SOLAR RADIATION RESOURCE ASSESSMENT PROJECT

Program Overview of Fiscal Year 1993

Contents

The mission of the Solar Radiation Resource Assessment Project is to provide essential information about the solar radiation resource to users and planners of solar technologies so that they can make informed and timely decisions concerning applications of those technologies.

THE SOLAR RADIATION RESOURCE ASSESSMENT PROJECT

Producing electricity, heating and lighting buildings, and destroying hazardous waste—the sun's energy can be used for all these purposes and more. The solar radiation available at a location is an important factor when determining whether a solar technology's application is economically viable.

The Project

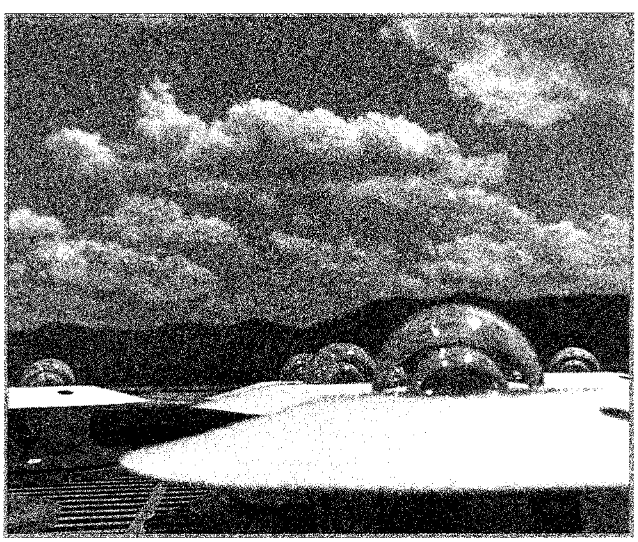
The Solar Radiation Resource Assessment Project provides planners and users of solar technologies with information on the best times and locations to use the sun's energy resource. The project team accomplishes this by producing and disseminating relevant and reliable information about solar radiation.

The U.S. Department of Energy (DOE) established this assessment project to facilitate the deployment of solar technologies. Managed in the Analytic Studies Division of the National Renewable Energy Laboratory (NREL), the project is the major activity of DOE's Resource Assessment Program, which is funded and monitored by the Photovoltaics Division of the Office of Solar Energy Conversion.

Supporting Activities

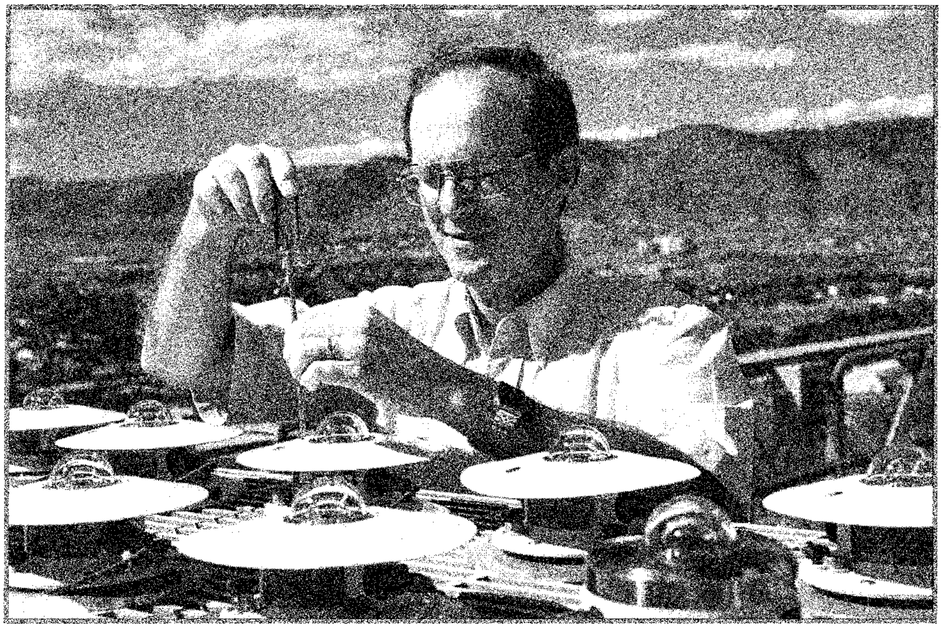
To produce top-quality information about solar radiation, the project supports many activities. It provides technical and financial support for solar radiation measurement stations; it calibrates, tests, and evaluates measurement instruments; it develops and validates solar radiation models; and it creates data bases and associated products, such as manuals and maps.

One major supporting activity of the project is the National Solar Radiation Data Base, a new data base that contains improved and up-to-date solar radiation and meteorological data. Using this updated information enables planners and designers to better gauge the performance of solar technologies at specific locations. Another supporting activity is the Historically Black Colleges and Universities Solar Monitoring Network. Consisting of six monitoring stations in the Southeast and East, this network has collected valuable solar radiation data since 1985.



David Parsons, NREL

Precision instruments, known as pyranometers, are among the instruments used to measure solar radiation.



Warren Gretz, NREL

Project team member Tom Stoffel calibrates pyranometers at the Solar Radiation Research Laboratory.

NREL's Solar Radiation Research Laboratory also contributes to the project's output of superior data. This laboratory, located in Golden, Colorado, supplies the outdoor research and calibration capabilities for the project. At this laboratory, project team members calibrate and test solar measurement systems and obtain solar radiation values for the area.

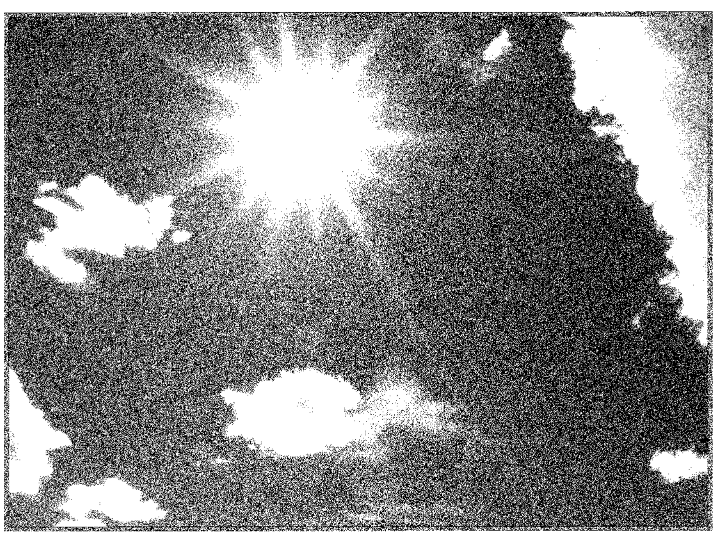
In addition to these activities, the project keeps in touch with the needs of the solar industry and others by responding to requests for solar radiation resource data and assessment methods. This outreach activity helps the team determine what information is relevant and how it is best presented and delivered.

