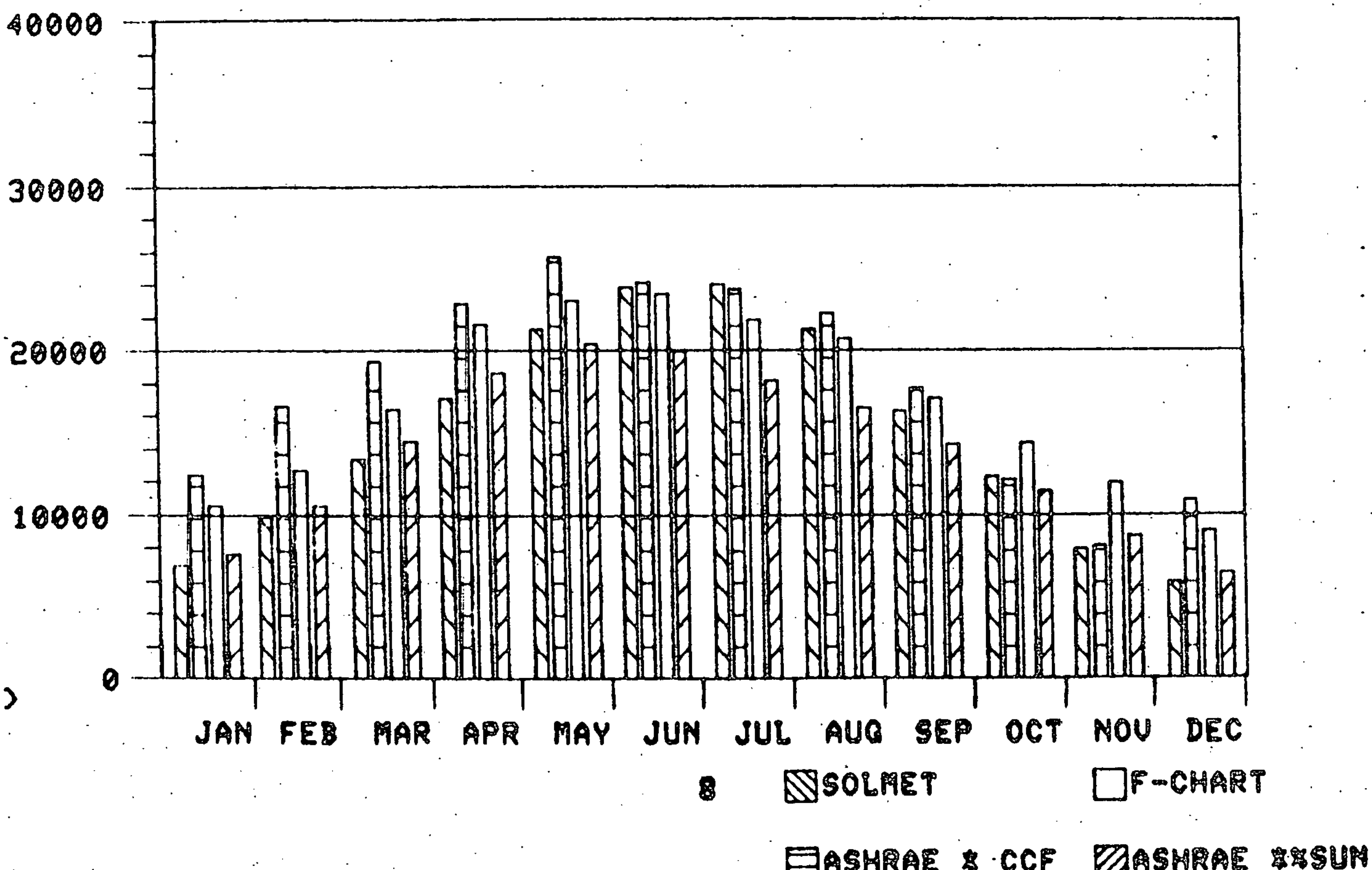
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: CAR,ME   WBAN NO: 14607



SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: CHA,SC   WBAN NO: 13880



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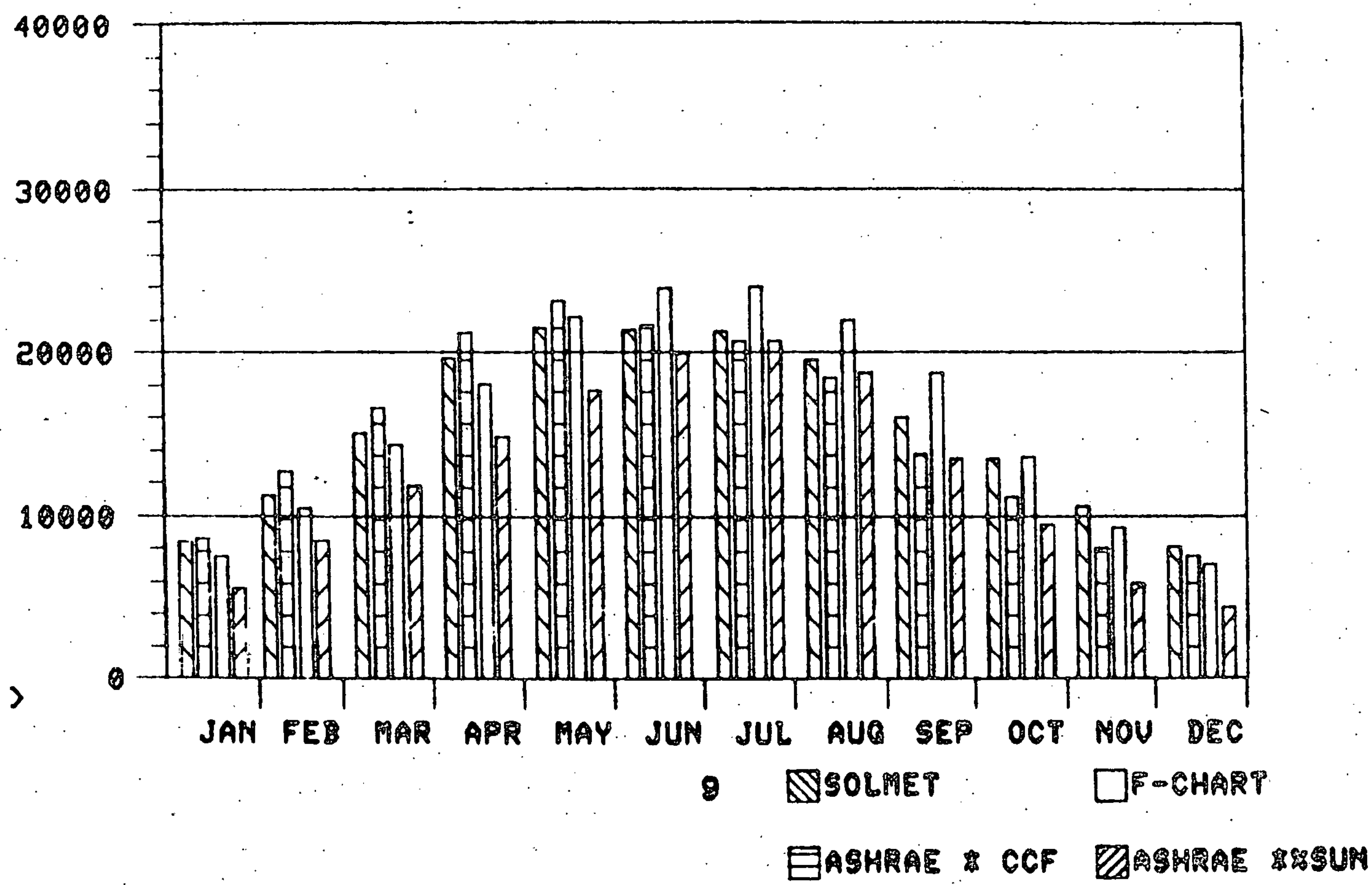
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: COL,MO   WBAN NO: 13983



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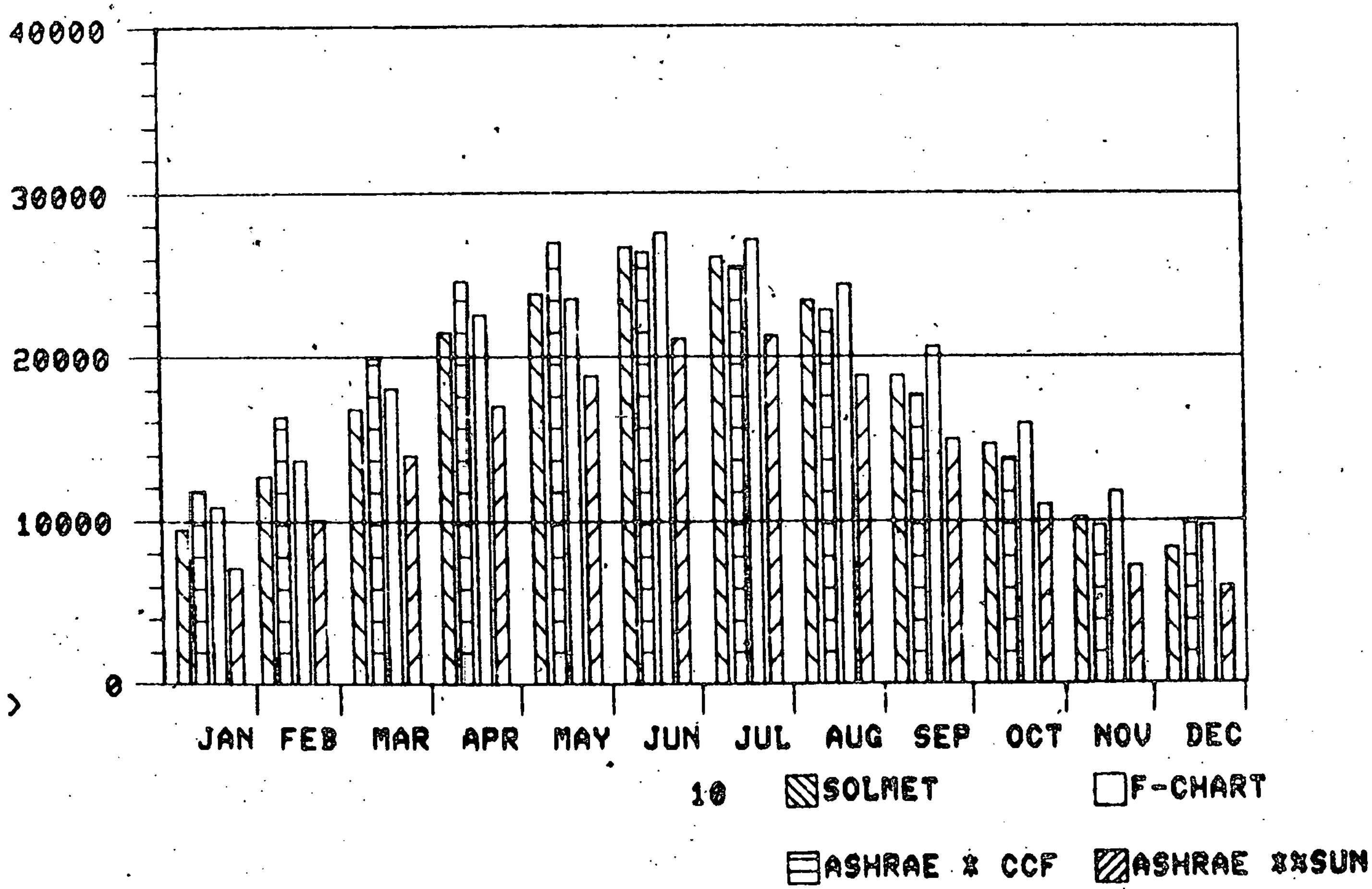
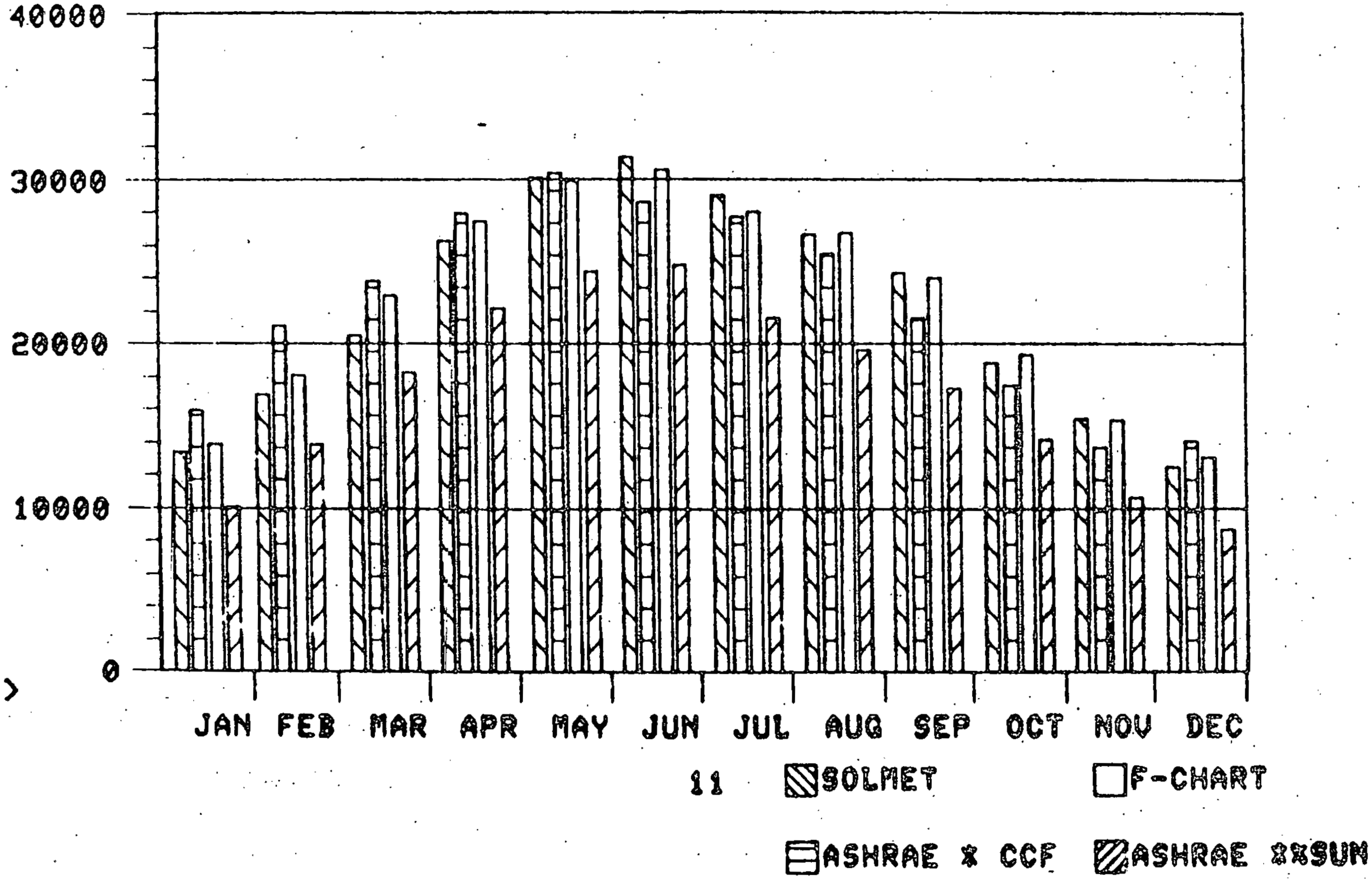
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: DCT,KA   WBAN NO: 13985



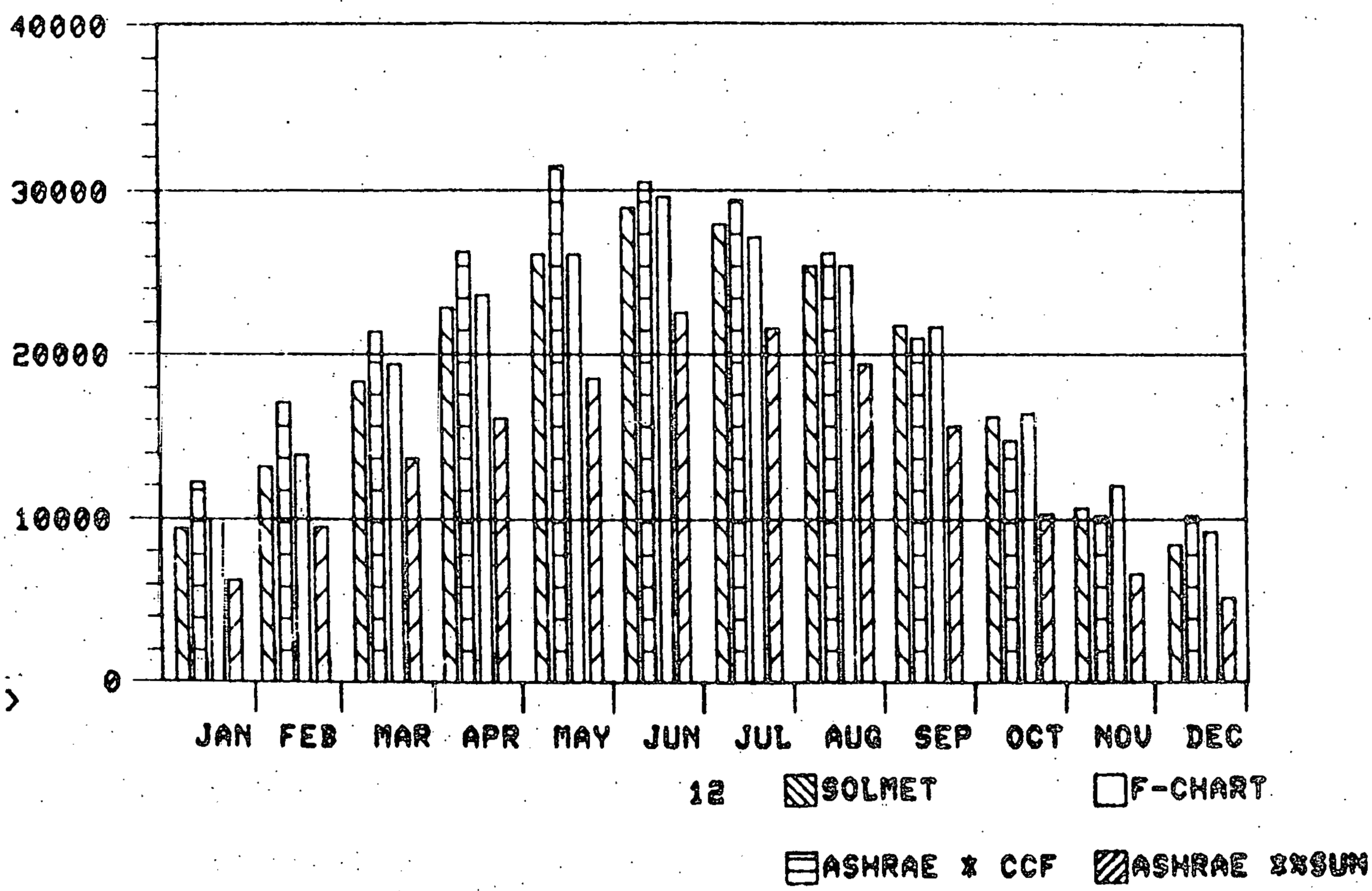
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: ELP,TX   WBAN NO: 23044



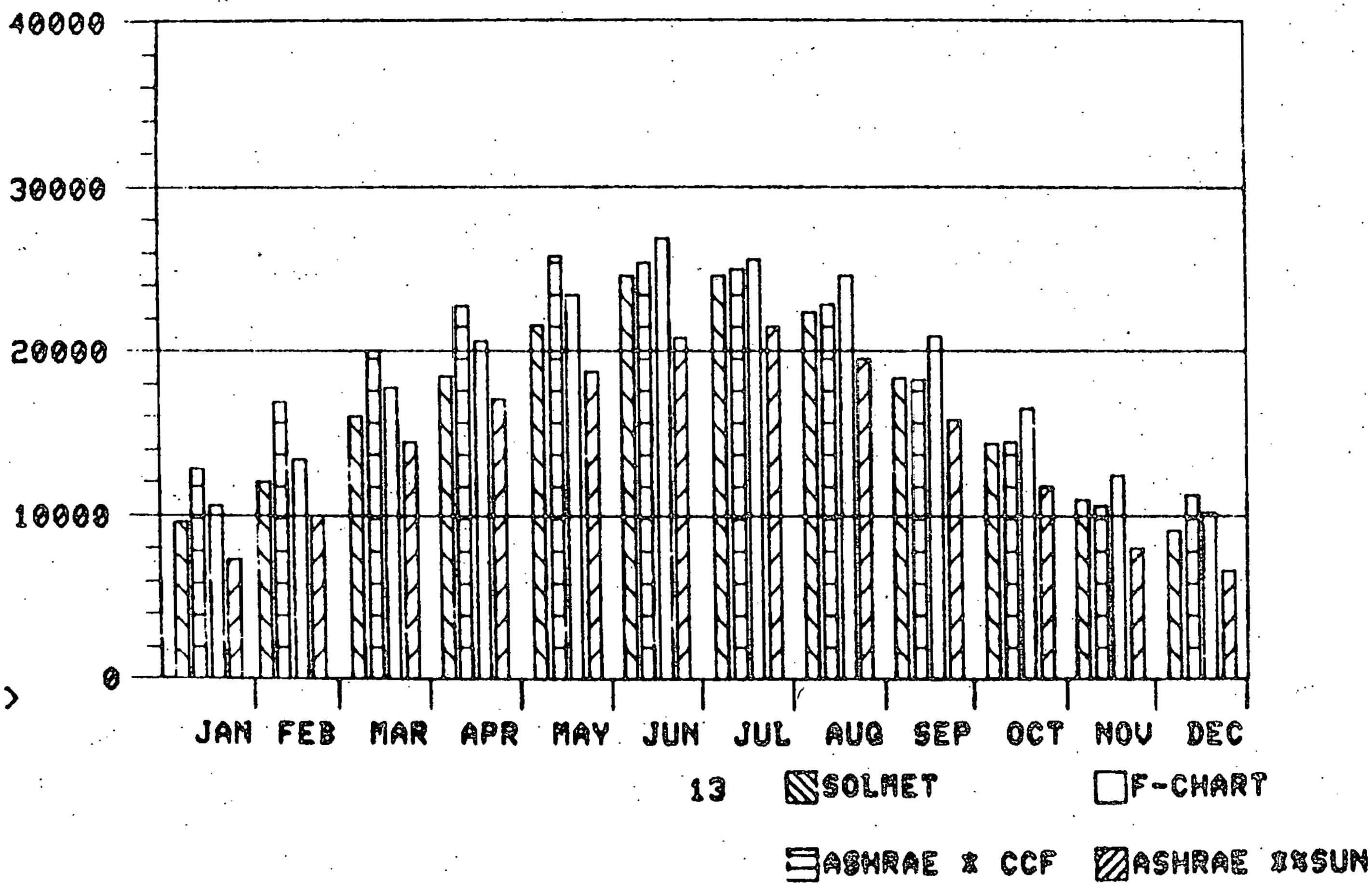
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: ELY,NV   WBAN NO: 23154



SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

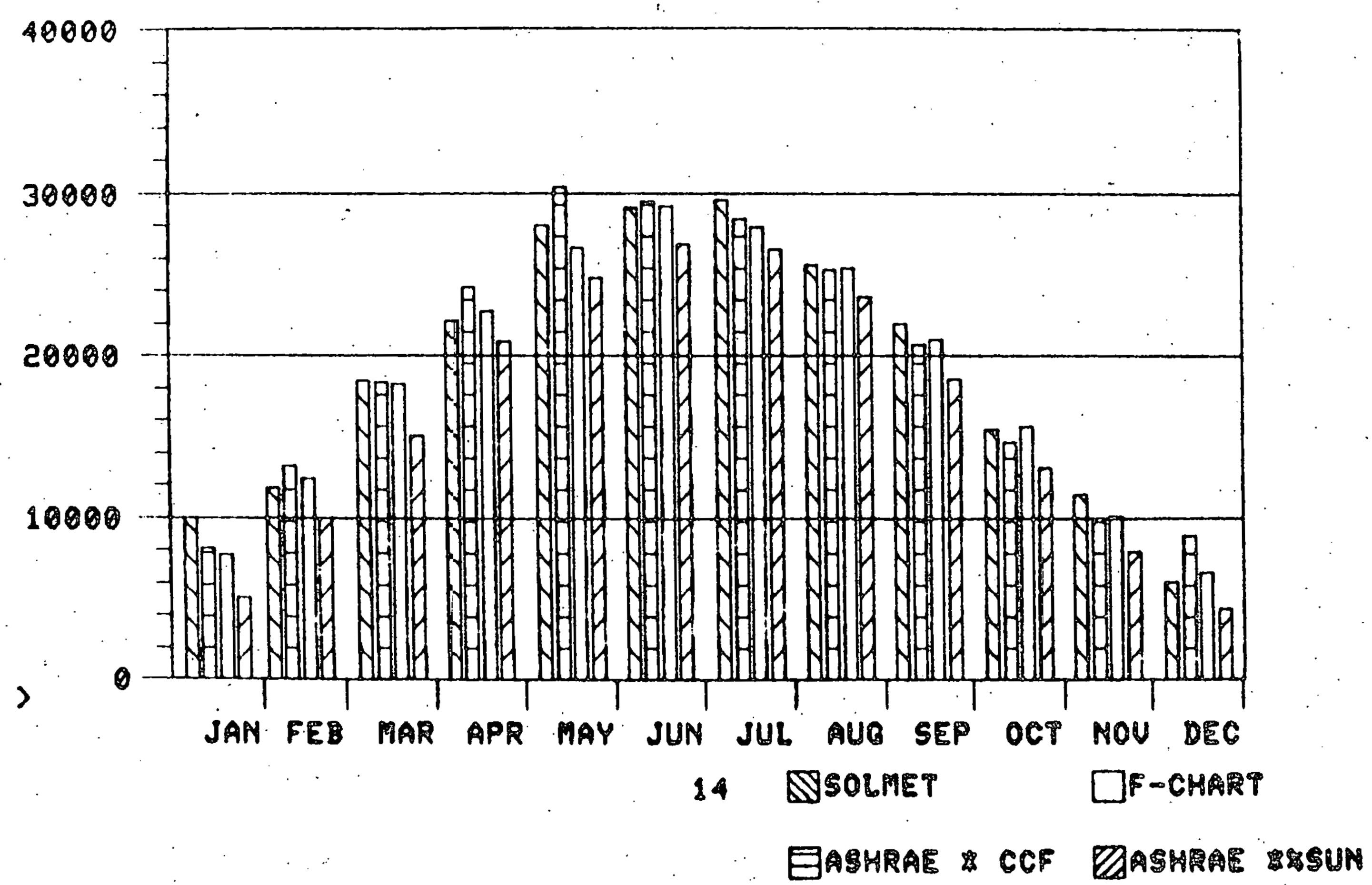
LOCATION: FTW,TX   WBAN NO: 3927



88

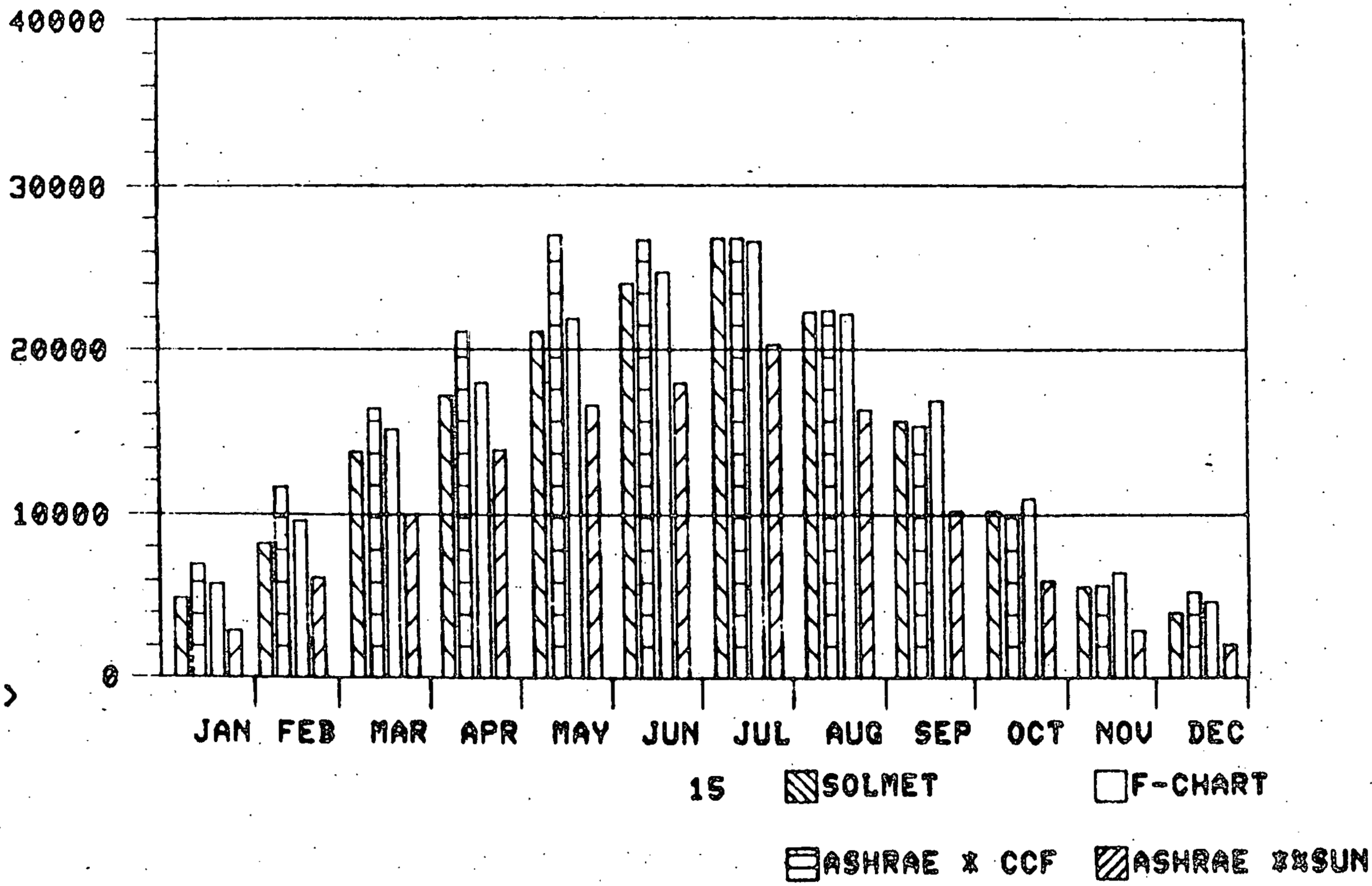
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: FRE,CA   WBAN NO: 93193



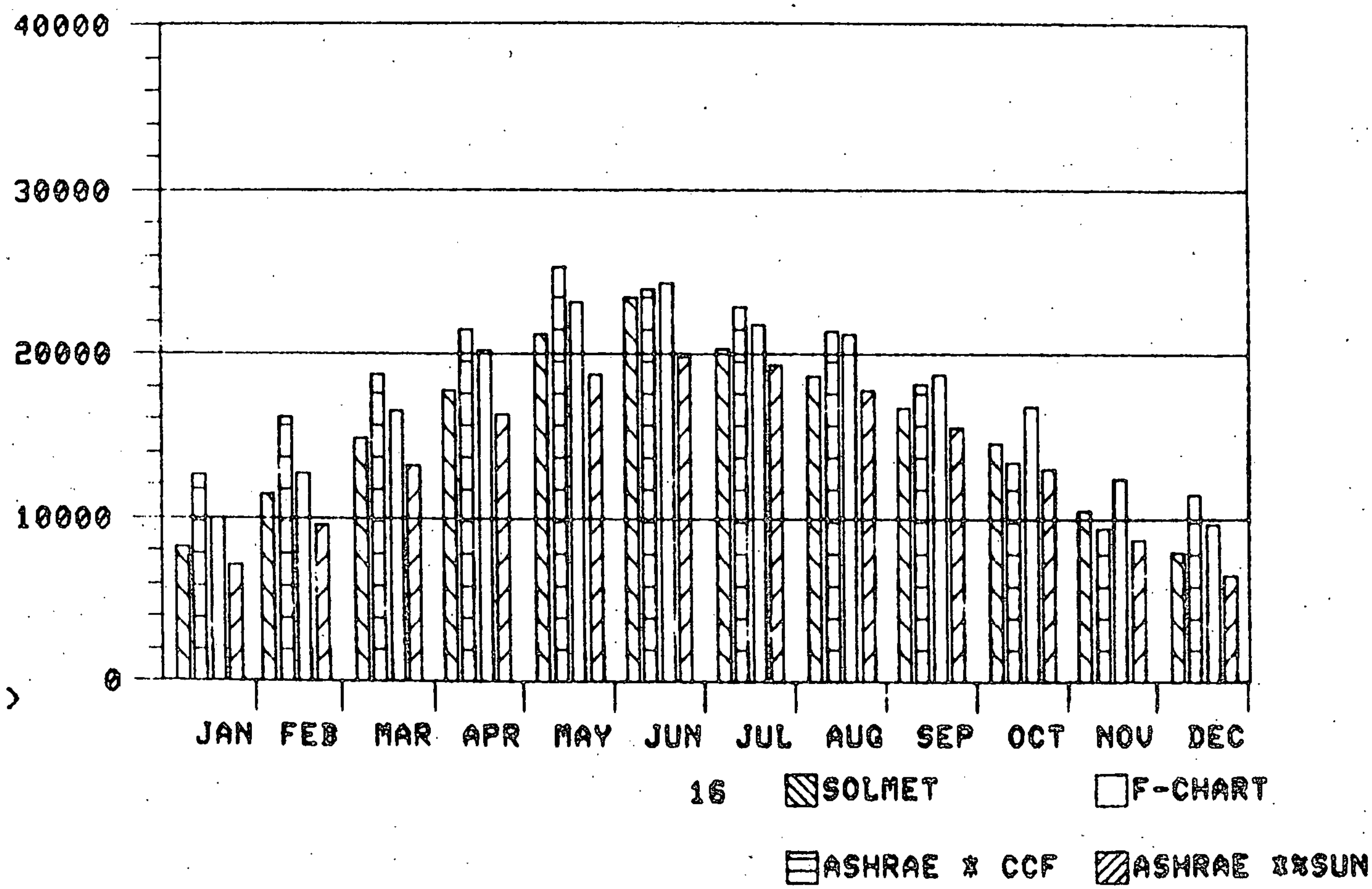
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: GRF,MT   WBAN NO: 24143



SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

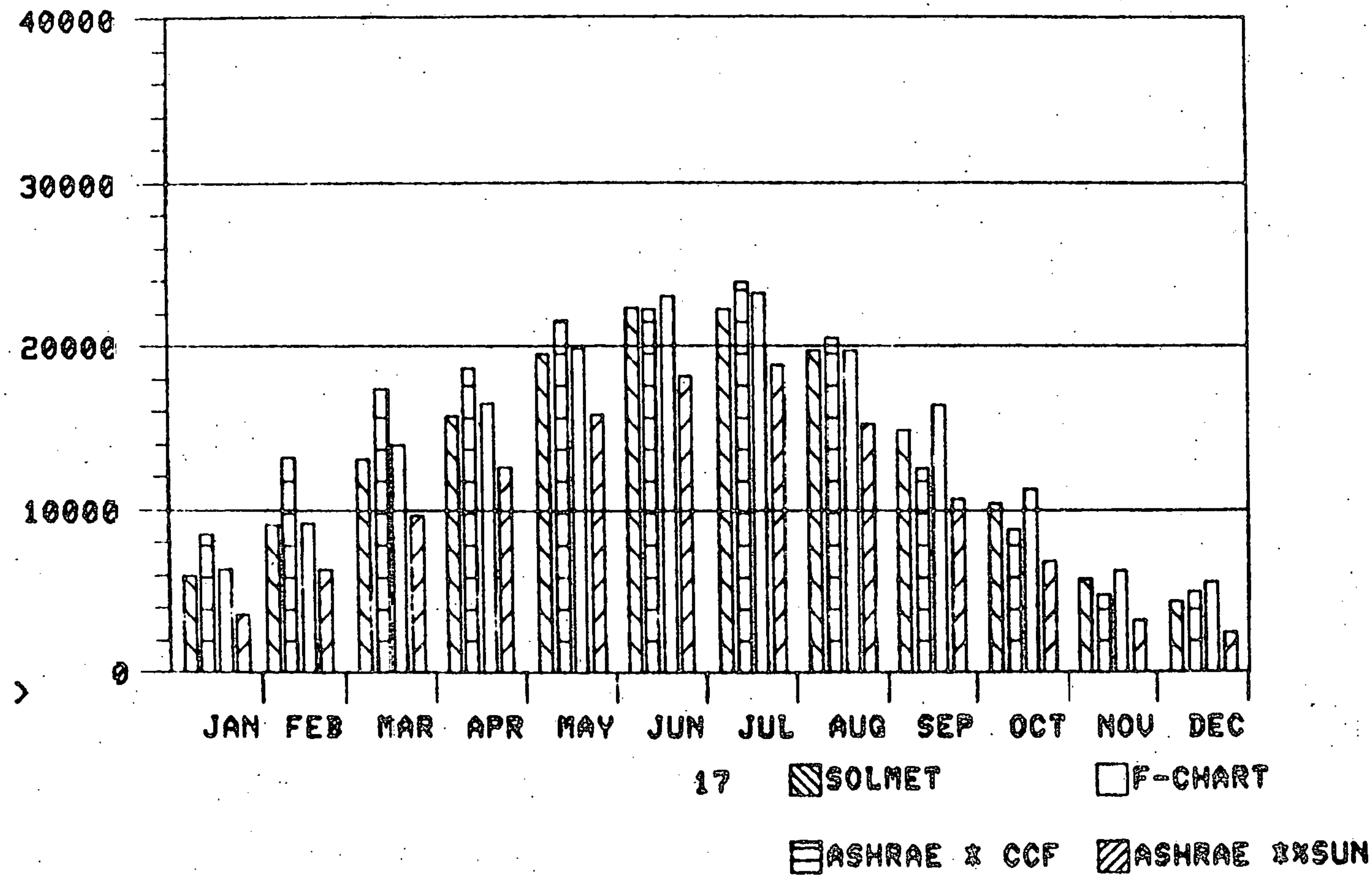
LOCATION: LCH,LA   WBAN NO: 3937



06

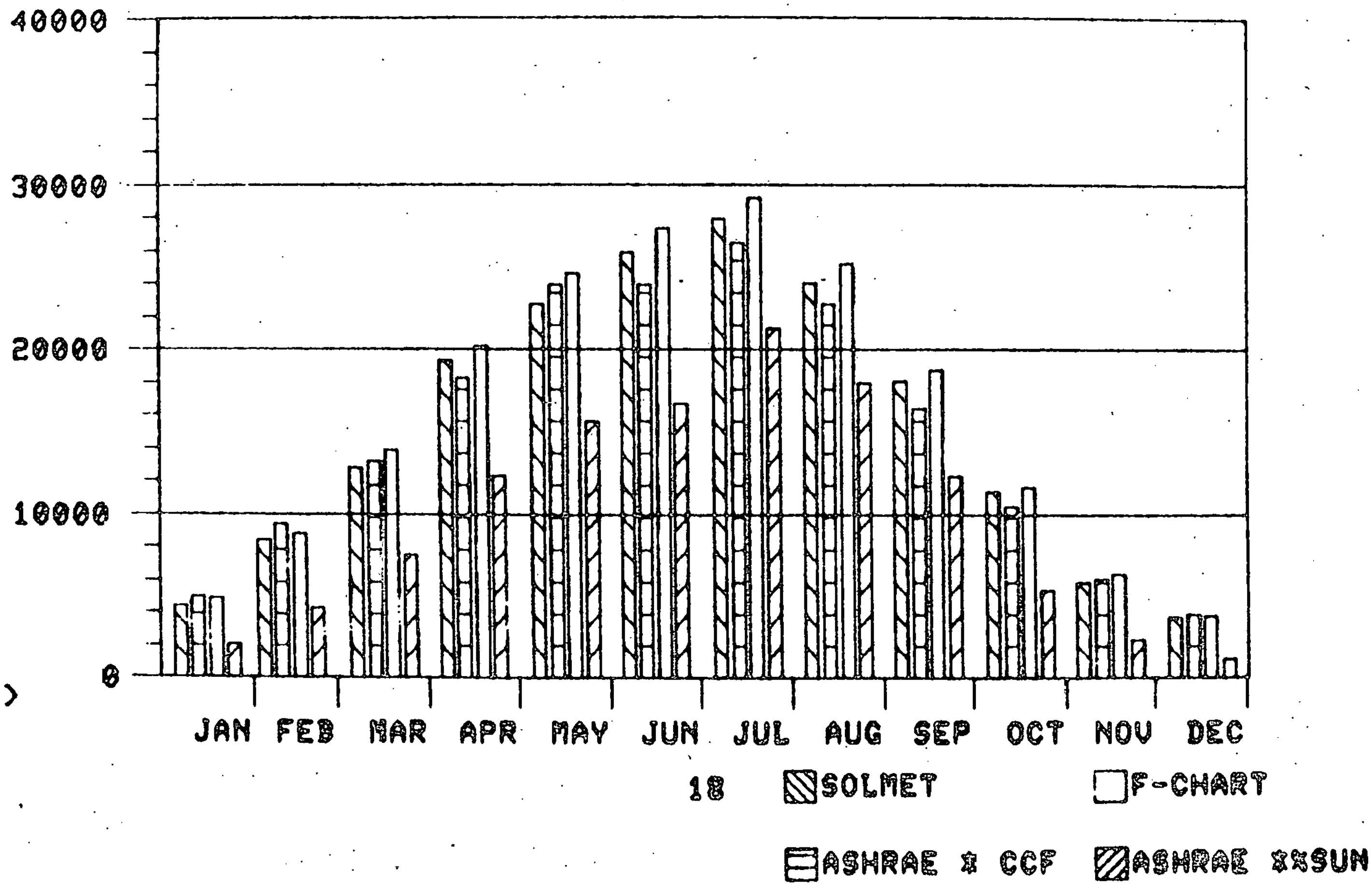
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: MAD,WI   WBAN NO: 14837



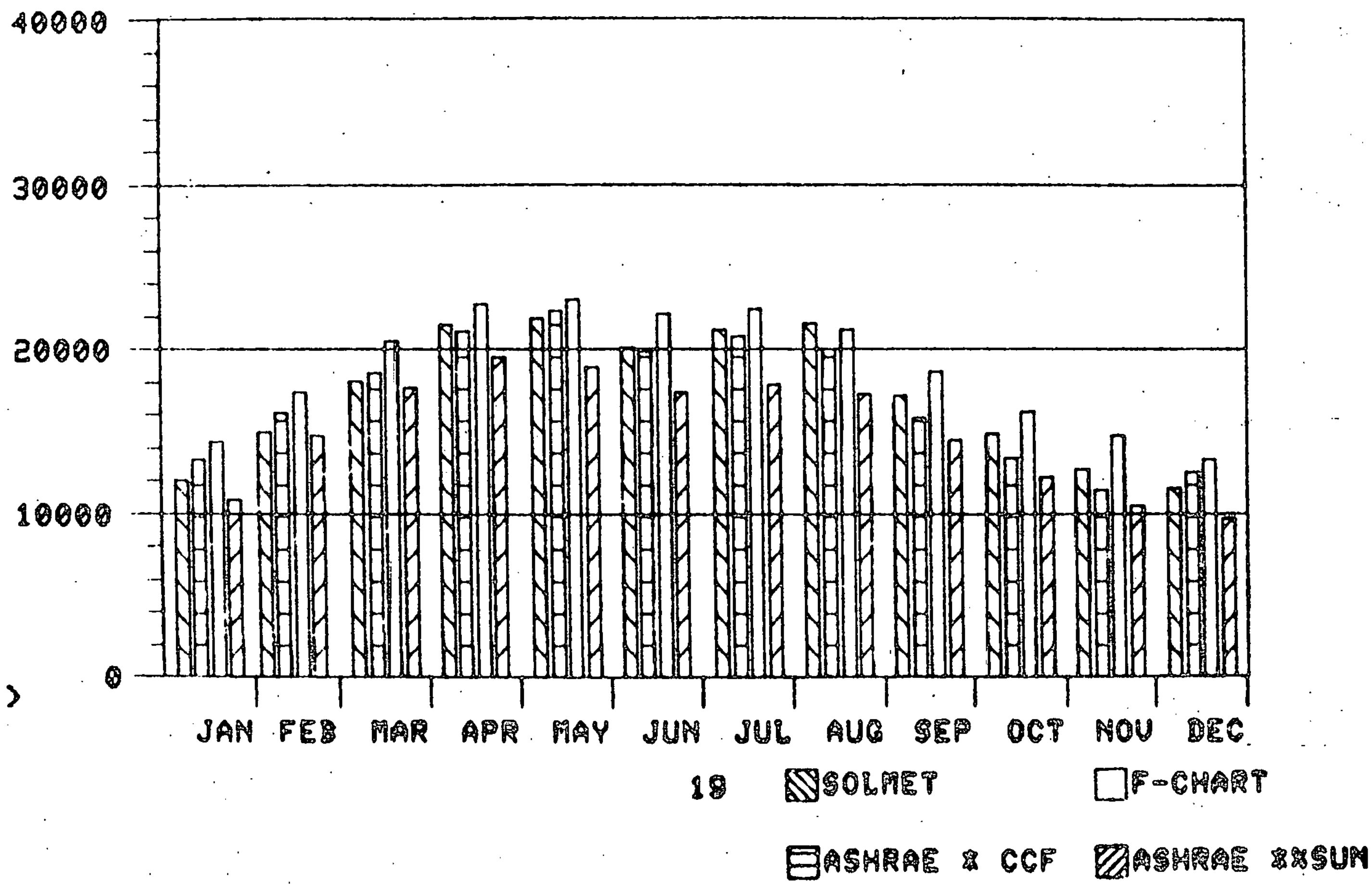
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: MED,OR   WBAN NO: 24225



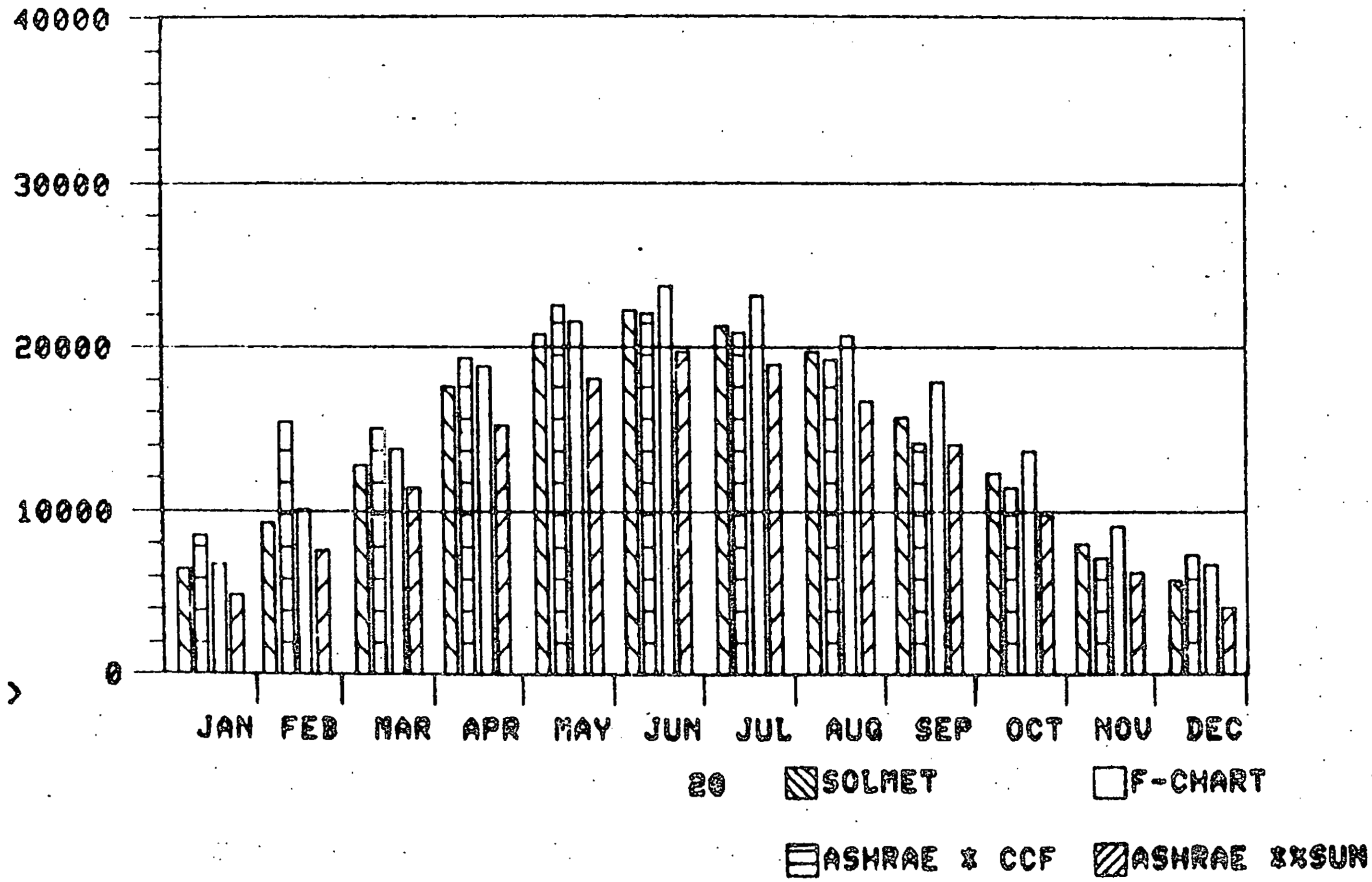
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: MIA,FL   WBAN NO: 12839



SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

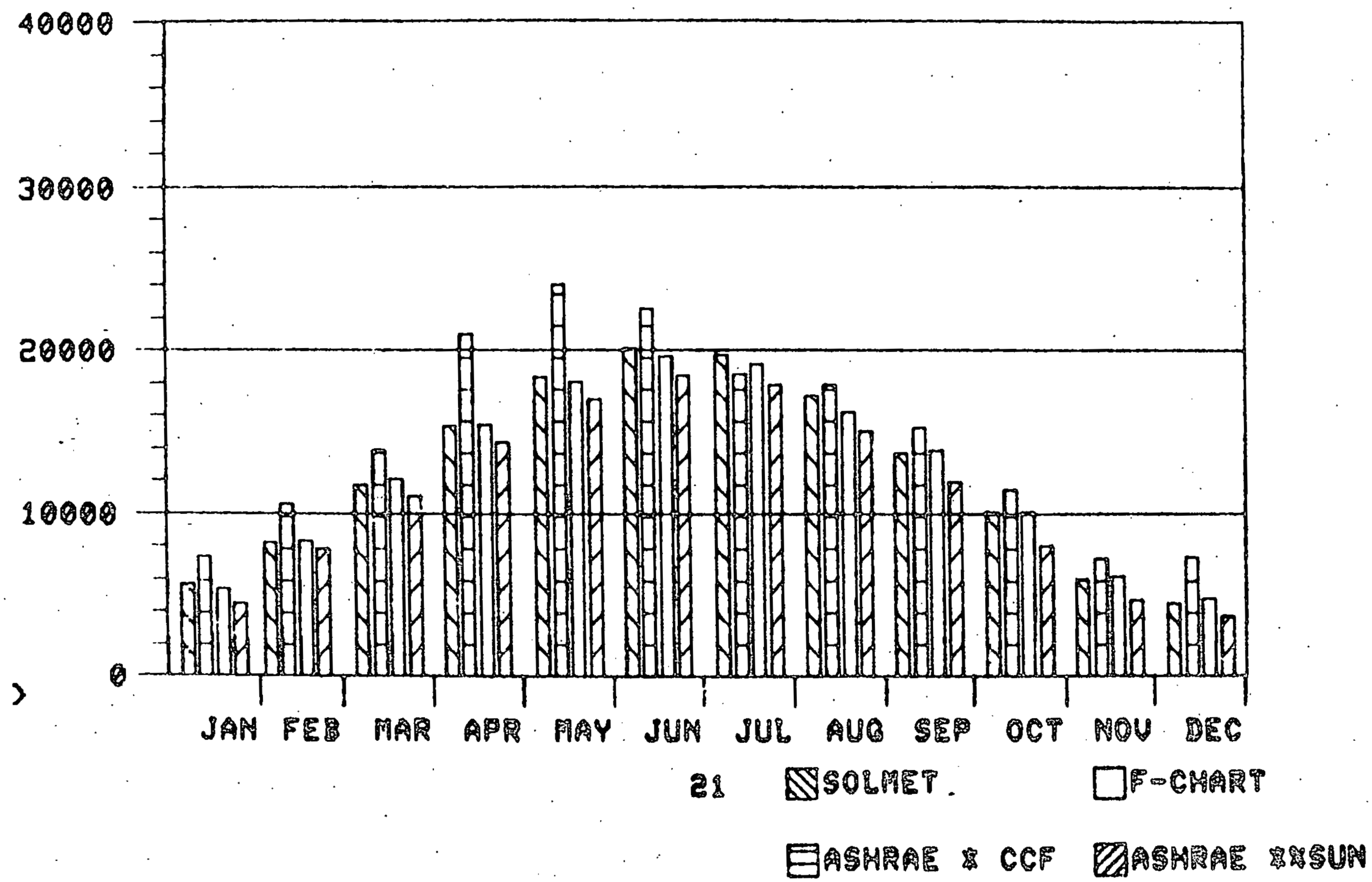
LOCATION: NAS,TN   WBAN NO: 13897



94

SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

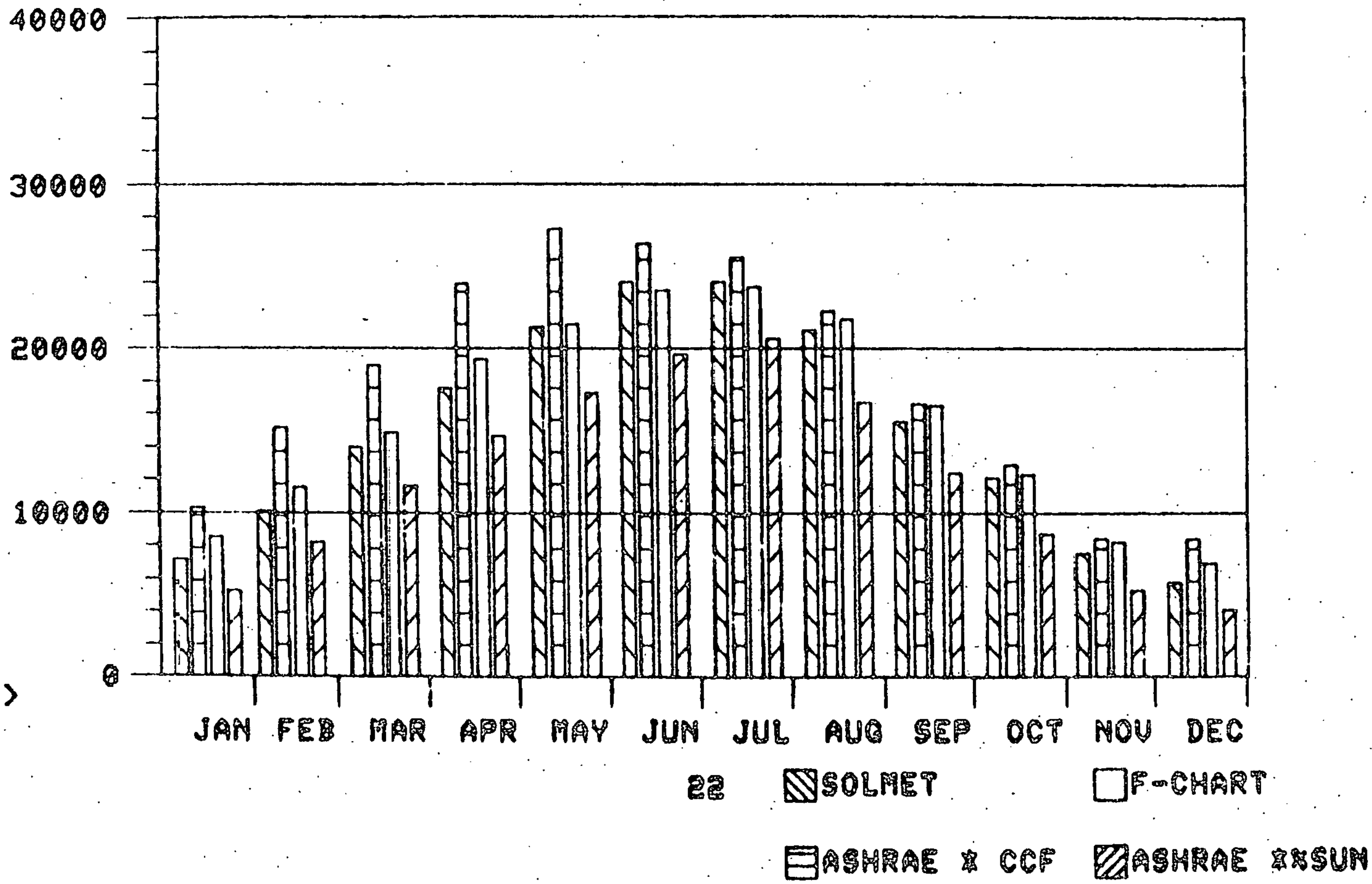
LOCATION: NWY,NY   WBAN NO: 94706



95

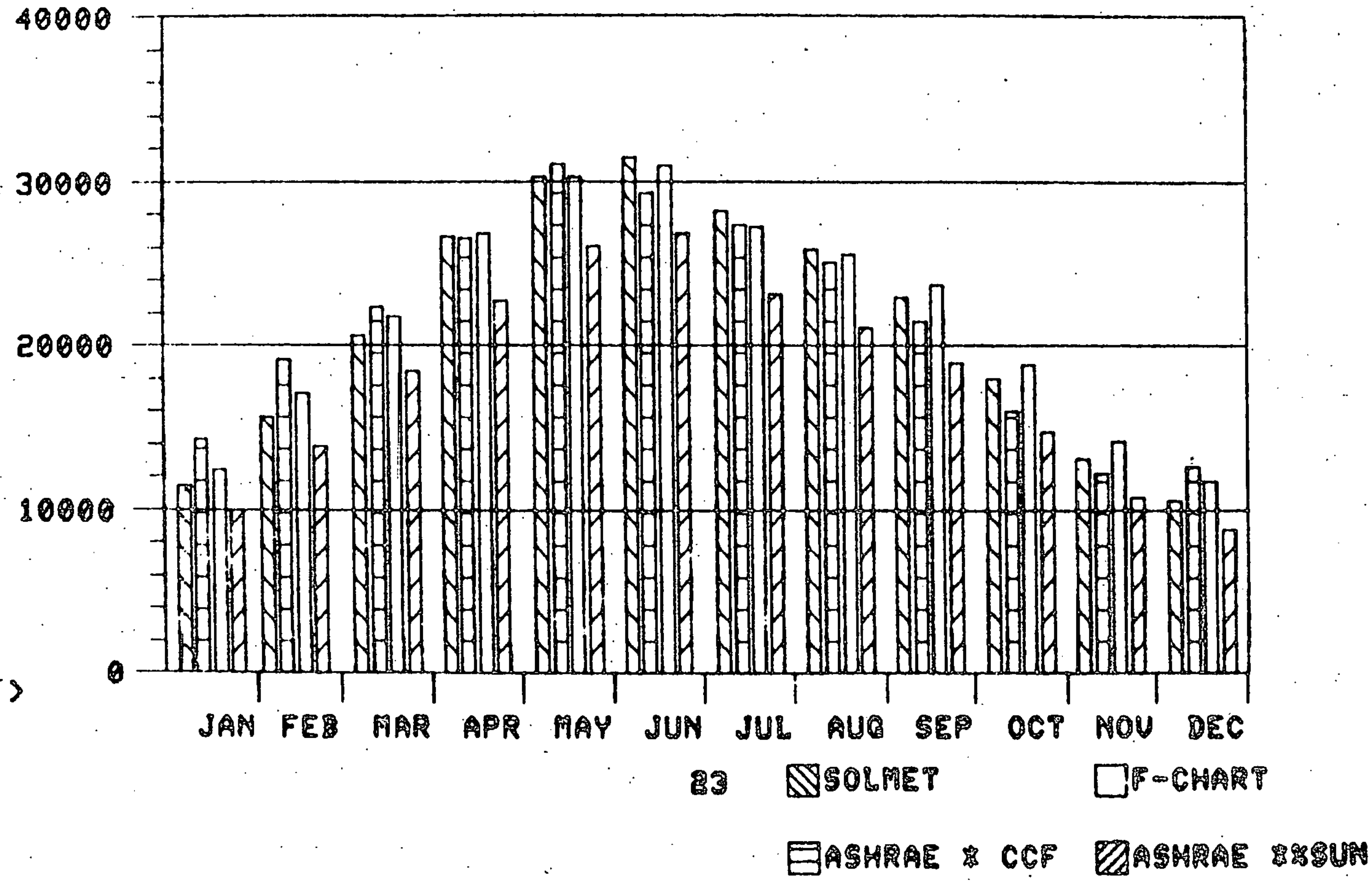
SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: OMH,NE   WBAN NO: 94918



SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

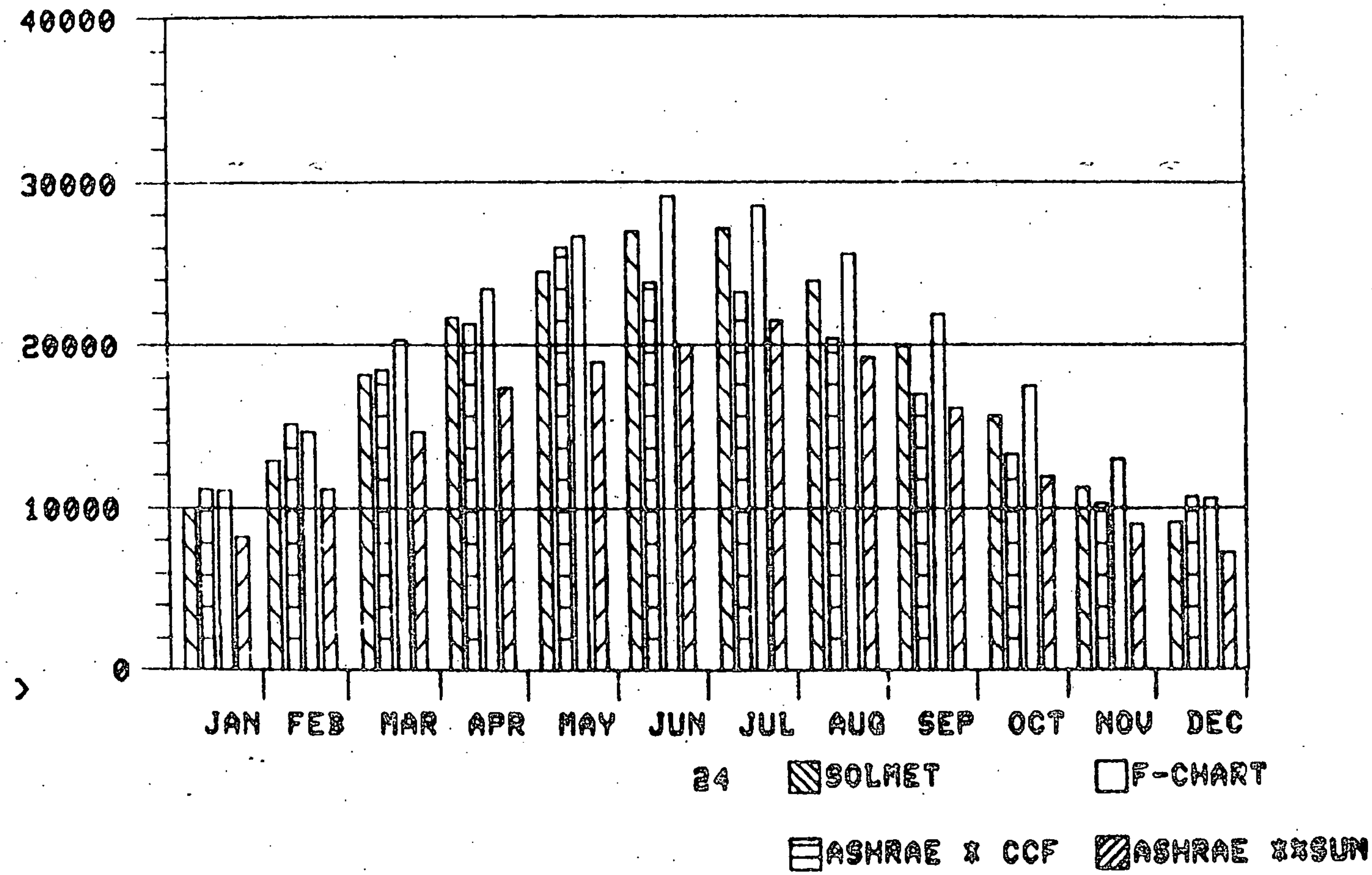
LOCATION: PHO,AR   WBAN NO: 23183



97

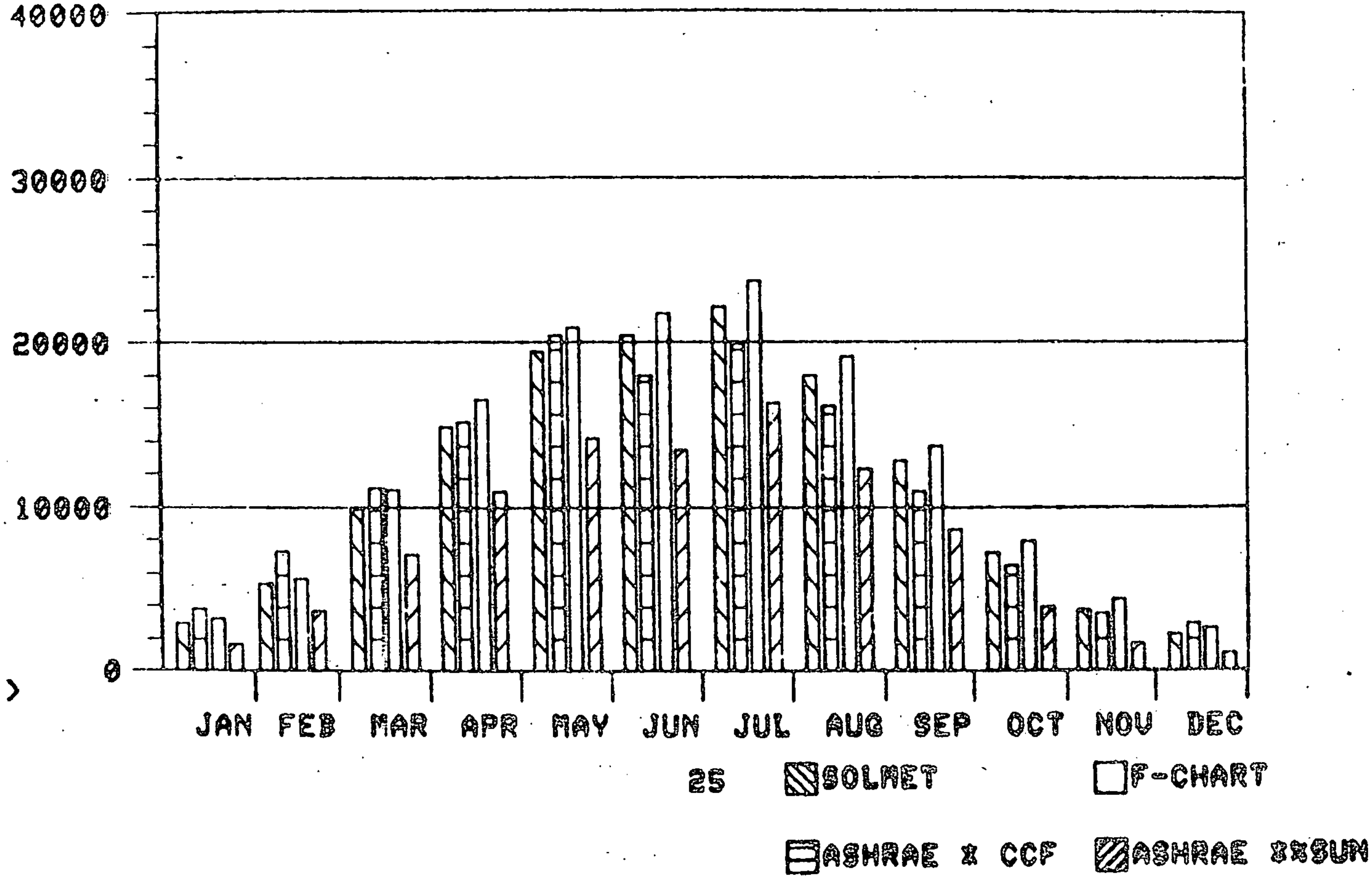
SUMMARY OF SOLAR R[illegible]ATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: SMA,CA   WBAN NO: 23236



SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: SEA,WS   WBAN NO: 24233

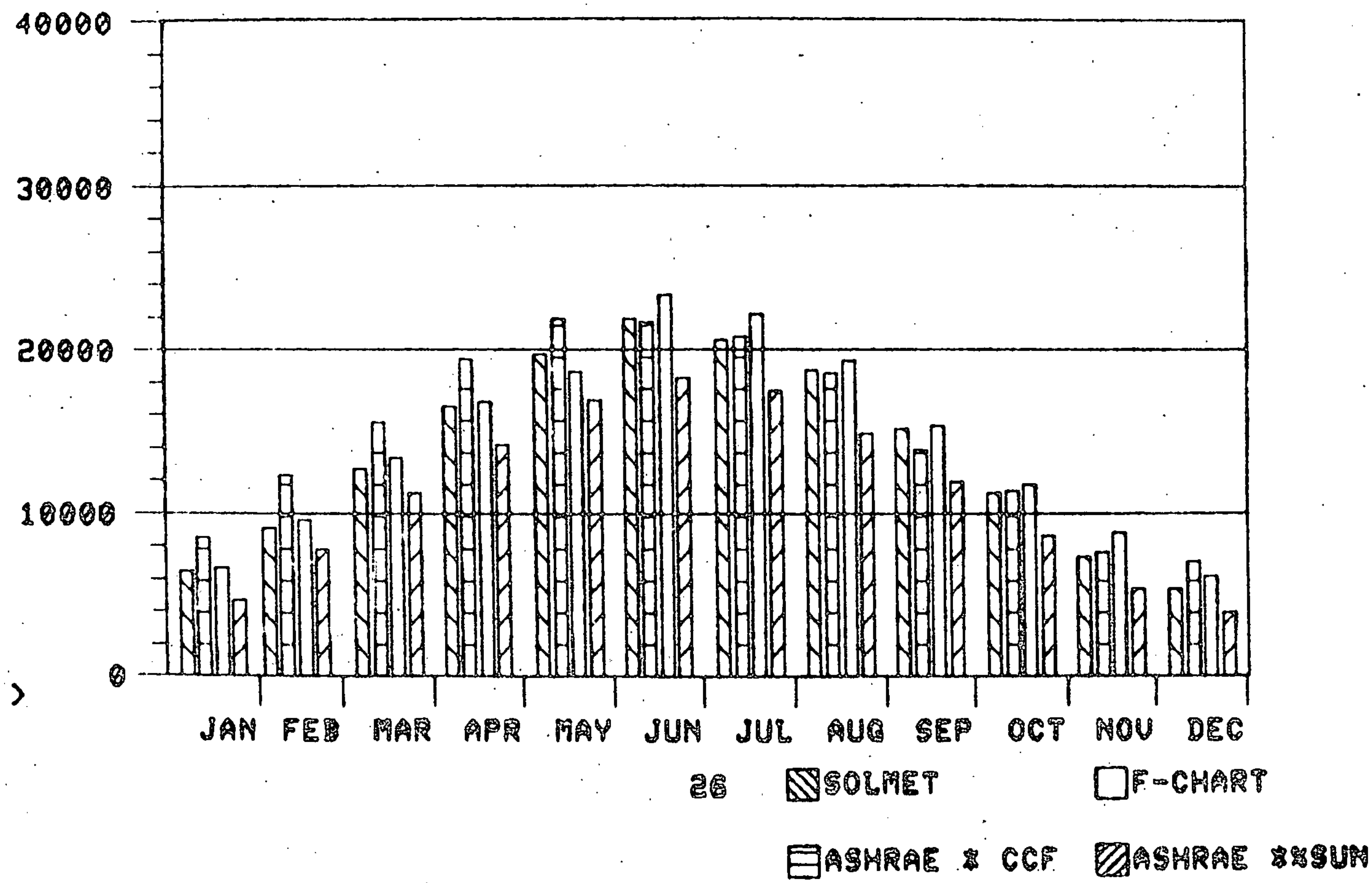


66

25

SUMMARY OF SOLAR RADIATION USING FOUR DATA SOURCES
AVERAGE DAILY VALUES PER MONTH - (KJ/M**2-HR)

LOCATION: WAS,DC   WBAN NO: 93722



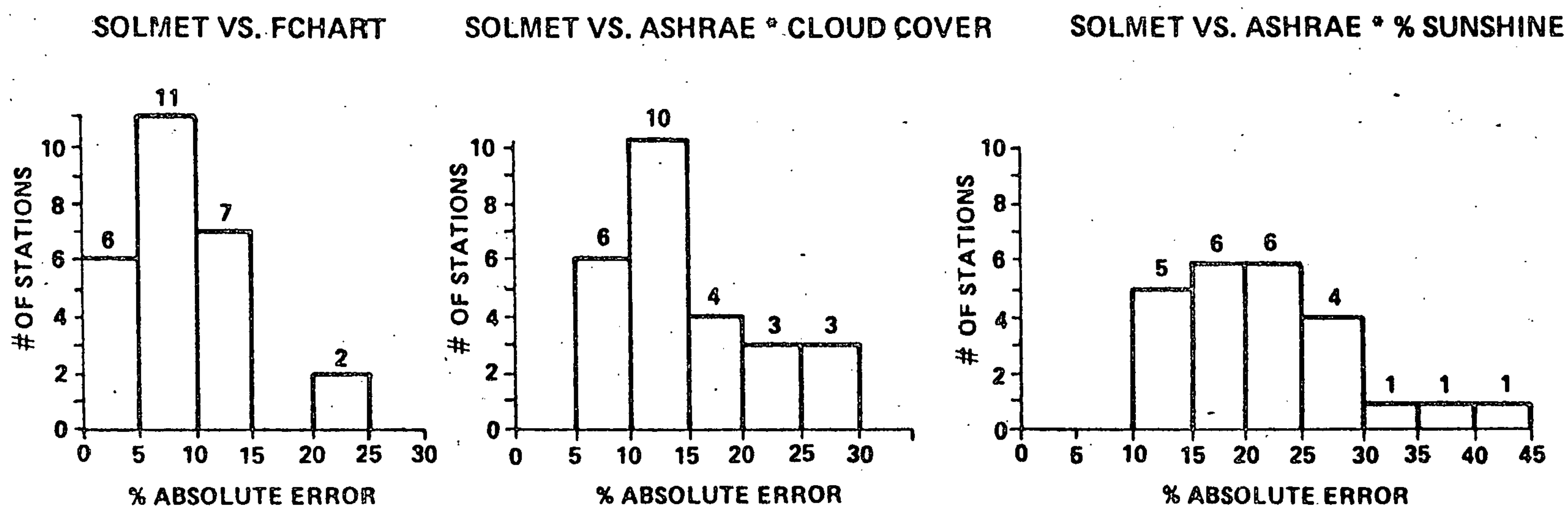
ORGANIZATION:	MARSHALL E FLIGHT CENTER	NAME: R. SCHLAGHECK
EL12	COMPARISON OF DATA BASES AGAINST SOLMET	DATE: SEPT 1977

	STATION NAME	SOLMET VS F CHART	SOLMET VS ASHRAE % SUN	SOLMET VS ASHRAE CCF
1.	ALB, NM	5.7%	25.1%	8.9%
2.	ALP, FL	13.7%	12.9%	9.8%
3.	BIS, ND	11.9%	32.2%	16.4%
4.	BOS, MS	3.9%	18.0%	25.9%
5.	BRO, TX	4.6%	20.2%	14.8%
6.	HAT, NC	20.5%	*	12.4%
7.	CAR, ME	12.3%	*	26.7%
8.	CHA, SC	22.6%	11.6%	29.0%
9.	COL, MO	9.4%	22.6%	9.4%
10.	DCT, KA	8.0%	22.0%	11.7%
11.	ELP, TX	3.4%	23.0%	10.5%
12.	ELY, NV	4.1%	29.4%	13.7%
13.	FTW, TX	10.8%	16.4%	14.6%
14.	FRE, CA	5.9%	17.8%	10.5%
15.	GRF, MT	8.6%	31.6%	16.7%
16.	LCH, LA	13.3%	11.3%	21.7%
17.	MAD, WI	7.0%	28.4%	18.4%
18.	MED, OR	6.0%	42.0%	7.0%
19.	MIA, FL	10.7%	12.6%	6.0%
20.	NAS, TN	8.8%	16.6%	15.9%
21.	NWY, NY	2.6%	12.2%	22.7%
22.	OMH, NE	7.9%	21.4%	23.7%
23.	PHO, AR	4.8%	15.3%	9.6%
24.	SMA, CA	10.4%	20.2%	11.3%
25.	SEA, WS	9.5%	35.8%	14.8%
26.	WAS, DC	6.3%	19.3%	13.6%
	AVG. TOTAL	8.95%	21.58%	15.22%

*MISSING DATA FOR THAT PARTICULAR STATION.

EL5098

COMPARISON OF SOLMET DATA TO OTHER METHODS



ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME: R. SCHLAGHECK
EL12	SUMMARY	DATE: SEPT 1977

- SIGNIFICANT DIFFERENCES OCCUR BETWEEN SOLMET AND ANALYTICAL PREDICTOR TECHNIQUES

- AT THIS TIME NO RECOMMENDATION OF AN ACCURATE PREDICTOR METHOD FOR GENERATING MONTHLY SOLAR RADIATION VALUES AT A NON SOLMET SITE IS GIVEN

- MSFC WELCOMES FURTHER INVESTIGATIONS OF PREDICTOR TECHNIQUES THAT PROVIDE A MORE ACCURATE METHOD OF ESTIMATING MONTHLY AVERAGE INSOLATION FOR NON NETWORK SITES

- MANY OF THE SOLMET SITES HAVE LARGE PERIODS OF MISSING DATA. WILL THE GAP FILLED SOLMET TAPES CHANGE THE LONG TERM AVERAGES FOR THESE SITES?

NATURAL VARIABILITY OF SOLAR RADIATION

L. Machta and G. Cotten, NOAA

The natural variations in solar radiation play a major role in the design and effectiveness of solar collectors to satisfy energy requirements. The diurnal variation and the role of clouds are all too evident. But less evident is the variation of solar radiation averaged over month, season, year, and longer time periods. Typical examples are discussed below.

There exists a host of solar-radiation parameters which can be used in the design of the collector or storage system besides the obvious mean value. The frequency distribution of numbers of successive days with less than a prescribed amount of energy (for storage or supplementary energy design) is another characteristic which varies from one time period to another. However, for simplicity the discussion will be limited to annual or 5-yr average values of global (i.e., direct plus diffuse) solar radiation.

Fig. 1 shows the annual and 5-yr periodic variation of global solar radiation. As expected, for the two extreme months at Dodge City, KS, the yearly variation greatly exceeds the longer period of averaging variation. Furthermore, the absolute value of variation is larger in June when the absolute values themselves are about three times as large, than in December. Notice here how misleading a single month like June, 1967, might be in representing a long-term average. But even more important, the figure points out the demand on the design engineer to decide what year or level of radiation should be selected.

Fig. 2 provides some statistics such as the standard deviations of the annual and 5-yr variability to the 24-yr climatological average expressed as a percentage. The year-to-year variation ranges among the stations from 6 to 14 percent in December and 4 to 8 percent in July. The variability of 5-yr average is appreciably smaller in almost all stations.

Finally, Fig. 3 compares the variability of December and July averages in Washington, DC, expressed in the same units as those of Fig. 2 with the errors created by the exclusive use of cloudiness and precipitation (see paper by Machta and Cotton elsewhere in the proceedings) to predict the same monthly values of solar radiation. Washington, DC, variations may be somewhat worse than many of the 26 rehabilitated stations because measurements were made at a number of different places in and near Washington. However, if the relative numbers are representative of other places, as is probable, then the predictive errors are about half of the natural variability.

FIGURE 1

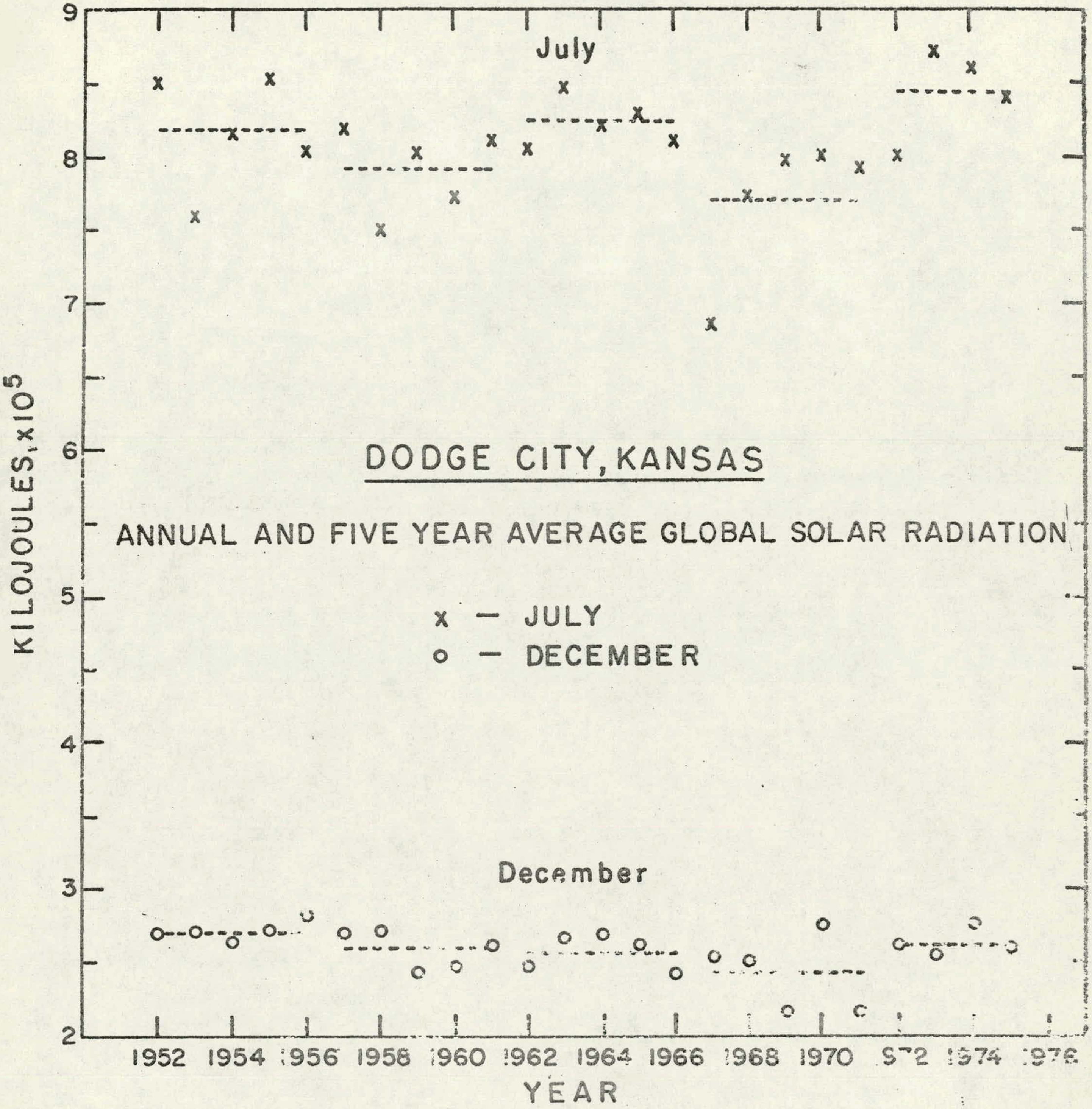

July
DODGE CITY, KANSAS
ANNUAL AND FIVE YEAR AVERAGE GLOBAL SOLAR RADIATION
x — JULY
o — DECEMBER
December
KILOJOULES, x10^5
9
8
7
6
5
4
3
2
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1974
YEAR

FIGURE 2

VARIABILITY OF ANNUAL AMOUNTS OF GLOBAL SOLAR RADIATION

STATION	YEAR TO YEAR		FIVE YEAR TO FIVE YEAR	
	(100 x ONE STANDARD DEVIATION / MEAN LONG TERM AVERAGE)			
	DEC	JULY	DEC	JULY
DODGE CITY, KS	6.6	5.0	4.2	3.5
BISMARCK, ND	6.9	6.1	1.3	3.8
MADISON, WI	13.2	7.6	8.6	2.0
NASHVILLE, TN	13.6	7.6	7.6	4.6
CAPE HATTERAS, NC	7.6	7.8	3.9	3.9
LAKE CHARLES, LA	10.3	7.1	4.3	3.3
EL PASO, TX	6.6	5.0	3.4	3.1
ALBUQUERQUE, NM	6.9	4.4	3.1	3.5
GREAT FALLS, MT	10.8	7.3	9.0	2.5

FIGURE 3

AN EXAMPLE OF ERRORS IN GLOBAL SOLAR RADIATION PREDICTIONS USING CLOUDS AND PRECIPITATION

WASHINGTON, D.C.

1952-1975 (INCLUSIVE)

NATURAL VARIABILITY		PREDICTIVE ERRORS	
$\frac{\sigma}{\text{MEAN}} \times 100$		$\frac{\sigma}{\text{MEAN}} \times 100$	
DEC.	JULY	DEC.	JULY
9.1%	10.2%	4.1%	5.1%

THE NOAA/ARL SOLAR RESEARCH FACILITY, BOULDER, COLORADO

E. Flowers, NOAA/ARL

The primary functions of the Boulder facility are:

1. To maintain standard instruments
2. To calibrate pyranometers and pyrheliometers
3. To test specimen instruments
4. To measure radiation locally and develop relationships

STANDARD INSTRUMENTS

The maintenance of standard instruments involves the determination of their characteristics (linearity, temperature, cosine (for pyranometers) and spectral responses, etc.), establishment of traceability of calibration from primary reference sources, and finally the documentation of these data through publication of results.

The SRF has a Kendall cavity radiometer as a primary reference. This instrument is self-calibrating and makes measurements of absolute irradiance. Secondary reference instruments which are maintain at NOAA/ARL are an Ångström compensation pyrheliometer and a Smithsonian silver disk pyrheliometer. All three of these instruments took part in the International Pyrheliometric Comparison (IPC) held at the World Radiation Center in Davos, Switzerland in 1975. At this comparisons, the ratio between the Davos PACRAD (Kendall) and the SRF Kendall was found to be 1.0004.

Working standard pyrheliometers (Eppley NIPs) are compared directly with the Kendall radiometer at regular intervals at Boulder. Table I gives the results of these comparisons along with data from a Kahl pyrheliometer and a Matrix (solar cell) pyrheliometer. The response values give the relationship between the International Pyrheliometric Scale (IPS) and the Absolute Scale of radiation. Instrument 1330 is the NOAA reference and gives NOAA's version of IPS; Eppley 14856, Kahl 56114 and Matrix 2457 reflect the IPS as interpreted by these manufacturers.

Figure 1 is the calibration chain for the NOAA instruments. The top part of the chart shows pyrheliometers; the bottom part shows pyranometers. All instruments calibrated at Boulder by the SRF utilize this chain and all instruments are calibrated on the Absolute Radiation Scale. Since for NOAA, the IPS is embodied in instrument 1330 which has a ratio of 0.975 with the Kendall radiometer, all instruments calibrated by the SRF will give irradiance values about 2.5% higher than instruments calibrated earlier by the National Weather Service on the IPS. The relationship between scales is given in figure 2 which was taken from a report by C. Fröhlich (1).

PYRANOMETER CALIBRATIONS

Calibration is transferred from a pyrheliometer to a pyranometer by the shade method. In this procedure, separate measurements are made with the pyranometer of the global (direct plus diffuse) and diffuse irradiance. The difference of these two measurements is the vertical component of the direct irradiance, which is compared with a measurement of the direct component made with a pyrheliometer to derive the pyranometer calibration factor. Figure 3 shows values of the derived pyranometer calibration factor for instrument Spectrolab 73-1, plotted as a function of the sun's elevation angle. The apparent slope of the data indicates a departure from a true cosine response.

Shade calibrations are made only for the reference pyranometers. Other pyranometers are calibrated by direct comparison with a reference pyranometer in sunlight. The method used by the SRF is shown in figure 4. Along the top of the figure are the data-logger channel number, and instrument identification and type (whether reference or test). Each line represents one scan of the data logger beginning on the minute indicated on the left. The values are read as millivolt outputs from the instruments. Note that the reference instrument (9012) is read every 5 or 6 channels. The data used for the calibration are the 10-minute average values for the test and reference instruments. A reference value for each test instrument is obtained by linear interpolation between successive reference values. For each test instrument a regression equation is calculated from the 10-minute data for the entire daylight period. The bottom line of the figure gives the results of this calculation. The calibration value for the test instrument is calculated by substituting the known calibration value for the reference instrument into the regression equation. Calibration values are obtained for each day of comparison and a final value determined as the mean of about 14 daily values. For Eppley PSP and Spectrolab pyranometers, the standard deviation of the daily value from the 14-day mean is usually between 0.2 and 0.5%.

Figure 5 presents calibration statistics for a group of specimen pyranometers from various manufacturers for August 1977. The response value gives the relationship between the SRF level of calibration and the level of the manufacturer. The standard deviation is the variation of the daily value from the mean. The column labelled "S.E." is the average standard error of a single 10-minute value from the value predicted by the regression equation for that day, expressed in units of irradiance. The Lambda, Matrix and Rho Sigma instruments are photocell detectors; all of the others are thermopile detectors. The Eppley 10018 (model 848) and Kahl 1282 (manufactured by Schenck) are black-and-white receivers.

LABORATORY TESTS

The SRF has made temperature-response tests of all of the instruments from the different manufacturers and on many of the Eppley PSP and Spectrolab pyranometers which will be used in the NOAA network. Figures 6 and 7 give temperature response curves for a compensated (Eppley PSP 14886) and an uncompensated (Kipp) pyranometer. In most cases (but not all) the compensated pyranometer will be corrected to give errors less than $\pm 1\%$. The curve for the Kipp is a typical curve for an uncompensated instrument. The curve for the Kipp suggests that it will give too large a reading as the temperature decreases.

Mos of the instruments from the various manufacturers have been tested to determine the effects of tilt on their sensitivity. Figure 8 gives the response curves for the instruments tested.

LOCAL RADIATION MEASUREMENTS

At Boulder we are making measurements of:

- Global irradiance in the wavebands $>$295nm, $>$395nm, $>$530nm and $>$695nm
- Direct irradiance
- Diffuse irradiance (with a shadow band)
- Ultraviolet irradiance (295-385nm)

Figure 9 is a copy of the Boulder data which includes a calculation of the solar elevation angle, a derived diffuse irradiance and various other ratios. A tilted measurement will soon be made and included in the array.

REFERENCE:

(1) Fröhlich, C., The IPS 1956 Now in Use, Fourth International Pyheliometer Comparisons, Scientific Discussions, WRC, Davos, Switzerland, October 1975.

TABLE 1

PYRHELIOMETER CALIBRATIONS

COMPARISONS WITH PACRAD (TMI 67502) - BOULDER, 1976-1977

INSTRUMENT	NUMBER DAYS	NUMBER OBS.	RESPONSE	S.D.[1] (%)	S.D.[2] (%)
EP 1330	30	2198	0.975	± 0.36	± 0.32
EP 14856	18	1394	0.964	0.20	0.17
KAHL 56114	8	569	0.936	0.16	0.16
MATRIX 2457	11	1495	0.946	0.64	0.32

1. STANDARD DEVIATION OF THE DAILY VALUE FROM THE MEAN
2. AVERAGE STANDARD DEVIATION OF A SINGLE OBSERVATION WITHIN A DAY FROM THE DAILY VALUE

NOAA CALIBRATION CHAIN

FIGURE 1

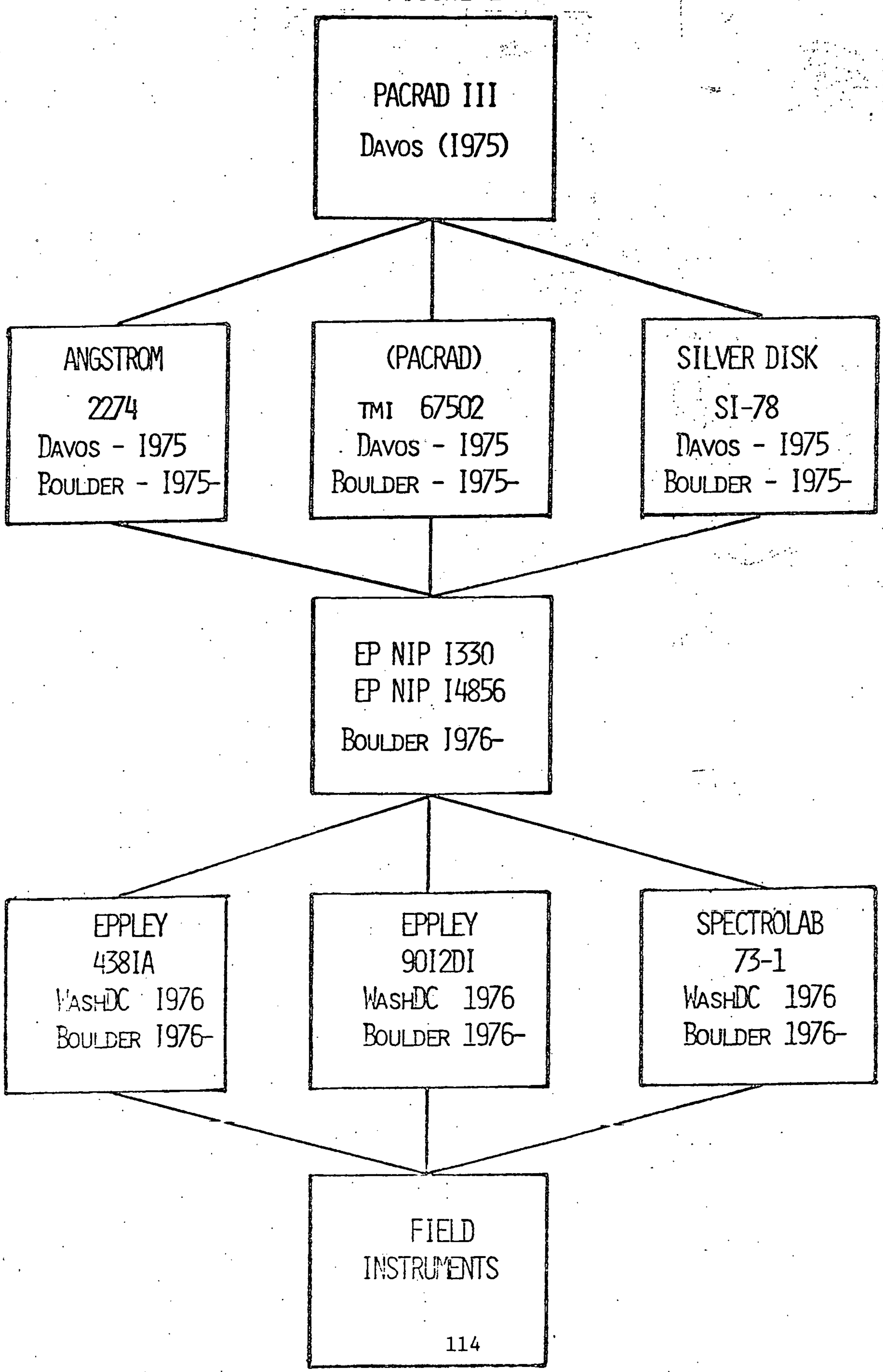
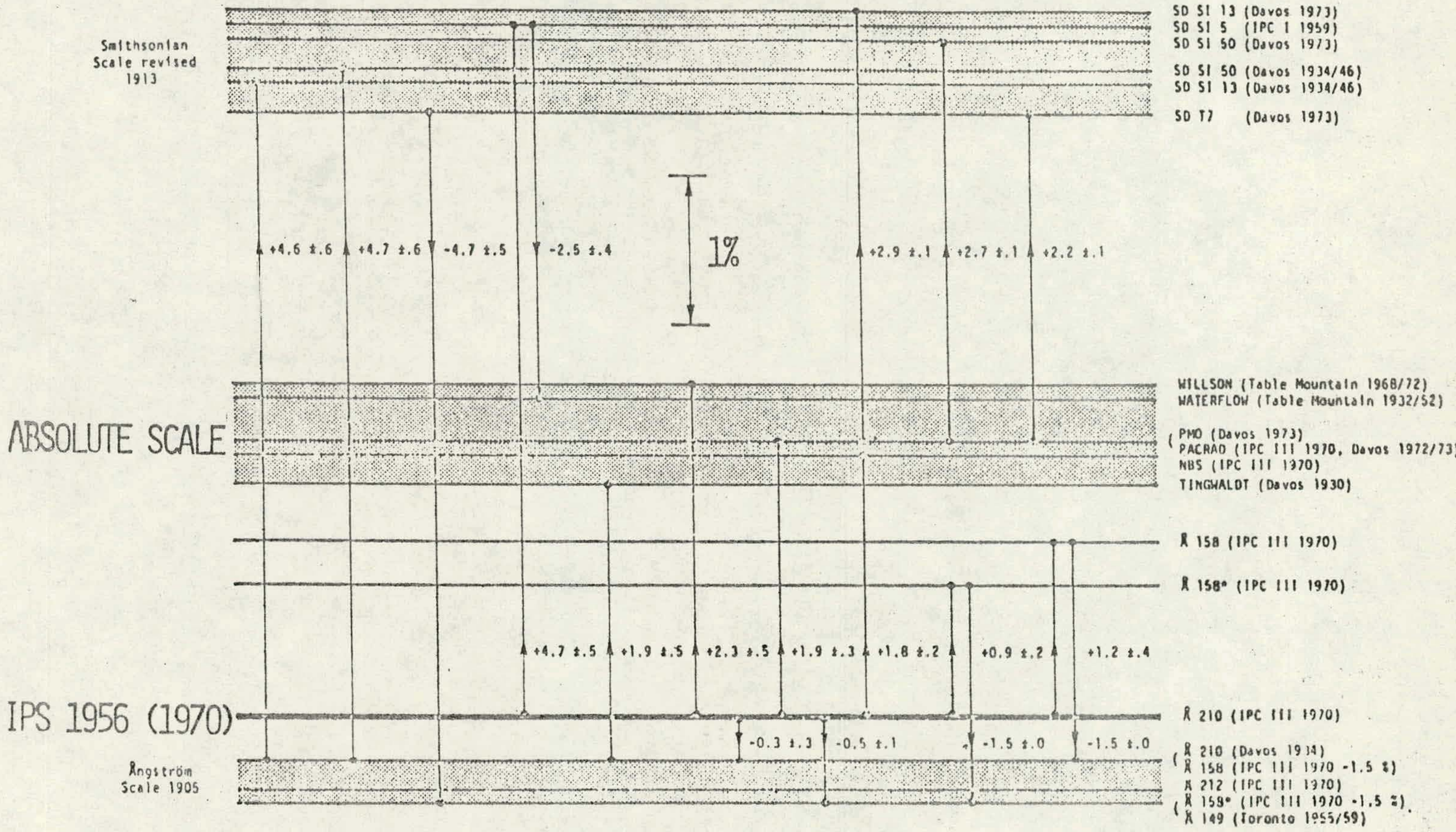


FIGURE 2

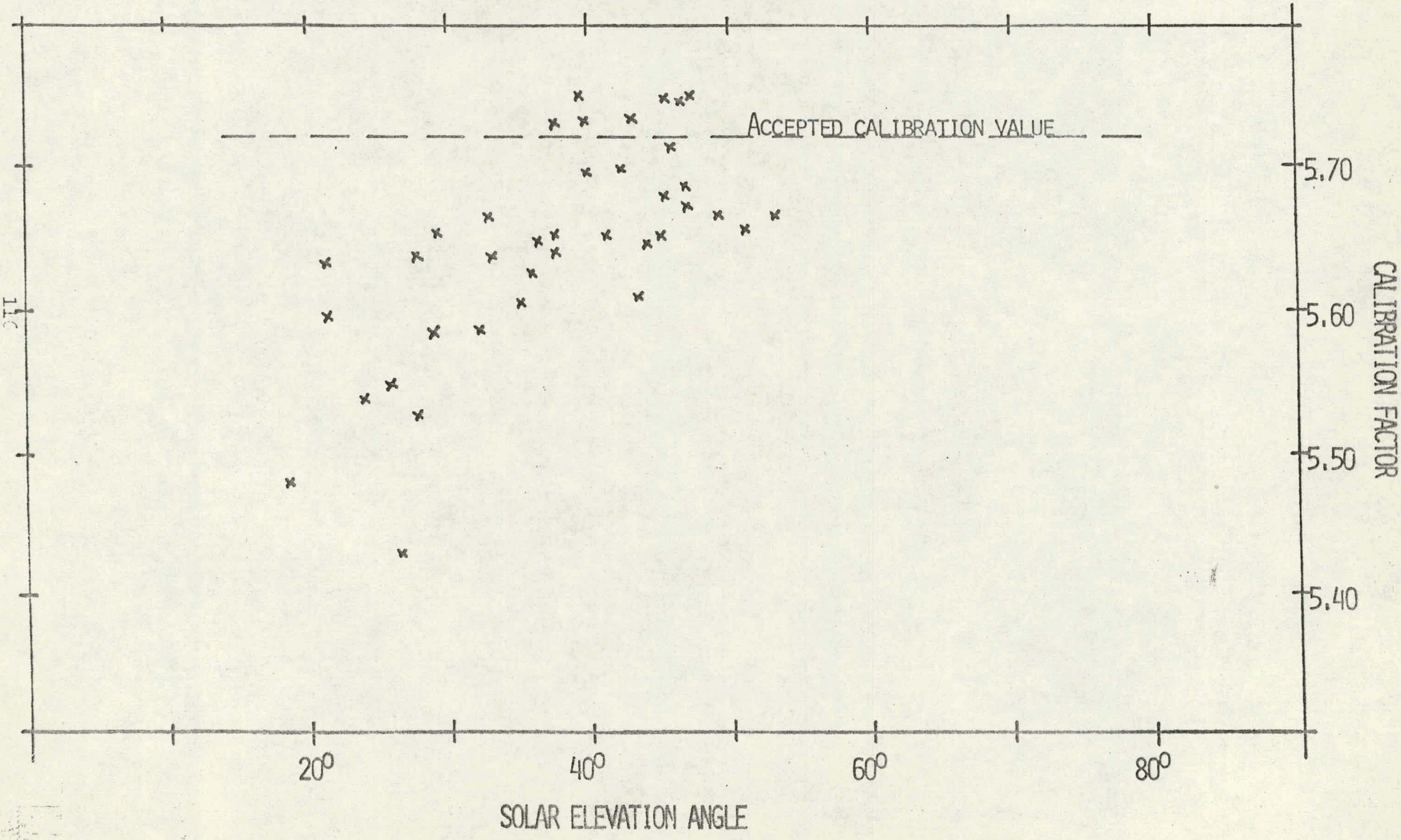


Summary of the relation between scales. All Silverdisc data are reduced to 2/4 mode measurements.

