5.6 OVERVIEW OF THE SURFACE METEOROLOGY AND SOLAR ENERGY (SSE) PROJECT: AN INNOVATIVE WEB-BASED DATA SET FOR THE RENEWABLE ENERGY INDUSTRY

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1. INTRODUCTION

1.1 Background Information

Renewable energy technologies (RETs) are expected to provide between 5% and 10% of the world's energy within 25 years, and rise to 50% by the year 2050. The estimated average growth rate of the photovoltaic market is 25% per year through the year 2010 (Maycock 2000). Growth in wind turbine sales has averaged 40% per year for the past 5 years. (Gipe 2000) Utility grid-connected solar thermal power plants will be cost competitive with fossil fuel plants in the near future; and various international organizations are currently offering significant economic incentives to deploy initial plants (Rennels 2000). During the last decade renewable energy sources contributed substantially to the growth in U.S. energy production, outpacing all fuel sources except for nuclear energy (National Energy Policy 2001).

Crucial to the success of RETs is the availability of accurate, global solar radiation and meteorology data. The focus of a Surface meteorology and Solar Energy (SSE) commercial outreach project by NASA's Earth Science Enterprise (ESE) is to make this resource information available to users in the renewable energy industry by way of the Internet. The SSE data set, Release 4, is a satellite derived 10-year climatology of insolation, cloud cover, temperature, surface pressure, surface reflectance, relative humidity, and wind parameters available on a 1^0 latitude by 1^0 longitude global grid system. This new release, available for the Fall of 2001, provides new monthly meteorology and radiation parameters based on recommendations by the renewable energy industry. This paper provides an overview of the SSE web site and estimated uncertainties of insolation, temperature, surface pressure, relative humidity, and wind design parameters through comparison with ground measurement data.

1.2 Marketing Approach

The initial release of the SSE web site, in 1997, proved to be less than successful. Scientific in nature, it did not appeal to data users in the renewable energy industry. Out of a disappointing beginning, the investigators of the SSE project developed a methodology for making the SSE web site a success and have continually implemented these steps for all subsequent releases. The methodology, derived from the book *The End of Marketing As We Know It,* is as follows (Zyman 1999):

1. Create a prototype data set
2. Research the industry
3. Decide the niche for the data set
4. Foster a relationship with potential users
    a) learn their business
    b) ask the right questions
    c) openly bow to their demands
5. Partner to increase demand
6. Advertise honestly and ask the industry to use the data set
7. Position the data set against the competition
8. Specialize: continually reinvent the data set
9. Cultivate new users and cater to established users
10. Change – if our efforts are not working

1.3 Users

The SSE data set has been utilized as a standalone data source for researchers around the world involved in RETs. Over 2225 registered users from 46 states and 94 countries have accessed the web site generating approximately 500,000 hits since June 1999. Over the past several months, the web site is averaging 35,000 hits per month from users in non-profit organizations, universities, commercial businesses, and financial institutions. Organizations include The World

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Bank, UNESCO, Winrock International, International Financial Corporation, BP Amoco, Shell, and the USDA Forest Service. In addition to being a standalone source for data, the SSE web site is also linked to two software packages: RETScreen® and SolarSizer. RETScreen® is a standardized and integrated renewable energy project analysis software tool developed by Natural Resources Canada's CANMET Energy Diversification Research Laboratory (CEDRL). Users of RETScreen® evaluate the annual energy production, costs, and financial viability of RET projects for any location of the globe by incorporating insolation and meteorology data into the software. SolarSizer is a professional software tool for designing and sizing photovoltaic systems. The software is available through the REPP-CREST (Renewable Energy Policy Project) web site (http://solstice.crest.org/).