Through these and other activities, the project supports the information needs of the solar industry, including developers, designers, suppliers, and installers of solar technologies; government agencies; educational organizations; researchers; and the general public.

The sun's energy can be harnessed effectively and economically at many locations when the variability and amount of the solar resource are considered. Determining that amount and variability requires understanding the solar resource and how to assess it.

Variability of Solar Radiation

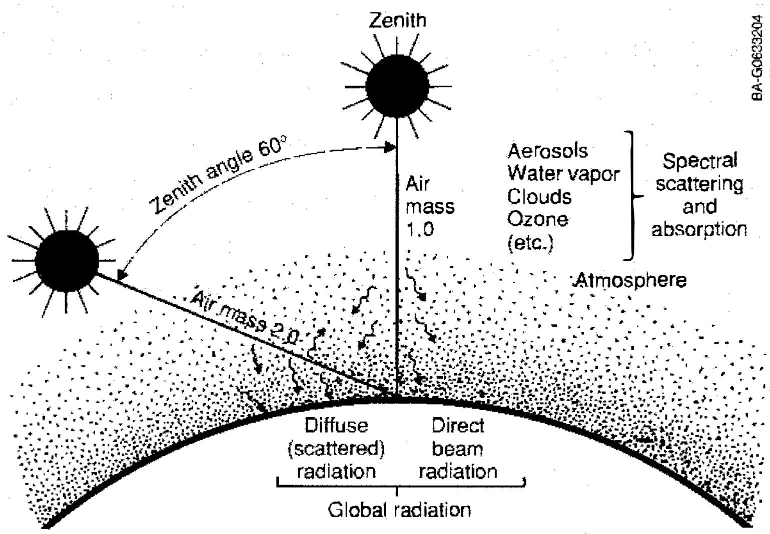
The amount of solar radiation reaching the Earth's surface varies greatly because of changing atmospheric conditions and the changing position of the sun in the sky, both during the day and throughout the year. Cloudiness is the predominant atmospheric condition that determines the amount of solar radiation that reaches the Earth. Consequently, cloudy regions receive less solar radiation than the cloud-free desert climates of the southwestern United States. For any given location, the solar radiation reaching the Earth's surface decreases as the cloud cover increases.



Understanding the sun's interaction with clouds is an important part of evaluating the variability of the solar resource.

Local geographic features, such as mountains, oceans, and large lakes, influence the formation of clouds; therefore, the amount of solar radiation received by these areas may be different from that received by adjacent land areas. For example, the mountains may receive less solar radiation than the foothills and plains a short distance away because winds blowing against the mountains force air to rise; clouds form as the moisture in the air cools. Coastlines can also receive a different amount of solar radiation than areas farther inland. Where the changes in geography are less pronounced, such as in the Great Plains, the variability of total solar radiation is less.

Seasonal and Atmospheric Variations



The elevation of the sun above the horizon, or conversely, the angle of the sun from the vertical (straight up or zenith), determines air mass. Air mass values are higher when the sun is lower in the sky. For example, air mass is 1 when the sun is directly overhead and the angle of the sun from the zenith direction is 0°; air mass is 2 when the angle is 60°. The air mass value at any particular time depends on the location (latitude), the time of day, and the day of the year.

When the sun is closer to the horizon, direct beam radiation must pass through a longer distance in the Earth's atmosphere than when the sun is overhead. This longer path results in more scattering and absorption of the solar radiation. The atmosphere through which the solar radiation passes is also quite variable. Significant variables are atmospheric turbidity (haziness caused by aerosols such as dust), water vapor, and clouds.

So how does the atmosphere affect solar radiation? It basically acts as a dynamic filter absorbing and scattering solar radiation. It creates spatial (geographic), temporal (hourly, daily), and spectral (wavelength) variations in solar radiation that researchers must characterize or describe with respect to these variations' effects on operating solar energy conversion systems.

Measurements of Solar Radiation

Three elements of solar radiation reaching the Earth's surface can be measured: total radiation (also called global radiation) and its two components, direct beam and diffuse radiation. As the name implies, direct beam radiation travels in a direct line from the sun. Diffuse radiation, on the other hand, has been scattered out of the direct beam by molecules, aerosols, and clouds. Because diffuse radiation comes from all regions of the sky, it is also referred to as sky solar radiation. On clear days, the portion of global solar radiation that is diffuse is about 10% to 20%; on cloudy days, that proportion can be as much as 100%.

For good-quality solar resource assessment, at least two of the three elements need to be measured. In practice, however, it is wise to measure all three elements. By doing so, researchers can verify the quality of the data by using the following equation:

global = diffuse + direct x cosθ
where cosθ is the cosine of the solar zenith angle.

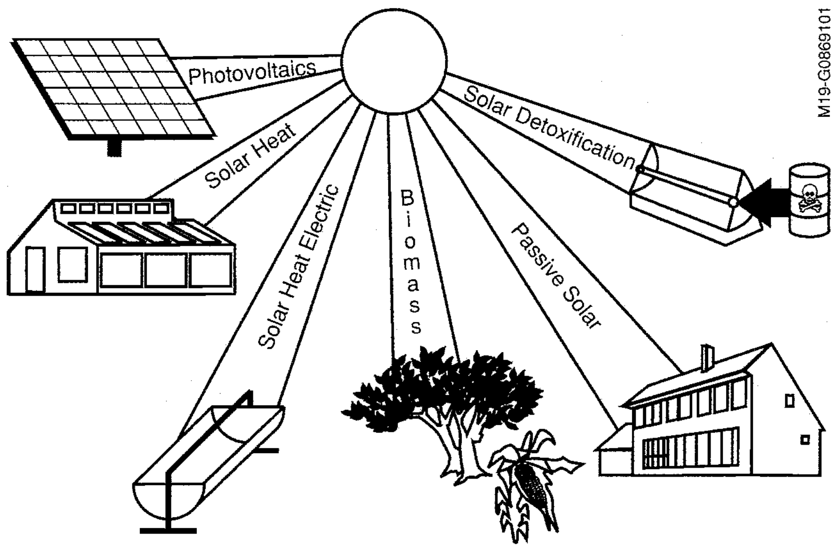
This check can alert researchers to equipment and operational problems.