FIGURE 3

TRANSFER (SHADE) CALIBRATION

PYRANOMETER SP 73-1



SAMPLE OF DATA ANALYSIS FOR PYRANOMETER CALIBRATION

FIGURE 4

CHANNEL	30	31	32	33	34	35	36	37
INSTR ID	EP 9012	EP14886	EP12687-Q	EP14888	EP10565	EP10107	EP 9012	EP11935
INSTR TYPE	REF	TEST	TEST	TEST	TEST	TEST	REF	TEST
77213 1200	4.995	9.391	8.939	8.837	8.817	3.167	4.993	9.260
77213 1201	4.984	9.372	8.918	8.810	8.786	3.156	4.980	9.242
77213 1202	4.974	9.348	8.899	8.795	8.767	3.149	4.976	9.233
77213 1203	4.971	9.344	8.894	8.791	8.756	3.149	4.976	9.232
77213 1204	4.971	9.348	8.900	8.793	8.760	3.147	4.971	9.223
77213 1205	4.974	9.350	8.899	8.793	8.770	3.150	4.973	9.227
77213 1206	4.974	9.349	8.898	8.790	8.769	3.150	4.972	9.227
77213 1207	4.995	9.385	8.937	8.827	8.800	3.162	4.998	9.270
77213 1208	4.989	9.373	8.927	8.817	8.789	3.158	4.991	9.256
77213 1209	4.965	9.330	8.887	8.776	8.750	3.144	4.965	9.206
REF AVG	4.979	4.979	4.979	4.979	4.979	4.979	4.980	4.980
TEST AVG		9.359	8.910	8.803	8.776	3.153		9.238
STD DEV	.011	.020	.019	.019	.021	.007	.011	.019
K*		6.879	6.549	6.470	6.451	2.318		6.790
IRRADIANCE	1.360						1.361	

CALIBRATIONS:

INTERCEPT	-.11303	-.08982	-.10130	-.08264	-.02515	-.13463
SLOPE	1.89771	1.80689	1.78389	1.77936	.63688	1.87610
STD ERROR	.08347	.04924	.08541	.06112	.02202	.08999
CAL VALUES	6.83259	6.52338	6.42775	6.42980	2.30583	6.73189

PYRANOMETER CALIBRATIONS
(REFERENCE: EP9012D1)

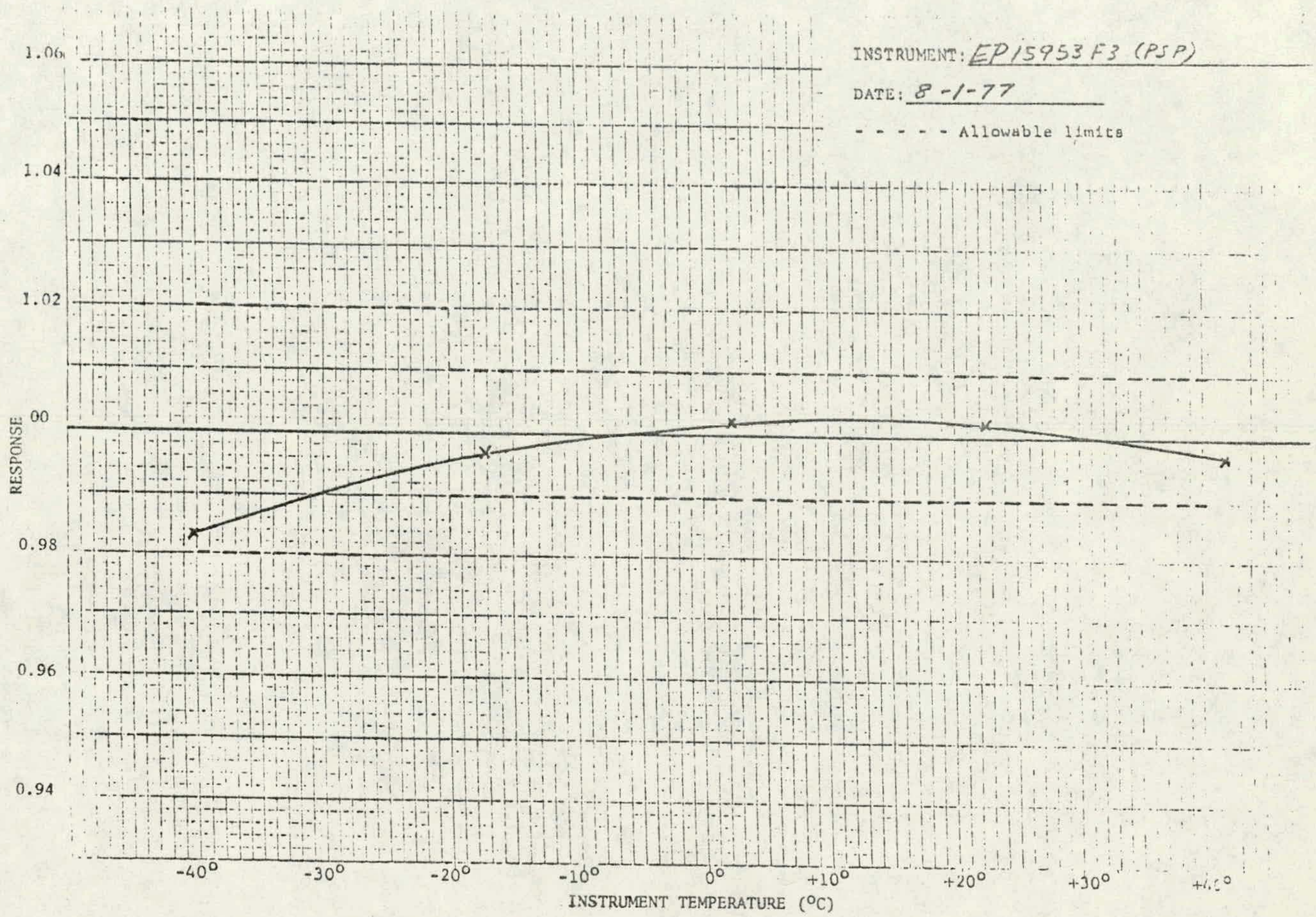
INSTRUMENT	NUMBER OF DAYS	RESPONSE	S.D.[1] (%)	S.E.[2] (W/M^2)
HY-CAL 56237	30	1.19	± 1.13	17.4
KAHL 56114	30	1.02	1.46	17.4
LAMBDA 658-7607	31	1.06	1.16	8.2
LINTRONIC 1083A	30	0.73	4.67	32.0
MATRIX 2484	31	--	0.99	11.5
EPPLEY 10018 (M-848)	30	1.04	0.79	8.4
KAHL 1282 (SCHENCK)	31	1.00	0.59	10.4
SPECTRAN 2069	31	0.93	1.19	17.3
RHO SIGMA 129	31	--	3.29	20.7
KIPP 752492	31	0.97	0.48	7.2
EPPLEY 14886 (PSP)	31	1.01	0.59	5.3
SPECTROLAB 73-96	31	0.97	0.51	5.1

1. STANDARD DEVIATION OF THE DAILY VALUE FROM THE MEAN
2. MEAN STANDARD ERROR OF A 10-MINUTE VALUE

FIGURE 5

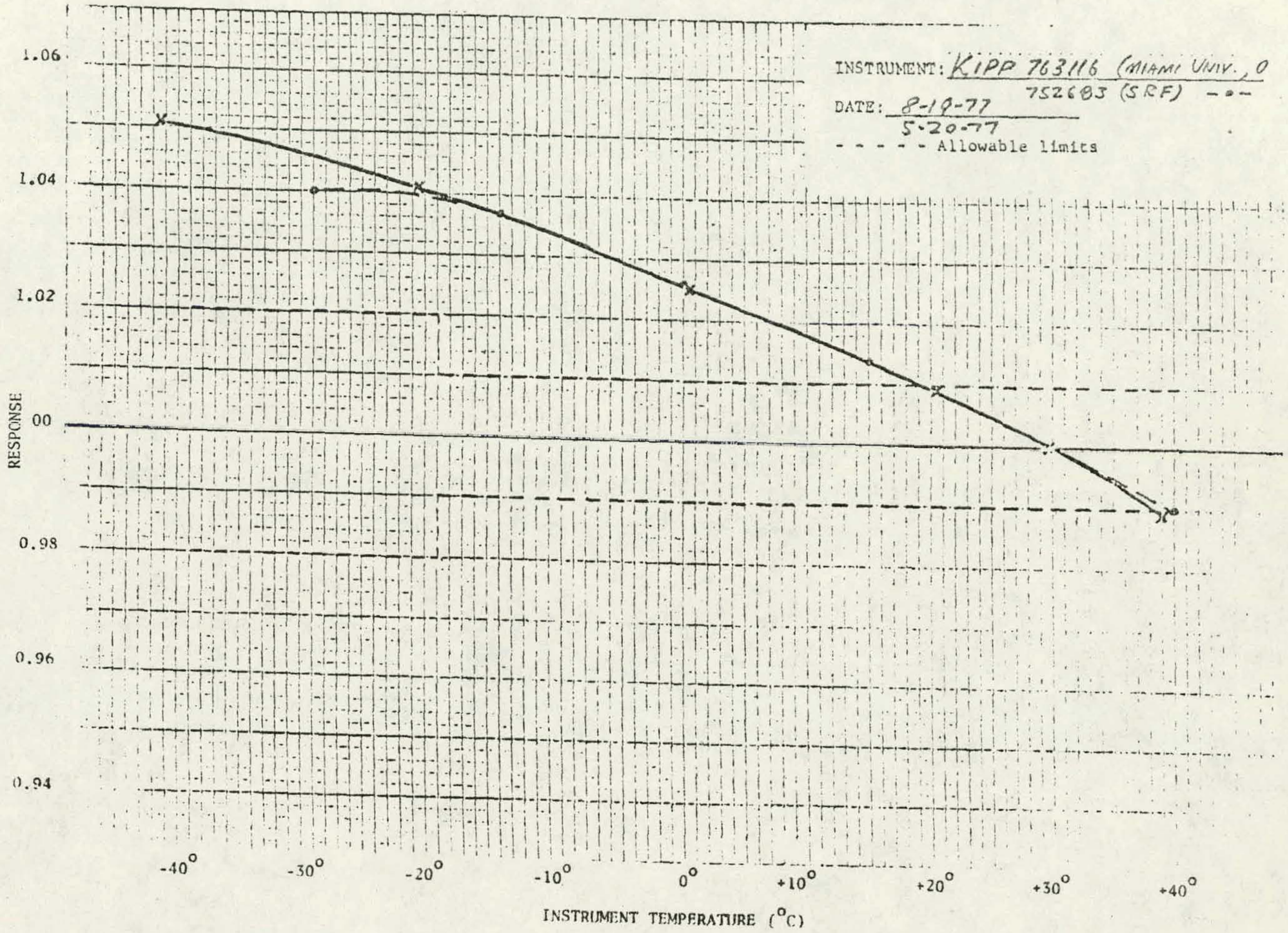
TEMPERATURE RESPONSE TEST

FIGURE 6



TEMPERATURE RESPONSE TEST

FIGURE 7



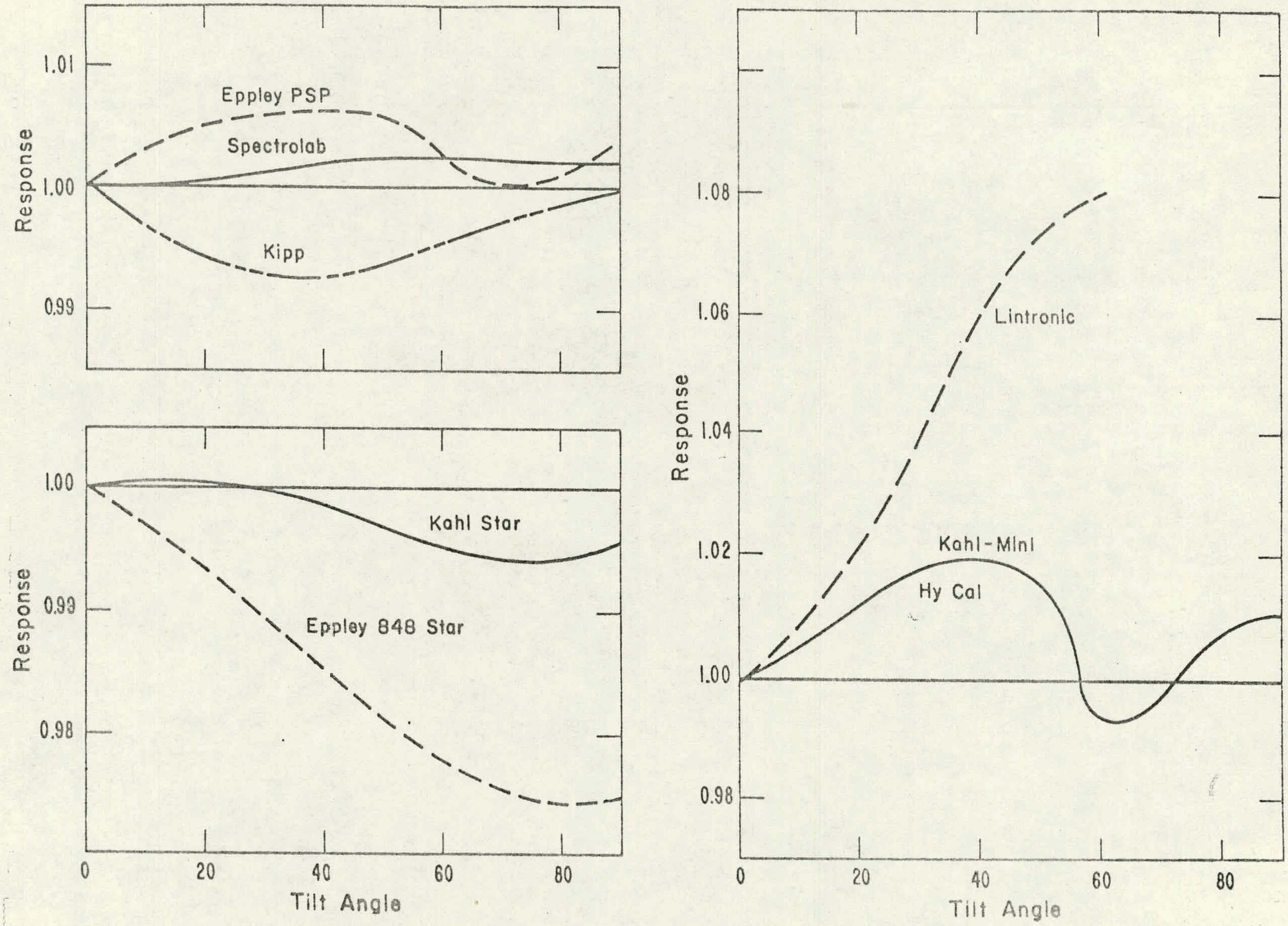

1.01
1.00
0.99
Response
Eppley PSP
Spectrolab
Kipp
1.00
0.99
0.98
Response
Kahl Star
Eppley 848 Star
0
20
40
60
80
Tilt Angle
1.08
1.06
1.04
1.02
1.00
0.98
Response
Lintronic
Kahl-Mini
Hy Cal
0
20
40
60
80
Tilt Angle

FIGURE 8

FIGURE 9

	IRRADIANCES									RATIOS		
COMPONENT	TOTAL	DIFFUSE	DIRECT	WL>395	WL>530	WL>695						
INSTRUMENT	EP14887	EP11937	EP14856	EP14889	EP14860	EP14861	SOLAR	CALC	>395	>530	>695	DIFF
CALIBRATION	100.38	114.60	124.22	107.54	114.41	109.85	ANGLE	DIFFUSE	TOTAL	TOTAL	TOTAL	DIRVC
77039 1130	548.18	52.26	867.55	513.93	418.63	295.17	34.7	54.41	.938	.764	.538	.1058
77039 1131	554.70	52.60	878.11	519.31	423.55	298.46	34.7	54.56	.936	.764	.536	.1052
77039 1132	539.34	52.72	850.91	505.65	411.88	289.89	34.7	54.35	.938	.764	.537	.1067
77039 1133	532.21	52.37	838.11	498.66	406.04	285.94	34.8	54.19	.937	.763	.537	.1090
77039 1134	536.23	52.03	844.70	502.53	409.24	288.03	34.8	54.13	.937	.763	.537	.1079
77039 1135	516.35	51.68	808.18	482.53	391.85	275.50	34.8	54.60	.934	.759	.534	.1120
77039 1136	506.82	51.57	790.91	472.42	383.62	269.46	34.9	54.85	.932	.757	.532	.1141
77039 1137	507.32	51.66	794.76	476.13	387.51	272.43	34.9	52.88	.939	.764	.537	.1137
77039 1138	538.54	52.14	849.17	506.41	412.79	290.00	34.9	52.72	.940	.767	.539	.1073
77039 1139	563.53	52.49	889.29	528.24	430.30	301.76	34.9	54.48	.937	.764	.535	.1031
AVERAGE	534.32	52.15	841.17	500.59	407.54	286.66	34.8	54.14	.937	.763	.536	.1087
STD DEV	19.206	.406	33.872	18.483	15.521	10.987	.08	.742	.0022	.0027	.0022	.0037

Processing and Quality Control of National Weather Service Radiation Data

Ward R. Seguin, NOAA

Last spring NOAA's Center for Experiment Design and Data Analysis (CEDDA) was asked to quality control and process the solar-radiation data being collected by the NWS at 38 stations, all of which have been acquiring global solar radiation since January, 1977. Diffuse and direct radiation sensors are gradually being added to a few of the stations.

The NWS acquisition system records as many as three channels of integrated, 1-min radiation values on cassette in a digital format. Hourly integrated values are recorded on printed paper tape. A 2-channel, paper strip-chart recorder is used as backup for recording global and diffuse radiation. All data are recorded in LST.

Regardless of the recording media, it is first necessary to copy the data onto a computer readable format. Data on printed paper tapes are punched on computer cards; cassettes are copied onto computer tape, and strip-charts are available for digitizing. The cassettes are the primary source of data, with the printed tapes and strip-charts serving as backups.

As Fig. 1 indicates, after the data have been put into a computer-readable format, they are read by a computer, and the hourly integrated values are printed out for manual review. Several checks are made such as:

1. Punched data compared with printed paper tape.

2. Hourly values from the cassettes are compared with the printed paper tapes.

3. Printed tape and cassette data are spot-checked against the strip-charts.

4. Global radiation for clear skies and small solar zenith angles are compared with those predicted by Dr. Machta's model.

5. Global, diffuse, and direct values are compared for reasonable agreement.

Dr. Machta's model incorporates the following variables in predicting clear-sky global radiation:

1. Zenith angle: calculated from time of day, day of year, la[illegible]e and longitude.

2. Eart[illegible]distance: calculated from day of year.

3. Precipitable water: monthly climatological value, corrected for lesser average values on clear days than for monthly average, for extra water vapor above 500 millibars, and station altitude.

4. Turbidity: monthly climatological value, value often estimated by interpolation or judgment about air clarity, adjusted for altitude.

5. Albedo: estimated from the ground cover and literature reports.

6. Station altitude: given.

To determine whether the observed values or the modeled values are in error, a careful examination is made of global radiation values that differ from the model by more than 5 percent. Current weather information collected by the stations, including visibility and

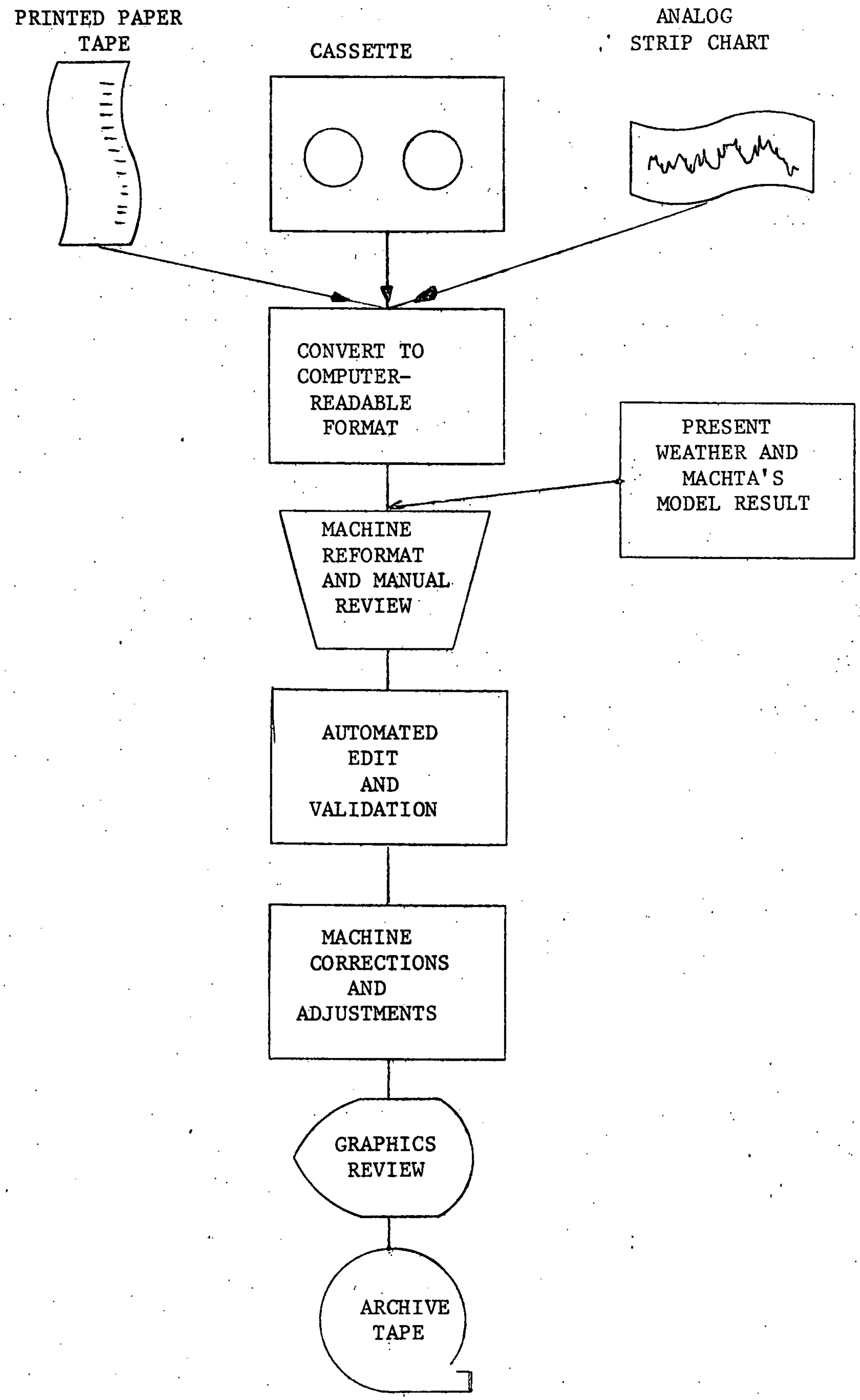

PRINTED PAPER TAPE
CASSETTE
ANALOG STRIP CHART
CONVERT TO COMPUTER-READABLE FORMAT
PRESENT WEATHER AND MACHTA'S MODEL RESULT
MACHINE REFORMAT AND MANUAL REVIEW
AUTOMATED EDIT AND VALIDATION
MACHINE CORRECTIONS AND ADJUSTMENTS
GRAPHICS REVIEW
ARCHIVE TAPE

Fig. 1

cloud cover, are used to determine how applicable the model results are. Precipitable water,turbidity, and albedo can vary significantly, thus affecting the validity of the model.

Automatic computer editing and validation procedures are not specified at this time. However, it is hoped that many of the manual validation schemes mentioned above can be computerized and quality check points assigned to data.

Once data have been edited, adjustments are made as need. For example, changes in the transfer equations corresponging to changing clibrations of the sensors require that the data be rescaled. Also, diffuse radiation data, require adjustment of the shade ring mounted on each sensor.

A careful graphics review of each variable is planned, in which CEDDA's interactive graphics system is used. This system enables the analyst to plot time series of each radiation variable on a color cathode ray tube (CCRT) and to interactively assign check points to delete erroneous data.

Once the data have been thoroughly reviewed and checked, they are sent to the NCC, for merging with the meteorological data in the SOLMET format. Present plans call for placing of hourly integrated global and diffuse radiation data (where available) from January through June, 1977, in the archive not later than December 31, 1977. The remaining half-year's hourly data will be archived not later than March 31, 1978. Integrated 1-min values that can be recovered from the cassettes before March 1, 1978, will be archived by March 31, 1978.

The Canadian Network

Ron Latimer, AES, Ontario

To start with, I will tell you where I fit into the Canadian organization and then describe our network, calibration centers and our quality control progress. All of our energy systems are controlled by the Department of Energy, Mines, and Resources, in Ottawa. I am in the Department of the Environment, specifically in its Atmospheric Environment Service (AES) located in Alberta. In fact ours is one of the few government services that is not in Ottawa. It is equivalent to the American Weather Service. All of the funding that comes through us has to do with solar-radiation data applications and is supplied by our National Research Council. It is primarily funded by the Division of Building Research. Most of the applications that we now find being promoted in Canada have to do with building research.

Within the AES, my job has to do with solar radiation. What we do is maintain standards. We establish and maintain the network, quality-control and archive the data, publish the data, and do a small amount of research. However, I have no mandate to collect data for solar-energy purposes. Our network was established for climatological purposes some 25 years ago. The fact that we now are supplying users with solar-energy data is an additional task to our primary purpose.

Our network consists of 54 stations, 52 of which record global solar data. It has 8 diffuse, 5 reflected, and 25 net total solar radiation stations. This network has grown primarily through demands for data to quantify climate, and it began with 32 radiosonde stations across Canada. Thus, we have the vertical-column temperature, relative humidity, wind velocity and direction, at the same site as well as synoptic information. Some of these sites also provide hourly reports. There also are stations at each major agricultural experiment station, some of the fishery research stations and a number at major urban centers. Altogether, we publish 90 hourly radiation summaries each month in a Monthly Radiation Summary.

All of these stations are sited in accordance with WMO criteria; locations can be found in the WMO guide. With the network above 60°N latitude we use the Eppley PSP. South of it, we use the Kipp and Zonen solarimeter. The PSP instrument is temperature-compensated, but the Kipp is not. The Eppley has slightly better cosine properties; we use it in the Arctic because some stations during the summer measure 24 hours of sunshine. We use the Middleton net pyradiometer for the net-radiation instrument. We use a Honeywell class 15 recorder universally; it has an 11-in chart width and operates at 1-in/hr. Attached to these are Librascope ball and disc integrators, the output from which is displayed on Sodeco printing counters for each solar hour. Both the recorder and the integration system are operated on solar time. We now have 17 years' experience with this system, but it is becoming obsolete; and we are planning to change to a system using electronic integrators and magnetic recorders. Each meteorological service has a central office which covers about seven large regions. In each region, we have a program for training local personnel. We also have a headquarters' site where we train some personnel. All of the students who go through our meteorological training programs are familiarized with the maintenance and operation of the radiation equipment. We also have equipment manuals for our system as well as observation manuals. In the regional system, we depend very much on use of the regional inspectors. These people usually visit stations perhaps every few months over a year. It is their function to inspect all of the radiation systems as well as the other meteorological systems and to report to the regional office and, in turn, to the headquarters. Thus, we have very tight control on what is happening and not happening. We also get situation reports from these stations. A typical one might be that someone has erected a structure that is going to obstruct our radiation sensors. The input to the data system is at headquarters. All the charts, and the integrator print-up data have station log sheets which are sent to the data management team at headquarters every two weeks.

The other thing I want to talk about is the National Atmospheric Radiation Center. This is the group I have at headquarters, and consists of myself and two technicians. We maintain all the standards for Canada in terms of our international standards and in terms of pyrheliometers and pyranometers. We have control of the calibration of the network and we also function as a control center for university groups and others within Canada that wish us to make special instrumentation studies. This means that we calibrate about 150 sensors a year on the average, and the network is recalibrated at least once every two years. We also do research in terms of testing sensors for temperature effects, cosine response, and inversion effects. One thing that we do immediately when an instrument is received is that we put it on a gnomometer cable where we make sure that the instrument's spirit level is, in fact, level. We have three facilities: the headquarters laboratory, in Toronto; the mountain observatory, at Mt. Kobau, in British Columbia; and a meteorological research station, which is just outside the city. This is where we do most of our out-of-doors work.

Now, I would like to say something about our Quality Control and Publications. A team of 8 people are involved in this effort, and most of these people have been involved in it for 10 to 15 years. What we do is scrutinize every analog record. Every recorder chart is looked at, and it is matched with corresponding integrator tape. Selected hours from our hand-scaled and two-week period are hand-scaled and compared with the integrator data to make sure that there is a correspondence between the analog record and the integrator record. We then keep a careful check on sunlight and sunset times, based on solar noon, on clear days to make sure that there is not a slight shift in times that observers may have set the clocks improperly. We also compare clear-day data with computer data. And I think our computer data is probably very similar to yours, Lester, etc. It is a model Carpentier used many years ago and we started to use where we have records of stations with clear-day data.

We have used this from about the RT 1 1957. We also make use of the station log because it contains appropriate notes of what has been happening during the two-week period. For example, the recorder and integrator is set on solar time and periodically adjusted by a minute or so. This is noted. Also if adjustment is made of an unlevel instrument it is noted. The removal of frost or dew or something from the bulb of the instrument is also noted. All this information is helpful. Adequate quality control data is based on this information. All of our systems are inspected on a daily basis. The data from the integrator tapes come out each month and they are usually published about six months after the fact so there is a lag about six months. We also have a computer punch card archive. And all of these data are on magnetic tapes. Anyone who wants to use it is charged just the cost to copy it. And I think we do it on a yearly basis so I think all of the data are available on tape to September 1, 1976. In closing, I would like to make a remark about publications. I have here a copy of data that have been published for the provence of Alberta, and I have a manuscript here which covers all of it for Canada for 15 cities. These are data from individual radiation stations; what is given are the data from in-plant services; these are computers for a particular site at 10° elevation for every 45° of aspect around the azimuth. The data for the direct, diffuse, reflective, and total on the surface, and for each month of the year; these are daily readings. And it also gives in terms of a chart up-date. Along here is the average period of days, along here the radiation, and these are the percentiles. This work was done for us by Dr. John Hay and the University of

British Columbia, and the model that he has used for this work is a composite one. He has found that taking into account multiple reflections on the surfaces and clouds that can greatly improve the scattering using the Lou-Jourdan technique. So he has used this technique in his model for finding reduced sky radiation. The model is described in this publication and the computer program is also in this publication. This publication can also be obtained from the Alberta Research Council. The other one, as I said is manuscript, and it will be published for the Atmospheric Environment Service Program. It will probably be published early in the new year. If anyone wishes to have a copy, it probably will be available by next summer.

DATA QUALITY CONTROL

GENE CARTER, UAH-JEEC

This discussion yesterday was intended to show, without getting into details, that the guidelines being prepared are organized and oriented, by requirement, toward user requirements and justifications for networks.

In subsequent discussions, we addressed all of those problems which were raised. Whether we have achieved that has to await the final document.

Ron Stewart stated last evening that there are at least two points of view which must be addressed. These are the user requirements now and in the future; and the need for quality data to meet those requirements, even though the requirements may not be clear.

Quality control must address this second point.

There are several organizations with publications which describe solar-radiation measurements and how to take them. These include NWS (USWB), WMO, IGY, and Canadian Weather Service.

There is not a concise set of procedures to follow for establishing and operating a solar-radiation station that will produce quality data; however such a document is needed. The preparations of such a document would be a challenging task for the quality control panel.

Typical of the items to be addressed in achieving quality control are those shown on Fig. 1. The quality control group should be able to improve upon them. Guidelines for such an effort are implicit in a form which is available. The preparation of such a document would be a worthy contribution by a talented and knowledgeable group.

