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NASA CLIMATOLOGICAL DATA FOR RENEWABLE ENERGY ASSESSMENT

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ABSTRACT

This article presents the latest parameters and delivery methods that provide global solar energy and meteorological resources on the Internet. Over the past several years the number of parameters in the Surface meteorology and Solar Energy Data Set has tripled. The newest parameters include solar geometry, a suite of wind speed and wind direction data, diffuse, direct normal and tilted surface solar irradiance. Requests by users and recommendations by the renewable energy industry have prompted the growth.

INTRODUCTION

NASA's Prediction of Worldwide Energy Resource (POWER) Project is developing data sets from Earth Science Enterprise climate research to support renewable energy industries. The Surface meteorology and Solar Energy (SSE) Data Set [1] contains solar parameters principally derived from satellite observations and meteorology parameters from an atmospheric model constrained to satellite and sounding observations. It is a 10-year climatology (1983-1993) interpolated to a one-degree latitude by one-degree longitude grid. The global coverage of the SSE data set fills the gap where remote locations lack ground measurement data. Most ground measurement stations are located near populated regions that may have natural or urban influence on the local climate. The SSE data set can augment ground measurement data affected by microclimates. There are parameters for sizing and pointing solar panels, solar thermal applications, cloud information, temperature, humidity, and wind parameters. The SSE data are considered accurate for preliminary feasibility studies of renewable energy projects.

SSE WEB SITE

The SSE web site <http://eosweb.larc.nasa.gov/sse/> delivers documents on the fly with a user-friendly interface. All choices are plainly layed out for data retrieval. Users can access data by entering a particular latitude and longitude location, or panning on an image of the globe and zooming into the area of interest. Users can create customized data tables by choosing from an extensive list of over 150 monthly averaged solar energy and meteorology parameters. Data selection is grouped by their most probable application. Users can select just the parameter data tables of interest to them. Parameter definitions can be displayed below their respective data tables. Dynamic data mapping allows users the freedom of displaying global color maps of monthly averaged parameters or zooming in on any region as small as six by six degrees of latitude and longitude. Additional resources include accuracy, methodology, usage statistics and a form for submitting questions.

ESTIMATED UNCERTAINTY

Comparisons to ground measurement data are made prior to including additional satellite-derived parameters in the SSE data set. Table 1 identifies the ground site data used.

Data in these databases spanned from a few to 30 years. Not all ground stations operated continuously. When more than one ground measurement station was located in an SSE grid region, the ground measurements were averaged for comparison to the SSE data. It is generally considered that measured data are more accurate than satellite-derived and modeled values. Unfortunately, measurement uncertainties are not precisely known for these ground measurement data sets.

TABLE 1 Ground Site Data Sources

Organization	Ground Site Data
DOE National Renewable Energy Laboratory (NREL)	World Radiation Data Centre (WRDC) and several U.S. universities
Natural Resources Canada	RETScreen® Weather database
NOAA Climate Monitoring and Diagnostics Laboratory (CMDL)	selected sites
Swiss Federal Institute of Technology	Global Energy Budget Archive (GEBA) and Baseline Surface Radiation Network (BSRN)
University of Texas	Texas Solar Radiation Data Base (TSRDB)
The State University of New York at Albany's Atmospheric Sciences Research Center	various sites

TABLE 2 Bias And RMS Uncertainty Range Estimates Of The Basic SSE Parameters

Parameter	Bias Difference Range	RMS Difference Range
Horizontal Solar Insolation	-2% - +3%	12% - 15% (14% - 17% El Nino)
Horizontal Diffuse Irradiance	-5% - +5%	14% - 22%
Direct Normal Irradiance	-12% - -3%	15% - 26%
Near-Surface Air Temp (K)	-1.1% (< 243K) - - 0.02% (>263K)	3.2% (< 243K) - 1.1% (>263K)
Near-Surface Relative Humidity (%)	2% (potential RET sites) 5% (all sites)	9.7% (potential RET sites) 15% (all sites)
10-m Airport Wind Velocities	-0.2 m/s - +0.2 m/s	0.82 m/s - 1.2 m/s

Note: diffuse and direct normal irradiance values reflect probable Release 4 numbers from unfinished accuracy comparisons

For this reason, SSE differences from ground measurements are considered as estimates of uncertainty. Following usual industry standards, estimated uncertainty is assumed to be the Root-Mean-Square (RMS) difference when large sample sizes exist and statistical correlation has been performed. Estimated uncertainty is the average of the absolute values of each error when sample sizes are smaller. Bias is included in the RMS values (Table 2).