Spectral Distribution of Solar Radiation

The optimum use of certain technologies may require knowledge of the spectral, or wavelength, distribution of solar radiation because different types of solar technologies use different wavelengths of the spectrum. For example, photovoltaic devices respond primarily to wavelengths in the visible and near-infrared region of the spectrum, whereas solar detoxification units use energy from the ultraviolet region. Location, climate, and atmospheric conditions influence the spectral distribution of solar radiation.

Researchers can measure the spectral distribution of solar radiation with a spectroradiometer. This instrument measures the solar radiation intensity at discrete wavelengths. Because spectroradiometers are complex and relatively expensive, and their operation and maintenance require a significant effort, they are not routinely used for long-term data collection. Rather, researchers use spectroradiometers to establish data bases that provide values of representative spectra for a wide range of climates and locations.

Data about spectral solar radiation can be used to study the sensitivity of spectrally selective solar technologies, such as photovoltaics, "smart windows," and biomass. These technologies can be sensitive to geographical, seasonal, and diurnal variations in the solar spectrum.



These technologies convert sunlight into usable forms of energy. Guided by solar resource assessment data, designers and planners can optimally design and locate these solar energy technologies.

Assessment of the Solar Resource

Solar resource assessment provides information about the availability of solar radiation at different locations. It also involves determining how much solar radiation is available to specific energy-producing or energy-saving technologies, such as photovoltaic panels or smart windows.

Making this determination requires measuring and characterizing the nature of solar radiation and the parameters that affect it. It also involves measuring solar radiation at various locations to quantify the resource, developing models to estimate solar radiation based on available meteorological data, and performing studies using measured or modeled data to show the amount of solar radiation available and how it varies geographically and by season and year.

Solar resource assessment information facilitates the optimal use of solar technologies. Among the solar energy technologies that can benefit from information about the solar resource are the following:

- **Solar electric (photovoltaic) for converting solar radiation directly into electricity**
- **Solar heat (thermal) for heating water for industrial and household uses**
- **Solar thermal electric for producing steam to run turbines that generate electricity**
- **Solar fuel technologies for converting biomass (plants, crops, and trees) into fuels and by-products**
- **Passive solar designs for lighting and heating buildings**
- **Solar detoxification for destroying hazardous waste using concentrated sunlight.**

The economics of these technologies not only depend on the costs of equipment and operation, but also on the amount of solar radiation available and the percentage of solar radiation that can be converted into the desired energy product.

During FY 1993, the Solar Radiation Resource Assessment Project team participated in several activities that produced top-quality solar radiation data and delivered that data to industry, government, and others.

Measurements of the Solar Resource

The project team continued its leadership in conducting measurements at the Historically Black Colleges and Universities (HBCU) monitoring network in the southeastern United States and at NREL's own Solar Radiation Research Laboratory. During FY 1993, the team accomplished improvements in both programs.

HBCU Monitoring Network

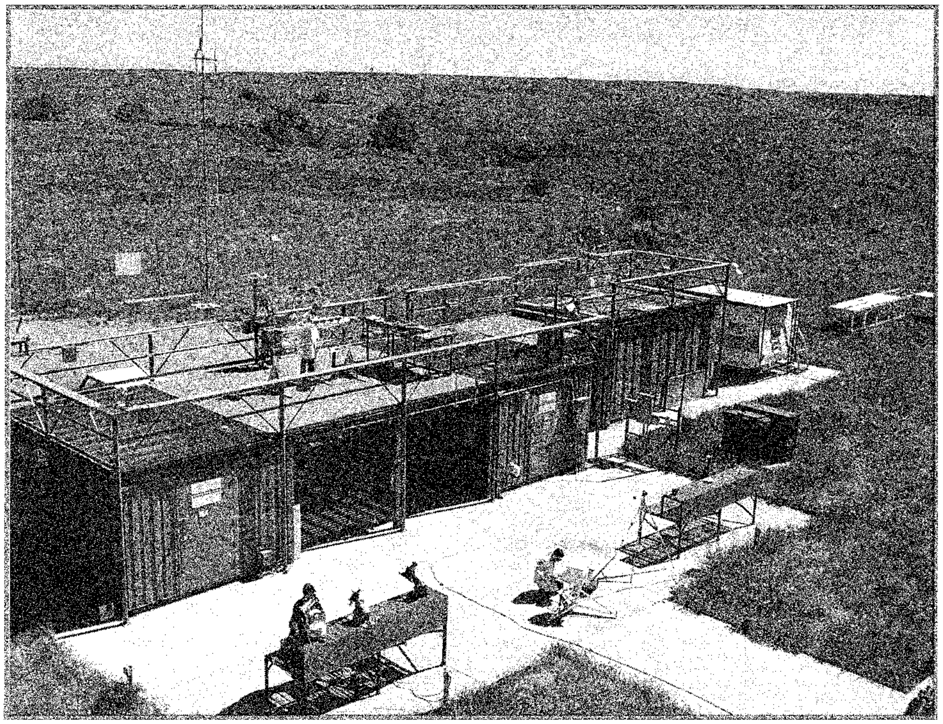
For almost a decade, NREL has funded and overseen the HBCU network. Consisting of six monitoring stations in the southeastern and eastern United States, the HBCU network continues to be a good source of measured solar radiation data and provides an opportunity for engineering students to gain experience in the solar energy field.

During FY 1993, the project team gained remote access to the data at each HBCU station by installing dial-up modems on the data loggers. Now project team members can review daily the data collected at each site, which reduces the time required to identify instrument problems and expedites the data archival process.

