RELEASE 3 NASA SURFACE METEOROLOGY AND SOLAR ENERGY DATA SET FOR RENEWABLE ENERGY INDUSTRY USE

Charles H. Whitlock, Donald E. Brown, William S. Chandler and Roberta C. DiPasquale
Science Applications International Corporation
One Enterprise Parkway, Suite 300
Hampton, VA 23666-5845

Nathalie Meloche and Gregory J. Leng
Natural Resources Canada – CANMET Energy Diversification Research Laboratory
1615 Lionel-Boulet Blvd.
Varennes, Quebec J3X 1S6

Shashi K. Gupta and Anne C. Wilber
Analytical Services & Materials, Inc.
One Enterprise Parkway, Suite 300
Hampton, VA 23666-5845

Nancy A. Ritchey
Computer Sciences Corporation
3217A North Armistead Ave
Hampton, VA 23666-1379

Ann B. Carlson, David P. Kratz, and Paul W. Stackhouse
NASA Langley Research Center
Hampton, VA 23681-0001

ABSTRACT

This paper reviews Release 3 of the NASA Surface meteorology and Solar Energy (SSE) data set consisting of resource parameters formulated for assessing and designing renewable energy systems. The SSE data set is available free-of-charge over the Internet (http://eosweb.larc.nasa.gov/sse/). This new release contains more accurate estimates of resource parameters in comparison to previous releases. Also, additional meteorological parameters have been included based on recommendations by the renewable energy industry. This new SSE data set is formulated from NASA satellite- and reanalysis-derived insolation and meteorological data for the 10-year period from July 1983 through June 1993. Results are provided for 1^{O} latitude by 1^{O} longitude grid cells over the globe. The SSE global data set makes it possible to quickly evaluate the potential of renewable energy projects for any region of the world and is considered to be accurate for preliminary feasibility studies of renewable energy projects. This paper provides estimated uncertainties of insolation, temperature, surface pressure, relative humidity, and wind design parameters through comparison with ground measurement data.

1. INTRODUCTION AND BACKGROUND

1.1 Surface meteorology and Solar Energy Data Set

Renewable energy technologies (RETs) are poised to change the face of the world's energy market. These technologies range in complexity from the introduction of solar ovens and simple photovoltaics panels into rural communities to the construction of commercial buildings with integrated photovoltaics and large thermal and wind generating power plants. 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 easily accessible to the renewable energy industry by way of the Internet. The SSE data set, Release 3, is a satellite- and reanalysis-derived 10-year climatology of insolation, cloud cover, temperature, surface pressure, surface reflectance, relative humidity, and wind parameters available on a 1^{O} latitude by 1^{O} longitude global grid system. This new release, available Fall 2000, contains more accurate estimates of resource parameters in comparison to previous releases. Also, additional meteorological parameters have been included based on recommendations by the renewable energy industry.

1.2 SSE Data Users

The SSE data set has been utilized as a standalone data source for researchers around the world involved in RETs. Researchers from non-profit organizations, universities, commercial businesses, and financial institutions have accessed previous releases of the web site. Organizations include The World 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 RETScreen®, 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 on the globe by incorporating insolation and meteorology data into the software.

1.3 Ground Measurements Versus Satellite Data

Historically, climatological profiles of insolation and meteorology parameters calculated from ground measurements have been used for determining the viability of RET projects. These climatological profiles are used for designing systems that have low failure rates. Although ground measurement data has been used successfully in the past for implementing RETs, there are inherent problems in using them for resource assessment. Ground measurement stations are located throughout the world, but they are situated mainly in populated regions. In remote areas (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 measurements, the SSE data set is a continuous and consistent 10-year global climatology of insolation and meteorology data on a 1^{O} by 1^{O} 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 area 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 areas 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. This paper 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 measurements.

2. ESTIMATED UNCERTAINTY OF THE RELEASE 3 SSE DATA SET

2.1 Ground Measurement Data

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 for 1195 sites for the period from 1964 through 1993 from their 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 measurements 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 (New York: W.W. Norton & Company, 1991). It is emphasized that larger values of uncertainty can occur in actual practice, however, they are not 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 International Satellite Cloud Climatology Project Version D (ISCCP D-1) cloud information and NASA Goddard Earth Observing System Version 1 (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 episodic heavy smoke or pollution aerosols events that are not included in multi-year averages. 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.

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

Bias differences are included in the RMS values used to estimate the above uncertainties. Average bias differences for the NREL data set range from -2.0% to +3.3% depending on the year. Average RETScreen bias differences range from +1.0% to +2.5% depending on the near-average 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 had very slight El Nino characteristics, and 1990 could be classified as a small El Nino based on Southern Oscillation Index values.

