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A Physics-Based GOES Product for Use in NREL's National Solar Radiation Database

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A PHYSICS-BASED GOES PRODUCT FOR USE IN NREL'S NATIONAL SOLAR RADIATION DATABASE

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ABSTRACT: Publicly accessible high-quality and long-term satellite-based solar resource data sets reduce barriers to solar grid penetration. Models that produce solar resource information from satellites have been in development for more than three decades. Two widely used approaches derive solar resources from satellites: (1) an empirical approach that relates ground-based observations to satellite measurements and (2) a physics-based approach that considers the radiation received at the satellite and creates retrievals to estimate clouds and surface radiation. Although empirical methods have been traditionally used for computing surface radiation, the advent of faster computing has made operational physical models viable. The Global Solar Insolation Project (GSIP) is an operational physical model from the National Oceanic and Atmospheric Administration (NOAA) that computes global horizontal radiation (GHI) using the visible and infrared channel measurements from geostationary operational environmental satellites (GOES). GSIP uses a two-stage scheme that retrieves cloud properties and uses those properties in the Satellite Algorithm for Surface Radiation Budget (SASRAB) model to calculate surface radiation. The National Renewable Energy Laboratory, University of Wisconsin, and NOAA have recently collaborated to adapt GSIP to create a high-temporal and spatial resolution data set. The product initially generates the cloud properties using the AVHRR Pathfinder Atmospheres-Extended (PATMOS-x) algorithms [1] while calculating the GHI and diffuse horizontal radiation (DHI) using SASRAB. Comparisons to ground sites resulted in the finding that the satellite-based surface radiation suffered from a significant low bias. To remove this bias, we tested and applied three new radiative transfer algorithms that required aerosol optical depth and precipitable water vapor as inputs. These experiments showed significant improvement in the clear-sky radiation. The data sets are currently being incorporated into the widely used National Solar Radiation Data Base.
Keywords: Solar Resource; Global Horizontal Irradiance; GHI; Direct Normal Irradiance; DNI; Irradiance; Satellite; GOES

1. INTRODUCTION

Photovoltaic system performance and concentrating solar power rely on accurate measurements of the solar radiation resources available for power conversion. Measuring solar resources accurately can lead to a reduction in the investment risks associated with installing and operating solar energy systems. Further, understanding the impact of parameters such as clouds, aerosols, water vapor, etc., on the incoming solar resources is essential to accurately design renewable energy systems. Solar radiation resources are acquired using ground measurement and/or modeled data, which are complementary. Ground-measured data is inadequate because there are a very limited number of measurement stations in long-term operation, but they are essential in modeled solar data validation. To fill the gap, modeled data, such as that derived from satellites, provides measurements for creating solar resource assessment maps on a global scale. In this paper, we discuss and analyze a physics-based GOES Surface and Insolation Product (GSIP) satellite-derived solar radiation data set that uses cloud properties in the Satellite Algorithm for Surface Radiation Budget (SASRAB) model to calculate surface radiation. Previously, this data set demonstrated a low bias under clear-sky conditions. To correct the bias, we tested and implemented better and fast clear-sky radiative transfer models. The radiative transfer models were validated using a high-quality ground-based solar data set obtained from the National Oceanic and Atmospheric Administration's Surface Radiation (SURFRAD) (www.srrb.noaa.gov/surfrad/sitepage.html). Prior to using the ground-based solar data, data quality schemes were applied to detect any data issues caused by equipment and operational related errors, unclean instruments, or instrument limitations provided by manufacturer specifications, etc.

2. METHOD

Seven locations were selected for the validation study (Figure 1). The evaluation was made by comparing the ground-based data to the satellite-derived data on a half-hourly time interval. In this report, we illustrate the comparison results and any presence of systematic (bias) or random (scatter) tendencies in the satellite-derived data. For our comparisons, we screened out high solar zenith angles above 80 degree. Differences were calculated as modeled minus the ground observations. The ground-based observations were available at 1-minute resolution; the satellite-based results were available every 30 minutes for 4-km resolution pixels [2]. The ground data was averaged to 30 minutes to account for spatial scales of the satellite. This particular averaging time was chosen to match the satellite time interval.