The HBCU network's monitoring stations are located at Bethune-Cookman College, Daytona Beach, Florida; Bluefield State College, Bluefield, West Virginia; Elizabeth City State University, Elizabeth City, North Carolina; Mississippi Valley State University, Itta Bena, Mississippi; South Carolina State University, Orangeburg, South Carolina; and Savannah State College, Savannah, Georgia.

Tom Stoffel, NREL

Tom Whitney, principal investigator, and James Malloy, engineer, inspect solar radiation measurement equipment at South Carolina State University. South Carolina State University is one of six monitoring stations in the HBCU network.


Warren Gretz, NREL

NREL's Solar Radiation Research Laboratory in Golden, Colorado

Integrated Surface Irradiance Study (ISIS)

The project team collaborated with the National Oceanic and Atmospheric Administration (NOAA) on its revised solar radiation monitoring network, ISIS. The revised network will have about six research-quality measuring stations, called SURFRAD (SURFace RADiation). In addition, approximately 10 to 15 of the original SOLRAD (SOLar RADiation) stations operated by NOAA's National Weather Service since the late 1940s will be upgraded.

Solar Radiation Research Laboratory
NREL's Solar Radiation Research Laboratory (SRRL) provides the outdoor research and calibration capabilities needed by the project. Located on top of South Table Mountain, near NREL's offices, the laboratory also supports the solar radiation and meteorological measurement needs of other programs at NREL.

In September 1993, SRRL was the site of a 3-week intercomparison of 14 absolute cavity radiometers. These special instruments are used to calibrate solar-measuring devices by providing radiometer traceability to the World Radiometric Reference. Participants in the intercomparison included NREL, the National Oceanic and Atmospheric Administration, and the Eppley Laboratory.

Information about solar radiation values obtained at SRRL was published in FY 1993. *Summary Information and Data Sets for NREL's Solar Radiation Research Laboratory 1981–1991* summarizes information on available solar radiation and describes hourly data sets for solar radiation and meteorological elements measured from 1981 to 1991.

Alternative Ways of Measuring Surface Solar Radiation

When researchers lack solar radiation measurements for a specific site, they can use models built on meteorological data to estimate the radiation values. Although less accurate, this is often the only option available. Many models use cloudiness data based on observations made by a trained meteorologist who looks at the sky and estimates the amount of cloud cover in tenths. A clear sky rates a cloud cover value of 0 tenths, and an overcast sky rates a cloud cover value of 10 tenths. Researchers can derive cloud cover data from weather satellites as well.

One of the program's more notable modeling achievements is the development of the National Solar Radiation Data Base, completed in the summer of 1992. Because of a limited amount of measured data, NREL researchers, using meteorological data from National Weather Service stations, developed a model to estimate more than 90% of the solar radiation data for this data base. The model, METSTAT (METeorological-STATistical), uses meteorological data and statistical algorithms to produce a data base of long-term data similar to one developed from measured data. Researchers will give METSTAT extensive documentation and validation over the next several years and will study its use for enhancing international data bases.

Cloud cover information and other data obtained from satellites also can be used to estimate solar radiation at any location on Earth. The project team has plans to use satellite data for enhancing the National Solar Radiation Data Base and for developing international solar resource information.