QUALITY CONTROL

- SITE SELECTION
  - EXPOSURE
  - FACILITIES
- INSTRUMENT SELECTION
  - GLOBAL RADIATION
  - DIFFUSE RADIATION
  - DIRECT RADIATION
- RELATED MEASUREMENTS
- RECORDING
- CALIBRATION
- TESTS
  - CLEAR DAY TESTS
  - COMPARISON TESTS
- DATA COLLECTION, FORMATS, PROCESSING, DISSEMINATION, STORAGE AND RETRIEVAL

Fig. 1

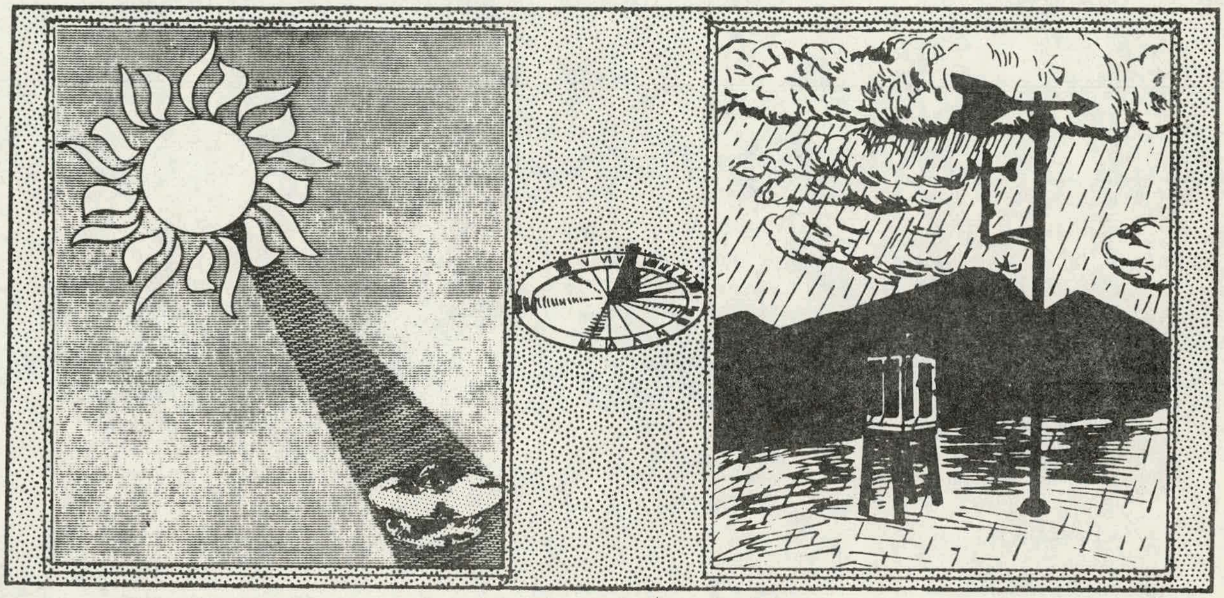
The NOAA Rehabilitated and Cloudiness Estimated Data

Frank Quinlan, NCC

SOLMET

VOLUME 1 - USER'S MANUAL

TD - 9724



Hourly Solar Radiation-Surface Meteorological Observations

TAPE DECK			PAGE NO.
9724	SOLMET		1

IDENTIFICATION / **SOLAR RADIATION OBSERVATION** (RADIATION VALUES KJ/m²)

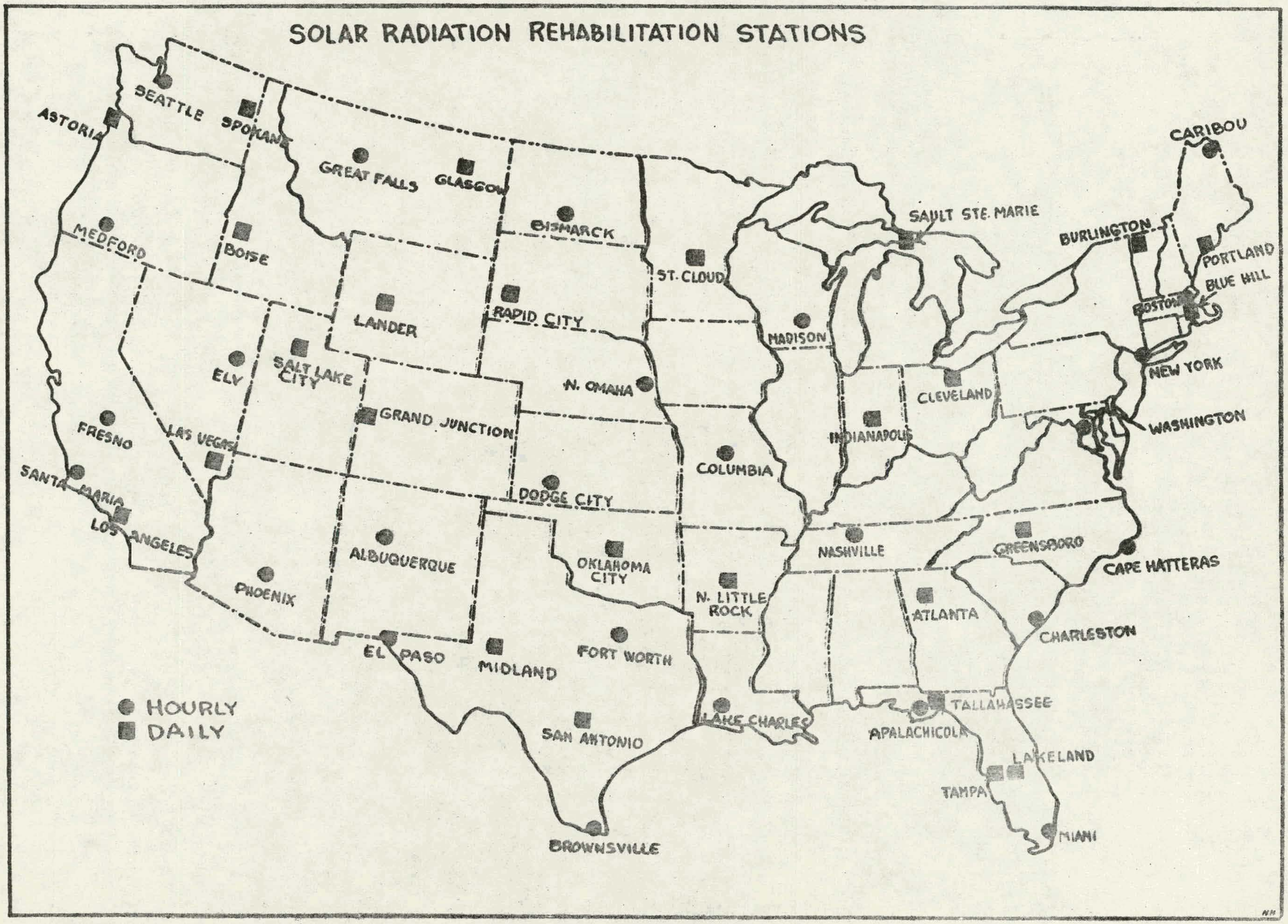
	TAPE DECK #	WBAN STN #	SOLAR TIME YR	MO	DY	HRMN	LST TIME	ETR KJ/m²	DIRECT	DIFFUSE	NET	TILTED	GLOBAL OBS	GLOBAL ENG COR	GLOBAL STD YR COR	A	B	SUNSHINE MIN
	9724	XXXXX	XX	XX	XX	XXXX	XXXX	XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	1XXXX	XX
FIELD NUMBER	001	002	003				004	101	102	103	104	105	106	107	108	109	110	111

SURFACE METEOROLOGICAL OBSERVATION

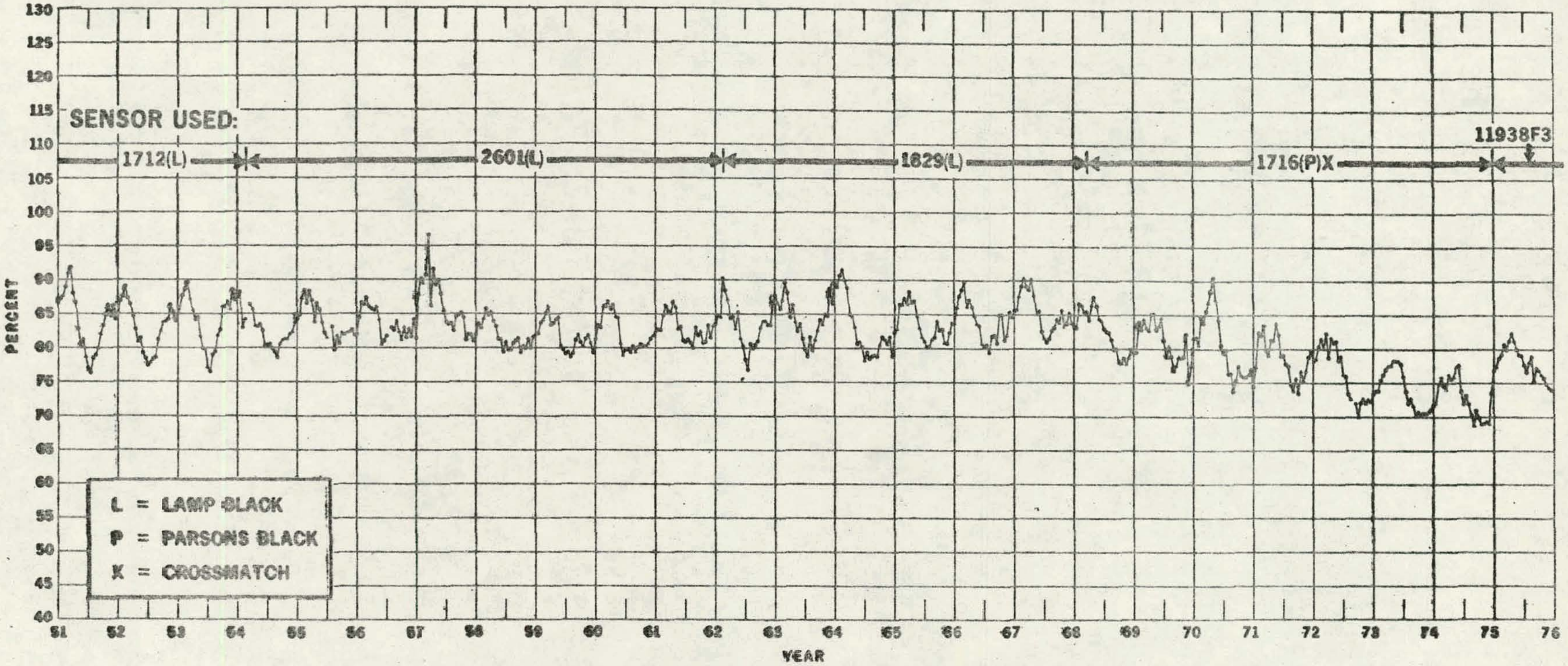
OBS TIME LST	CEILING dam	SKY COND	VSBY hm	WEATHER	PRESSURE kPa SEA LEVEL	PRESSURE STATION	TEMP °C DRY BULB	DEW-PT.	WIND DIR deg	WIND SPD m/s	CLOUDS TOTAL	LOWEST AMOUNT	LOWEST TYPE	LOWEST HEIGHT dam	SECOND AMOUNT	SECOND TYPE	SECOND HEIGHT dam	SUM AMT	THIRD AMOUNT	THIRD TYPE	THIRD HEIGHT dam	SUM AMT	FOURTH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

TAPE FIELD NUMBER	TAPE POSITIONS	ELEMENT
001	001 - 004	TAPE DECK NUMBER
002	005 - 009	WBAN STATION NUMBER
003	010 - 019	SOLAR TIME
004	020 - 023	LOCAL STANDARD TIME
101	024 - 027	EXTRATERRESTRIAL RADIATION
102	028 - 032	DIRECT RADIATION
103	033 - 037	DIFFUSE RADIATION
104	038 - 042	NET RADIATION
105	043 - 047	GLOBAL RADIATION ON A TILTED SURFACE
106	048 - 052	GLOBAL RADIATION ON A HORIZONTAL SURFACE - OBSERVED DATA
107	053 - 057	GLOBAL RADIATION ON A HORIZONTAL SURFACE - ENGINEERING CORRECTED DATA
108	058 - 062	GLOBAL RADIATION ON A HORIZONTAL SURFACE - STANDARD YEAR CORRECTED DATA
109, 110	063 - 072	ADDITIONAL RADIATION MEASUREMENTS
111	073 - 074	MINUTES OF SUNSHINE
201	075 - 076	TIME OF TD 1440 OBSERVATION
202	077 - 080	CEILING HEIGHT
203	081 - 085	SKY CONDITION
204	086 - 089	VISIBILITY
205	090 - 097	WEATHER
206	098 - 107	PRESSURE
207	108 - 115	TEMPERATURE
208	116 - 122	WIND
209	123 - 162	CLOUDS
210	163	SNOW COVER INDICATOR

7/77

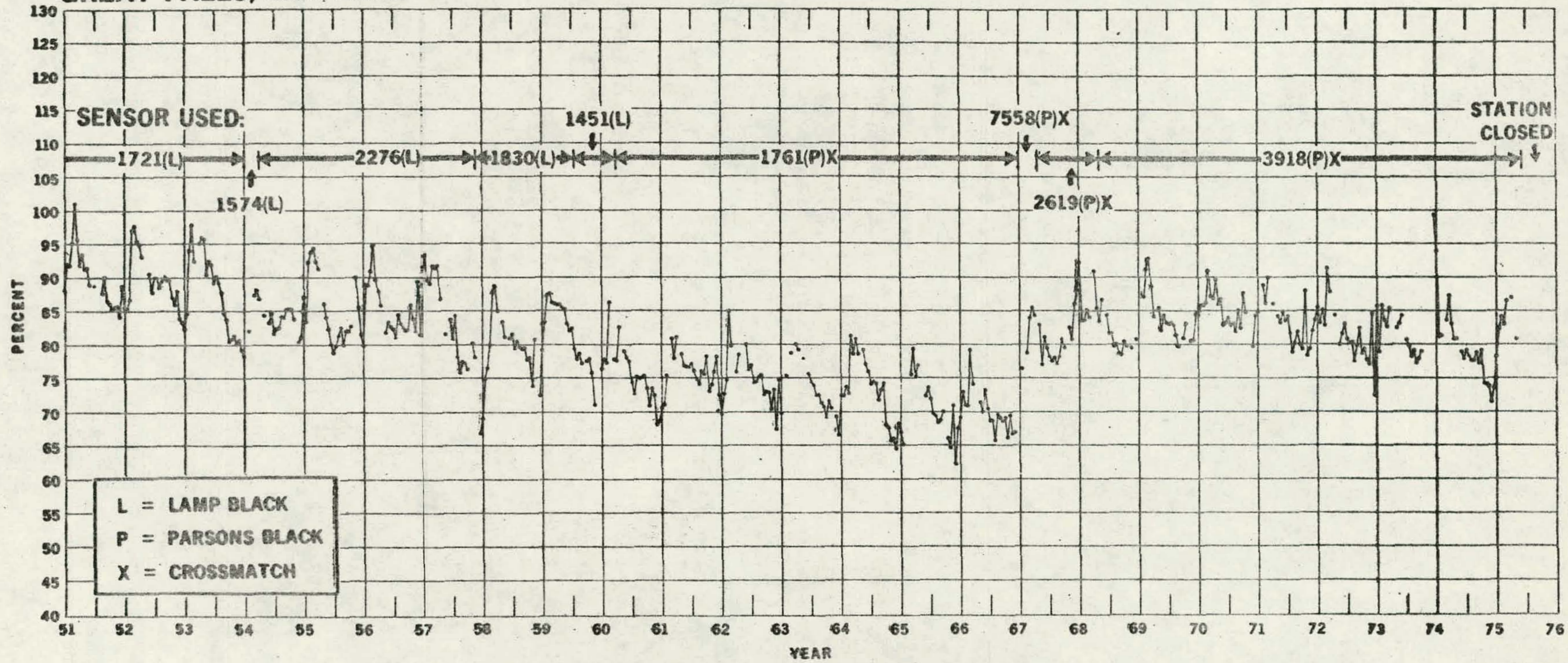

SOLAR RADIATION REHABILITATION STATIONS
SEATTLE
SPOKANE
ASTORIA
GREAT FALLS
GLASGOW
CARIBOU
BISMARCK
SAULT STE. MARIE
BURLINGTON
PORTLAND
BLUE HILL
BOSTON
MEDFORD
BOISE
ST. CLOUD
RAPID CITY
LANDER
MADISON
ELY
SALT LAKE CITY
N. OMAHA
NEW YORK
CLEVELAND
GRAND JUNCTION
WASHINGTON
INDIANAPOLIS
FRESNO
LAS VEGAS
COLUMBIA
SANTA MARIA
DODGE CITY
LOS ANGELES
NASHVILLE
GREENSBORO
CAPE HATTERAS
ALBUQUERQUE
OKLAHOMA CITY
PHOENIX
N. LITTLE ROCK
ATLANTA
CHARLESTON
EL PASO
MIDLAND
FORT WORTH
LAKE CHARLES
TALLAHASSEE
APALACHICOLA
SAN ANTONIO
LAKELAND
TAMPA
MIAMI
BROWNSVILLE
HOURLY
DAILY

EL PASO, TEXAS



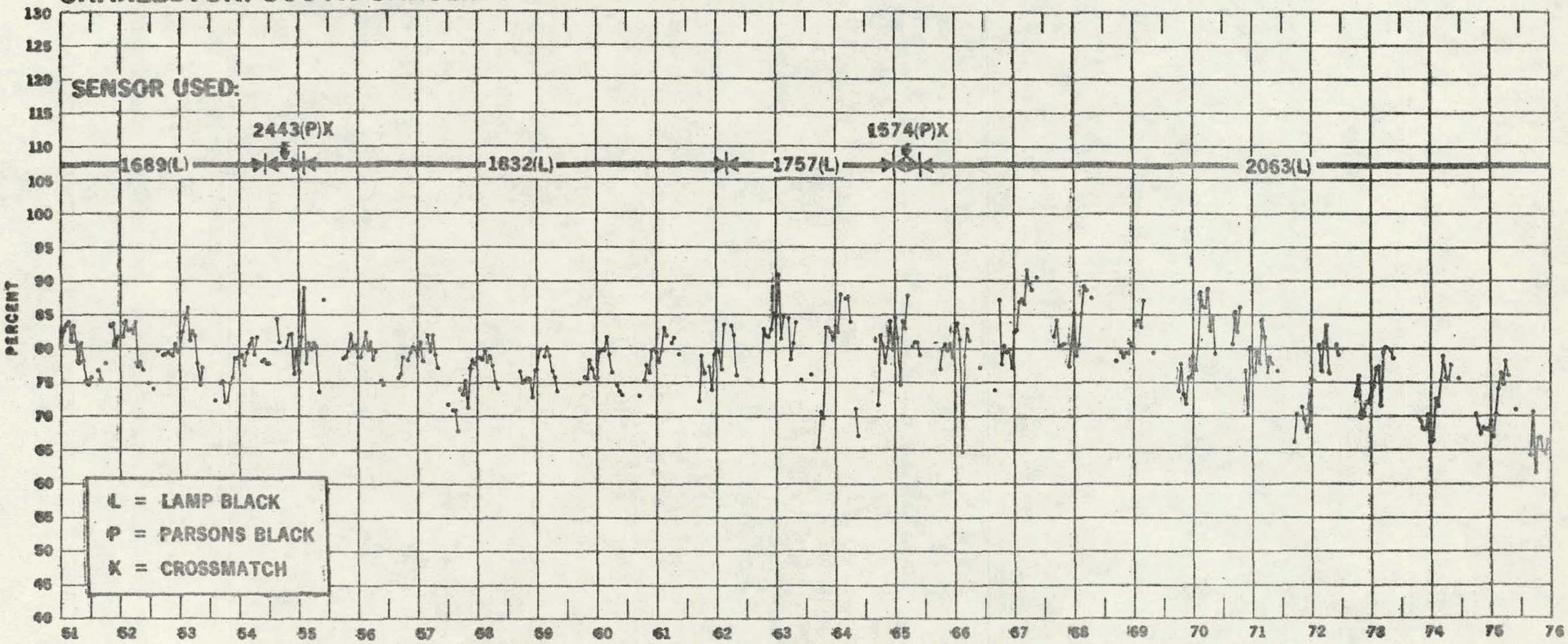
PERCENT OF ETR AT TRUE SOLAR NOON (15 DAY AVERAGES)

GREAT FALLS, MONTANA



PERCENT OF ETR AT TRUE SOLAR NOON (15 DAY AVERAGES)

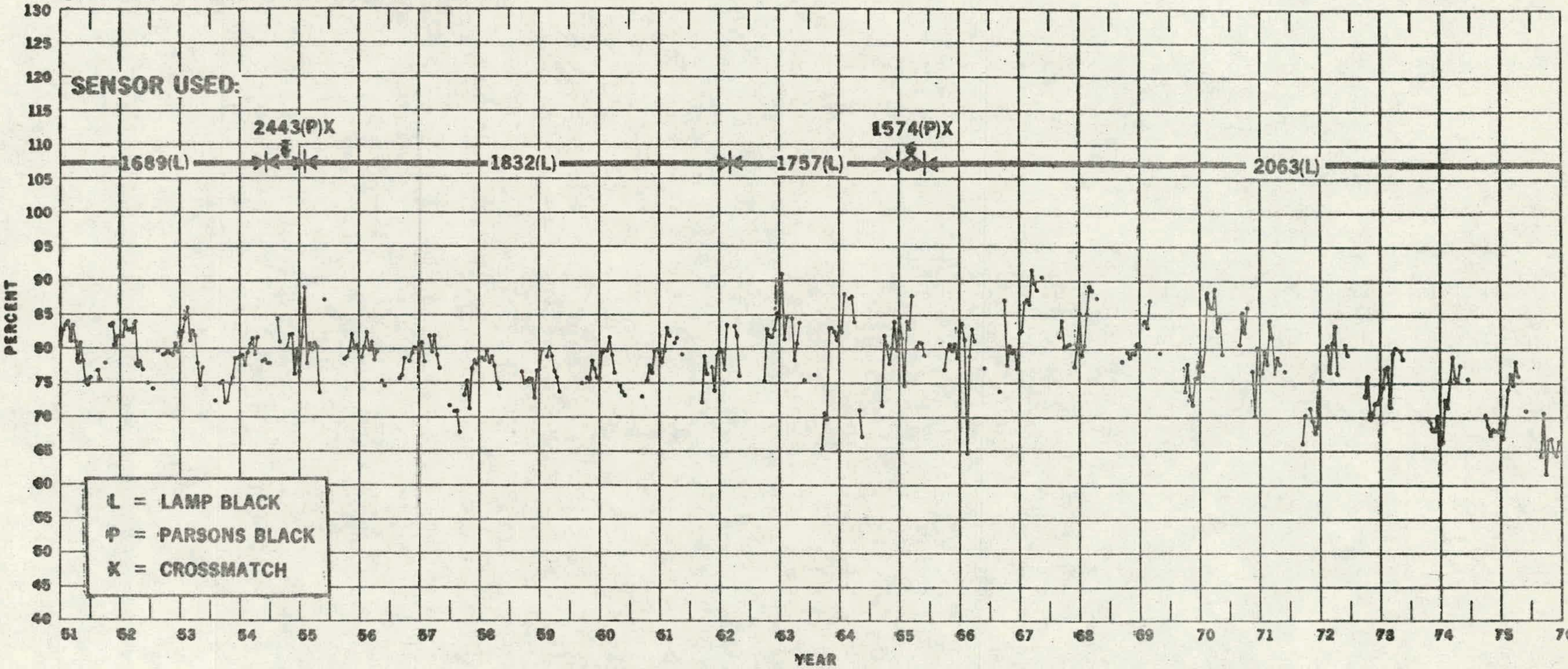
CHARLESTON, SOUTH CAROLINA



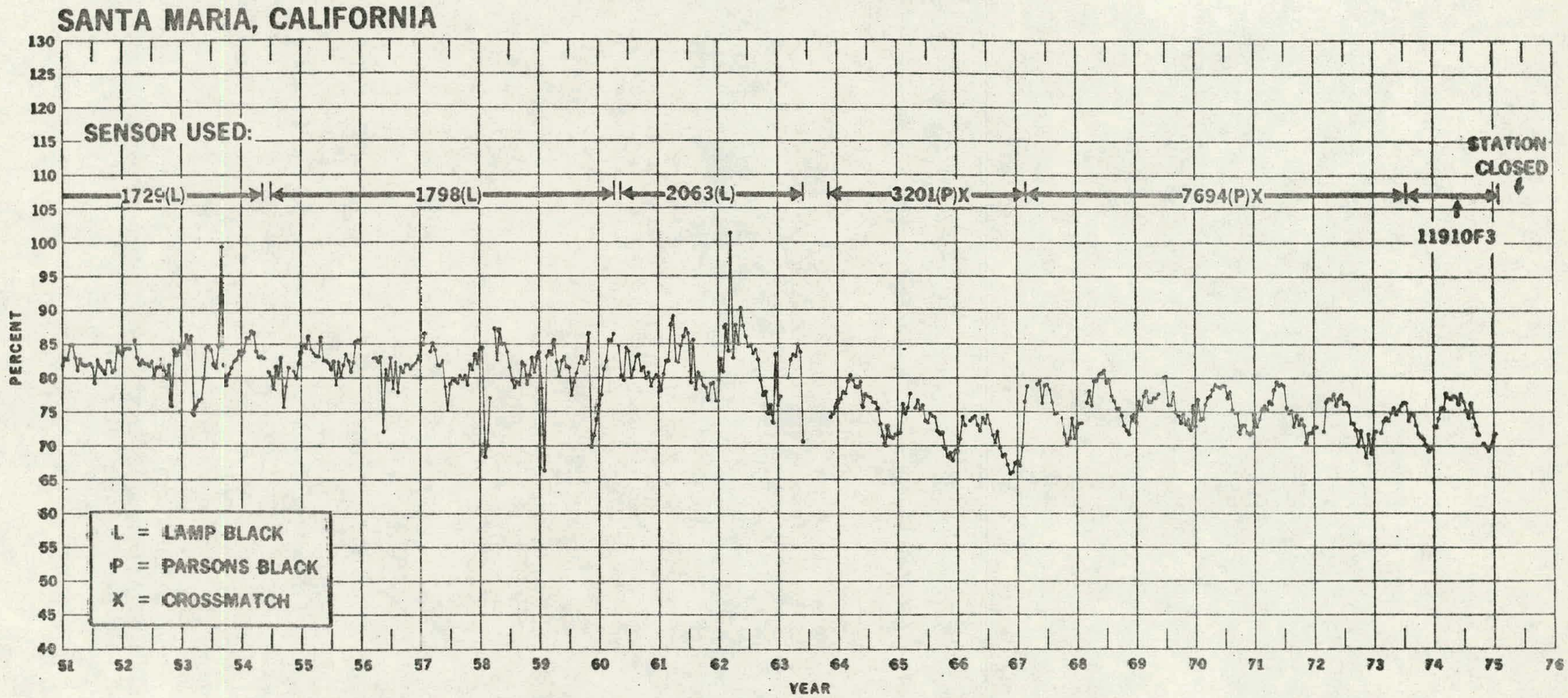
PERCENT OF ETR AT TRUE SOLAR NOON (15 DAY AVERAGES)

142

CHARLESTON, SOUTH CAROLINA

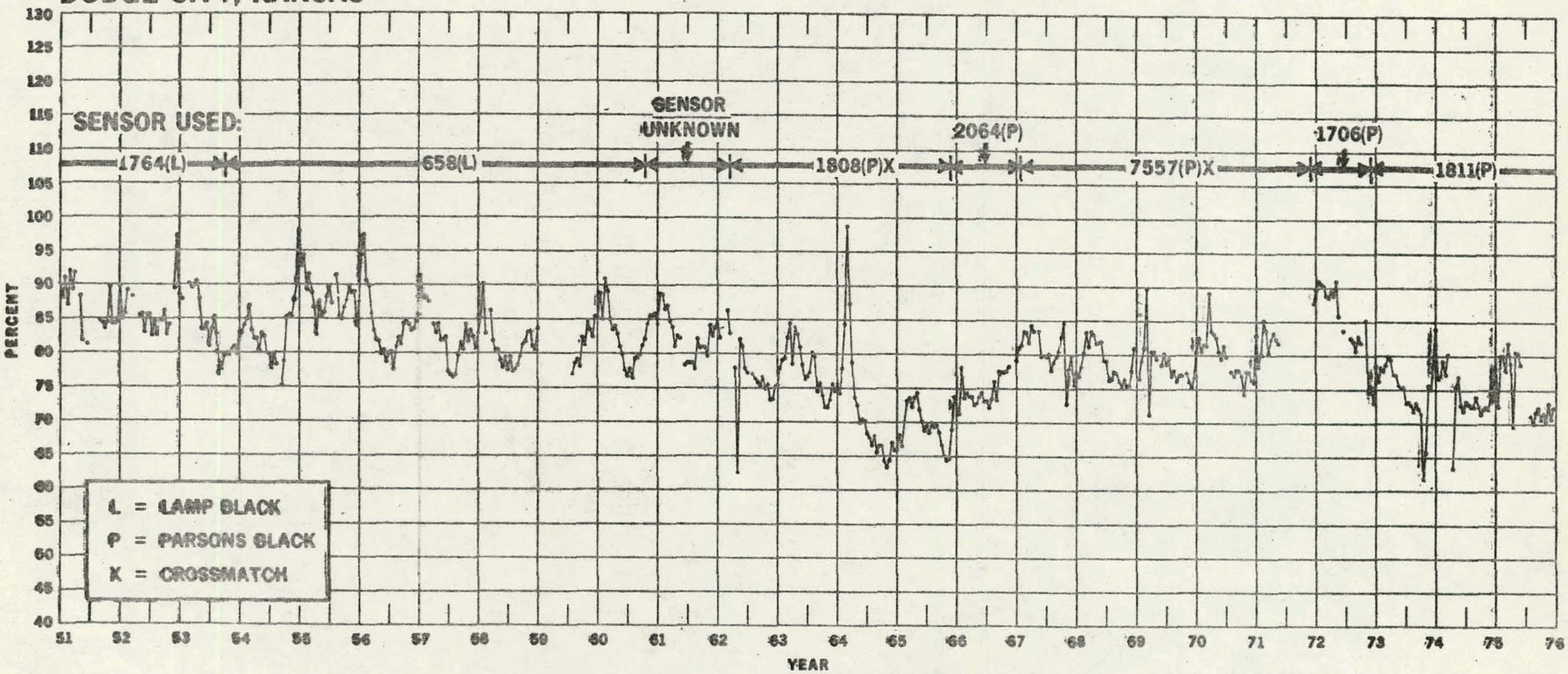


PERCENT OF ETR AT TRUE SOLAR NOON (15 DAY AVERAGES)



PERCENT OF ETR AT TRUE SOLAR NOON (15 DAY AVERAGES)

DODGE CITY, KANSAS



PERCENT OF ETR AT TRUE SOLAR NOON (15 DAY AVERAGES)

STA	YR		01	02	03	04	05	06	07	08	09	10	11	12	ANN	STA
03927	55	A	372	336	400	420	450	480	478	434	414	372	360	348	4864	03927
		B	0	0	0	0	0	0	0	0	0	0	0	0	0	
		C	0	0	0	0	0	0	0	0	0	0	0	0	0	
		D	0	0	0	0	0	0	0	0	0	0	0	0	0	
		E	0	0	0	0	0	0	0	0	0	0	0	0	0	
		F	372	336	400	420	450	480	476	434	411	372	360	348	4859	
		G	372	336	400	420	450	480	478	434	414	372	360	348	4864	
		H	0	0	0	0	0	0	0	0	0	0	0	0	0	
		I	372	336	400	420	450	480	476	434	411	372	360	348	4859	
		J	0	0	0	0	0	0	0	0	0	0	0	0	0	
		K	0	0	0	0	0	0	0	0	0	0	0	0	0	
		L	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		M	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		N	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		O	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		P	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		Q	744	672	744	720	744	720	744	744	720	744	720	744	8760	

STA	YR		01	02	03	04	05	06	07	08	09	10	11	12	ANN	STA
03927	56	A	372	348	400	420	450	480	478	434	414	372	360	348	4876	03927
		B	0	0	0	0	0	0	0	0	0	0	0	0	0	
		C	0	0	0	0	0	0	0	0	0	0	0	0	0	
		D	0	0	0	0	0	0	0	0	0	0	0	0	0	
		E	0	0	0	0	0	0	0	0	0	0	0	0	0	
		F	372	348	400	420	450	476	476	434	411	252	360	348	4747	
		G	372	348	400	420	450	480	478	434	414	372	360	348	4876	
		H	0	0	0	0	0	4	0	0	0	120	0	0	124	
		I	372	348	400	420	450	476	476	434	411	252	360	348	4747	
		J	0	0	0	0	0	0	0	0	0	0	0	0	0	
		K	0	0	0	0	0	0	0	0	0	0	0	0	0	
		L	744	696	744	720	744	720	744	744	720	744	720	744	8784	
		M	744	696	744	720	744	720	744	744	720	744	720	744	8784	
		N	744	696	744	720	744	720	744	744	720	744	720	744	8784	
		O	744	696	744	720	744	720	744	744	720	744	720	744	8784	
		P	744	696	744	720	744	720	744	744	720	744	720	744	8784	
		Q	744	696	744	720	744	720	744	744	720	744	720	744	8784	

STA	YR		01	02	03	04	05	06	07	08	09	10	11	12	ANN	STA
03927	57	A	372	336	400	420	450	480	478	434	414	372	360	348	4864	03927
		B	0	0	0	0	0	0	0	0	0	0	0	0	0	
		C	0	0	0	0	0	0	0	0	0	0	0	0	0	
		D	0	0	0	0	0	0	0	0	0	0	0	0	0	
		E	0	0	0	0	0	0	0	0	0	0	0	0	0	
		F	367	336	400	420	450	480	476	434	411	372	360	348	4854	
		G	372	336	400	420	450	480	478	434	414	372	360	348	4864	
		H	5	0	0	0	0	0	0	0	0	0	0	0	5	
		I	367	336	400	420	450	480	476	434	411	372	360	348	4854	
		J	0	0	0	0	0	0	0	0	0	0	0	0	0	
		K	0	0	0	0	0	0	0	0	0	0	0	0	0	
		L	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		M	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		N	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		O	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		P	744	672	744	720	744	720	744	744	720	744	720	744	8760	
		Q	744	672	744	720	744	720	744	744	720	744	720	744	8760	

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

SOME RESULTS TO DATE

HOURLY GLOBAL RADIATION WITH CLEAR SKIES

ALBUQUERQUE APRIL

STD ERR

AM SR = $1920 + 4610\ ZA + 422\ ZA^2 - 2060\ ZA^3$ 67

PM SR = $1920 + 4620\ ZA + 524\ ZA^2 - 1720\ ZA^3$

CONSTANT IN EQUATION:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1950	1960	1930	1920	1910	1850	1780	1780	1820	1880	1920	1940

EL PASO APRIL

STD ERR

AM SR = $1870 + 4430\ ZA + 530\ ZA^2 - 1300\ ZA^3$ 77

PM SR = $1870 + 4430\ ZA + 388\ ZA^2 - 1090\ ZA^3$

BISMARCK APRIL

AM SR = $1850 + 4180\ ZA + 382\ ZA^2 - 1700\ ZA^3$ 66

PM SR = $1850 + 4290\ ZA + 145\ ZA^2 - 2120\ ZA^3$

*ZA = $\cos\theta - 0.5$

HOURLY GLOBAL RADIATION WITH CLOUDY SKIES

ALBUQUERQUE

	CORR	STD ERR
OPAQUE AMOUNT		
$SR = SR_{CS}$ [1.01 - 0.49 OPQ (TENTHS)]	.79	303
OPAQUE AMOUNT AND SUNSHINE		
$SR = SR_{CS}$ [0.60 + 0.40 SS (FRAC.HR) - 0.25 OPQ (TENTHS)]	.88	232
OPAQUE AMOUNT + CLOUD TYPES		
$SR = SR_{CS}$ [1.01 - (CLOUD TYPES)]	.81	285
SUNSHINE AMOUNT ONLY		
$SR = SR_{CS}$ [0.62 + 0.38 SS (FRAC. HR)]	.84	270

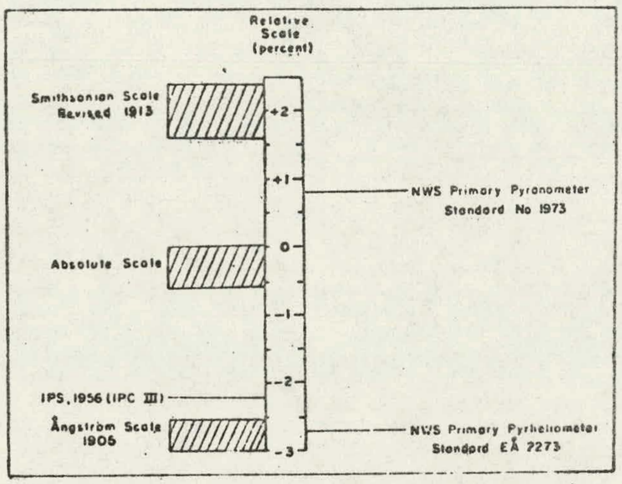
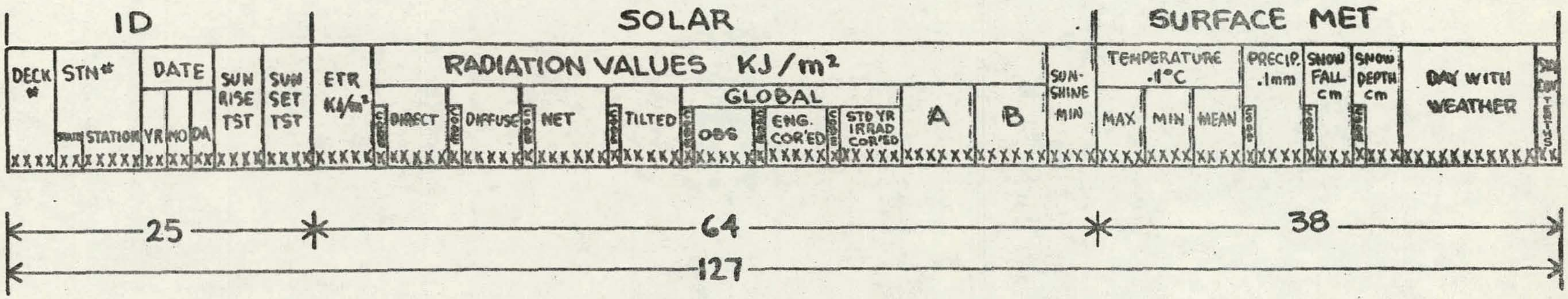


Figure 2. Radiometric scales (after Fröhlich, 1973) and NWS standards.