Most of the table values are given in percent because of the large variability, except for the airport wind velocities in meters per second (m/s). The differences here are computed from the global set of surface data for each parameter. The exception is Relative Humidity where a 200 site subset was constructed from seven continental regions representing potential Renewable Energy Technology (RET) site locations. All numbers represent the data currently located on the SSE web site except for the 10-meter wind velocities, diffuse irradiance, and direct normal irradiance which have recently been improved and will be included in the next release of the data set. Many application parameters are directly derived from these parameters such as heating degree-days that depend on temperature.

NEW PARAMETERS FOR THE SSE WEB SITE

Over the past several years the SSE data set has grown from 57 parameters to over 150 parameters based on recommendations by the renewable energy industry. The newest parameters include solar geometry, a suite of wind speed and wind direction data, diffuse, direct normal and tilted surface solar irradiance. Many of these, for example wind speed (Figure 1), include diurnal information. Following is a brief description of the newest parameters available.

Solar Geometry. Solar geometry calculations are performed on the fly for any grid location chosen. Available parameters are:

- Solar Noon
- Daylight Hours
- Daylight cosine solar zenith angle
- Hourly solar angles from horizon
- Hourly solar azimuth angles

Wind Parameters. A considerable amount of analysis was performed to calculate 50-meter wind speed from the atmospheric model output and estimate 10-meter wind speed over or through seventeen vegetation types [2].