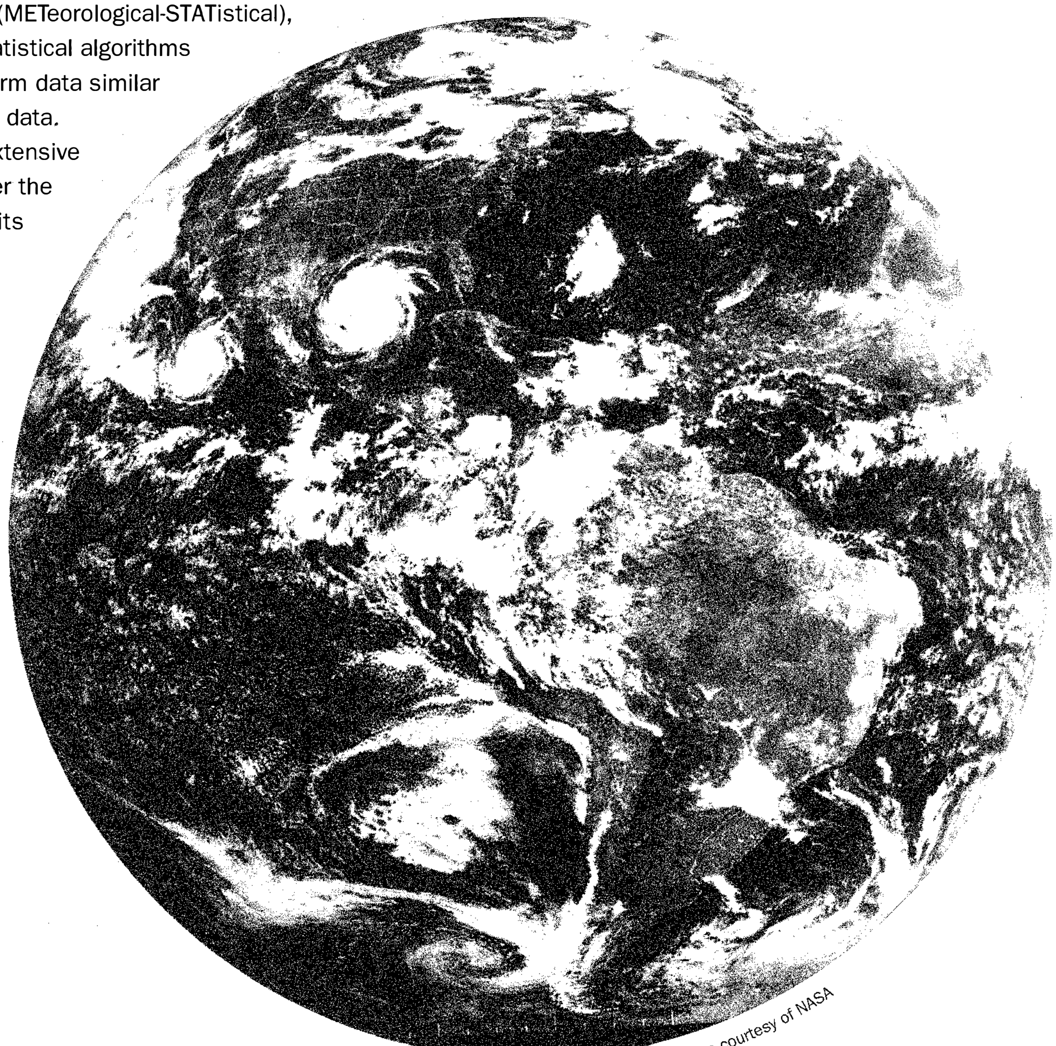
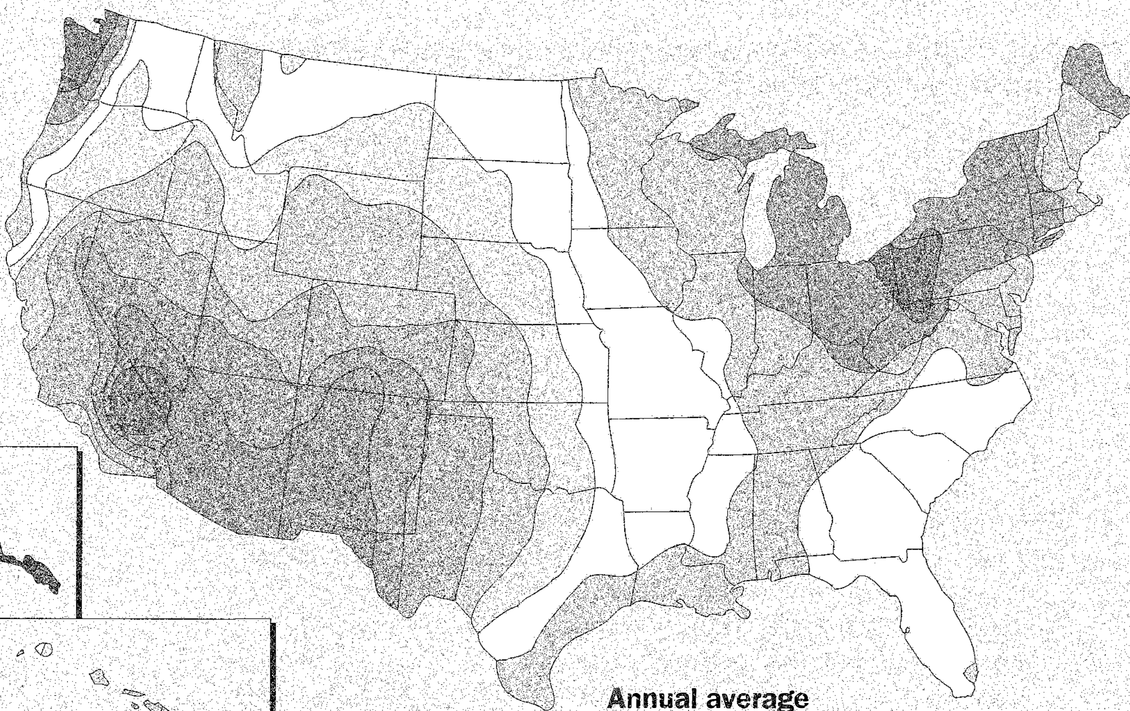
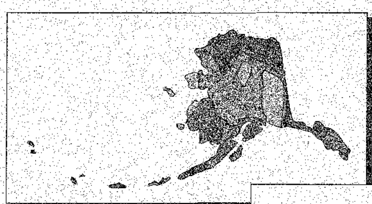
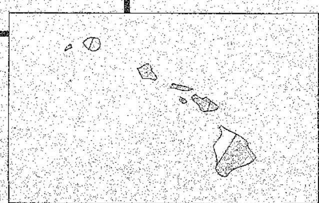


Photo courtesy of NASA

NREL's Geographic Information System produced these contour maps showing the mean values of annual direct normal and global horizontal radiation.



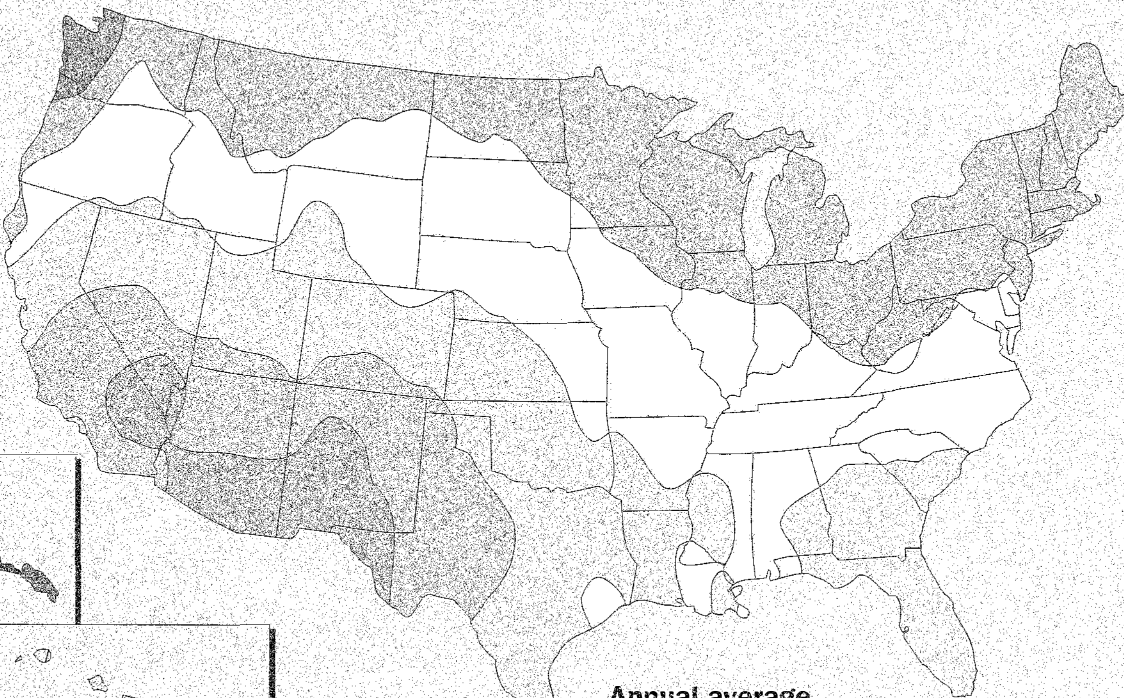


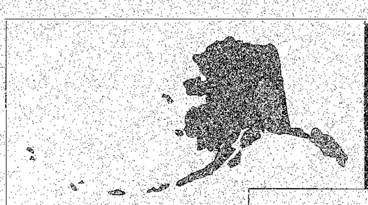


Annual average direct normal solar radiation

kWh/m² per day

- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- 4.5 to 5.0
- 5.0 to 5.5
- 5.5 to 6.0
- 6.0 to 6.5
- 6.5 to 7.0
- 7.0 to 7.5





