Improving the Accuracy of the National Solar Radiation Database (1998–2016)

Preprint

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National Renewable Energy Laboratory

Presented at the 2018 European PV Solar Energy Conference and Exhibition (EU PVSEC)
Brussels, Belgium
September 24–28, 2018

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Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-5D00-72410
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Suggested Citation
Sengupta, Manajit, Anthony Lopez, Aron Habte, and Yu Xie. 2018. *Improving the Accuracy of the National Solar Radiation Database (1998–2016): Preprint*. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5D00-72410. https://www.nrel.gov/docs/fy18osti/72410.pdf.

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IMPROVING THE ACCURACY OF THE NATIONAL SOLAR RADIATION DATABASE (1998–2016)

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ABSTRACT:
The National Solar Radiation Database (NSRDB) provides gridded satellite-based data sets for the United States and other parts of North and South America using cloud properties retrieved from the Geostationary Operational Environmental (GOES) series of satellites. These cloud properties in combination with ancillary atmospheric parameters are used in the Physical Solar Model (PSM) to compute solar radiation. This paper seeks to 1) describe the changes made in the PSM for the recent update to the National Solar Radiation Database (NSRDB 1998–2016) and 2) examine the performance of this update by comparing the data to high-quality ground-based measurements. We summarize the changes to the input data for the radiative transfer models as well as updates for the processing algorithms. We also analyze the performance and accuracy of the NSRDB across the United States. Additional details of the data set and model are described in [1]–[4].

Keywords: NSRDB, PSM, MERRA-2, Aerosol

1 INTRODUCTION

The National Solar Radiation Database (NSRDB) provides a foundational public data set that underpins a large range of research activities that take place within the solar energy industry. The NSRDB data are used as inputs to performance and economic models to improve the accuracy of grid integration studies; facilitate energy modeling using the System Advisor Model (SAM) and PVWatts; enable resource planning using the National Renewably Energy Laboratory's (NREL's) Regional Energy Deployment System (ReEDS), Resource Planning Model (RPM), and Distributed Generation Model (dGen); the U.S. Energy Information Administration's National Energy Modeling System (NEMS) model; as well as production cost modeling using PLEXOS. Therefore, advancing the science used to produce high-quality solar resource data sets is essential to achieve higher penetrations of photovoltaic and concentrating solar power on the grid, reduce integration and deployment costs, and ultimately reduce project risk [5]. As described in [[1]–[4], the current NSRDB, which is V3, is developed using the Physical Solar Model (PSM) V3. The PSM is a unique model that addresses the physics of clouds, aerosol, water vapor, and the primary atmospheric constituents impacting solar radiation. Aerosol and ancillary data sets were obtained from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) (sample parameters are illustrated in Figure 1)

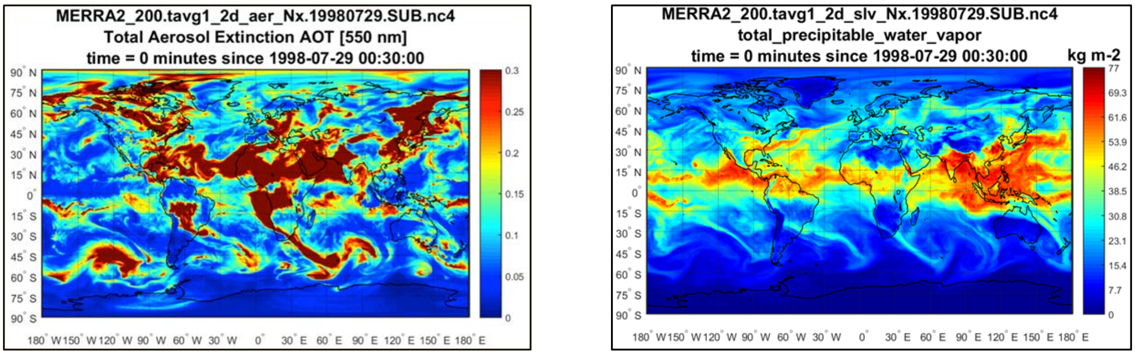

Figure 1: Sample aerosol optical depth and precipitable water vapor data from MERRA-2

2 METHOD

The development of the NSRDB is a computationally intense process because of its high temporal and spatial resolutions and the large volume of diverse input data. Figure 2 demonstrates the complexity of the NSRDB processing and data delivery; however, the use of NREL's high-performance computing capabilities enables the timely processing and delivery of the NSRDB data sets.

