PROGRESS ON UPDATING THE 1961–1990 NATIONAL SOLAR RADIATION DATABASE

Dave Renné
Stephen Wilcox
Bill Marion
Ray George
Daryl Myers
Tom Stoffel
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393
david_renne@nrel.gov
stephen_wilcox@nrel.gov
bill_marion@nrel.gov
ray_george@nrel.gov
daryl_myers@nrel.gov
tom_stoffel@nrel.gov

Richard Perez
Atmospheric Sciences Research Center
251 Fuller Road
State University of New York
Albany, New York 12203
perez@asrc.cestm.albany.edu

Paul Stackhouse Jr.
NASA/Langley Research Center
21 Langley Blvd., MS-420
Hampton, VA 23681-2199
p.w.stackhouse@larc.nasa.gov

ABSTRACT

The 1961–1990 National Solar Radiation Data Base (NSRDB) provides a 30-year climate summary and solar characterization of 239 locations throughout the United States. Over the past several years, the National Renewable Energy Laboratory (NREL) has received numerous inquiries from a range of constituents as to whether an update of the database to include the 1990s will be developed. However, there are formidable challenges to creating an update of the serially complete station-specific database for the 1971–2000 period. During the 1990s, the National Weather Service changed its observational procedures from a human-based to an automated system, resulting in the loss of important input variables to the model used to complete the 1961–1990 NSRDB. As a result, alternative techniques are required for an update that covers the 1990s. This paper examines several alternative approaches for creating this update and describes preliminary NREL plans for implementing the update.

1. INTRODUCTION

The 1961–1990 National Solar Radiation Data Base (NSRDB) was completed by the National Renewable Energy Laboratory (NREL) in 1992. The database consists of serially complete hourly modeled and measured solar radiation data for 239 locations in the United States. Data records include associated meteorological measurements such as temperature, humidity, cloud cover, and visibility. Measured solar radiation data are included in the data sets when available for 52 NSRDB *primary* stations, but even among those, no station has more than a few years of measured data. All remaining solar data were modeled using a meteorological-statistical (METSTAT) solar radiation model. Within the entire NSRDB, about 93% of the data are modeled.

Since its completion, this database — along with associated products such as solar radiation data manuals and typical meteorological year data — has been widely used by solar planners and designers, building architects and engineers, and renewable energy analysts. A 1971–2000 database would not only provide access to the most recent climate information but also support ongoing efforts to track the effects of climate change and interannual climate variability on the solar resource. For example, a number of long-term trend analyses indicate that solar radiation may be decreasing in many areas around the world because of a combination of an increasing trend for cloudiness and an increasing quantity of atmospheric particulates.[1] The Intergovernmental Panel on Climate Change's Third Assessment Report also indicates that cloudiness may be increasing due in part to an increasing amount of moisture in the atmosphere, which is associated with a warmer climate.

To maintain the integrity of a long-term climatological record, a consistent method across the entire period of record must be employed for measuring, modeling, or summarizing the parameters. This requirement is the most formidable challenge for developing a plan for updating the database. The major reason for this is the significant changes that occurred in the 1990s in the way the National Weather Service (NWS) obtains hourly observations. As part of a modernization and cost-cutting effort, the NWS began replacing human observers with the Automated Surface Observing System (ASOS). These changes began in the early 1990s, and the majority of stations changed over by the mid- to late-1990s (see Figure 1). ASOS stations use an entirely different scheme for estimating cloud cover and no longer provide both the opaque and total cloud cover observations that were key input parameters for METSTAT.

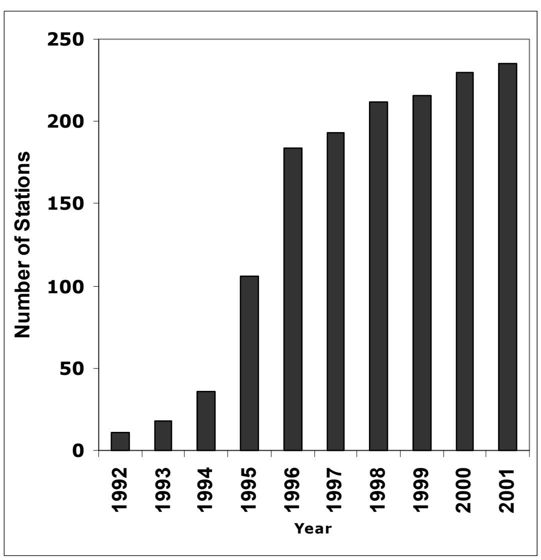

Fig. 1: National Weather Service total conversions from human observation to ASOS.