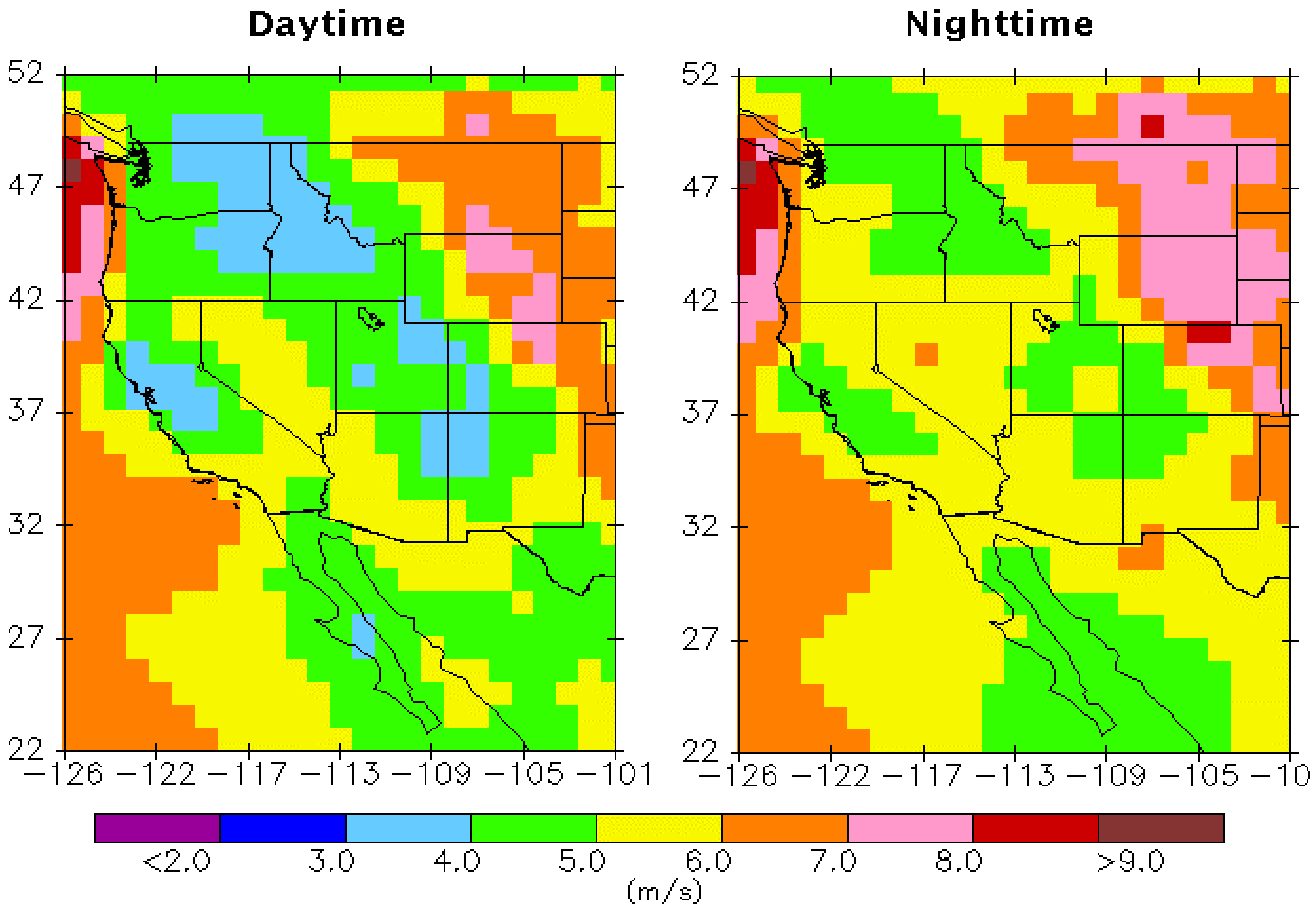

Fig. 1 January Diurnal 50-Meter Wind Speed (10-Year Average)

Wind velocities at 50-meter heights have been referenced to soil, water, ice or snow surfaces rather than the "effective" surface that is often considered to be in the upper portion of the vegetation canopy. For example, 50-meter SSE winds are only 30 meters above the "effective" surface of a 20-meter high forest. Using the 50-meter reference winds, close-to-surface wind estimates can be computed and these are useful to a wide range of industries including small wind, hybrid renewables, agriculture, architecture, hydrology, and public health in populated and mixed vegetation regions.

One new wind parameter, the percent difference from the average wind speed at 50 meters, is an indicator of inter-annual variation. Another wind parameter presents the percent of time that the wind speed at 50 meters falls within a range (0-2, 3-6, 7-10, 11-14, 15-18, >19 m/s). 50-meter wind speed, wind direction and air temperature are available at three-hour intervals. As an example, these data are useful for the installation of wind turbines on a wind farm. Installing turbines that are least affected by the wake of adjacent turbines can be accomplished by knowing the wind direction associated with the most productive wind conditions. Seasonal or diurnal variations may become apparent when reviewing the SSE wind data for a location.

Arctic Heating Degree Days. The SSE parameter, heating degree days, is the monthly accumulation of degrees when the daily mean temperature is below 18° Celsius. The SSE Project Team responded to user requests for heating degree days based on 10° and 0° C by calculating arctic heating degree days (below 10° and 0° C) for inclusion on the web site.

Interannual Variation Of Insolation. Global interannual variation of insolation [3] is provided as a percent difference minimum and maximum from the 10-year monthly average. This information can assist in designing solar power systems with adequate backup features.