The NSRDB update incorporates MERRA-2, which superseded MERRA in 2016. MERRA-2 uses a more advanced data assimilation scheme and better simulates the amount of aerosols and other variables in the atmosphere [6]. In the NSRDB processing, the interpolation and extrapolation methodologies were updated to maintain physical consistency while adapting low-resolution MERRA-2 output to the higher resolution NSRDB. The MERRA-2 variables used in the NSRDB are hourly at a 50-km^2 spatial resolution, which is then interpolated to match the 4-km by 4-km grid and half-hourly temporal resolution. Understanding the impacts of these changes on the solar resource and quantifying the uncertainty are essential for accurately designing utility-scale solar energy conversion systems.

Validation of the NSRDB was carried out by comparing the data to ground-based measurements from the seven National Oceanic and Atmospheric Administration's (NOAA) Surface Radiation Budget Network (SURFRAD) stations. These sites were selected because their ground-based measurements are high quality because the instruments are well calibrated and maintained. The surface data were averaged from 1–3 minutes to 60 minutes (one-half hour before and after the

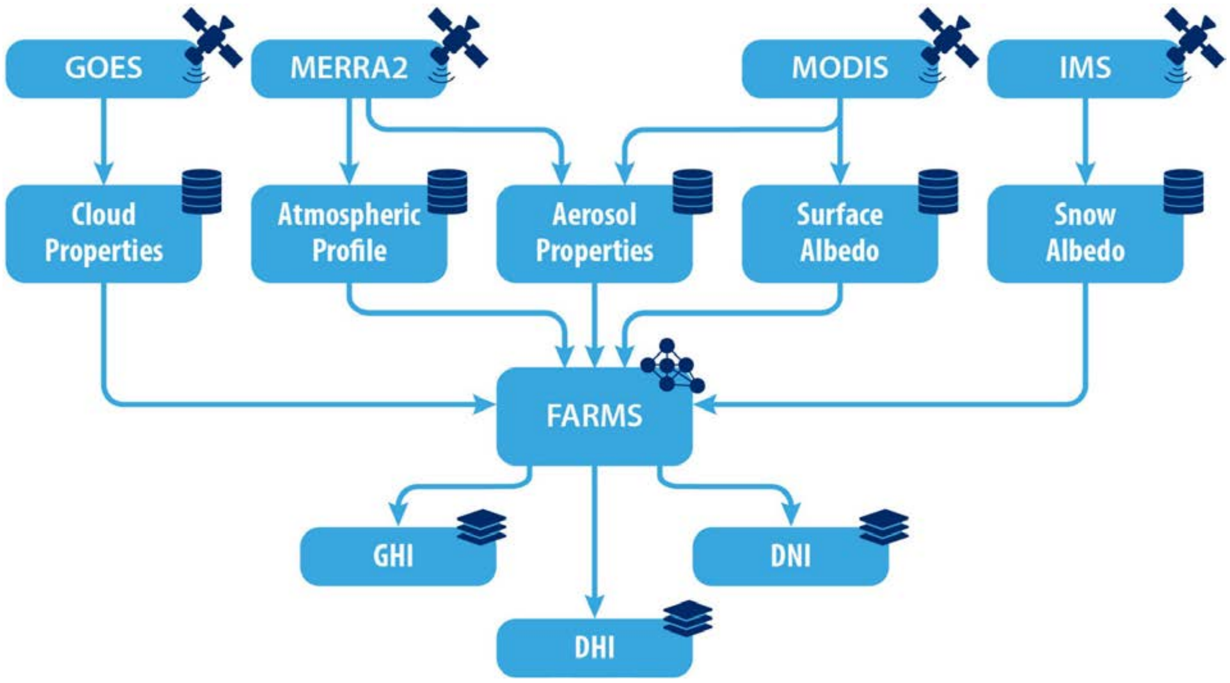

Figure 2: NSRDB processing framework

hour) to compare them with the hourly data from the NSRDB.