Thus, a variety of alternative approaches have been considered to create a database for the 1990s as well as to anticipate how future decades can be added to the database. These alternatives include either (1) modifying the METSTAT model to accommodate the ASOS observations or (2) using satellite imagery to estimate solar resources on a uniform spatial grid.

Both of these approaches would make use of existing high-quality surface measurement programs maintained by a number of agencies and organizations during the 1990s. Because of the numerous extensive changes in the observational network, serious consideration has been given to the second approach. The overall scheme involves the following activities:

1. Evaluation of surface measurement network data in the 1990s

2. Use of the NASA surface meteorology and solar energy 1° resolution data set through the 1990s and back into the 1980s so that a comparison with concurrent METSTAT model runs for select stations can be made

3. Application of the high-resolution satellite-derived approach by SUNY/Albany for the entire United States, beginning with the late-1990s.

2. ISSUES OF CLOUD OBSERVATIONS

Of all atmospheric phenomena, clouds have the greatest influence on the magnitude of solar radiation that reaches the surface of the Earth. As such, accurate cloud observations are crucial to all meteorological-based solar radiation models. The original NSRDB used cloud observations made by the NWS observers and archived by the National Climatic Data Center (NCDC). These observations included both total and opaque cloud cover estimates (in tenths of skies) and were reported at one- to three-hour intervals. From this information, the METSTAT model calculated translucent cloud cover (total minus opaque) and used both opaque and translucent cloud cover as parameters for estimating solar irradiance.

In the mid-1990s, the NWS began a transition from human observation to automated observation using the ASOS. This transition poses two obstacles to an updated NSRDB:

1. <u>A change in measurement methodology</u>
   The ASOS reports a single cloud cover estimate based on an analysis of clouds detected at the zenith

over a period of 30 minutes rather than an instantaneous estimate based on observing the entire sky dome. Although the ASOS method provides a useful estimate of cloud cover and may produce an estimate as reliable as the human observation, the two methods very likely do not produce directly comparable measurements. Further, although human observers report cloud estimates to the nearest one-tenth sky, the ASOS reports broader ranges of cloud cover based on octals: 0% (CLR), 0–25% (FEW), 25–50% (SCT), 50–87% (BKN), and 87–100% (OVC).

2. <u>A change in reported parameters</u>
   The ASOS is not capable of reliably detecting clouds above 12,000 feet and as such does not attempt to differentiate between total cloud cover and opaque cloud cover as did human observers. Translucent clouds (cirrus) are most prevalent at altitudes higher than the ASOS can detect; hence, the ASOS data lacks the ability to report the traditional total and opaque cloud cover estimates necessary to derive translucent clouds.

These two issues have an important effect on the goal of the updated NSRDB to identify and reveal long-term trends in solar radiation. Climatic changes influencing the magnitude of solar radiation are expected to be on the order of a fraction of a percent per year and perhaps only a few percent over the 30-year period of an updated NSRDB. Therefore, a reporting bias of even a few percent in the most significant model input parameter could confound attempts to see any true climatic influence on solar radiation between the early- and late-1990s. By one estimate, a bias of one-tenth in cloud reporting could cause errors in solar radiation estimates of more than 10% (3). In this context, it is significant that the resolution of the ASOS is typically 2.5/10 and at best 1.3/10.

Other lesser, though still significant, issues regarding cloud observations exist. One is the practice of modifying or augmenting ASOS cloud observations with human observations when qualified observers are on duty. This practice has been documented at some larger commercial airports (4) and may imply a known and accepted discrepancy between ASOS and human observations (and possibly substandard automated observations at times). But in addition, it makes more difficult the jobs of separating the two observing methods, characterizing differences between them, and modifying the model to accommodate the differences.

To conclusively determine the differences between human and automated cloud observations, a study would be necessary to compare the two sets of concurrent observations. Most studies of ASOS versus human observations have focused on the needs and applications of aviation — for instance, a comparison of cloud ceiling height and horizontal visibility. We are continuing to seek studies that compare cloud cover observations.