Annual average global horizontal solar radiation

Dissemination of Solar Resource Information

In FY 1993, the project team presented the National Solar Radiation Data Base and developed a variety of products from the new data base.

National Solar Radiation Data Base

In the summer of 1992, the project team completed a 3-year update and upgrade of our nation's primary solar radiation data base, the SOLMET/ERSATZ data base. Using information from the new data base, the National Solar Radiation Data Base, researchers can produce reports, manuals, charts, and maps in user-friendly formats. One such product, soon to be published, is a solar radiation data manual for flat-plate and concentrating collectors.

Seminar about Solar Radiation Resource Assessment

To introduce the new solar radiation data base, project team members hosted the seminar Recent Advancements in Solar Radiation Resource Assessment. This 3-day seminar took place in Denver, Colorado, during November 1992. About 70 people attended, representing electric utilities, universities, national laboratories, private industry, and DOE.

Team members explained the contents of the new data base and the scientific principles and methods used for its development. In addition, invited speakers presented information on other recent advancements pertaining to resource assessment. On the last day, a panel discussion on resource assessment needs took place to help prioritize future resource assessment activities.

CD-ROM Version of the New Data Base

Project team members provided technical support and review to the National Climatic Data Center (NCDC) when it put the National Solar Radiation Data Base on a three-volume CD-ROM set. This set can be ordered from NCDC by contacting User Support at (704) 259-0682.

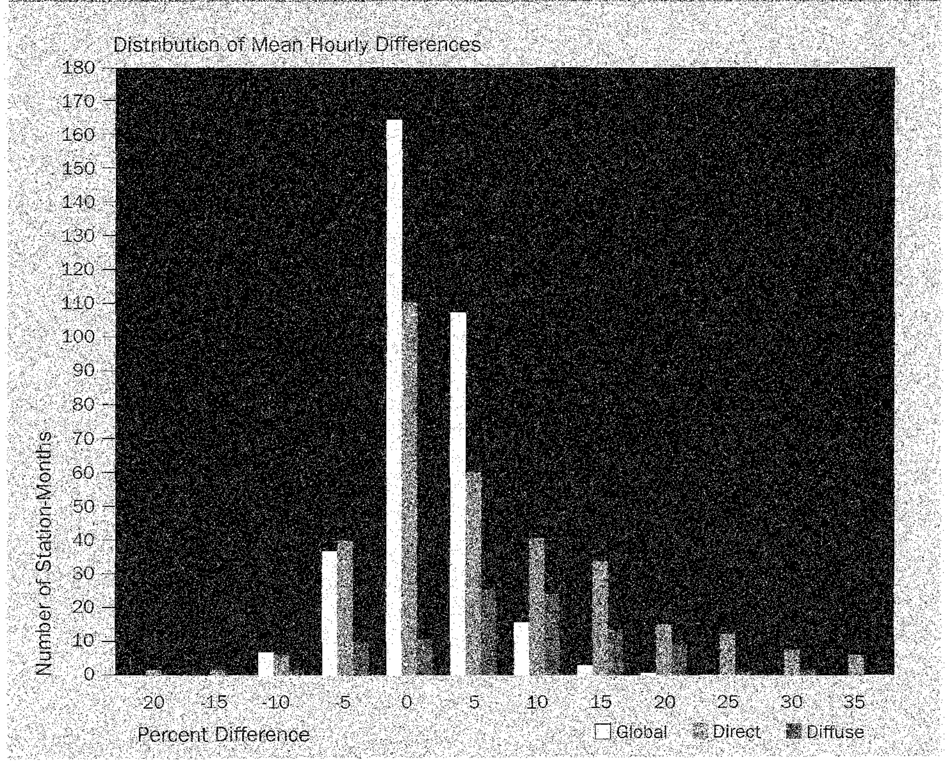
National Solar Radiation Data Base

The National Solar Radiation Data Base contains hourly values of measured or modeled solar radiation data and meteorological data for 239 National Weather Service stations from 1961 to 1990. NREL completed Version 1.0 in 1992. Version 1.1 will be completed in early 1994.

Data from two types of stations—primary and secondary—make up this data base. Primary stations, of which there are 56, measured solar radiation for at least part of the 30 years. The remaining 183 secondary stations made no solar radiation measurements at all. For these stations, researchers used the METSTAT model, which is derived from meteorological data such as cloud cover.

The National Solar Radiation Data Base is distributed on CD-ROM by the National Climatic Data Center, Asheville, North Carolina, as a three-volume set (eastern, central, and western United States). Each volume is $100.

The Comparison of the Old and New Data Bases



On an annual basis, the comparison of the old data base with the National Solar Radiation Data Base showed that global horizontal radiation data for 40% of the monitoring stations differed by more than 5%; data from some stations differed by as much as 18%. For direct beam radiation, data for 60% of the stations differed by more than 5%; data for some stations showed differences of as much as 33%. Differences between the two data bases were even greater when compared on a monthly basis.