Diffuse And Direct Normal Irradiance. Solar thermal power applications can benefit from estimates of global direct normal irradiance (DNI) and the interannual variability of

DNI. Two methods of calculating DNI are currently being tested and compared to ground site data. One of the primary parameters in the SSE data set is insolation, which is the monthly-average total solar irradiance on a horizontal panel estimated by an improved Staylor method [4]. The Page [5] and RETScreen® methods [6] use SSE insolation and calculate diffuse irradiance via different algorithms. The Page model performs clearness index variance comparisons on ground measurement reference stations to compute diffuse irradiance. The model was originally supplied with 10 reference stations. It has been updated to include over 70 reference stations in both the northern and southern hemispheres representing a variety of climatologies. DNI calculations are extended through these two methods. Figure 2 shows the July results for RETScreen®. The current plan is to provide results from both methods on the SSE web site.

Fig. 2A

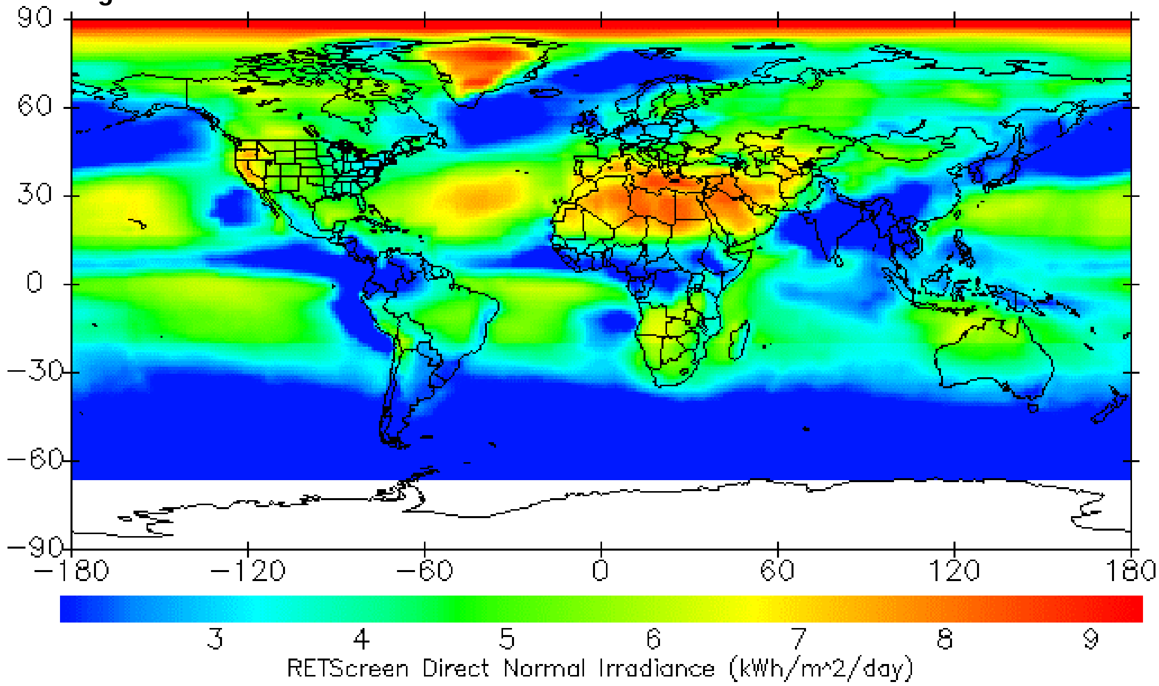

Fig. 2B

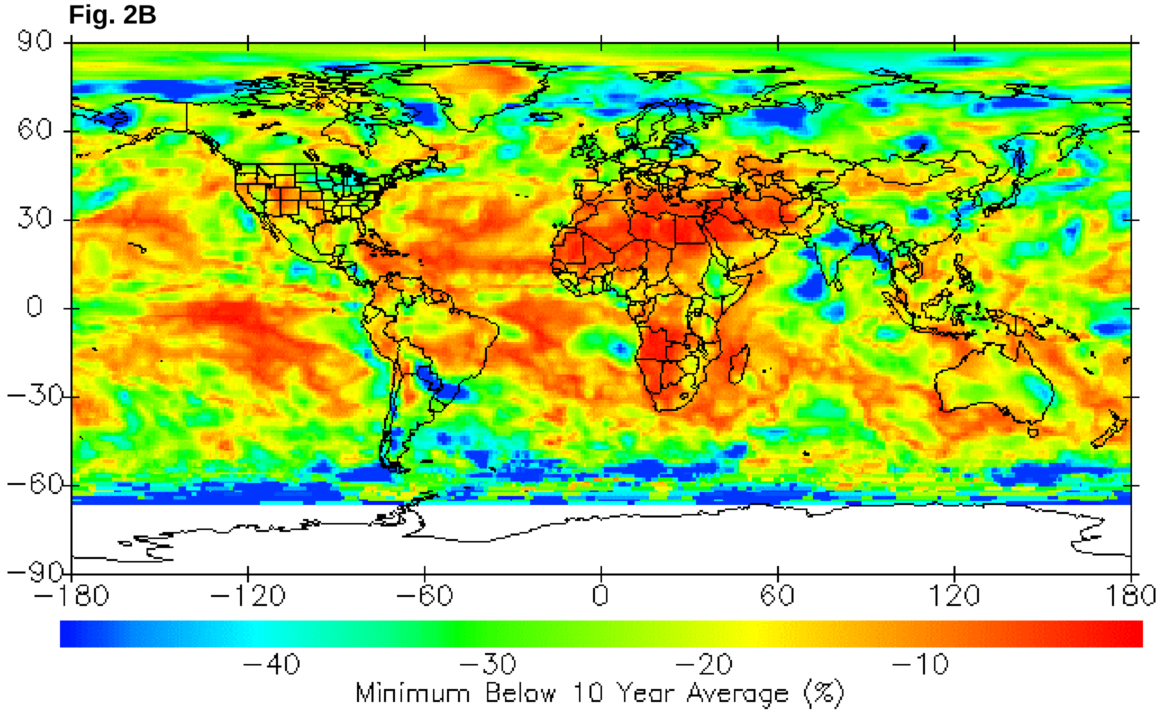

Fig. 2C

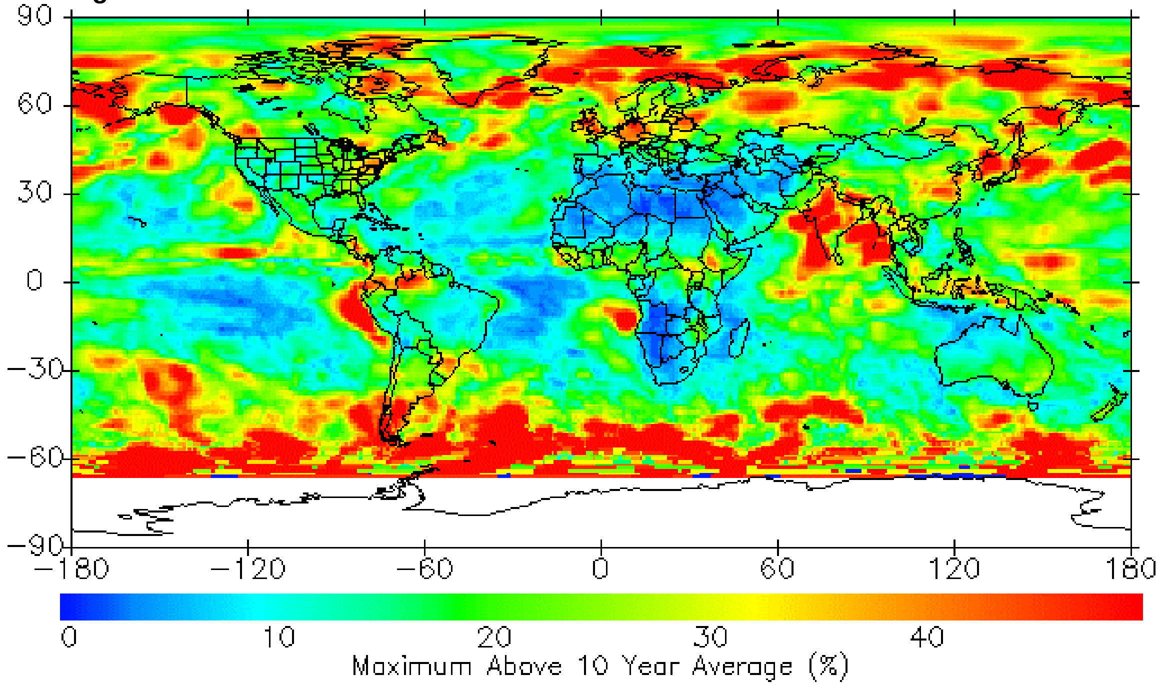

Fig. 2 A-C July Average, Minimum And Maximum Direct Normal Irradiance Calculated Using The RETScreen® Extended Method (10-Year Average)

Tilted-Panel Irradiance. Analysis of several methods of calculating irradiance on a tilted-panel surface from horizontal insolation is progressing. Results from the Page and RETScreen® algorithms will be presented on the SSE web site. The Perez method [7] for non-isotropic diffuse is incorporated into the Page method. This method yields higher summertime values. Data plots that compare the two methods for one location are shown in Figure 3. Efforts to continually refine the global resource assessment data are ongoing and many new ideas have come from user comments and requests.