Finally, the METSTAT model requires inputs of both total and opaque cloud cover observations to derive the necessary translucent cloud cover. This information is used for direct solar transmittance and atmospheric scattering (diffuse). ASOS specifications indicate that detecting high clouds and differentiating between opaque and translucent clouds is beyond its capabilities. However, to modify METSTAT to accommodate the single, limited ASOS cloud observation would cut deeply into the inner algorithms of the model. To be successful, such an effort would (1) need to be closely examined for its effect on modeled output and (2) probably have to be applied uniformly across the entire period of record of human observations using only the opaque (rather than total) cloud estimates.

In summary, there are significant differences between ASOS and human cloud observations that make continued use of the METSTAT model difficult:

1. Characterizing the differences between human and automated observations at best would be based on a limited sample size (one year from limited sites).

2. A thorough study and understanding of the human/ASOS differences would not address the lack of differentiation between total and opaque observations.

3. Modifying the METSTAT model would set in motion an entirely new set of research and development issues.

4. Working to accommodate ASOS cloud estimates in METSTAT would not resolve the questions about the validity of long-terms trends.

3. <u>SATELLITE-DERIVED SOLAR RADIATION</u>

Advances in the past 10 years have made satellite-derived solar estimates a practical, if not desirable, alternative to meteorological-based solar models. This method has the additional benefit of producing solar radiation estimates with much higher spatial resolution compared with the technique of interpolating between NSRDB ground stations. Although the volume of input data would be much higher than that used for the NSRDB, the input data are much more consolidated (satellite image files). It is also likely that satellite-derived solar estimates will be the method of choice as satellite technology improves, satellite models are advanced, and the need for higher-resolution contouring increases.

Two methods are being considered for use in any updated solar radiation database. One method, developed by the NASA/Langley Research Center, uses the global network of geostationary and polar orbiting weather satellites to provide a long-term, gridded global data set at a 1° by 1° spatial resolution. In the near future, a 12-year data set will be made publicly available. The U.S. portion of this data set will be invaluable in providing a consistent, high-quality, modeled data set that spans the period of NWS changeover to the ASOS observational system.

A second satellite-based methodology is the high-resolution site/time-specific scheme developed at SUNY/Albany in New York (2). This empirical method uses imagery from the GOES-East and GOES-West geostationary weather satellites, which provide continuous weather observations across all of North America. This method produces hourly time series of all solar resource components (global horizontal, direct normal, and diffuse) at a very high spatial resolution (10 km by 10 km has been chosen for this study). A current disadvantage of this particular method is the availability of satellite images. The GOES satellite images required for this method have been archived by project researchers only since 1998. Although satellite-derived solar data for 1998–2000 would likely be available to this project at very low or no cost, this leaves a gap of about 7 years from 1991 through 1997. This would either necessitate the METSTAT methods of the original NSRDB (for which input cloud data do not exist for the latter part of the gap) or the acquisition of additional satellite data for those years not covered by the METSTAT method. If consistency issues are successfully addressed, a derived NSRDB could be produced from gridded data for the 239 stations in the NSRDB to provide a serially complete data set for applications that require NSRDB as input. A more practical, though possibly much more expense, approach involves acquiring all necessary hourly satellite data for the entire decade of the 1990s.

4. <u>OPTIONS FOR PRODUCING A 1971–2000 SOLAR DATABASE</u>

The creation of an updated NSRDB that spans the 1990s and meets the goal of revealing long-term trends in the magnitude and variability of solar radiation must first solve the problem of the discontinued human sky observations. The most attractive methods to replace the METSTAT model are the high-resolution, satellite-derived methods such as those of Perez (2). However, a plan must be developed to identify any bias that exists between the METSTAT model and the satellite model (and ultimately to identify biases with measured solar data). This would be done most effectively by comparing concurrent data from both models.

Around 1995, three developments occurred that are significant to a concurrent comparison:

1. Change from human cloud observations to ASOS observations
2. Beginning of satellite image archiving by Richard Perez
3. Switchover of solar radiation network management and configuration.