1.4 Surface meteorology and Solar Energy Web Site, Release 4

Release 4 of the SSE data set is considered to be accurate for preliminary feasibility studies of renewable energy projects and is available, free-of-charge, over the Internet (http://eosweb.larc.nasa.gov/sse/). The data set is a continuous 10-year global climatology (1983-1993) of satellite-derived insolation and meteorology data. The irradiance and cloud data are derived from the International Satellite Cloud Climatology Project (ISCCP) D1 data set and processed through the Langley parameterized Shortwave Algorithm (LPSA) to derive surface radiation budget parameters (Gupta et al. 2001). ISCCP data are processed on a 2.5^0 equal area grid system and then interpolated to a 1^0 equal angle grid system for web site distribution. The meteorological parameters are processed from Goddard Earth Observing System Version 1 (GEOS-1), supplied by the NASA Goddard Data Assimilation Office. GEOS-1 is a reanalysis product that blends surface and upper air observations with satellite retrievals. The data are processed on a 2.5^0 equal-area grid system and then interpolated to a 1^0 equal angle grid system for web site distribution. Over 100 monthly averaged satellite-derived parameters are available on the web site for download in plot, text (regional subset data files), or data table formats. Insolation parameters are available for solar cooking, sizing and pointing of solar panels, solar thermal applications, sizing battery storage systems, and sizing surplus-product systems. Geometry and cloud information, temperatures, heating and cooling degree days, frost days, and wind velocities are also included. Daily satellite derived data files are available for insolation, top-of-atmosphere insolation, and air temperature. Global and user-defined regional plots can be created for most of the satellite-derived parameters. Daily ground site data measurements of insolation are provided for approximately 1200 ground site stations (courtesy of the World Radiation Data Center).

Additional solar parameters, direct normal and diffuse radiation, have been added to this release. These solar parameters have been estimated by processing LPSA monthly global horizontal irradiance through the Page conversion model (Page 1961). 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. Also new GEOS –1 10-meter and 50-meter wind velocity estimates have been added, including percent difference for wind speed at 10-meters from average wind speed at 50-meters based on 17 vegetation types. All form and parameter changes and additions to the web site have been included based on recommendations by the renewable energy industry.

2. DISCUSSION OF PARAMETER ESTIMATED UNCERTAINTIES

2.1 Ground Measurements Vs. Satellite Data

Historically, climatological profiles of insolation and meteorology parameters calculated from ground measurement data have been used for determining the viability of RET projects. These climatological profiles are used for designing systems that have low failure rate. Although ground measurement data has been used successfully in the past for implementing RETs, there are inherent problems in using ground measurement data for resource assessment. Ground measurement stations are located throughout the world, but they are situated mainly in populated regions. In remote regions (where many RETs are implemented) measurement stations are limited. Also, at any particular station data recording can be sporadic leading to incomplete climatological profiles; and, data inconsistencies can occur within a station and from one station to another. In contrast to ground measurement data, the SSE data set is a continuous and consistent 10-year global climatology of insolation and meteorology data on a 1^0 by 1^0 grid system. Although the SSE data within a particular grid cell are not necessarily representative of a particular microclimate, or point, within the cell; the data are considered to be the average over the entire region of the cell. For this reason, the SSE data set is not intended to replace ground measurement data. Its purpose is to fill the gap where ground measurements do not exist, and to augment data where ground measurements do exist. In utilizing the SSE data set, the renewable energy resource potential can be determined for any location on the globe and is considered to be accurate for preliminary feasibility studies for renewable energy projects. The following sections will describe the limitations of the SSE satellite data set; and, provide estimates of the levels of uncertainty for insolation, temperature, surface pressure, relative humidity, and wind through comparisons with quality ground measurement data.

2.2 Ground Measurement Data Sets

Historical ground measurements were obtained from CEDRL and the National Renewable Energy Laboratory (NREL). The 30-year average RETScreen Ground Monitoring Stations Weather Database ("RETScreen") database from CEDRL contains temperature, wind, humidity, and insolation data from 1000+ sites. The RETScreen database is available from the RETScreen Website (http://retscreen.gc.ca). NREL distributes the World Radiation Data Center (WRDC) ground measurement data for insolation for1195 sites for the period from 1964 through 1993 on the following web site (http://wrdc-mgo.nrel.gov/). All ground stations were not operating for every year in either data set. When more than one ground measurement station was located in a grid cell, the ground measurement values were averaged for comparison to the SSE data. It is generally considered that measured data are more accurate than satellite-derived values. Unfortunately, measurement uncertainties are not precisely known for either ground measurement data set. For this reason, SSE differences from ground measurements are considered as estimates of uncertainty. Following usual industry standards estimated uncertainty is assumed as 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. Both methods give similar magnitudes of error according to *Statistics* by Freedman, Pisani, Purves, and Adhikari (1991). It is emphasized that larger values of uncertainty can occur in actual practice; however, they will not be frequent.