Fig. 3A

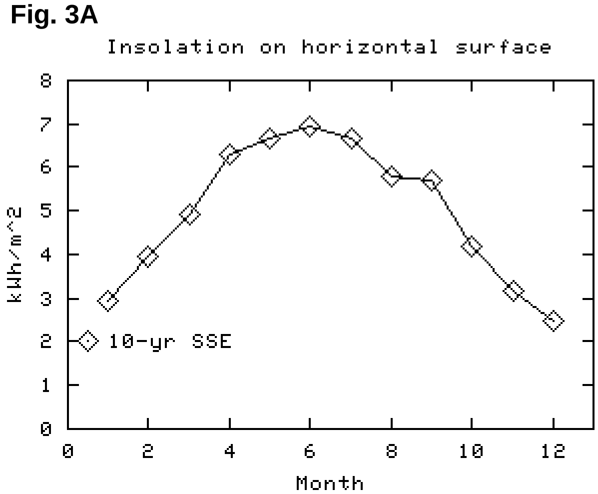

Fig. 3B

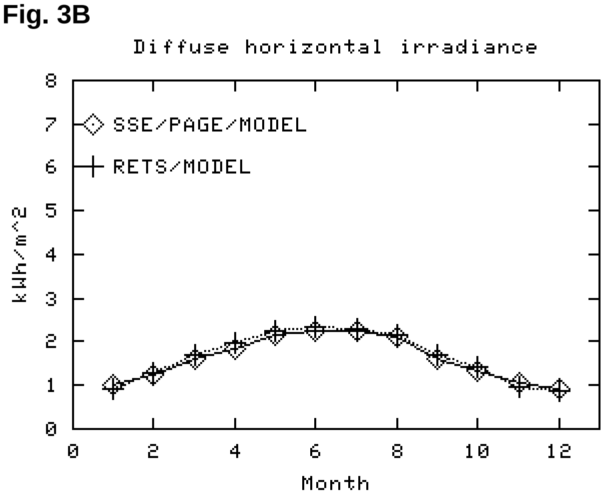

Fig. 3C

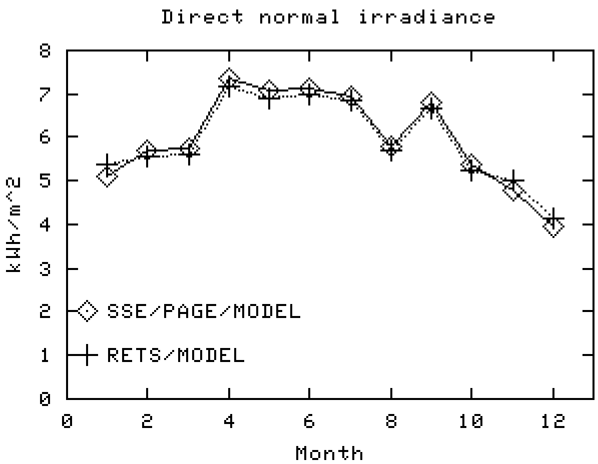

Fig. 3D

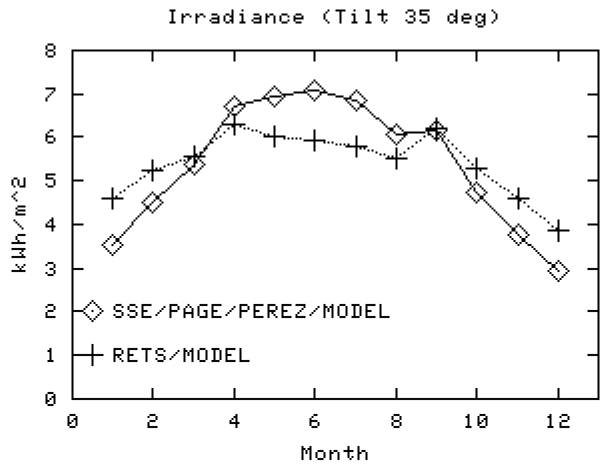

Fig. 3 A-D Irradiance Data For Albuquerque, Nm (10-Year Average)

Once the analysis is complete, DNI and tilted-panel irradiance values will be added to the SSE web site. These calculations will be made on the fly from existing SSE parameters and the newly added solar geometry calculations. A detailed methodology section and additional references will be provided on the web site.

RENEWABLE ENERGY DESIGN TOOLS

Collaboration with renewable energy industry partners has resulted in co-developed applications for easy insertion of the SSE data into several renewable energy design tools. An SSE web site application provides twelve parameters to eight models in RETScreen®, a renewable energy project analysis software tool developed by CANMET Energy Technology Centre (CETC) - Varennes [8]. SolarSizer, the Center for Renewable Energy and Sustainable Technology's professional tool for designing and sizing photovoltaic systems, seemlessly ingests time series and monthly averaged insolation data from the SSE web site when those data types are required [9].

CONCLUDING REMARKS

The NASA SSE Release 4 data set described in this article contains parameters with improved accuracy and new types of resource information formulated for assessing and designing renewable energy systems anywhere in the world. Previously, this type of information has only been available from a limited number of ground measurement stations clustered in populated and industrialized regions around the world. The SSE data are not intended to replace quality ground measurement data. However, the SSE data are considered accurate for preliminary feasibility studies for renewable energy systems. When used is