SOLDAY



149

RADIATION CODES

0 = Observed

1 = Estimated

2 = Estimated from cloud model

3 = Estimated from sunshine model

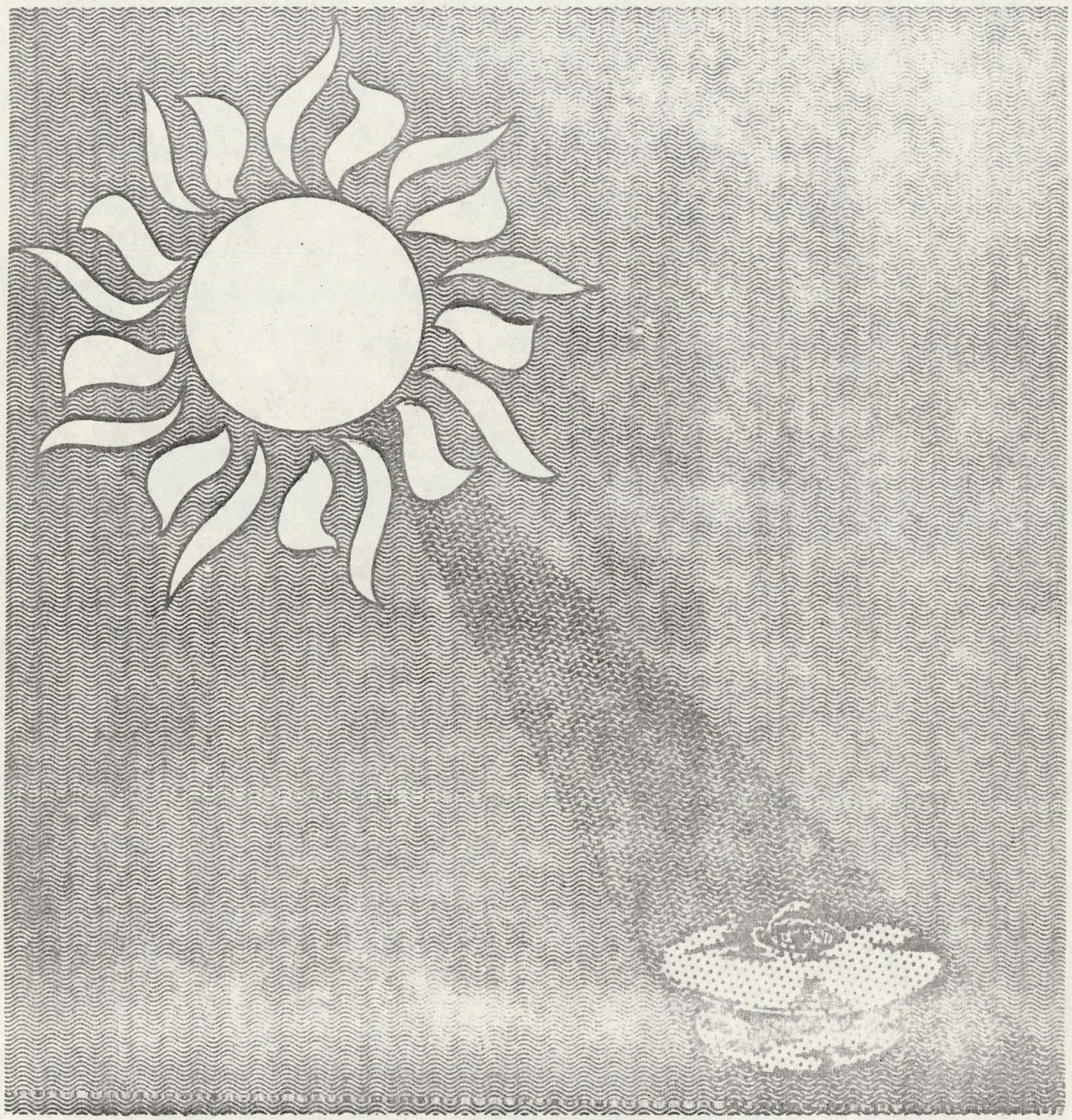
WEATHER PHENOMENA

Col. 115 = Fog
116 = Heavy Fog
117 = Thunder
118 = Sleet
119 = Hail
120 = Rain
121 = Snow
122 = Glaze
123 = Dust or Sand
124 = Smoke or Haze
125 = Blowing Snow

Format is FORTRAN Compatible - NO OVERPUNCHES
- MISSINGS CODED-"9's"

MONTHLY SUMMARY
SOLAR RADIATION DATA

JANUARY 1977



noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA SERVICE / NATIONAL CLIMATIC CENTER ASHEVILLE, N.C.

Pages 1 and 2 will contain:

Introduction

Description of Network

Reference to International Scale

Description of Parameters

Parameter Codes

Reference to NCC Archives
(SOLMET/SOLDAY)

STATION 93734 WASHINGTON-STERLING VA N38 59 W77 28 PYRANOMETER SPEC SB-76 JUNE 1977

TOTAL RADIATION FOR EACH HOUR ENDING AT TRUE SOLAR TIME (KILOJOULES PER SQUARE METER)

DAY	C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
01	1					28	680	1584	2458	3242	3881	4333	4568	4568	4333	3881	3242	2458	1584	680	28					41548
02	1					30	687	1590	2463	3246	3884	4336	4570	4570	4336	3884	3246	2463	1590	687	30					41610
03	1					32	693	1596	2467	3249	3887	4338	4572	4572	4338	3887	3249	2467	1596	693	32					41666
04	1					34	700	1601	2472	3252	3889	4340	4573	4573	4340	3889	3252	2472	1601	700	34					41722
05	1					36	706	1606	2476	3255	3892	4342	4575	4575	4342	3892	3255	2476	1606	706	36					41778
06	1					38	712	1611	2479	3258	3894	4344	4576	4576	4344	3894	3258	2479	1611	712	38					41824
07	1					40	717	1615	2483	3261	3896	4345	4578	4578	4345	3896	3261	2483	1615	717	40					41870
08	1					42	722	1619	2486	3263	3898	4347	4579	4579	4347	3898	3263	2486	1619	722	42					41912
09	1					44	727	1623	2489	3266	3900	4348	4580	4580	4348	3900	3266	2489	1623	727	44					41954
10	1					45	731	1627	2492	3268	3901	4349	4581	4581	4349	3901	3268	2492	1627	731	45					41988
11	1					47	735	1630	2494	3270	3903	4350	4582	4582	4350	3903	3270	2494	1630	735	47					42022
12	1					48	738	1633	2497	3271	3904	4351	4583	4583	4351	3904	3271	2497	1633	738	48					42050
13	1					49	742	1636	2499	3273	3905	4352	4583	4583	4352	3905	3273	2499	1636	742	49					42076
14	1					50	745	1638	2501	3274	3906	4352	4584	4584	4352	3906	3274	2501	1638	745	50					42100
15	1					52	747	1640	2502	3275	3906	4353	4584	4584	4353	3906	3275	2502	1640	747	52					42118
16	1					52	749	1642	2503	3276	3907	4353	4584	4584	4353	3907	3276	2503	1642	749	52					42132
17	1					53	751	1643	2505	3277	3907	4353	4584	4584	4353	3907	3277	2505	1643	751	53					42145
18	1					54	753	1644	2505	3277	3908	4353	4584	4584	4353	3908	3277	2505	1644	753	54					42156
19	1					54	754	1645	2506	3278	3908	4353	4584	4584	4353	3908	3278	2506	1645	754	54					42164
20	1					55	755	1646	2506	3278	3908	4353	4584	4584	4353	3908	3278	2506	1646	755	55					42170
21	1					55	755	1646	2506	3278	3908	4353	4584	4584	4353	3908	3278	2506	1646	755	55					42170
22	1					55	755	1646	2506	3278	3907	4353	4583	4583	4353	3907	3278	2506	1646	755	55					42166
23	1					55	755	1645	2505	3277	3907	4352	4582	4582	4352	3907	3277	2505	1645	755	55					42160
24	1					55	755	1645	2505	3276	3906	4351	4582	4582	4351	3906	3276	2505	1645	755	55					42150
25	1					54	754	1644	2504	3276	3905	4351	4581	4581	4351	3905	3276	2504	1644	754	54					42138
26	1					54	752	1643	2503	3275	3904	4350	4580	4580	4350	3904	3275	2503	1643	752	54					42122
27	1					53	751	1642	2502	3273	3903	4349	4579	4579	4349	3903	3273	2502	1642	751	53					42104
28	1					53	749	1640	2500	3272	3902	4347	4578	4578	4347	3902	3272	2500	1640	749	53					42082
29	1					52	747	1638	2499	3270	3900	4346	4577	4577	4346	3900	3270	2499	1638	747	52					42058
30	1					51	744	1636	2497	3269	3899	4345	4575	4575	4345	3899	3269	2497	1636	744	51					42030
MEAN						47	735	1630	2494	3268	3901	4348	4580	4580	4348	3901	3268	2494	1630	735	47					42008

STATION 93734 WASHINGTON-STERLING VA N38 59 W77 28 PYRANOMETER SPEC SB-76 JUNE 1977

TOTAL RADIATION FOR EACH HOUR ENDING AT TRUE SOLAR TIME (KILOJOULES PER SQUARE METER)

DAY	C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
01	2					28	680	1584	2458	3242	3881	4333	4568	4568	4333	3881	3242	2458	1584	680	28					41548
02	2					30	687	1590	2463	3246	3884	4336	4570	4570	4336	3884	3246	2463	1590	687	30					41610
03	2					32	693	1596	2467	3249	3887	4338	4572	4572	4338	3887	3249	2467	1596	693	32					41666
04	2					34	700	1601	2472	3252	3889	4340	4573	4573	4340	3889	3252	2472	1601	700	34					41722
05	2					36	706	1606	2476	3255	3892	4342	4575	4575	4342	3892	3255	2476	1606	706	36					41778
06	2					38	712	1611	2479	3258	3894	4344	4576	4576	4344	3894	3258	2479	1611	712	38					41824
07	2					40	717	1615	2483	3261	3896	4345	4578	4578	4345	3896	3261	2483	1615	717	40					41870
08	2					42	722	1619	2486	3263	3898	4347	4579	4579	4347	3898	3263	2486	1619	722	42					41912
09	2					44	727	1623	2489	3266	3900	4348	4580	4580	4348	3900	3266	2489	1623	727	44					41954
10	2					45	731	1627	2492	3268	3901	4349	4581	4581	4349	3901	3268	2492	1627	731	45					41988
11	2					47	735	1630	2494	3270	3903	4350	4582	4582	4350	3903	3270	2494	1630	735	47					42022
12	2					48	738	1633	2497	3271	3904	4351	4583	4583	4351	3904	3271	2497	1633	738	48					42050
13	2					49	742	1636	2499	3273	3905	4352	4583	4583	4352	3905	3273	2499	1636	742	49					42076
14	2					50	745	1638	2501	3274	3906	4352	4584	4584	4352	3906	3274	2501	1638	745	50					42100
15	2					52	747	1640	2502	3275	3906	4353	4584	4584	4353	3906	3275	2502	1640	747	52					42118
16	2					52	749	1642	2503	3276	3907	4353	4584	4584	4353	3907	3276	2503	1642	749	52					42132
17	2					53	751	1643	2505	3277	3907	4353	4584	4584	4353	3907	3277	2505	1643	751	53					42145
18	2					54	753	1644	2505	3277	3908	4353	4584	4584	4353	3908	3277	2505	1644	753	54					42156
19	2					54	754	1645	2506	3278	3908	4353	4584	4584	4353	3908	3278	2506	1645	754	54					42164
20	2					55	755	1646	2506	3278	3908	4353	4584	4584	4353	3908	3278	2506	1646	755	55					42170
21	2					55	755	1646	2506	3278	3908	4353	4584	4584	4353	3908	3278	2506	1646	755	55					42170
22	2					55	755	1646	2506	3278	3907	4353	4583	4583	4353	3907	3278	2506	1646	755	55					42166
23	2					55	755	1645	2505	3277	3907	4352	4582	4582	4352	3907	3277	2505	1645	755	55					42160
24	2					55	755	1645	2505	3276	3906	4351	4582	4582	4351	3906	3276	2505	1645	755	55					42150
25	2					54	754	1644	2504	3276	3905	4351	4581	4581	4351	3905	3276	2504	1644	754	54					42138
26	2					54	752	1643	2503	3275	3904	4350	4580	4580	4350	3904	3275	2503	1643	752	54					42122
27	2					53	751	1642	2502	3273	3903	4349	4579	4579	4349	3903	3273	2502	1642	751	53					42104
28	2					53	749	1640	2500	3272	3902	4347	4578	4578	4347	3902	3272	2500	1640	749	53					42082
29	2					52	747	1638	2499	3270	3900	4346	4577	4577	4346	3900	3270	2499	1638	747	52					42058
30	2					51	744	1636	2497	3269	3899	4345	4575	4575	4345	3899	3269	2497	1636	744	51					42030
MEAN						47	735	1630	2494	3268	3901	4348	4580	4580	4348	3901	3268	2494	1630	735	47					42008

TOTAL DAILY RADIATION (KILOJOULES PER SQUARE METER) JUNE 1877

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	MEAN
03927 FORT WORTH TX	41378	41422	41460	41496	41536	41568	41594	41624	41650	41574	41592	41710	41730	41744	41754	41754
	41776	41780	41780	41784	41782	41780	41772	41776	41754	41742	41728	41712	41684	41572		41677
03937 LAKE CHARLES LA	41180	41214	41246	41278	41306	41334	41358	41380	41402	41424	41438	41454	41466	41478	41488	41484
	41502	41504	41506	41508	41506	41502	41494	41488	41480	41468	41456	41442	41426	41406		41421
03945 COLUMBIA MO	41548	41608	41664	41722	41774	41820	41870	41910	41946	41982	42014	42046	42070	42094	42116	42128
	42144	42152	42162	42158	42164	42162	42158	42142	42132	42118	42098	42078	42050	42022		42002
12832 APALACHICOLA FL	41148	41180	41214	41244	41270	41296	41316	41340	41358	41380	41396	41408	41422	41434	41442	41452
	41454	41458	41460	41460	41458	41454	41450	41442	41434	41424	41412	41394	41378	41360		41377
12839 MIAMI FL	40724	40750	40768	40784	40804	40820	40836	40848	40860	40870	40882	40890	40894	40900	40908	40910
	40910	40912	40914	40908	40908	40900	40898	40892	40884	40874	40866	40854	40844	40828		40861
12919 BROWNSVILLE TX	40738	40762	40780	40800	40820	40834	40850	40862	40876	40886	40894	40904	40912	40916	40920	40926
	40928	40926	40930	40928	40922	40920	40914	40908	40900	40890	40882	40872	40860	40844		40877
13880 CHARLESTON SC	41382	41428	41466	41502	41538	41568	41602	41628	41656	41678	41698	41722	41736	41750	41762	41770
	41778	41784	41786	41788	41782	41786	41784	41772	41758	41750	41734	41716	41698	41660		41683
13897 NASHVILLE TN	41514	41560	41612	41660	41704	41744	41784	41818	41854	41882	41912	41934	41954	41974	41994	42006
	42016	42022	42030	42034	42032	42028	42020	42016	42002	41988	41972	41950	41932	41902		41895
13901 STEPHENSVILLE TN	41342	41380	41422	41454	41480	41520	41548	41578	41602	41624	41646	41662	41680	41694	41702	41714
	41718	41728	41726	41728	41726	41722	41716	41710	41700	41686	41674	41658	41638	41620		41627
13985 DODGE CITY KS	41542	41602	41654	41706	41752	41802	41842	41884	41920	41950	41982	42010	42036	42056	42076	42088
	42100	42110	42116	42118	42120	42116	42110	42100	42088	42076	42054	42036	42012	41982		41968
14607 CARIBOU ME	41282	41384	41468	41544	41618	41688	41756	41818	41876	41926	41976	42020	42058	42084	42122	42146
	42172	42184	42188	42206	42208	42206	42198	42184	42170	42152	42128	42100	42064	42026		41896
14837 MADISON WI	41476	41550	41620	41680	41754	41816	41872	41922	41974	42016	42056	42092	42124	42152	42178	42202
	42218	42228	42240	42248	42248	42246	42238	42232	42216	42196	42174	42148	42118	42082		42044
23050 ALBUQUERQUE NM	41476	41528	41574	41618	41658	41698	41734	41766	41796	41824	41852	41872	41892	41910	41926	41940
	41948	41954	41962	41962	41962	41958	41954	41940	41934	41920	41904	41884	41868	41838		41835
23154 ELY NV	41548	41614	41670	41726	41780	41828	41874	41918	41958	41990	42028	42058	42084	42110	42128	42142
	42162	42168	42178	42178	42182	42176	42172	42158	42150	42130	42110	42082	42066	42038		42014
24143 GREAT FALLS MT	41250	41344	41424	41512	41590	41680	41728	41792	41848	41902	41952	41996	42040	42074	42102	42134
	42152	42172	42180	42182	42184	42190	42182	42174	42156	42134	42110	42082	42048	42004		41944
24225 MEDFORD OR	41502	41572	41640	41708	41768	41826	41882	41930	41978	42018	42058	42098	42128	42158	42176	42200
	42218	42230	42236	42240	42240	42240	42234	42224	42212	42194	42172	42146	42148	42082		42047
24233 SEATTLE-TACOMA WA	41252	41344	41430	41514	41590	41662	41720	41780	41852	41906	41954	41998	42042	42072	42106	42134
	42154	42170	42182	42190	42192	42194	42182	42174	42158	42136	42112	42082	42046	42010		41945
93734 WASHINGTON-STERLING VA	41548	41610	41668	41722	41776	41824	41870	41912	41954	41988	42022	42050	42076	42100	42118	42132
	42146	42156	42164	42170	42170	42168	42160	42150	42138	42122	42104	42082	42058	42030		42006

PANEL I, NETWORKS

Ronald Stewart, Chairman
Mike Rigney, Cochairman
Gené Carter, Assistant

The general questions addressed were:

1. What measurements are required at each station?
2. What are the criteria for a station location?
3. What are the costs of installation and operation of a station?

The workshop format for Networks required each participant to introduce himself and to answer the first question only after which answers could be given at random with appropriate comments. In the second and third sessions participants were asked to identify the classification of data they required. The accompanying tables summarize answers to these questions.

1st Session Highlights

1. There was basic interest in some of the standard meteorological parameters, but most seem to be taken for granted.

2. Substantial interest was shown in global measurements, with spectral data and direct/diffuse receiving special discussion. The specific interest in spectral data was also surprising, with agriculture, biomass, photochemistry, photovoltaics, etc., being mentioned as "users."

3. There also was interest in visibility measurements, ultraviolet spectral, international data source as models, urban effects, aerosols, and SO_2.

4. Some concern was expressed about the use of the shadowband, i.e., accuracy, corrections, standardization.

5. The necessity for bench mark stations in limited numbers, and under strict, long term control was discussed. Could bench mark stations support regional/state networks by providing calibration, and/or focal point of networks.

6. The possibility was brought up of spreading out the cost of calibrating equipment by running annual or semi-annual regional/state calibration workshops. Each individual would pay his own way and bring his own equipment for calibration with a standard. In this way costs could be shared.

7. An answer was proposed to the question: what does it cost to set up, maintain and operate a station, and then to disseminate data?

<u>Estimates of Solar Radiation Station Costs - Two Scenarios</u>

(a)	(b)
Equipment \$15 - 20,000 plus One-quarter man-year for operation plus travel, repairs, and dissemination (quality control and computer processing may add the equivalent of one-quarter man year).	Equipment \$10,000 plus Simplify station, use less expensive equipment Student help equivalent to \$4,000/yr.

Action Items -

1. Increase spectral measurement capability as soon as possible.

2. Identify possible future users and their needs, and prepare for these needs, both nationally and internationally.

3. Initiate a research program to resolve the shadowband issue immediately. An initial step would be to standardize and provide interim correction procedures until research is completed, then correct all data.

4. Encourage support for the concept of bench mark stations.

5. Try the regional calibration workshop idea--does it work? How accurate are instruments which pass through this procedure?

Additional Written Comment -

There is a need to create three levels of networks: primary, NOAA in at least two climatic zones of each state; secondary, university or research institution in state operate network with NCC Class I quality, formats, etc.; tertiary, university or SEO operate network which is inexpensive, but answers some local (state) need.

2nd Session Highlights

1. The majority requested need for Class I data quality; several were also willing to use II and III. (The issue of who is the "user" and what are his needs reappeared in this context.)

2. Majority requested need for global, direct and diffuse data.

3. Circumsolar, night-time sky conditions, and temperatures were also requested.

4. Spectral data, water vapor data for specific studies were also considered needed.

5. The need to cite specific data being requested during demonstration phase was brought out.

6. A discussion arose on the present acceptance angles of concentratinq collectors and projections for the future. This led to the question: how does this influence our circumsolar measuring techniques?

7. There was a consensus of agreement that general meteorological observations were all right but that they were not really needed unless specific for a site.

8. It was agreed that the closer together the stations are within the network, the more accurate each instrument must be.

9. The question arose as to what is a reasonable period for data-taking to be useful in solar measurement and demonstration.

10. There was agreement on the need to measure all energy terms, heat flux, etc., and to use radiosonde for checking site characteristics.

11. The need to improve site selection procedures and to pay more attention to existing models was stressed.

<u>Estimates on Solar Radiation Station Costs</u>

$8,500 equipment (PSP, diffuse, integrator)
$200/month computer
¼ man year
12 variables (no cost given but may be based on usual direct, dif, NIP, and wx data)
½ man year ($25,000)
24 hr/day, 7 day/wk (research station will cost $100,000/yr operation and maintenance)

Action Items -

1. Identify future "user" and his network needs.

2. Match concentrating collector acceptance angles and range of circumsolar measurements.

3. Stress to all information and/or workbook disseminators that the U.S. and its territories have a wide range of sun angles, including the sun being located <u>north</u> of a station during some part of the year, a condition which affects computer programming, modelling, etc.

4. Optimize network station locations by statistical computer techniques.

5. Encourage states to provide financial support for solar programs.

6. Provide answer to what the future relationship is between off-peak pricing and available solar energy and if the forecast of solar radiation availability can be improved.

<u>3rd Session Highlights</u>

1. While this session also requested global, direct and diffuse data, several members stressed the need for data on a tilted surface, using a standard angle such as 60°.

2. Agricultural interests described the need for water conservation which is directly related to energy conservation because of the fieldpumps involved. DOE currently is studying the use of solar-energy powered water pumps; therefore, this combination requires further solar data.

3. Network station numbers and distribution include a call for a 25-50 solar-radiation station network with an additional 6 to 10 stations which collect spectral, circumsolar, and other data.

4. There is great interest in downward long wave radiation, net radiation, ultraviolet spectral, turbidity.

5. There is also interest in supporting better instrumented climatic stations.

6. A need exists for better data in rough terrain for the forestry and tourist industries.

7. Similarly, there is a need for one well-instrumented station above 10,000 ft (or at least one at high elevation).

8. Efforts in the concentrator area (both photovoltaic and thermal) will require better circumsolar data and spectral data. It is probable that most future systems will be single axis.

9. The objectives seen for networks differ considerably. A network may be designed for a specific purpose, and the data could have a limited number of users. On the other hand, a network could be designed for long-term data-gathering and archival purposes. Its use would probably be spread out over a longer time period and involve larger numbers of persons.

10. There is a need to determine the periodicity of cloud cover in the short term and how it affects solar thermal readings, i.e., fair weather cumulus drifting by.

11. An acceptance angle for concentrating collectors of $\pm 2^{o}$ off the sun center is suggested.

<u>Estimates of Solar Radiation Station Costs (based on Multisite Plan)</u>

$4,000 to $5,000 for site preparation per instrument
$5,000 per channel of information for operations and maintenance costs (including processing)

Action Items -

1. Upgrade climatic stations to include solar (global, direct, diffuse) and consider establishing bench mark station.

2. Improve data availability in rough terrain (new techniques possibly).

3. Resolve aperture needs for circumsolar data acquisition.

Panel 1 Attendance

September 27 - 38, 1977

COOPERATOR	1st Session	2nd Session	3rd Session
STATES			
Colorado	X		
Florida		X	
Hawaii	X		
West Virginia			X
Kansas	X		
Ohio Energy & Res. Dev.		X	
UNIVERSITIES & RESEARCH			
University of Nebraska			X
Utah State	X		
Colorado State			X
University of Puerto Rico		X	
University of Delaware		X	
University of Oregon			X
University of Alabama		X	
University of Florida	X		
University of Michigan	X		
Argonne Laboratories		X	
Lewis Research Center	X		
University of New Mexico	X		
CONTRACTORS			
Marshall Space Flight Center		X	X
Jet Propulsion Laboratory		X	
AGENCIES			
NOAA: EM			X
ARL			X
EDS			X
NWS	X		
ERDA: DIVISION OF SOLAR ENERGY			X
Chicago Research		X	
SERI	X		
Smithsonian	X		
EPA	X		

Panel 1 Attendance (cont)

COOPERATOR	1st Ses-sion	2nd Ses-sion	3rd Ses-sion
AGENCIES			
NASA			X
CEEDO, Tyndall AFB			X
AES, CANADA			X
OTHERS			
USAF	X		
Maryland Energy Office		X	
TOTALS	13	10	12 = 35

Panel 1 Survey of Solar Radiation Measurements

COOPERATOR	Direct	Diffuse	Global	Spectral	UV	Circumsolar	Night	Tilted	Turbidity	Reflective
STATES										
Colorado	X		X							
Florida	X	X	X							X
Hawaii		X	X	X						
West Virginia	X		X							
Kansas			X							
Ohio Energy & Res. Dev.				X		X	X			X
UNIVERSITIES & RESEARCH										
University of Nebraska	X		X							
Utah State	X	X	X						X	X
Colorado State	X		X						X	
University of Puerto Rico	X	X	X							
University of Delaware	X		X			X				
University of Oregon	X	X	X							X
University of Alabama	X	X	X							
University of Florida	X		X	X						
University of Michigan	Those needed for special proj., coastal study									

Panel 1 Survey of Solar Radiation Measurements (cont)

COOPERATOR	Direct	Diffuse	Global	Spectral	UV	Circumsolar	Night	Tilted	Turbidity	Reflective
UNIVERSERTIES & RESEARCH										
Argonne Laboratories		X	X			X				
Lewis Research Center	X	X	X							
University of New Mexico			X							
CONTRACTORS										
Marshall Space Flight Center	X	X	X					X		X
Jet Propulsion Laboratory	X	X	X				X			
AGENCIES										
NOAA: EM	X	X	X							
ARL	X		X	X		X				X
EDS	X	X	X							
NWS	X	X	X							
ERDA: DIVISION OF SOLAR ENERGY	X									
Chicago Research	X	X	X	Need for all data						
SERI	X									
Smithsonian	X	X	X	X	X					
EPA	X		X	X	X				X	
NASA	Not recorded									
CEEDO, Tyndall AFB	X		X					X		
AES, CANADA		X	X	X	X			X		
OTHERS										
USAF	No defined requirements									
Maryland Energy Office	No defined requirements									
TOTALS	24	15	27	9	3	4	2	3	3	6

Panel 1 Survey of Meteorological Data

COOPERATOR	Temperature	Wind	Precipitation	Water Vapor	Evaporation	Cloud Cover	Pressure	Visibility	Weather	RAOB	Soil Temp.
STATES											
Colorado	X	X		X		X					
Florida	X		X			X					
Hawaii											
West Virginia	X	X	X	X		X	X	X	X		
Kansas											
Ohio Energy & Res. Dev.						X					
UNIVERSITIES & RESEARCH											
University of Nebraska											
Utah State											
Colorado State	X	X		X		X					
University of Puerto Rico											
University of Delaware	X		X	X		X				X	
Univeristy of Oregon											
University of Alabama											
University of Florida	X					X	X				
University of Michigan											
Argonne Laboratories											
Lewis Research Center											
University of New Mexico	X	X			X						
CONTRACTORS											
Marshall Space Flight Center	X	X	X	X		X					
Jet Propulsion Laboratory	X			X		X					
AGENCIES											
NOAA: EM	X	X		X							
ARL	X	X		X							
EDS	X	X		X	X	X					X
NWS	X	X	X	X		X	X	X	X		
ERDA: Divison of Solar Energy											
Chicago Research											
SERI				X							
Smithsonian											
EPA								X			
NASA											
CEEDO, Tyndall AFB	X	X		X							
AES, CANADA											
OTHERS											
USAF											
Maryland Energy Office											
TOTALS	14	10	5	12	2	11	3	3	2	1	1

PANEL 2, QUALITY CONTROL

Nick Patapoff, Chairman
Ed Flowers and Ward Seguin, Cochairmen
Jeremy Goddard and Bill Reid, Assistants

The general questions addressed by the panel were:

1. Station Quality Control

   - What tests should be made and at what frequency?
   - What are the software requirements?
   - On cloudy days should a shadowband or NIP be used?
   - What are the calibration requirements?
   - What are the costs of quality control?

2. Central Processing Requirements

   - What methods are needed for comparing data?
   - What are the software requirements?
   - What are other central processing methods which should be considered for adoption?

The discussions concentrated in six specific areas: site selection, instruments, related maintenance, training, field calibration, and central processing.

Site Selection

An initial comment indicated that without a 360° view, a site should not be considered in the first place. This is not always a requirement that is possible to satisfy because of several other concerns, however. World Meteorological Organization (WMO) standards should be met in site selection and establishment. A description of the site, complete with panoramic photographs, should be provided together with all published data recorded at the location; thus, a user will be fully cognizant of the site's situation. The site description should be updated each year to note changes in local albedo values (which should be less than 0.2) and to record changes in any man-made obscurations, such as smoke plumes, jet contrails, etc. The annual review should generally note other changes in the original site specifications as they influence the accuracy of solar radiation measurements.

Instruments

Upon arrival, all instruments should be acceptance-tested either at a central facility or against a single reliable source at the station. A site with multiple sensors would be able to calibrate in-house.

"Drift" does not appear to be the problem it was thought to be; it was agreed that it was sensor-dependent on an individual basis.

There should be traceability on all instruments back to WMO standards. The response characteristics of each instrument should be known with respect to linearity, temperature compensation, and cosine response.

It was emphasized that a log-book on each instrument should be kept and which records maintenance, calibrations, relocations, etc.