3 RESULTS AND DISCUSSION

The NSRDB through the PSM model constitutes an important scientific advancement because additional information content provided either from new ancillary data and/or from using newer generation satellites will automatically flow into improvements in the accuracy of the data set. As described in [6], the improvements in MERRA-2 bring observations and numerical models together in a unified standardized framework resulting in high-quality ancillary information. Hence, the PSM model easily assimilated the new MERRA-2 data set. Table 1 shows the MERRA-2 parameters used in the NSRDB and data variables distributed using the NSRDB website (https://nsrdb.nrel.gov).

Validation of the NSRDB 1998–2016 was conducted by comparing it to satellite-modeled and good quality ground-based measurement data. The results showed that satellite-derived hourly data have a systematic error (bias) of less than ±5% for global horizontal irradiance (GHI) and ±10% for direct normal irradiance (DNI) when compared to hourly averaged ground data. Further, as described in [3], we implemented a comprehensive uncertainty determination approach using the Guide to the Expression of Uncertainty in Measurement (GUM) [7]. The approach identifies the source of uncertainties and quantifies standard uncertainties using the measure of statistic for each source. The standard uncertainties are then combined using the root sum squared method (Figure 3). The statistics such as bias and root mean square error were derived by comparing the NSRDB data to the seven measurement stations from NOAA's SURFRAD. The evaluation was conducted for hourly values, daily totals, monthly mean daily totals, and annual mean monthly mean daily totals and demonstrates the quality of the new data sets currently available from the NSRDB (Figure 3).

The hourly data set demonstrated higher uncertainty; however, with increasing average timescales, the uncertainty approaches the measurement uncertainty, e.g., annual. As described in [3], one reason for the high uncertainty in the hourly data set is because the NSRDB pixel represents a 4-km by 4-km area, whereas a ground-based solar measurement represents only a small area above the measuring station. The subpixel variability in clouds appears to contribute to increased differences.

Table 1. Data set in the NSRDB

Data used in the PSM:	**Data Delivered to:**
• MERRA-2 o Atmospheric pressure o Surface albedo o Aerosols o Aerosol optical thickness o Single-scattering albedo o Aerosol Angstrom parameter o Total ozone o Precipitable water. • GOES (PATMOS-X retrievals) o Cloud effective radius o Cloud optical depth o Cloud type. • Moderate Resolution Imaging Spectroradiometer/National Snow and Ice Data Center o Surface albedo.	• GHI • DNI • Diffuse horizontal irradiance (DHI) • Clear-sky GHI, DNI, and DHI • Cloud type • Dew point** • Air temperature* • Atmospheric pressure • Relative humidity** • Solar zenith angle • Precipitable water • Wind direction** • Wind speed.**
* From MERRA-2 **Recalculated from MERRA-2	

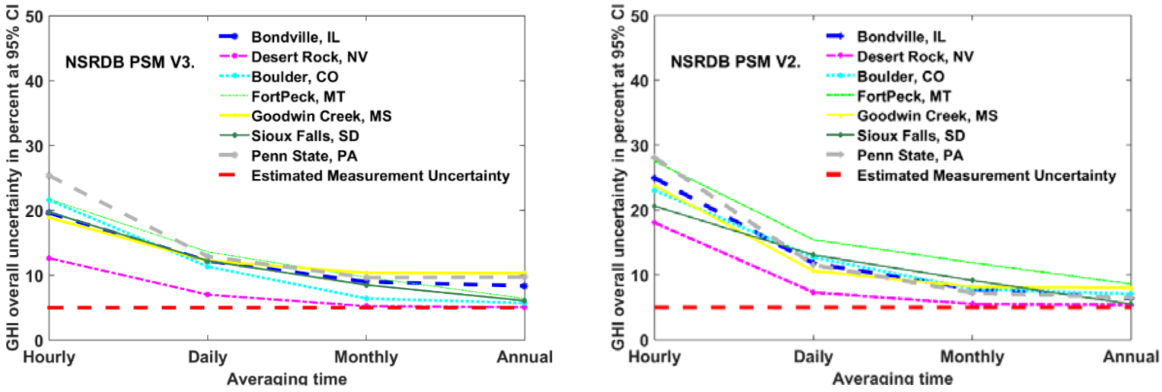

Figure 3: Overall uncertainty estimation GHI for NSRDB PSM V3 (left) and PSM V2 (right) using seven ground-based solar measurement locations. Data used in this figure are from 1998–2015.