conjunction with analysis tools like RETScreen® these data make it possible to quickly compare the benefits of renewable energy systems to conventional systems. Such analyses can provide substantial cost savings to users installing individual household renewable energy systems, industries developing the technologies, and governments initiating regional renewable energy programs. In the new global energy market where renewable energy systems are being considered along with conventional energy sources, the NASA SSE data set provides a consistent climatology of insolation and meteorological data for resource assessment on a global scale.

INDUSTRY CONTRIBUTORS

The following organizations have made significant technical contributions to the success of the SSE project:

- BP Solar International - Provided information on present industrywide methods used to estimate direct and diffuse irradiance.
- GPCo - Provided independent assessment of wind data.
- National Renewable Energy Laboratory (NREL) - Provided the WRDC ground site insolation data that are incorporated into the SSE web site as part of an Interagency Agreement.
- CANMET Energy Technology Centre (CETC) - Varennes - Provided temperature, wind, humidity, and insolation data from 1000+ sites to verify SSE data.
- Numerical Logics, Inc. - Provided independent assessment of accuracy results.
- Solar Energy International (SEI) - Participated in a cost-sharing partnership, which involves the Center for Renewable Energy and Sustainable Technology (CREST). Both companies advised on the renewable energy industry, and develop applications of the data.
- Solar Household Energy, Inc. - Advised on SSE web site development.
- The State University of New York at Albany, Atmospheric Sciences Research Center - Provided models for direct and diffuse irradiance calculations.

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