Related Maintenance

General maintenance scheduling is determined by the environment of the site. Levelling, cleaning of the dome, and dessicant checks should optimumly be performed on a daily basis (certainly in a Class I system) unless the environment is particularly benevolent. An evaluation should be made of the cost-effectiveness of using air jets for dome cleaning; they work well in keeping domes frost-free in the Arctic and should function well to clear away dust, snow, jet fuel, or whatever else might obscure the dome. However, the details of calibrating, with or without the air jet, need to be established. The air jet would effect the operating temperature of the instrument over ambient. A maintenance check-list must be devised and kept to control procedures. It must be signed by the person responsible for maintenance checks.

Training

A training manual should be published for personnel at the solar-radiation-monitoring station. These personnel should be motivated to perform with the diligence necessary to obtain the most reliable and accurate data. Strip charts, while of limited use as an accurate data source, are invaluable for recording bad data as they occur. To this end, strip chart speeds should be decreased to 2 cm/hr (they need not be very accurate), and training manuals should illustrate examples of bad data characteristics as shown in strip-chart printouts. Thus, the station operator will quickly recognize when something is amiss with the input; an automated data-acquisition system tied directly into a central processing system might allow a week to pass before a malfunction is noticed.

Field Calibration

Sensors -

In considering sensors, it was emphasized that the orientation with respect to north of the instrument at the site should be the same as its orientation when it is at the calibration facility. Side-by-side calibrations should be made at the site on a quarterly basis. A field calibration should also be made prior to sending an instrument back to a calibration facility. This action would provide a check on the instrument should it be damaged enough in transit to affect its performance.

Processor/recorder -

The processor/recorder system should also be calibrated. The system should be able to recognize negative values during calibration to a fixed input; such calibration could be done automatically any time after dark. A fixed input would be produced from the instrument source to run through the system back to the central processing facility to provide an electroncis check-out.

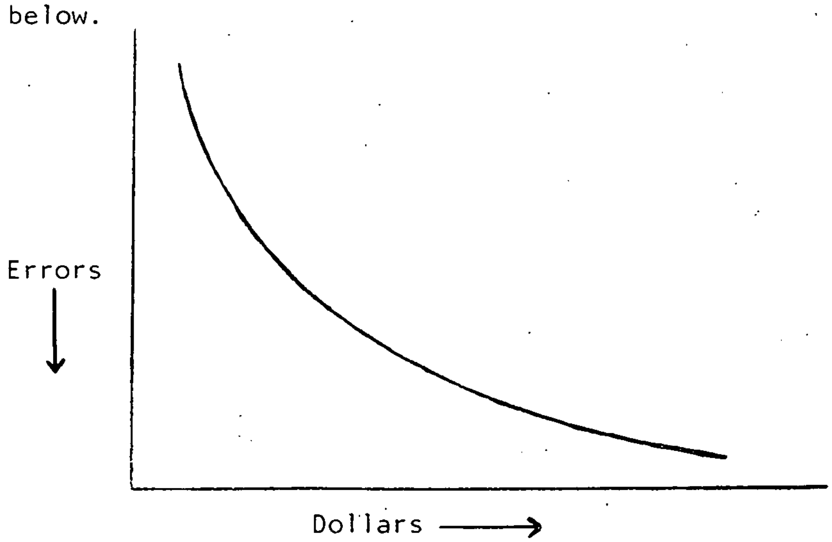
Central Processing

Training is needed for central processing personnel in the recognition of bad data. Personnel must be able to judge the "reasonableness" of data. Recorded data should be compared with Dr. Machta's model, or the equivalent, on an hourly basis in order to recognize bad data as soon as possible.

Archived data should include the calibration values before and after recordings were made; a year's data should have the pre-and past-calibration values noted.

Summary

The class of data which is required determines the quality and, consequently, the cost of the site, the instruments, the maintenance schedule, and the processing requirements. This relationship is shown graphically below.



PANEL 3, SOLAR RADIATION DATA: ARCHIVE AND DISSEMINATION POLICIES

Gene Clark, Chairman
Frank Quinlan, Cochairman
D. L. Christensen, Assistant

Data Archiving

Archive Formats -

The majority of panel members agreed that most data user needs would be served if solar radiation data is archived in local standard time rather than local solar time. Such a time base best serves the needs of architects and solar energy engineers because all other design data are already archived on local standard time. Conversion of hourly insolation totals from one time base to another would introduce (small) errors unless the conversion used a file of radiation data with time intervals much shorter than an hour. New NWS insolation data will be archived at 1-minute intervals at the NCC and this short interval file will be maintained for at least two years. Conversion of time base from this 1-minute data will not introduce errors.

Several panel members noted that there will be the following requirements for insolation data archived on local solar time:

1. The World Radiation Center (WRC) requires local solar time.
2. Climatologists and meteorologists use local solar time.
3. Architects and engineers can recognize asymmetries in morning-afternoon insolation most easily using local solar time. Major asymmetry would affect the optimum solar collector azimuth.

It was suggested that to serve these and other purposes an hourly insolation file based on local solar time be constructed from the 1-minute data before these data are erased.

Types of data to be archived -

The panel agreed that at least the following data should be archived:

1. Direct normal insolation. Archive time-intervals shorter than hourly are justified by the short time-constants of some of the collectors and systems using concentrated insolation.

2. Total insolation on the horizontal. For most purposes archive time-intervals shorter than hourly are not justified for these data.

3. Ambient temperature and wind data coincident with items 1 and 2.

4. Total (global) and direct normal insolation spectral information especially suited for photovoltaic cells.

5. Total (global) insolation spectral information especially suited for photosynthesis.

6. Minutes of sunshine should be archived. Recently, this has been neglected. These data will serve as a source of redundancy and quality control for both estimated and measured insolation.

Discussion -

Divergent opinion was expressed with regard to the need for direct measurement of total insolation on tilted surfaces. One point of view would archive measurements from tilted pyranometers viewing typical or artificial ground planes. In northern climates, a tilt of latitude $+15^{o}$ above the horizontal would be representative of winter-heating projects.

In climates where solar air conditioning may be practical a tilt of latitude -15^{o} would be representative.

Another point of view considered all measurements made by tilted pyranometers as too specific for a particular site to be of general use.

Divergent opinion was also expressed with regard to methods of measuring spectral information. Filtered pyranometers were generally preferred since they yield the most widely useful information. However, durable filter-domes for all required frequencies and band widths are not now available. Standardized silicon cells were also suggested for special purpose spectrum measurements.

Detailed spectral information in the ultraviolet range would be useful, but instrumentation commercially available will not produce data worthy of archiving.

It was noted that future users of spectral information will have diverse needs, and the following groups should be consulted before making the final choice of filter frequencies and band widths: photochemists, botanists, agronomists, agrobiologists, energy engineers and physicists involved with photovoltaics, climatologists, dermatologists, epidemiologists.

Action items -

1. Input from the users of spectral information should be solicited before choosing filter frequencies and band widths. Filter-domes with new durability, frequency and band width characteristics may be needed.

2. Further development of commercial instrumentation for detailed ultraviolet measurements should be stimulated.

3. The role of circumsolar radiation in various types of concentrating collector systems and microclimates should be evaluated. If circumsolar radiation is found to be significant, further development of commercial circumsolar radiation instrumentation should be encouraged.

4. Research should be funded which compares various approaches to estimation of total insolation on tilted surfaces. These include estimation based on direct measurement of total insolation on a horizontal surface. (See item 5 below.) Also, estimation based on local observation of opaque cloud cover or sunshine duration.

5. Research should be funded to evaluate the errors inherent in the widely used isotropic model for diffuse skylight and to develop a more accurate model for the distribution of skylight over the skydome. This will allow more accurate estimation of total insolation on tilted surfaces.

6. If justified by the results of action items 4 and 5 above, total insolation on tilted surfaces should be measured and archived.

Data Dissemination -

Archival practices

Five to six weeks between data measurement and completed archiving was considered short enough to serve most user needs, and this goal can be achieved by the National Climatic Center (NCC).

Some users will have immediate need for measured data, but these needs should be met outside the data-archiving channel. (See action item below.)

Computerized archival data should be disseminated in all widely used codes and formats so that users are not required to purchase new equipment in order to make use of the data.

Action items -

1. Local offices of the NWS should consider furnishing information to the media on total insolation received during the day. Units should be kwh/m^2. Radiation data should be estimated from cloud cover if not measured locally. (Dr. Lester Machta's group at NOAA has developed a model of insolation based on a cloud cover and precipitation which could be used as the estimation tool.) These data would raise public awareness and serve the immediate data needs of some users, e.g., system performance evaluation for engineers and irrigation scheduling for farmers.

2. As a preface to item 1, pilot projects should be conducted in order to measure media response to the addition of solar-radiation data to the weather report. These pilot projects should be conducted in both regions of high and low public interest in applied solar energy. Data on regional public interest levels is available from the Technical Transfer Program of the Solar Division of DOE (ERDA) and from the National Solar Energy Information Center (NSEIC).

3. Typical solar climatological years should be constructed for each of the more than 200 cities for which measured or estimated solar data are available. Typical year climatological data relevant to solar system design should be archived, and their use should be required in performance studies in all publicly-funded solar projects. Not only will this save design costs associated with local choice of typical years, but it also will assure that system design alternatives are evaluated against a single climatic baseline.

4. System performance based on the University of Wisconsin's F-chart program should be widely disseminated. This program should be updated with composite, typical-year data based on the best currently available solar data (NOAA's SOLMET and SOLDAY).

5. As one method of disseminating solar-related climatological data, a new climatological atlas should be issued. User opinion on atlas contents should be solicited, and the following list of data can be used to stimulate user opinion:

   - National isophotes of total daily insolation on the horizontal for average days of each month. These should be based on estimated as well as measured data.

   - Frequency distributions of days with daily total insolation exceeding various thresholds. This can be presented as a set of histograms for selected cities as well as in chart form. These selected cities should be typical of their geographical or demographic regions.

   - Data on daily totals of direct normal (beam) insolation corresponding to 1 and 2 above.

   - Hourly profiles of total insolation on the horizontal for average days of each month. These data should be presented graphically on local solar time to reveal morning-afternoon asymmetry.

   - Isoclines of percent of extraterrestrial insolation on the horizontal based on the isoclines from 1 above.

   - Frequency distributions of percent of extraterrestrial insolation corresponding to 2 above.

   - Average monthly "hours of sunshine" data in the format of 1 above.

   - Frequency distributions of "hours of sunshine" per day for each month in the format of 2 above.

   - Daily average ambient dry bulb temperature data.

   - Daily average ambient wet bulb temperature data (for design of cooling towers and evaporatively-aided passive cooling systems).

   - Hourly profiles of dry bulb and wet bulb temperatures for an average day of each month.

   - Frequency distributions of daily extremes in dry bulb and wet bulb temperatures for each month.

- o Daily average wind speed for each month.
- o A profile of hourly average wind speeds for an average day of each month.
- o Monthly information on frequency distributions of speeds of 2-minute sustained winds.

6. Accompanying text for the atlas should include:

   - o Explanations of the methods of analysis used to compute the estimated solar data appearing in the atlas.
   - o Information on the thresholds of "sunshine switch" instruments used in observations of sunshine duration appearing in the atlas. (These devices are widely perceived as having highly variable thresholds.)
   - o Estimate of the probable range of error inherent in both measured and estimated atlas data.
   - o Brief description of the procedures and instruments used in observing the atlas data.
   - o Reference list of books and articles which explain and illustrate applications of the atlas data to solar system design.

7. A description of the proposed atlas should be published for comment in the professional journals of organizations such as ASHRAE, SMACNA, AIA, ASME, ISES, SEIA, homebuilders associations, electric and gas utilities, meteorological and climatological associations, agricultural engineering associations.

Mechanisms for data dissemination -

Strong support was expressed for the local dissemination of data. These local sources should distribute data which has been repackaged in forms especially appropriate for various user groups, and local sources should be able to understand user needs. Federal groups with programs which could furnish information for local dissemination are the DOE (ERDA), Technical Information Center of Oak Ridge, Tennessee; the DOE (ERDA) Division of Solar Energy Technical Transfer Programs; and the NOAA-National Climatic Center, Asheville, North Carolina.

Data needs -

Near-term data needs are described above. This section refers to longer term needs not now being met by archived data. Although all of the long-term needs could not be foreseen by the workshop panels, it is clear that there will be increasing future needs of two kinds:

- o Data for large-scale, concentrating collector projects using very high concentration ratios. These projects (e.g. solar-power generation projects utilizing large area heliostat fields) may require data on circumsolar radiation. Future information will be needed on short-time scale variations in direct normal radiation.

- Data for photovoltaic projects. More spectral data will be required for feasibility studies of photovoltaic projects using silicon and other materials. Spectral data for total (global) insolation and direct normal insolation should be measured separately in order to predict performance of photovoltaic projects using concentrators.

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The momentum of this meeting, and future ones, must not be lost when we all return to our offices and become involved in day-to-day affairs. We have got to let the people back home, the decision makers, the politicians, and the man in the street, know what we discussed here and how it related to them. We do not want to give them the impression that these three days were simply another conference in which engineers and scientists talked in esoteric equations and numbers. We must point out that solar radiation data is not being collected or needs to be collected simply for the sake of amassing archives. Once the people back home understand what we did as technicians and policy makers here, they will be more inclined to support local efforts to expedite the introduction of solar energy into their homes and businesses because they will have found out, through us, that this energy alternative is technically feasible and cost effective.

Again, I wish to thank you for attending and I look forward to seeing you all next year. In addition, I would like to thank the University of Alabama in Huntsville and NOAA for their contributions to the success of this conference.

Dr. Lester Machta, NOAA: I would like to add my thanks, and hereby declare the meeting over. Thank you very much for coming.

CONCLUDING REMARKS

Frederick Koomanoff, DOE (ERDA)

I would like to thank all of you for attending. We have all learned something, and that is the function of any kind of a workshop. I would like to leave with you an admonition I find more and more necessary to keep in mind as a result of traveling over the country. We have held three basic workshops as part of my branch's operation in environmental and technology assessment. We have been to cities such as Dover, New Hampshire and met with a hundred citizens of that community from the plumber to the banker, from the university professor to the butcher, the baker and candlestick maker. We have done the same thing in Eugene, Oregon and in Amherst, New Jersey. And one thing always seems evident and true: the American public is saying, "We like solar energy and we want it." I suspect that same public is saying to those of us who are approaching it too scientifically, wanting to measure solar radiation down to four or five decimal places and to study and restudy and build and rebuild: "Get out of our way, or we're going to walk right over you." It is there and I feel it is real and valid.

When I first went to ERDA, I felt that this philosophy was a very important one, that the President was the chairman of the board of the corporation, the Congress was the board of directors, and the public of this country was the stockholders and that ERDA was a great new venture corporation. Like any large business it was designed to take an idea and to find out if it was a marketable one with a "Return on Investment" to the American people. It is this philosophy that we must keep. What I am trying to say is that we all have to move now, and we have to move rapidly. We have to get the best possible answers to our "stockholders" so that they can make some choices which are intelligent and so they will not be ripped off or victimized by unscrupulous peddlars. Let me add here that we must also keep an eye on the future, while we are concerned with present needs.

Again, I do want to thank you all for coming to this meeting. Several things have been discussed which I have not thought about and which did not appear until this workshop. We certainly will try to take action on them when we can. However, we must keep in mind the comment made here, which is very true, that if the Federal Government cannot do it or should not do it, then it will have to be done at the state, county, or municipal level. Conceivably, there are situations in which actions will have to be undertaken by the individual to get things moving or accomplished. If we all work together, however, I think anything is possible. We will try to have another meeting in approximately a year from now. I hope that the next meeting will attract more state representatives like those from Maryland and Ohio and the others that were with us here.

The momentum of this meeting, and future ones, must not be lost when we all return to our offices and become involved in day-to-day affairs. We have got to let the people back home, the decision makers, the politicians, and the man in the street, know what we discussed here and how it related to them. We do not want to give them the impression that these three days were simply another conference in which engineers and scientists talked in esoteric equations and numbers. We must point out that solar radiation data is not being collected or needs to be collected simply for the sake of amassing archives. Once the people back home understand what we did as technicians and policy makers here, they will be more inclined to support local efforts to expedite the introduction of solar energy into their homes and businesses because they will have found out, through us, that this energy alternative is technically feasible and cost effective.

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Dr. Lester Machta, NOAA: I would like to add my thanks, and hereby declare the meeting over. Thank you very much for coming.

APPENDIX A

Attendees

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APPENDIX B

AGENDA

Second National Solar Radiation Data Workshop
Skyland, Virginia
September 26-28, 1977

September 26, 1977

INTRODUCTION

General chairman, Dr. Lester Machta, Air Resources Laboratory, Environmental Research Labs, National Oceanic and Atmospheric Administration (NOAA), Silver Spring, MD.

Micheal R. Riches, SOLAR, ERDA (DOE).

Keynote Address-Frederick Koomanoff, Environmental Resources Assessment Branch, SOLAR, ERDA (DOE).

SOLAR RADIATION NETWORKS, WHY AND WHERE

Network Rationale for Solar Energy Needs
David Christensen and Gene Carter, Johnson Environmental and Energy Center, University of Alabama in Huntsville (UAH)

Alternative Solar Radiation Networks Satellite Data
Dan Tarpley, Office of Operations, National Environmental Satellite Service, NOAA

Alternates to A Ground-based Solar Radiation Monitoring Network
Lester Machta and G, Cotton, Air Resources Laboratory, Environmental Research Laboratories, NOAA, Silver Spring,MD

The NOAA Network
Bill Eggert, Data Systems Division, National Weather Service, NOAA

The State of New Mexico Network and Solar Radiation Resource Assessment Project
Ray Bahm, Bureau of Engineering Research, University of New Mexico

New York State Solar Network
Ron Stewart, Atmospheric Science Research Center, State University of New York at Albany

The West Associates Solar Resource Evaluation Project
Nick Patapoff, Southern California Edison, Research and Development

Use of Synchronous Orbital Satellites
Thomas Vonder Haar, Department of Atmospheric Sciences, Colorado State University

Solar Radiation Energy Source Comparison Using SOLMET Data
E. S. Terry and Ron Schlagheck, System Analysis & Integration Laboratory, NASA/Marshall Flight Center, Huntsville, Alabama

Natural Variability of Solar Radiation
L. Machta and G. Cotton, Air Resources Laboratory, Environmental Research Laboratories, NOAA, Silver Spring,MD.

Puerto Rico's Monitoring Station at Mayaquez
Kenneth Soderstrom, Center for Energy and Environmental Research, Mayaquez, Puerto Rico

Hawaii's Micro-Climatic Problems and Solar Radiation Monitoring Network
Paul Ekern, Department of Civil Engineering, University of Hawaii

QUALITY CONTROL, INSURING GOOD DATA

The NOAA/ARL Solar Research Facility Boulder, Colorado
Ed Flowers, Solar Radiation Instrumentation Calibration Facility, NOAA/Boulder, Colorado

September 27, 1977

Data Processing and Quality Control
Processing and Quality Control of National Weather Service Radiation Data
Ward Seguin, Center for Experimental Design & Data Analysis (CEEDA) Environmental Data Service, NOAA/Washington,DC

The Canadian Network
Ron Latimer, Atmospheric Environment Service, Downview, Ontario, Canada

Data Quality Control
Gene Carter, Johnson Environmental & Energy Center, The University of Alabama in Huntsville, Huntsville, Alabama

Quality Control
Marvin Wesely, Argonne National Laboratory. Argonne,Illinois

NWS Climatological Benchmark Station Program
Lewis A. Pitts, Environmental Data Service, NOAA/ Washington, DC

Archiving and Dissemination Policies of Archiving Organizations

Technical Information Center
Phillip Rosser, ERDA/TIC, Oak Ridge, Tennessee

Technology Transfer Program of the Division of Solar Energy
Vincent Rice, SOLAR, ERDA (DOE)

Energy Extension Service and Solar Energy Research Institute
Jay Holmes, Office of Assistant Administrator for Solar, Geothermal, and Advanced Energy Systems, ERDA (DOE)

Charge to Panels
Fred Koomanoff, SOLAR, ERDA (DOE)

Panel Meetings

Panel #1 - Networks, Why and Where
Ronald Stewart, Chairman
Mike Rigney, Co-chairman
Gene Carter, Assistant

Panel # 2 - Quality Control, Insuring Good Data
Nick Patapoff, Chairman
Ed Flowers and Ward Seguin, Co-chairman
Jeremy Goddard and Bill Reid, Assistants

Panel #3 - Data Availability, Archiving and Public Dissemination
Gene Clark, Chairman
Frank Quinlan, Co-chairman
Dave Christensen, Assistant

<u>September 28, 1977</u>

Panel Report by Panel Chairman

Concluding Remarks
Fred Koomanoff, SOLAR, ERDA (DOE)
Dr. Lester Machta, NOAA

APPENDIX C

Variability of Solar Radiation with Geographical Location

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Abstract:

The variability in solar radiation received at the earth's surface at five geographical locations in the United States is investigated. The data consisted of hourly values of solar radiation for a period of 15 years. The effect of latitude, synoptic weather and geographical location on seasonal and annual values of solar radiation is studied and certain inferences drawn. Results indicate the dependence of solar radiation on synoptic weather patterns.

1. Introduction

Solar radiation varies greatly with the length of day, angle of the sun's rays to the ground and cloud coverage. Therefore, radiation should vary significantly with geographical location, altitude, and weather.

A major source of solar radiation data is the NCC. This organization has collated solar-radiation and related meteorological parameters for over 26 USWB stations for varying periods starting in 1952. The program is designated as SOLMET and data are available on tape and punch cards.

To find how solar-radiation data varies with geographical location and latitude, the SOLMET data were used for five stations selected for their specific geographical location. The five stations shown in Fig. 1 are given below with their latitudes:

(1) Bismarck, North Dakota (46°N)

(2) Fresno, California (37°N)

(3) Dodge City, Kansas (37°N)

(4) Nashville, Tennessee (36°N)

(5) Sterling, Virginia (38°N)

2. Annual variation of solar radiation at individual stations

Hourly observations of solar radiation were used to obtain daily total radiation. Seasonal values of the mean and standard deviation of the daily total global radiation were computed for each year from 1953 to 1967 and plotted in Fig. 2 to 6 for stations Sterling, Bismarck, Fresno, Dodge City and Nashville respectively. All the plots have a few common features:

(a) The spring and summer seasons have approximately the same amount of mean solar radiation.

(b) The fall and winter seasons' mean values group together.

(c) Maximum variability occurs in spring.

(d) Minimum variability occurs in winter except for Fresno where this occurs in summer.

In general, the variability in solar radiation was maximum for the spring with the values decreasing for summer, fall and winter. An exception to this was Fresno, California (Fig. 4), where summer season had the lowest variability and the other seasons had roughly the same values. This is characteristic of the dry summer season of California. The mean observations for Dodge City, Kansas (Fig. 5) show the maximum variation from year to year. A cyclic variation in mean radiation is seen for the 15 years of data reported here at least for spring and summer with a time period of about 5 years. The standard deviations of solar radiation also show this cyclic variation with the maximum values corresponding to minimum mean values and vice versa. The reason for this type of variation for Dodge City is probably due to the variations in the movement of synoptic weather patterns due to changes in large scale meteorological conditions.

3. Comparison of observations at different locations

A seasonal plot of the 15-year average mean daily total global radiation for Fresno, Bismarck, Sterling, Nashville, and Dodge City, shown in Fig. 7, depicts the expected solar-radiation regime with peaks in summer and the lows in winter and fall. Some relationship between the solar radiation received at a station and the latitude also exists, particularly in winter and fall with Bismarck, a higher-latitude station, receiving less solar radiation than Fresno, a lower-latitude station. However, there appears to be a more direct relationship between the amount of global radiation received on the surface and synoptic patterns and/or geographical location of a station. In spring and summer, data show that Nashville and Sterling, stations generally affected by the same synoptic patterns, receive less radiation than Bismarck, which is located at a higher latitude. In winter and fall, values of solar radiation are closer together than in spring and summer, showing the effect of widespread cloudiness across the United States on the amount of solar radiation received. Radiation received at Fresno in winter and fall is less or the same as that received at Dodge City, probably as a result of almost constant cloud cover or precipitation during the rainy season in California.

A seasonal plot of the 15-year average standard deviation of the daily total global radiation for the 5 stations shown in Fig. 8 reveals a direct relationship existing between the radiation received and the synoptic and/or terrain patterns. The plot actually is a measure of day-to-day variation in radiation received.

1. At each station the most variability occurs in spring.

2. There is a large variation in the day-to-day radiation received in summer and spring for Sterling, Bismarck, Dodge City, and Nashville, probably as a result of summer thunderstorms and spring frontal activity. This contrasts with the low variability observed in summer at Fresno due to the absence of clouds during the prolonged California dry season.
3. During fall and winter the amount of variability in radiation received is approximately the same at all stations because of the persistent patterns of clouds and precipitation occurring regardless of geographical location.

4. Conclusions

The amount of solar radiation available at a particular location and its degree of variability seem to depend to a large extent on the synoptic weather patterns. Hence the site evaluation for solar energy may have to be done on a location-to-location basis or at least on a small regional scale of similar geographical pattern.

Similar analyses are planned using SOLMET data for additional USWB stations to study the effect of latitude and geographical location on total global radiation received on a horizontal surface.

Acknowledgments

The authors would like to thank Joyce Tichler and Cathy Henderson for help in processing the data.

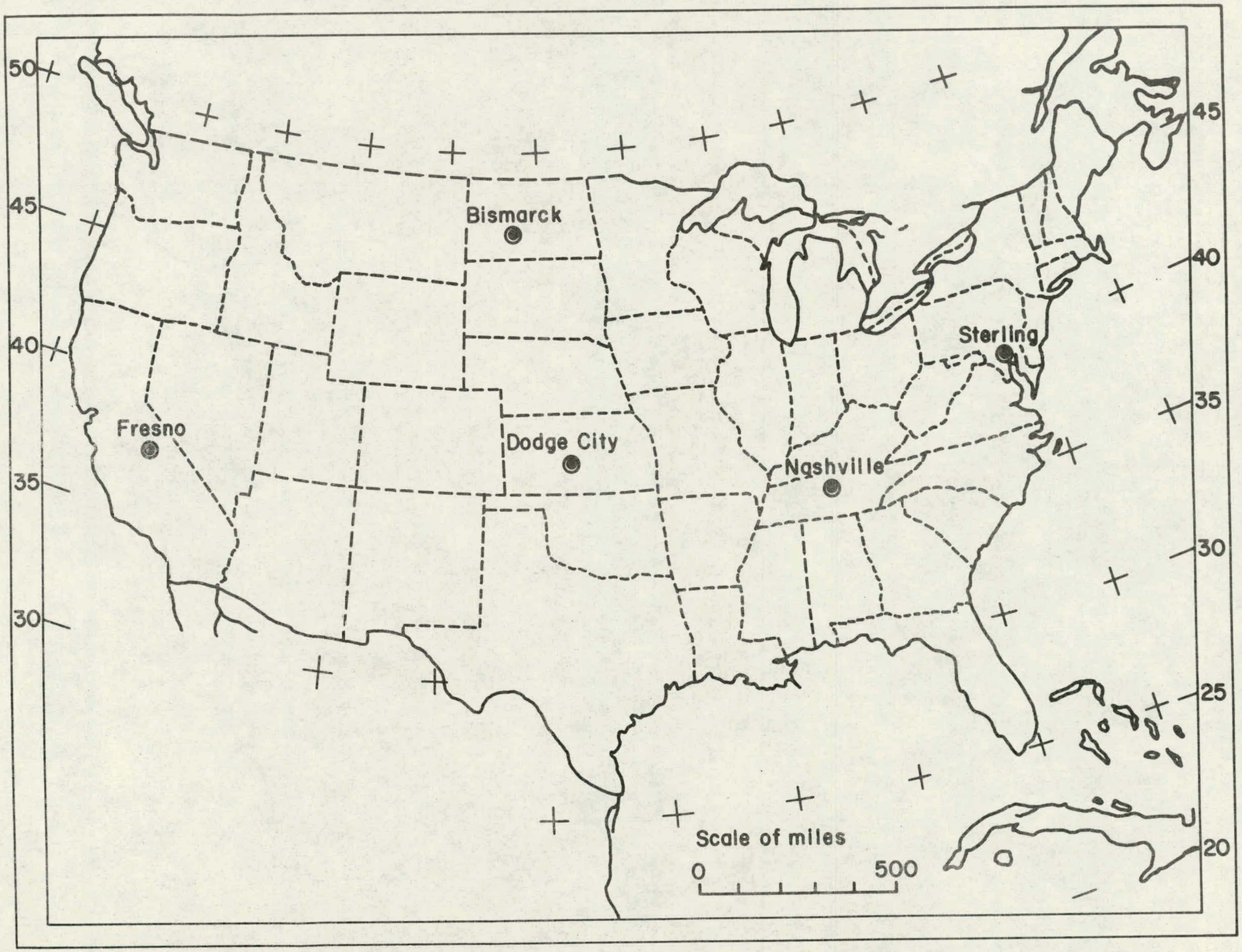

Fig. 1 Station location map

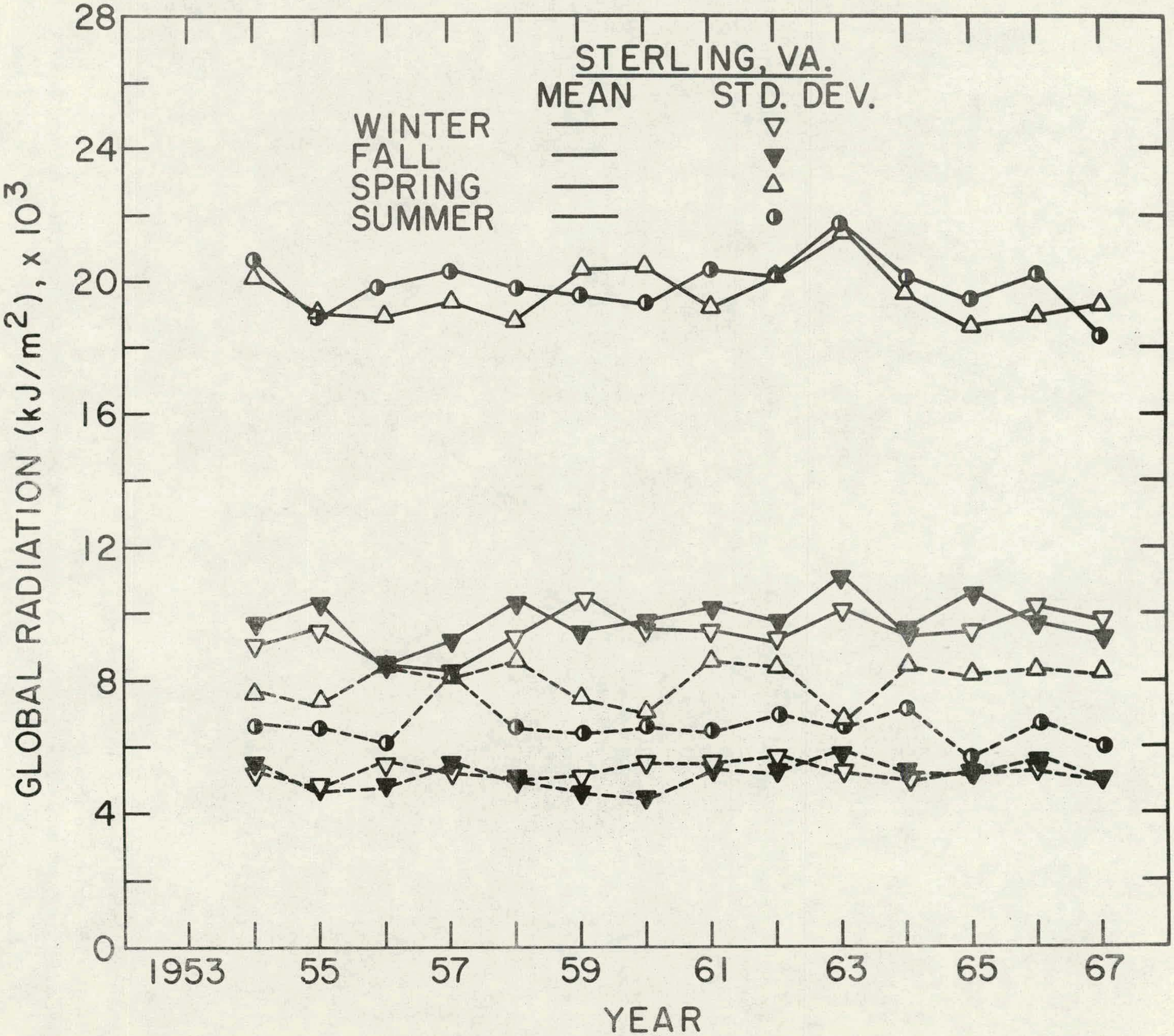

Fig. 2 Mean and standard deviation of daily total global radiation for Sterling, Virginia