Data from the new data base accounts for any recent climate changes and provides more accurate values of solar radiation. These values are believed to be more accurate for several reasons:

- **The new data base contains more measured data.**
- **Researchers used a better model to produce estimated values (more than 90% of the solar radiation data in both data bases are modeled).**
- **Researchers used improved calibration methods.**
- **Researchers used a more effective means to assess the quality of the data.**

Comparison of the New Data Base with the SOLMET/ERSATZ Data Base
Team members compared the National Solar Radiation Data Base with the SOLMET/ERSATZ data base and published the results in *A Comparison of Data from SOLMET/ERSATZ with the National Solar Radiation Data Base* (NREL/TP-463-5118). This station-by-station comparison of monthly and annual values of global horizontal and direct beam radiation revealed significant differences in the data bases. Consequently, using the new data for analysis or design of solar energy systems will give different results, which, based on the factors mentioned in the accompanying sidebar, are deemed to be more realistic.

Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors
The project team is developing a new solar radiation data manual based on the new data base. The manual will contain, for each of the 239 stations, 30-year monthly and annual averages of solar radiation values for 14 configurations of flat-plate and concentrating collectors. Minimum and maximum monthly and annual values also will be included, as well as pertinent climatic data.

The solar industry cooperated in the development of this manual by providing suggestions and ideas. The manual will be completed and available for distribution in early 1994.

New Typical Meteorological Years
Improving the typical meteorological year (TMY) for each monitoring station is possible now that the project team has completed the National Solar Radiation Data Base. TMYs are serially complete data sets of hourly values of solar radiation and meteorological elements for 1 year. They represent conditions judged to be typical over a long period, such as 30 years. TMYs are used for computer simulations of solar energy conversion systems and buildings. Because they are condensed into a 1-year time frame, they are easier and faster to use than 30-year data sets.

In FY 1993, the project team reviewed applicable methods for deriving TMYs, developed a plan, and distributed it for internal and external peer review. Comments and ideas of the reviewers are included in the final plan being implemented. The new TMYs will be completed and available for distribution in 1994.

Solar Data Display Using a Geographic Information System
The project team incorporated data from the new data base into NREL's Geographic Information System (GIS), a powerful tool for displaying geographically based data sets in ways that can facilitate the deployment of renewable energy technologies. From that data, the GIS produced preliminary color contour maps depicting solar resources in the United States.

GIS's capabilities permit layering data on one map to provide color-coded answers to complex problems. For example, three types of data, such as solar radiation values, land use restrictions, and electric transmission line locations, can be layered on one map. These layers of data show where opportunities exist for using solar technologies based on where the solar resource is good, where no land use restrictions exist, and where access to electric transmission lines is available.

Users Manual for Quality Assessment
Produced by project team members, the *Users Manual for the Quality Assessment of Solar Radiation Data* provides monitoring station and network operators with technical information and computer software instructions for assessing the quality of solar radiation data.

Reprinting of *Shining On: A Primer on Solar Radiation Data*
Requests for copies of *Shining On* for use in workshops sponsored by the Electric Power Research Institute prompted the reprinting of this publication. It uses a friendly question-and-answer format to explain the fundamentals about solar radiation data and their uses.

As the deployment of large-scale renewable energy projects nears, industry will place increasing importance on reliable and accurate resource assessment information.

An Expanded Program

DOE, through NREL, plans to meet the renewable energy industry's growing needs for high-quality resource information by expanding the Resource Assessment Program. This expansion will be supported with planned increased funding beginning in FY 1994.

The expanded program will focus on the development of a Renewable Energy Resource Data Center at NREL. Project team members plan to incorporate data from the Solar Radiation Resource Assessment Project, as well as data about other renewable energy technologies (wind, biomass, hydro, and geothermal), into a Comprehensive Renewable Energy Data Base.

Through the development of this data base, users will have ready access, for the first time, to renewable resource information presented in common formats for all technologies. This access will greatly improve the ability to plan and implement renewable energy systems, including hybrid systems.

Beginning in FY 1994, the project team will begin collaborative discussions with researchers involved in the evaluation of resources in other renewable technology areas to determine the format and availability of resource data that can be incorporated into the Renewable Energy Resource Data Center. In addition, these collaborations may lead to a pilot study with the wind program to develop a hybrid wind/solar data base. This data base would be one of the first major products of the center.

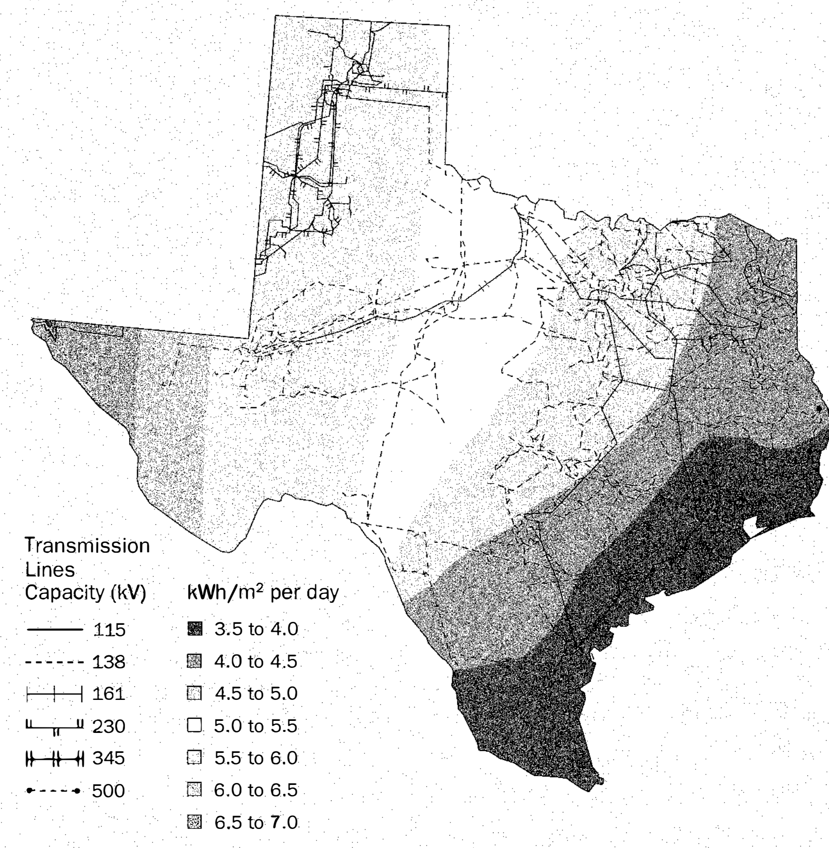
The expanded program will also focus on the establishment of a National Cooperative Solar Network (NCSN). Managed through regional centers selected by NREL from a competitive solicitation, this program will archive solar irradiance measurements collected by many existing solar and meteorological monitoring networks across the United States. In exchange for the data, NREL will provide technical assistance and offer calibration support to the participating networks through the regional centers.