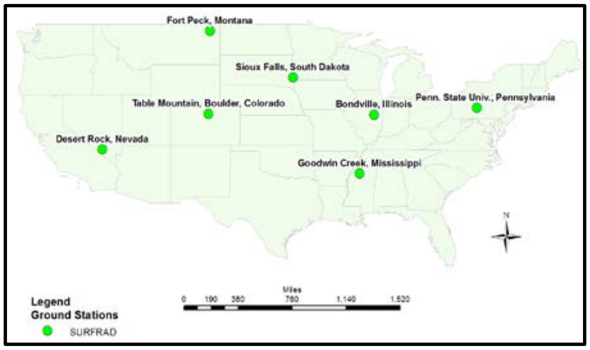

Figure 1: SURFRAD Stations included in the analysis

In a previous publication [3], we identified that replacing the SASRAB model in clear-sky situations with a different clear-sky model provides more accurate results and significantly lower bias. These radiative transfer models were run in [3] with aerosol optical depth (AOD) inputs from ground observations. Our goal was to apply the radiative transfer model to a satellite product, so we developed a satellite-based AOD data set using output from the MODIS and MISR satellites, which was scaled by ground AOD observations from AERONET sites. Preliminary validation of the AOD data was carried out before applying the AOD as an input to the clear-sky radiative transfer models and validating the results using ground observations of direct normal irradiance (DNI) and global horizontal irradiance (GHI).

3. RESULTS AND DISCUSSION

The spatial and temporal differences among ground measurements and satellite-derived data sets were analyzed. The ground measurements were averaged to half-hourly values before the comparison was conducted. This served two purposes: (1) to convert a point measurement to a representation of a finite area covered by a satellite pixel and (2) to provide a half-hourly average estimate that the satellite data is meant to represent. Further, investigating the differences and setting a uniform benchmark is essential to improving the existing satellite-derived data or creating other satellite-based methods to improve the underlying uncertainties.

As mentioned above, the GOES Surface and Insolation Product SASRAB algorithm created a low bias in clear-sky conditions [3]. In [3], it was also demonstrated that the use of either of three clear-sky radiative transfer models—Bird clear-sky model [4], REST2 [5] or SOLIS [6]—could be used to correct the bias. These radiative transfer models use ground-based AOD measurements that were available from the SURFRAD sites. After validating the clear-sky radiative transfer models and ensuring the data quality of the ground-based AOD, we conducted preliminary tests to validate the satellite-derived AOD. These tests were conducted through a comparison of the ground-based AOD from the SURFRAD stations, and results are presented in Table 1.

After this initial test, the gridded AOD data (Figure 2) was used as an input in the clear-sky transfer models.

Table 1: Mean and median differences among measured and satellite AOD (2000–2012)

SURFRAD Site	Mean Percentage Error (2000–2012)	Median Difference (2000–2012)
Table Mountain	11.6%	-4.8%
Desert Rock	-6.3%	-4.6%
Goodwin Creek	-2.9%	-8.1%
PSU	3.9%	-8.7%
Bondville	15.0%	2.7%
Fort Peck	8.0%	-2.4%
Sioux Falls	-3.4%	-16.8%

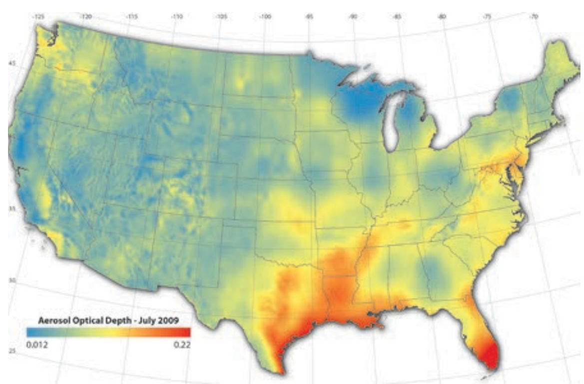

Figure 2: Example of mean daily aerosol distribution for July 2009 at 550-nm wavelength.

The following figures (Figure 3) show the bias and scatter of the differences when the ground-measured data was compared to the satellite-derived data or to the clear-sky transfer model calculations. The results from the figures demonstrate that the clear-sky radiative transfer plus the satellite-based AOD improve the original SASRAB insolation product. Figure 3 (left) shows the results of using satellite-based AOD and precipitable water vapor from the National Oceanic and Atmospheric Administration's Climate Forecast System Model compared to the original SASRAB insolation product for

GHI. Note that all the clear-sky models perform quite well compared to SASRAB. Figure 3 (right) shows the same for DNI. As stated in [3], the DNI is most sensitive to AOD, and this was also apparent in this analysis. The satellite-based AOD captures the true atmospheric AOD with a surprising level of accuracy when we compare it to the results from using ground-based daily AOD values. This is visible when the DNI in Figure 3 (right) is compared to Figure 3 (bottom), which shows DNI results using measured AOD and water vapor at the surface; this can be performed for only a handful of locations throughout the United States.