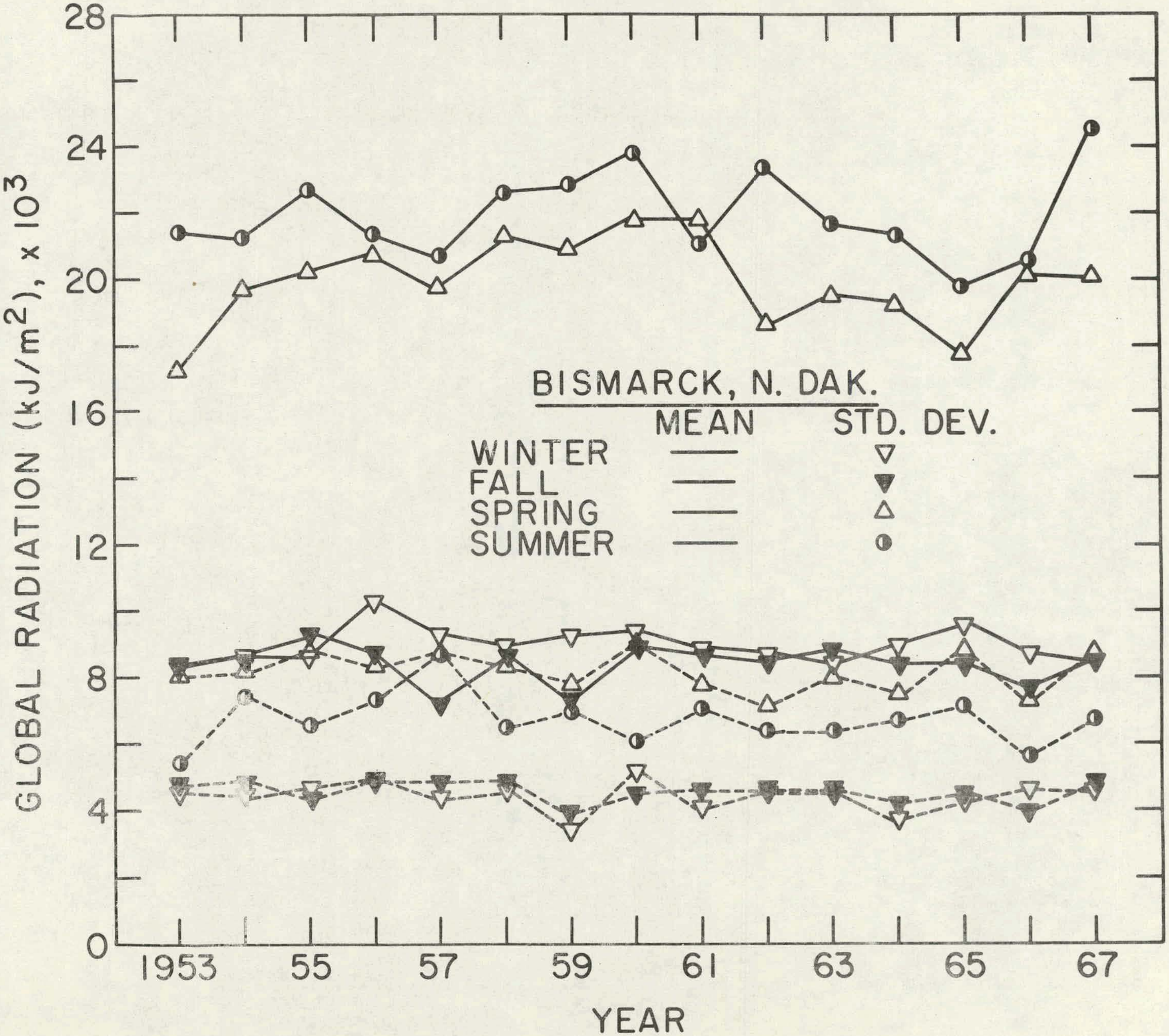

Fig. 3 Mean and standard deviation of daily total global radiation for Bismarck, N. Dakota

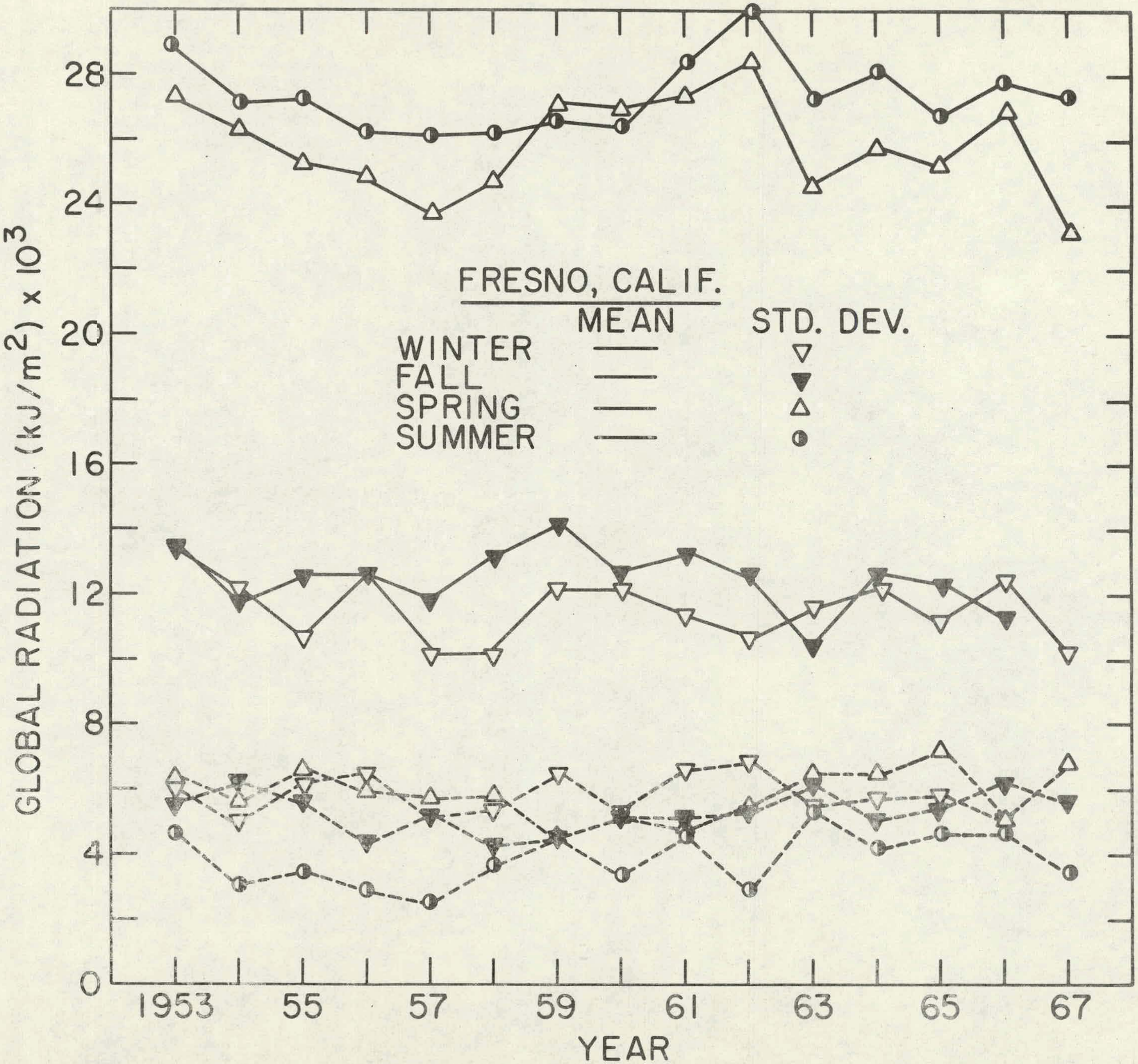

Fig. 4 Mean and standard deviation of daily total global radiation for Fresno, California

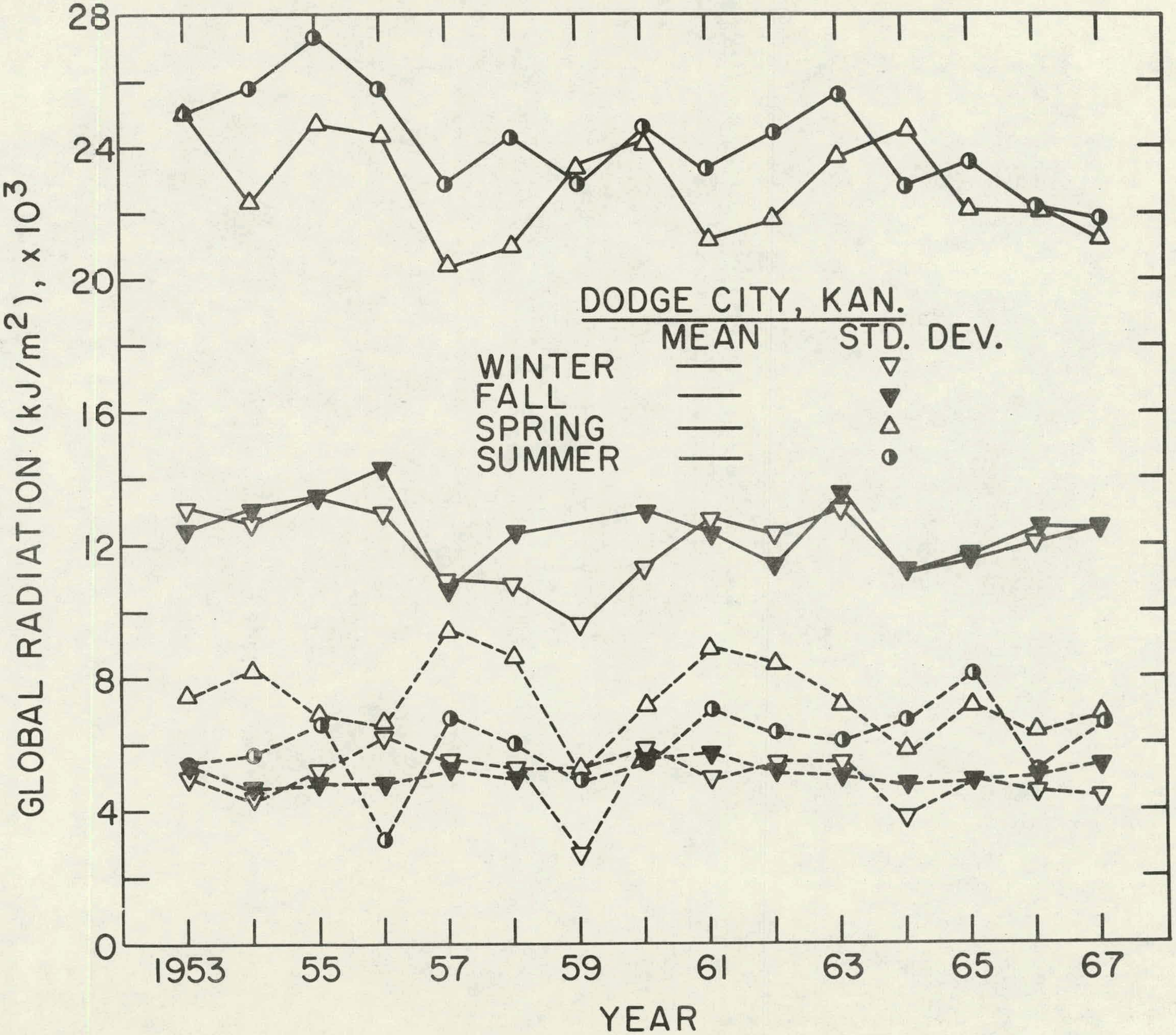

Fig. 5 Mean and standard deviation of daily total global radiation for Dodge City, Kansas

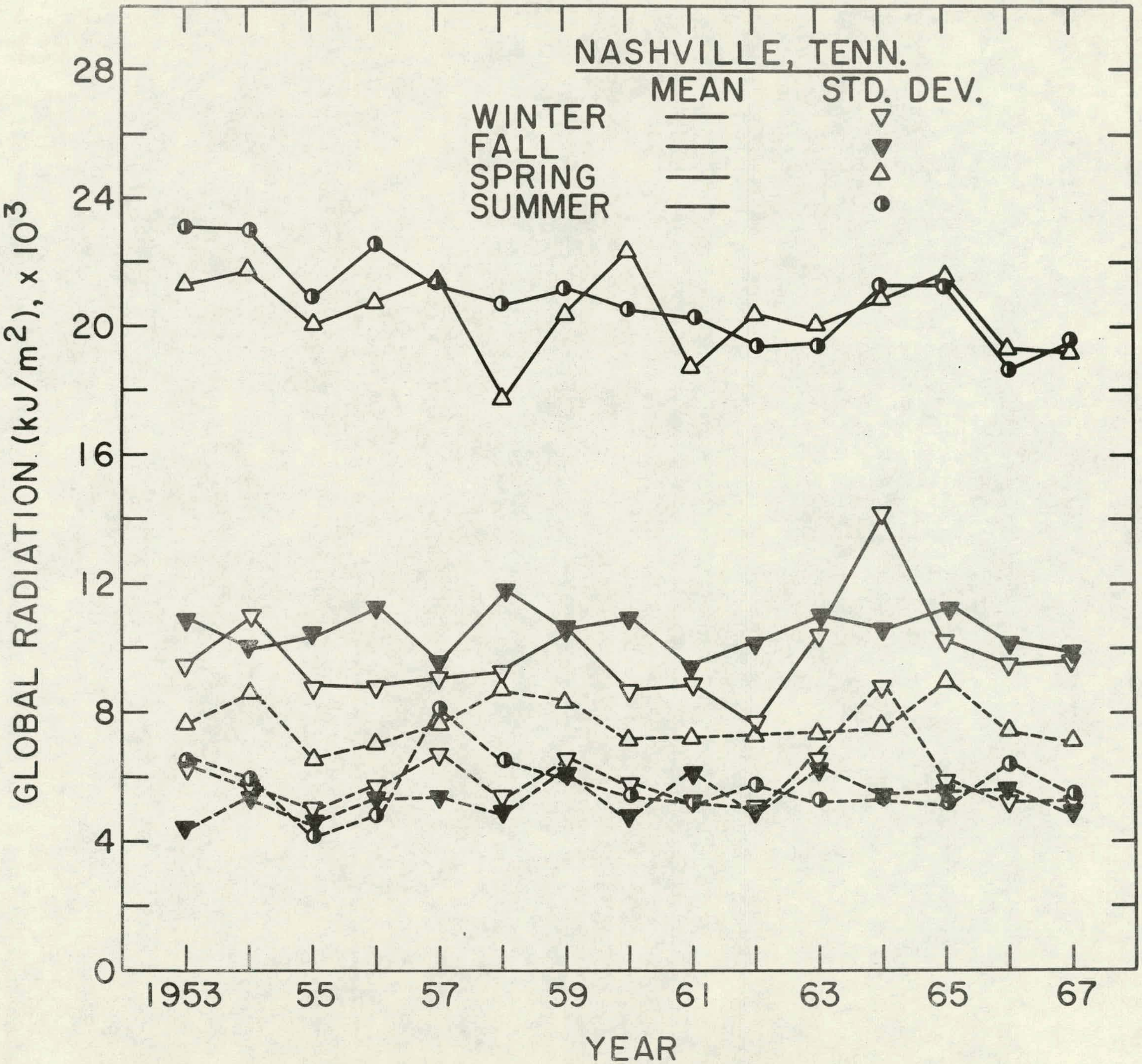

Fig. 6 Mean and standard deviation of daily total global radiation for Nashville, Tennessee

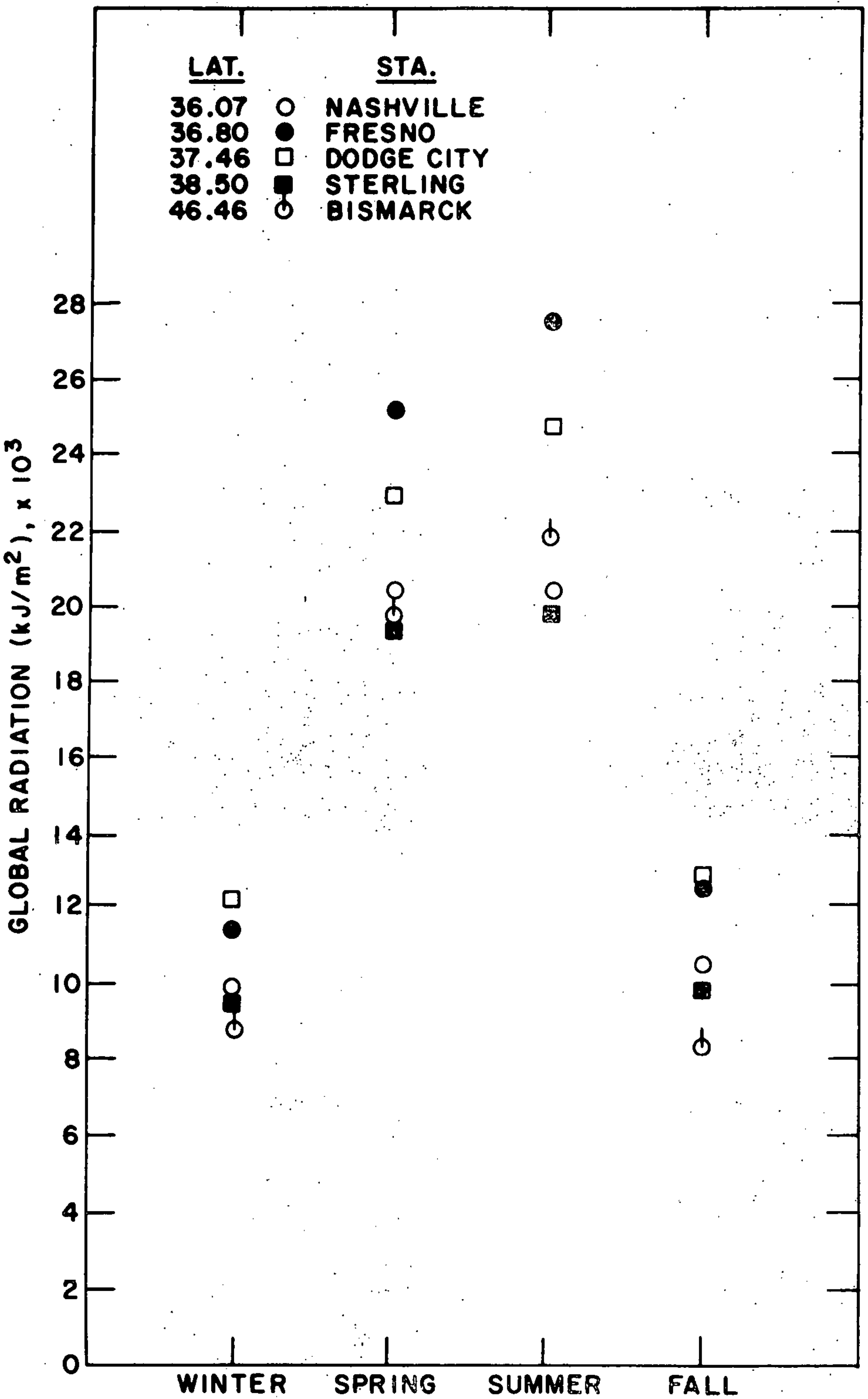

Fig. 7 Comparison of 15-year average daily total global radiation of different stations

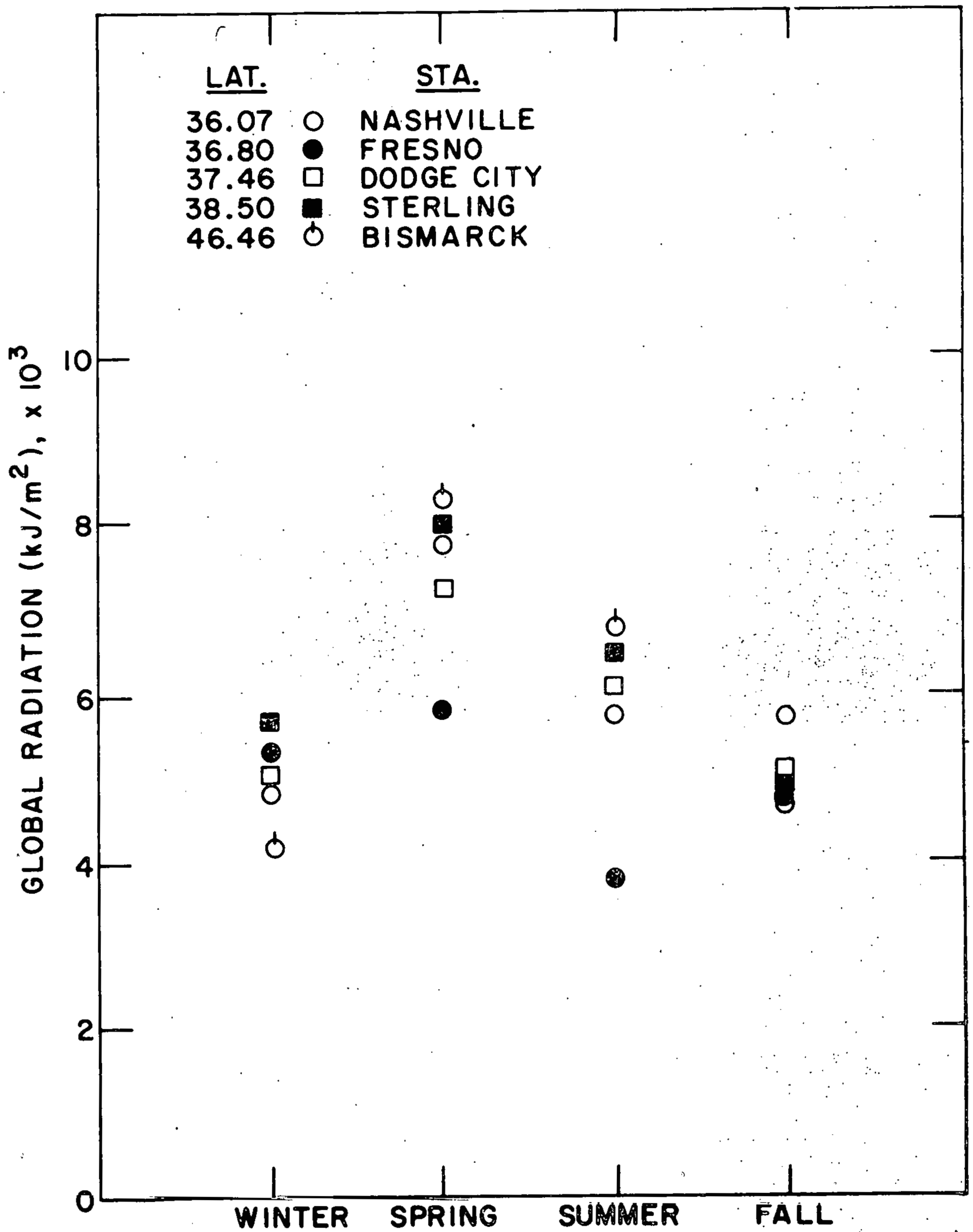

Fig. 8 Comparison of 15-year average standard deviation of daily total global radiation of different stations

APPENDIX D

TOWARD A NEW CLIMATIC REGIONALIZATION OF THE CONTIGUOUS UNITED STATES

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1. INTRODUCTION

Climatic classification - regionalization has been an extremely popular endeavor of climatologists blossoming in the late 1800's and continuing through the first half of this century to the present (Borgel, 1969; Leighly, 1974). Even though the previous literature is vast, the majority of work is now inadequate since most schemes are based upon theoretically weak and/or arbitrary decisions about (1) the number of regimes that exist, (2) what constitutes a boundary and/or where it should be drawn (3) which parameters of climate should be used to characterize climate, and (4) how those parameters should be summarized prior to the classification process in order that bias will be minimized. My purpose here is not to outline the numerous existing climatic classifications of the contiguous United States but rather to make a case for new and basic research within the field.

2. BACKGROUND

Perhaps the most well known climatic classification - regionalization is the multivariate scheme(s) developed by Köppen (1900) and later revised by himself and others many times. Unfortunately, the great majority of existing climatic classifications, exemplified here by Köppen's scheme, are now outdated in both their method of development and final form. Among the most confounding aspects of the Köppen system, for example, are its reliance upon (1) functionally isolated variables such as air temperature and precipitation, and (2) arbitrary decisions about what constitutes a climatic boundary, i.e. Köppen's boundaries are placed in zones of "natural" vegetation transition. More recently, climatologists have begun to consider additional climatic elements such as day length, relative humidity and frost, and the methods of defining boundaries and/or climatic homogeneity have become more rigorous. Objective procedures borrowed from the field of numerical taxonomy are now often used (Russell and Moore, 1976; Steiner, 1965). For an excellent discussion of the advancements and principles of numerical taxonomy see Sokal (1974). Like the multivariate classifications mentioned above, recent univariate and/or special purpose schemes have dealt predominately with those variables for which data were readily available and they too have employed the methods of numerical taxonomy (Dyer, 1975; Willmott, 1977a). The fundamental transfer processes and their associated energy variables, e.g. global and net radiation, however, are still being ignored even though many data are now available and a number of prominent climatologists and meteorologists have pointed out the need for an energy based climatology (Löf et al, 1966; NWRC, 1967a; NWRC, 1967b; NCC, 1977; Terjung, 1976). Only a very few papers have attempted classifications of the main energy variables, and unlike most of the above mentioned studies, all of these efforts have used subjective methods of classification (Terjung, 1970). The problem seems to be that climatologists steeped in theoretical and empirical approaches to the analysis of environmental transfer processes are generally ignorant about the nature and variety of objective procedures available for classification - regionalization purposes whereas climatologists having sufficient background in the mathematical and statistical methods of numerical taxonomy are not well trained or interested in environmental transfer processes or energy variables. As a result, we need to combine the theory and methods of an energy-based climatology and numerical taxonomy if we are to learn more about the fundamental character and spatial distributions of our climatic energy resources.

3. SIGNIFICANCE

Objectively defined univariate and multivariate regionalizations of the significant energy variables, e.g. global radiation, atmospheric counter radiation, terrestrial radiation, sensible heat flux, latent heat flux and ground heat flux, promise to upgrade our ability to make informed judgements in two important areas.

In the field of solar dwelling design, if "good" general designs are to be developed, architects must first have both an accurate picture of the number and character of climatic regimes in the United States as well as their spatial extent. Stations which epitomize each regime or region can then be objectively selected (see Willmott, 1977b) and energy efficient and/or solar houses can be designed in accordance with empirical and simulated information for each characteristic station's climate. Unfortunately, the general lack of such information has resulted in the design of dwelling types on the basis of inappropriate climatic classifications. A recent government publication (HUD, 1976), for example, presents solar dwelling design concepts for " the climatic regions of the United States" even though the four regions referred to are based upon Köppen's scheme and, therefore, contain virtually no consideration of the most important climatic variable -- solar radiation (figure 1). Other variables are considered by HUD (1976), but their antiquated notion of " climate, in most cases, is the primary form-giving factor" of each suggested house design (HUD, 1976: 97).

Of equal planning importance, objective information about the distribution of climatic regimes should significantly aid NOAA and other agencies concerned with data collection, management and dessimination in the selection of station sites which do not collect redundant data and, at the same time, are located in such a way that significant source regions of climatic variation are adequately represented in the station network. Preliminary results in an ongoing regionalization project concerned with identifying the minimum number and location of precipitation regimes and stations in California, for example, suggest that approximately 90 percent of the State's total precipitation variation can be anticipated by measuring precipitation at about five sites (see Willmott (1977a) for preliminary findings).

Figure 1. Climates of the Contiguous United States.
(Source: HUD, 1976)

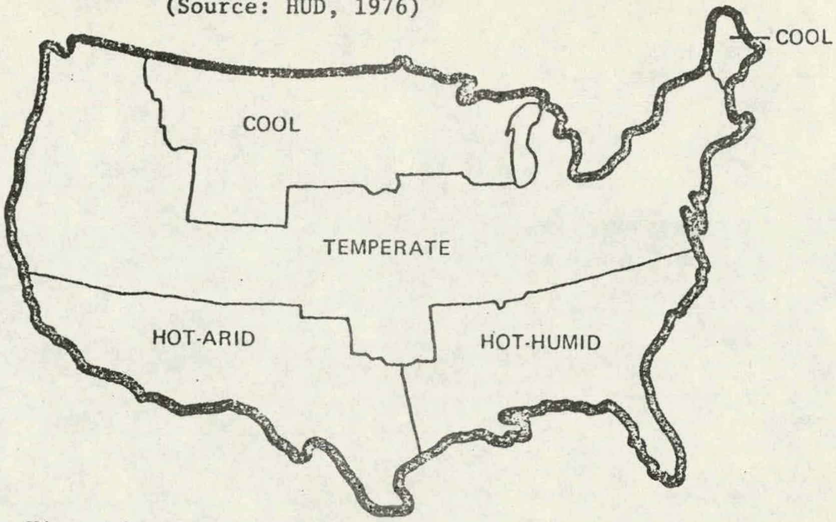


Figure 2. Climates of the Contiguous United States.
(Source: Steiner, 1965)

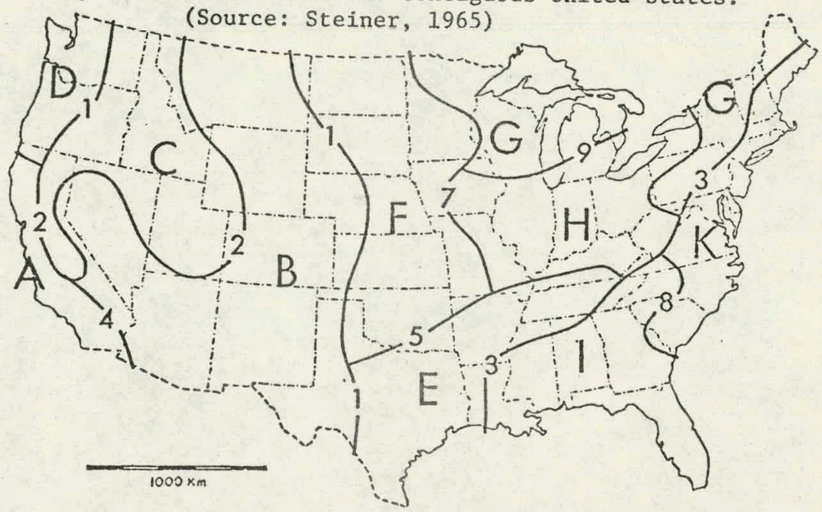
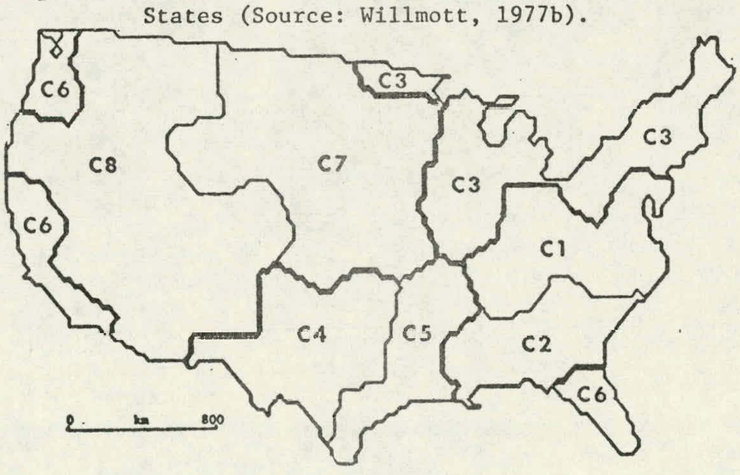


Figure 3. Radiation Climates of the Contiguous United States (Source: Willmott, 1977b).



If our results continue to confirm the preliminary findings, the cost associated with the collection, management and publication of California precipitation records from some 600 stations could be significantly reduced. Other findings associated with a recent climatic classification - regionalization of the contiguous United States, based on radiation, suggest a much different alignment of regimes and their representative stations than has so far been proposed (Willmott,1977b). Had similar analyses been worked on solar radiation data for the conterminous United States perhaps the location and number of stations in our "new" solar radiation network could have been more objectively chosen. Among the classifications that currently exist, a few appear to point the way to the "better" schemes of the future.

4. FIRST EFFORTS

Inspired in the early sixties by the work of economic - regional scientists (e.g. Berry, 1960), a number of climatologists applied the relatively objective methods of numerical taxonomy to climatic variables for purposes of classification - regionalization. Although the literature in numerical taxonomy was rapidly developing during this period, it appears to have been little known to climatologists

(Sokal and Sneath, 1963). The first, and perhaps best known multivariate effort was by Steiner (1965), who identified ten climatic regions in the contiguous United States using a potpourri of averaged climatic variables (figure 2). HUD (1976) would have been better advised to use Steiner's classification. Steiner employed a combination of methods which included factor analysis, distance grouping, and discriminant analysis. A number of others have followed Steiner and a few later applied similar techniques to the classification of single variables with the addition of an explicit consideration for the time dimension (Dyer, 1975; Willmott 1977a). Growing out of the early taxometric classifications of climate as they are represented by Steiner's work, and the more theoretical positions argued by Terjung (1976) and others, a recent study by Willmott (1977b) attempted to classify fundamental energy variables by means of numerical taxometric methods. The results and methods of that study will subsequently be briefly described here as a possible example of future work.

Using six hourly surface synoptic and daily radiosonde information from 62 station locations in the contiguous United States and 1975, daily totals of the main surface radiation budget terms, i.e. absorbed solar radiation, atmospheric counter radiation, and terrestrial radiation, were simulated over the year using an hourly dt by a modified version of a "comprehensive energy and moisture budget programme" (Vowinckel and Orvig, 1972). It should be noted that the use of a small dt, e.g. one hour, is essential to the identification of diurnal patterns and, subsequently, to an accurate estimation of daily totals. To do otherwise is to assume that the diurnal variation in weather from place to place is both random and inconsequential to the definition of climate. Following the simulation phase, P - mode principal components analyses and Ward's (1963) grouping algorithm were applied to the resultant annual radiation records in order to group the station records into relatively homogeneous classes. The similarity coefficient selected for analysis was the covariance coefficient because it does not destroy the metric as the correlation coefficient does. Regional boundaries were then located by a proximal mapping algorithm. The eight radiation regimes which emerged are (C1) a seasonally humid mid - eastern regime, (C2) a mildly seasonal southeastern regime, (C3) a severe winter northeastern regime, (C4) a dry south - central regime, (C5) a south - central transitional regime, (C6) a coastal regime, (C7) a dry severe winter north - central regime, and (C8) a dry upland - desert regime (figure 3). The stations that epitomized each of these regimes were also objectively selected -- by a distance evaluation algorithm (Willmott, 1977b: 140 - 141). Since the combinatorial use of physical climatic principles and numerical taxonomy yields a more theoretically satisfying, and probably more accurate definition of the distribution of climates, much more work needs to be undertaken as the only example of such classifications (Willmott, 1977b) is based upon a mere 62 stations and a single year. Moreover, the disposition of the radiation budget should enter into the classification process, i.e. we should consider both the temporal and spatial perturbations of the entire surface energy budget. Such classifications are essential if we are to make informed judgements on subjects which are directly or indirectly influenced by climate.

5. SUMMARY AND RECOMMENDATIONS

Previous literature is briefly reviewed and characterized as inadequate for the contemporary uses which are being made of climatic classifications - regionalizations. As a result, it is suggested that further work be undertaken which combines the most appropriate techniques from the field of numerical taxonomy and the principles of physical climatology (i.e. surface - boundary layer energy and moisture budget climatology) in order to define objectively the number and spatial extent of climatic regions in the conterminous United States. Univariate and/or special purpose classifications of significant climatic parameters also need to be rigorously derived. Such classifications should facilitate both the designers of energy efficient and/or solar dwellings as well as agencies involved in data collection . Two preliminary classifications of the contiguous United States are presented and described and it is suggested that they represent first efforts in the field.

APPENDIX E

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