● Geographic Information System

The Renewable Energy Resource Data Center

In FY 1993, the project team began to design and build the Renewable Energy Resource Data Center. Plans are for this activity to be substantially increased in FY 1994 as work progresses toward developing a center modeled after the Distributed Active Archive Centers. These centers have been established around the United States to archive and disseminate large, diverse data sets.

The Renewable Energy Resource Data Center will make available the information in the Comprehensive Renewable Energy Data Base. Furthermore, because of the importance of displaying the geographic variability of various renewable energy resources, along with other important energy-related data bases (such as the location of transmission lines and energy-generating stations) and demographic data bases, a geographic information system will be one of the primary tools of the new center. Center users will be able to access data via electronic mail. On-line user support, including menu-driven options and assistance, will be a primary feature of the center.



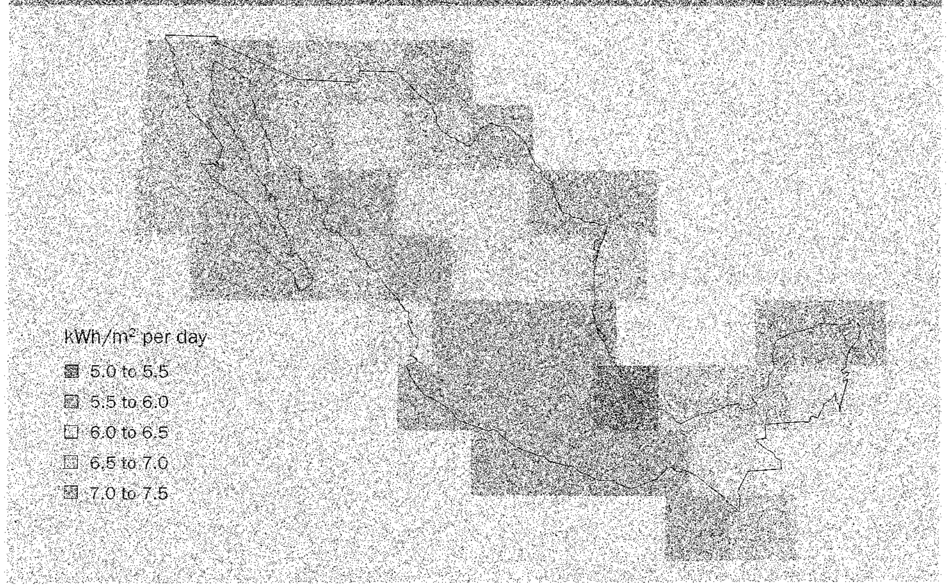
The Renewable Energy Resource Data Center will include GIS capabilities that will allow users to overlay resource information with other important data. This map of Texas, showing the distribution of direct normal solar radiation and the location of transmission lines, is an example of such a GIS product. This type of analysis helps users investigate the opportunity for deploying solar technologies near major transmission lines.

National and International Solar Resources

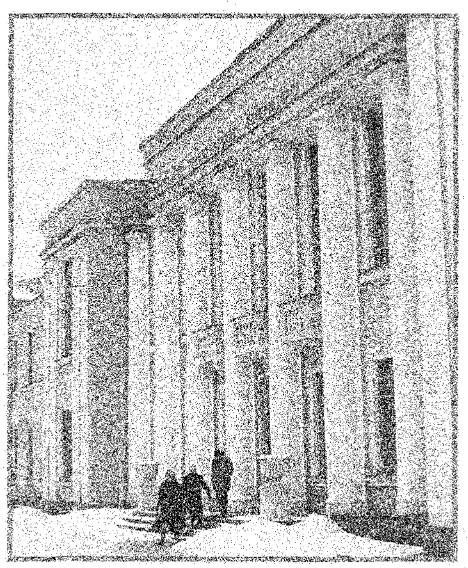
The Solar Radiation Resource Assessment Project continues to broaden its activities to meet the increasing needs of the renewable energy industry. For FY 1994 and beyond, the activities of the project will include the following:

- **Publishing the validation of the National Solar Radiation Data Base, the data manual for flat-plate and concentrating collectors, and the new TMY data sets**
- **Using GIS capabilities and the new national data base to generate seasonal and annual solar radiation maps for the United States and its territories tailored for various types of solar collectors**
- **Initiating a National Cooperative Solar Measurement Network Program to increase the number of stations measuring high-quality solar radiation data**
- **Expanding access to international solar radiation data by assisting the World Radiation Data Center in St. Petersburg, Russia**
- **Using satellite imagery to estimate solar radiation**
- **Providing users with electronic access to the Renewable Energy Resource Data Center at NREL.**

Satellite-Derived Solar Information



The project team will use satellite data from the NASA/Langley Research Center in Hampton, Virginia, to provide gridded, monthly average estimates of global horizontal solar radiation for any location on Earth. This gridded map of Mexico for July 1985 is an example of how the data will be displayed.



Steve Wilcox, NREL

The Main Geophysical Observatory in St. Petersburg, Russia, houses the World Radiation Data Center. Project team members will continue to assist with the upgrade of the hardware, software, and communications capabilities of the center. This upgrade will permit NREL and others to access the center's data archives electronically.

The vision of NREL's Resource Assessment Program is to be recognized throughout the world as the primary center for objective, accurate, timely, and relevant information on renewable energy resources and to enable industry and others to use this center of excellence to facilitate the deployment of renewable energy technologies.

Produced for the
U.S. Department of Energy

by the
National Renewable
Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

The National Renewable Energy
Laboratory is a national laboratory
of the U.S. Department of Energy.

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01; Printed Copy A02

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: *Energy Research Abstracts (ERA); Government Reports Announcements and Index (GRA and I); Scientific and Technical Abstract Reports (STAR);* and publication NTIS-PR-360 available from NTIS at the above address.

NREL/SP-463-6156
DE94000286
June 1994

Printed with a renewable source ink on paper
containing at least 50% wastepaper