Regarding Number 2, although satellite imagery is available for decades prior to 1998, its practical availability is limited by cost and, to a lesser extent, by image resolution. The acquisition costs of historical satellite imagery could overwhelm the project budget. Nonetheless, this avenue will continue to be investigated as pricing structures for acquiring historical imagery may change with time. It may also be practical to acquire a subset of historical images for the purpose of characterizing the effects on solar radiation modeling of the transition from human to automated observations.

Given this information, there is little if any overlap between the periods of record for input data to the METSTAT model and that for the high-resolution satellite method. Absent this overlap, any discontinuity across the transition may be difficult to determine. However, it could be inferred through the use of measured solar radiation that spans the time periods of the two methods. Unfortunately, in the third development noted above, the mid-1990s also saw significant changes in some of the long-term solar radiation networks — such as site shutdowns, site relocations, and changed instrumentation or measurement parameters. As a result, the list of long-term measurement sites that coincide with weather service stations may be as short or shorter than that for the original NSRDB. This limits the number and variety of sites available for a comparison. A key option for consideration here is the availability of the NASA Surface Meteorology and Solar Energy Data Set for this purpose. Although it is lower resolution than the SUNY/Albany method, it may be possible to identify key cells that could form a stable reference that spans the period in question.

In short, our efforts will concentrate on using whatever data and methods are available to determine if a transition validation is possible. Solving this problem is a priority, as this issue will require resolution throughout the life of any 30-year solar climate summary that includes the 1990s (through 1991–2020).

5. SUGGESTED APPROACH

With the phasing out of human cloud observations and rapidly advancing satellite solar resource assessment technology, we should ultimately move toward implementing a gridded data product, exploiting its superior spatial resolution. An early effort of this project will be to sponsor an NSRDB workshop to solicit and consolidate expertise to explore the validity of this direction and determine if support exists among potential database users. This workshop was scheduled to be held at NREL April 10–11, 2003. From such a discussion, a more unified approach will likely emerge that will create a more valuable product.

The initial effort should also involve sorting out the data discontinuity and developing a comparison of methods with a limited production of a 10-year database for the 1990s. A reduced number of sites could be selected based on their potential for validating the transition from METSTAT to the satellite model. A possible approach would be to:

1. Use METSTAT to produce hourly data from 1991 through the cessation of human cloud observations
2. Use the high-resolution SUNY/Albany satellite method to produce gridded hourly data for the United States using available satellite images
3. Produce an hourly NSRDB data set from the gridded data to merge with the METSTAT data (using pixels corresponding to ground stations)
4. Analyze the data across the transition using measured solar radiation and the 1° NASA Surface Meteorology and Solar Energy Data Set. Specifically, such an approach would involve the following tasks:
    a. Determine the availability of measured solar radiation data sets that include several years before and after 1995 and that coincide with NSRDB sites. (An expanded list of all data sets of known good quality may be valuable whether or not they span the transition period; they would be useful for overall model evaluation.)
    b. Identify a list of sites for the updated NSRDB.
    c. Obtain satellite-derived data.
    d. Run METSTAT for identified sites.
    e. Analyze results for consistency over the transition.

Once the data are produced and the analysis complete, we can consider these options:

1. Revert to a meteorological-based approach (modifying METSTAT or finding or developing another model).
2. Expand the satellite-based approach, developing the twin products of gridded data and a hybrid NSRDB for a 1971–2000 data set.
3. Drop the NSRDB product and begin expanding the gridded product on an annual or multi-annual basis. It is also possible that satellite images prior to 1998 could be acquired at less cost in the future, allowing for a gridded data set expanded backwards in time.

6. REFERENCES

(1) Renné, D. A Review of Long-Term Trends in Solar Resources, Proceedings of the American Solar Energy Society Annual Conference, 2001

(2) Perez, R., Seals, R. Production of Site/Time-Specific Irradiances from Satellite and Ground Data. NYSERDA Report 98-3, NYSERDA, Albany, NY, 1998

(3) Rymes, M., Preliminary Evaluation of Automated Surface Observing System (ASOS) Cloud Cover Data as Inputs to the METSTAT Model, internal NREL report, 1999

(4) Perez, R., Bonaventura-Sparagna, J., Kmiecik, M., George, R., and Renné, D. Cloud Cover Reporting Bias at Major Airports, Proceedings of the American Solar Energy Society Annual Conference, 2001