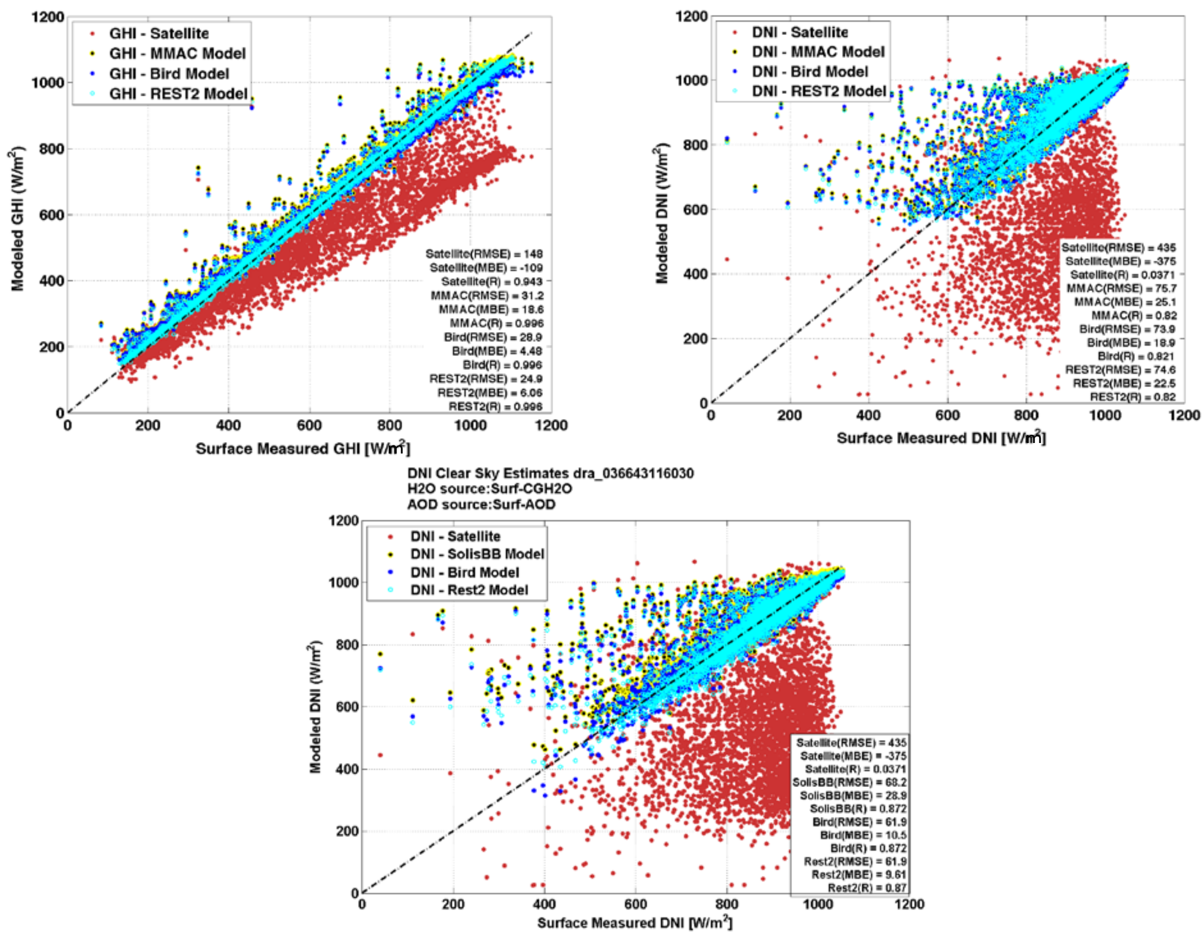

Figure 3: Desert Rock, Nevada, (left), GHI comparison among the transfer models and SASRAB using the satellite-based AOD and precipitable water vapor. (Right) The same comparison but for DNI. (Bottom) The same DNI comparison but using ground-based AOD and precipitable water vapor.

4. SUMMARY

Improved satellite-based models are essential to understand system efficiencies of solar renewable installations. Therefore, refining the original SASRAB satellite-derived data would benefit renewable energy installations. Previously, the satellite-derived SASRAB model demonstrated a low bias under clear-sky conditions; however, this paper validated the improvement of the model by employing clear-sky radiative transfer models. One of these models will be used to replace the SASRAB clear-sky insolation. Overall, using the SASRAB product demonstrated significant improvements in GHI and DNI insolation for most ground-based stations.

5. ACKNOWLEDGEMENT

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