2.2 Estimated Uncertainty of Solar Insolation Values

Satellite-based insolation values were obtained using the NASA Langley Parameterized Shortwave Algorithm (LPSA). Inputs to LPSA were NASA ISCCP D-1 cloud information and NASA GEOS-1 meteorology. Key concerns in the analysis of satellite-based insolation data are (1) uncertainty in land/water interface regions where cloud detection is more difficult from space and (2) the influence of abnormal heavy smoke or pollution aerosol levels that are not included in multi-year average data bases. Coastal regions were analyzed separately from interior regions to address the first item. Analysis was performed for near-average, El Nino, and La Nina years to assess the impact of changing aerosols in combination with changing clouds. Results from comparisons with monthly ground data over each year are given in Table 1.

Bias differences are included in the RMS values used estimate the uncertainties. Average bias differences for the NREL data set range from -2.0% to +3.3% depending on the year. It should be noted that the near-average years of 1983-2nd half and 1985 had very slight La Nina tendencies. 1984 and 1986 have very slight El Nino characteristics. 1990 could be classified as a small El Nino based on Southern Oscillation Index values.

TABLE 1: ESTIMATED UNCERTAINTY FOR SOLAR INSOLATION

Near-Average Years	NREL Interior Regions	NREL Coastal Zones	RETScreen All Regions
1983-2nd Half	11.7%	12.9%	
1984	13.8%	13.1%	13.9%
1985	13.5%	12.5%	13.1%
1986	13.1%	13.7%	12.6%
1990	15.5%	15.4%	13.4%
El Nino Years			
1987	14.5%	14.6%	N/A
1991	17.0%	15.3%	N/A
1992	15.4%	13.7%	N/A
1993-1st Half	14.9%	15.4%	N/A
La Nina Years			
1988	14.8%	13.8%	N/A
1989	14.9%	13.9%	N/A

On average the SSE solar insolation data are higher than ground measurment data; and the results suggest that satellite-based SSE solar insolation data are reasonably consistent for a wide range of global environments. It should be noted that usual regional pollution and smoke are accounted for in the SSE LPSA algorithm. Abnormally strong smoke or pollution events are not considered and may cause deterioration in accuracy. Summer atypical smoke in the western regions of the U.S. in 1988 and 2000 are examples of that type of situation. Smoke and pollution scatters and absorbs insolation, therefore decreasing the amount reaching the earth's surface. For strong smoke or pollution events, satellite estimates of insolation may be higher than ground measurements and may not be accurate within cities that have very high pollution relative to the surrounding countryside.

2.3 Estimated Uncertainties of Near-Surface Air Temperature

As noted in the table, 1986 is considered a near average year. SSE 10-m air temperatures for 1986 were compared to 30-year-average monthly RETScreen weather data from 1000+ ground sites over the globe. Unfortunately, results vary as a function of temperature.The uncertainty is largest for cold temperatures and is 3.2% for the temperature range from 203^0 K to 243^0 K. It decreases in a near-linear manner to 1.1% at 263^0 K and remains at 1.1% from 263^0 K to 313^0 K. Bias differences range from -1% (below 243^0 K) to -0.02% above 263^0 K. For the most part, RETScreen temperatures are warmer than SSE temperatures.

Near-surface temperature is a property that is converted into a number of design parameters in the renewable energy industry. An analysis of the effects of the above near-surface air temperature uncertainty on temperature-related hardware design parameters has been performed. A sample of approximately 200 potential renewable energy site locations in 7 continental regions has been selected for most parameters. The Heating degree-days parameter was calculated at 100 potential cold-weather sites. Ten-year average SSE values of these parameters have been compared with 30-year RETScreen values. Estimated uncertainties are shown in Table 2.