The NSRDB V3 demonstrates significant reduction in hourly uncertainty estimations compared to V2, as shown in Fig. 3. These improvements are clearly noticeable for all locations, especially Desert Rock, where the uncertainty was reduced to ~12% in V3 from ~18% in V2.

The monthly and annual averages for NSRDB V2 appear to be better for the eastern locations; this could be attributed to higher bias in NSRDB V3 where the clear and cloudy condition biases are either both positive or negative. However, NSRDB V2 appears to contain biases of opposing signs, resulting in cancellation of biases (Fig. 4.). This is clearly shown in the mean bias error (MBE) statistics in Fig. 4 for all-sky conditions, which provide some insights in explaining the overall uncertainty estimation described in Fig. 3. The MBE (Fig. 4 left panel) shows a positive bias for the eastern locations and a small negative bias for the western locations in the NSRDB V3. The western locations demonstrate significant improvement under cloud conditions, which are attributed to the changes implemented in NSRDB V3. In contrast, NSRDB V2 shows higher negative bias for the western locations; however, as mentioned, because of a cancellation of errors, the eastern locations showed better results under all-sky conditions.

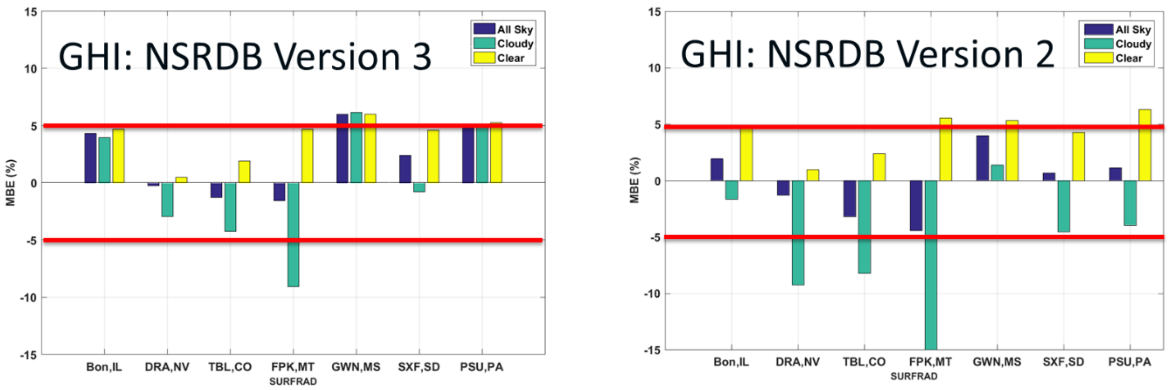

Figure 4: Estimated biases for seven ground-based solar measurement locations for NSRDB V3 and V2. Data used in this figure are from 1998–2015.

4 CONCLUSIONS

Comparisons of the NSRDB (1998–2016) V3 were assessed by comparing the data with selected ground-measured data under both clear- and cloudy-sky conditions and covered the period from 1998–2015. The results show improvement compared to the previous version of the NSRDB. The bias is ~ ±5%, and the overall uncertainty reduced significantly on the hourly biases. Overall, the current NSRDB shows less uncertainty compared to the NSRDB 1998–2015 data (PSM V2). The improvement is assumed to result from a combination of factors, including better downscaling methodologies, particularly in the interpolation and extrapolation used to align the multiple data sets to the same grid, the use of hourly values of aerosol information, and the use of surface albedo instead of interpolated monthly averages. Using hourly precipitable water vapor from MERRA-2 might have marginally contributed to the improvement too.

ACKNOWLEDGMENTS

This work was authored by Alliance for Sustainable Energy, LLC, the Manager and Operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

We acknowledge the DOE Solar Energy Technologies Office and its Systems Integration subprogram for supporting this research. Specifically, we thank Dr. Tassos Golnas, Technology Manager of Systems Integration, for his support and encouragement.

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