On average the SSE solar insolation data are higher than ground measurements, and the above results suggest that satellite-based SSE solar insolation estimates 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. Episodic 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 such situations. Aerosols from smoke and pollution scatter and absorb 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-meter air temperatures for 1986 were compared to 30-year average monthly RETScreen weather data from 1000+ ground sites over the globe. Original GEOS-1 temperatures are known to less accurate in cold climates. SSE performed an approximate linear correction in the range 223 K to 273 K to bring values over the globe in line with 30-year RETScreen values. Unfortunately, uncertainty on a global scale is still larger for cold temperatures. Estimated uncertainty is 3.2% for the temperature range 203 K to 243 K. It decreases in a near-linearly manner to 1.1% as temperature increased to 263 K. The 1.1% value appears constant from 263 K to 313 K. Bias differences range from -1% (below 243 K) to -0.02% above 263 K. Generally, 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 sites 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.

TABLE 2: ESTIMATED UNCERTAINTY FOR TEMPERATURE DESIGN PARAMETERS

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

Values are within 1% of averages in all 7 continental regions except for the Heating-degree days parameter. Values for that parameter range from 10.5% (N. and Central America) to 47.7% (South America) depending on region. This inconsistency suggests that small biases in cold-weather temperature can accumulate into larger biases in degree-day parameters. Another explanation may be that South America was impacted by many El Nino and La Nina events in the 30-year average period in a manner different from the other 6 continental regions. 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 approximation technique to estimate values was developed for use in Release 3 SSE. The procedure uses surface pressure, 10-meter temperature, and 10-meter specific humidity. Near-average year 1986 SSE results were correlated with approximately 800 RETScreen sites over the globe. Estimated global uncertainty is 15.3%, bias is 5%. SSE results are higher than RETScreen. Relative humidity was also tested using the 200 potential renewable energy sites in 7 continental regions. At these sites, average estimated uncertainty is 9.7%. All regions are within 2% of the average excluding Europe, which has an uncertainty of 5.4%.

2.5 Estimated Uncertainty for Surface Air Pressure

SSE surface air pressure and RETScreen values were correlated over the globe for 1986 with an estimated uncertainty of 3.6%. Bias differences average -1.5% with RETScreen values higher than SSE values. Surface air pressure was also tested using the 200 potential renewable sites in 7 continental regions. Estimated uncertainty is 2.4%. Most regions have similar values except the Southwest Pacific and South America experience 1.2% and 5.4% uncertainty, respectively.

2.6 Estimated Uncertainty for 10-meter Wind Speed

GEOS-1 wind speeds are originally provided on a 2^{O} latitude by 2.5^{O} longitude grid system. These values were interpolated to a 1^{O} grid system for the Release 3 SSE data. Localized topography effects are not accounted for in the SSE data set. GEOS-1 monthly average wind speeds generally range between 0.5 to 14 m/s in various regions of the globe.

RETScreen data are mostly from airports with wind data at unspecified heights above the ground. Heights are only provided for Canadian sites. An additional issue is that airports are usually not placed in locations where wind speeds are high for reasons of safety. RETScreen wind speeds range from 0.2 to 14.5 m/s. The mean value is 4.2 m/s. 1986 SSE values have been compared with 30-year RETScreen values in two ways.

- Correlations were first conducted using only those RETScreen sites where measurements were known to be at a 10-m altitude. These are approximately 100 Canadian sites. RMS differences are 1.96 m/s over a range from 1 to 11 m/s. Bias differences are -1.2 m/s with RETScreen values being higher than SSE.

- Correlations were also conducted using over 780 RETScreen wind sites. RMS differences are 1.86 m/s over the 0.2 to 14.5 m/s speed range. Bias differences are -0.73 m/s. Large differences are found in a few sites in the mountains or coastal regions with mountains. Values are almost always within a -3 m/s to +2 m/s uncertainty level over most flat, mountain, and coastal stations.

- Correlations with data from a sample of 162 sites in the 7 continental regions give an estimated uncertainty of 1.4 m/s.

3. CONCLUDING REMARKS

The NASA SSE data set (Release 3) 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 measurements. However, the SSE data are considered accurate for preliminary feasibility studies of RETs. When used in 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, to industries developing the technologies, and to 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.

4. ACKNOWLEDGEMENTS

The SSE web site is made possible through the following collaborations: Natural Resources Canada, National Renewable Energy Laboratory, Solar Energy International, Sun Frost, Inc., the Center for Renewable Energy and Sustainable Technology, Solar Household Energy, Inc., Numerical Logics, Inc., and the Atmospheric Sciences Research Center at The University at Albany.