Values were within 1% of averages in all 7 continental regions except for the Heating-degree days parameter. Values for that parameter ranged from 10.5% (N. and Central America) to 47.7% (South America) depending on region. This illustrates that small biases in cold-weather temperature can accumulate into larger biases in degree-day parameters. A reliable knowledge of temperature bias is required to correct the degree-day parameters. Additional work is planned to investigate this issue.

2.4 Estimated Uncertainty for Relative Humidity

Relative humidity is not available from NASA GEOS-1 data. An approximate procedure to estimate values was developed at the Langley Research Center for use in Release 3 SSE. Near average year 1986 SSE results were correlated with approximately 800 RETScreen sites over the globe. Estimated uncertainty (RMS value) is 15.3%; bias is 5%. SSE results were higher than RETScreen. Relative humidity was also tested using the 200 potential renewable energy site locations in 7 continental regions. At these sites, average estimated uncertainty was 9.7%. All regions were within 2% of the average excluding Europe, which had an uncertainty of 5.4%.

TABLE 2: ESTIMATED UNCERTAINTY FOR TEMPERATURE DESIGN PARAMETERS

PARAMETER	UNCERTAINTY
Near-Surface Air temperature - deg K	1.2%
Heating Design Temperature -deg K	1.3%
Cooling Design Temperature -deg K	1.4%
Summer mean daily temperature range - deg K	0.9%
Heating degree-days below 18 deg Celsius - deg K	14.6%

2.5 Estimated Uncertainty for Surface Air Pressure

SSE surface air pressure and RETScreen values were correlated over the globe for 1986. Estimated uncertainty from RMS values is 3.6%. Bias differences averaged -1.5% with RETScreen values higher than SSE values. Surface air pressure was also tested using the 200 potential renewable site locations in 7 continental regions. Estimated uncertainty from that test was 2.4%. Most regions were similar except the South West Pacific and South America experienced 1.2% and 5.4% uncertainty, respectively.

2.6 Description of 50-meter Wind Velocities and Estimated Uncertainty of new 10-meter Wind Velocities

Wind velocities at 50-meter heights have been referenced to soil, water, ice or snow surfaces. This approach is different from usual wind data referenced to roughness lengths of "effective" surfaces believed to be in the upper portion of the vegetation canopies. For example, 50-meter SSE winds would be only 30 meters above the "effective" surface of a 20-meter high forest. The actual surface as the reference allows close-to-the-surface wind estimates useful to a wide range of industries including small wind, hybrid renewables, agriculture, architecture, hydrology, and public health in populated and mixed vegetation regions. These SSE data alone are not appropriate when there are large topographic features within a cell. Wind industry organizations such as DOE/NREL (http://www.nrel.gov/wind), TrueWind Solutions (http://www.truewind.com), WIND Engineers, Inc. (http://www.WindEngineers.com) have expertise in assessing topography effects within a region.

The new 10-meter wind velocities are referenced to 50-meter wind velocities that are based on vegetation type for improved accuracy. Uncertainties are listed in Table 3. More detail on the SSE wind data is provided in Whitlock et al. (2001).

TABLE 3: ESTIMATED UNCERTAINTIES ASSUMING "AIRPORT"-TYPE GROUND SITES

	Release 4	Release 3
Canadian 10-m sites		
RMS (includes Bias)	.82 m/s	1.96m/s
Bias	-.20m/s	-1.20m/s
Global Sites *		
RMS (includes Bias)	1.10	1.86
Bias	-.10	-.70
Interior continental sites *		
RMS (includes Bias)	1.05 m/s	1.40 m/s
Bias	-.01 m/s	Not computed
Coastal sites *		
RMS	1.21 m/s	Not computed
Bias	.20 m/s	Not computed

* Undocumented instrument heights for most sites.

3. CONCLUDING REMARKS

The NASA SSE data set (Release 4) described in this paper contains more accurate and new types of resource information than previous releases and is formulated for assessing and designing renewable energy systems for any region of the world. This type of information has previously only been available from a limited number of ground measurement stations located mainly in populated cities throughout 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 of RETs. When used is conjunction with analysis tools such as 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 RETs are being considered along with conventional energy sources, the NASA SSE data set provides a consistent climatology of insolation and meteorology data for resource assessment on a global scale.

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