Improving the National Solar Radiation Database (NSRDB) Using a Physics-Based Direct Normal Irradiance (DNI) Model

Preprint

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Improving the National Solar Radiation Database (NSRDB) Using a Physics-Based Direct Normal Irradiance (DNI) Model

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Abstract. The National Solar Radiation Database (NSRDB) is a widely used resource providing satellite-derived solar data across the United States and globally. While the NSRDB employs a physical model for computing global horizontal irradiance (GHI), its current method for estimating cloudy-sky direct normal irradiance (DNI) relies on surface observations and empirical models. Recently, a novel physics-based approach, the Fast All-Sky Radiation Model for Solar applications with DNI (FARMS-DNI), was developed to enhance the DNI forecasting. FARMS-DNI incorporates both direct and scattered solar radiation within the circumsolar region, resulting in improved day-ahead DNI predictions when integrated into the Weather Research and Forecasting model with Solar extensions (WRF-Solar). This study integrates FARMS-DNI into the NSRDB algorithm to generate high-resolution DNI data from satellite resources. Our findings reveal that FARMS-DNI effectively mitigates the substantial DNI overestimation present in the conventional NSRDB across surface sites, particularly in conditions categorized as cloudy overcast. Consequently, this innovative model substantially enhances the overall accuracy of the NSRDB.

Keywords: DNI, Solar radiation, Radiative transfer

1. Introduction

The National Solar Radiation Database (NSRDB) is a widely used resource for solar energy applications [1-5]. It provides solar radiation data, as well as other meteorological products such as surface temperature and wind speed, which can be downloaded by users through the National Renewable Energy Laboratory's (NREL's) server, an application programming interface (API) service, or the Amazon Web Services (AWS) cloud services. The NSRDB provides information on global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI), and it also provides hyperspectral solar data for specific photovoltaic (PV) surfaces with various orientations. The NSRDB uses data from the Geostationary Operational environmental Satellite (GOES), the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2), and other ancillary data to assess solar radiation in 30-minute intervals from 1998–2018 with a spatial resolution of 4 km for the continental United States (CONUS) area. Since 2019, the NSRDB data have been available at an improved spatial resolution of 2 km and a higher temporal resolution of 5 minutes.

The current NSRDB algorithm uses the Direct Insolation Simulation Code (DISC) [6] to compute cloudy-sky DNI from the GHI computed using the Fast All-sky Radiation Model for Solar applications (FARMS). However, significant errors exist in the computation of DNI by DISC. For example, DISC is designed to calculate all-sky DNI by relying on empirical correlation derived from surface measurements of GHI and DNI. Consequently, the inherent biases in the empirical relationships and the computation of GHI can accumulate and ultimately result in a more substantial bias when estimating DNI. Further, a single GHI value can correspond to multiple combinations of meteorological conditions, each associated with a different DNI value. The consistent one-to-one mapping between GHI and DNI for a specific atmospheric condition can introduce noticeable errors in the DNI calculations. Numerical weather prediction (NWP) models have relied on the renowned Beer-Bouguer-Lambert law for the calculation of DNI. However, this algorithm neglects the contribution of scattered solar radiation within the circumsolar region. Consequently, when applied in solar forecasting, it frequently results in a substantial underestimation of DNI.

In response to the limitations of the existing DNI models, Xie et al. [7] introduced an innovative physics-based model, known as FARMS-DNI. This model has proven highly effective in the precise estimation of all-sky solar radiation within the circumsolar region. Its integration into the Weather Research and Forecasting model with Solar extensions (WRF-Solar) [8], as demonstrated by Xie et al. [9], has notably reduced forecasting biases in DNI.

2. Methodology

This study aims to improve the accuracy of the NSRDB algorithm by integrating FARMS with DNI (FARMS-DNI) [7] and a new parameterization of cloud transmittance [10]. While clear-sky DNI is computed using REST2 [11], consistent with the conventional NSRDB, a concurrent procedure is employed in cloudy-sky conditions. This procedure uses satellite cloud products to infer cloud transmittance and reflectance for both direct and total downwelling solar radiation, replacing the sequential computation by FARMS and DISC. The cloud transmittance and reflectance data are then incorporated with FARMS, FARMS-DNI, and the clear-sky computation to resolve the cloudy-sky GHI and DNI. Following the previous studies [12], the direct radiation observed by a surface-based pyrheliometer consists of the direct radiation in an infinite-narrow beam, the first order scattered radiation in the circumsolar region, and multiple reflection between the clouds and the land surface that falls into the circumsolar region.

The all-sky DNIs are computed at 19 surface sites within various networks, including the Surface Radiation Budget (SURFRAD), Solar Radiation (SOLRAD), the University of Oregon (UO), the U.S. Department of Energy Atmospheric Radiation Measurement (ARM), and NREL. The computation is performed using input data from the NSRDB for each 5-minute interval spanning the years 2019-2020. The SURFRAD network comprises 7 sites situated in Bondville, Illinois (BON); Desert Rock, Nevada (DRA); Goodwin Creek, Mississippi (GWN); Fort Peck, Montana (FPK); the Pennsylvania State University (PSU); Sioux Falls, South Dakota (SXF); and Table Mountain, Colorado (TBL). The SOLRAD network encompasses sites in Albuquerque, New Mexico (ABQ); Bismarck, North Dakota (BIS); Hanford, California (HNX); Madison, Wisconsin (MSN); Salt Lake City, Utah (SLC); Seattle, Washington (SEA); and Sterling, Virginia (STE). The UO network comprises 3 sites: Ashland, Oregon (ASO); Eugene, Oregon (EUG); and Silver Lake, Oregon (SIO). Additionally, there are ARM and NREL sites located at the Southern Great Plains (SGP) and Solar Radiation Research Laboratory (SRRL), respectively. In accordance with the NSRDB algorithm, the computation of DNI in the western and eastern regions relies on data from GOES-17 and GOES-16, respectively. For comparison with FARMS-DNI, DNI is also calculated using the conventional NSRDB algorithm, wherein DISC is employed to estimate DNI from the GHI simulated by FARMS.

3. Results

To evaluate the precision of FARMS-DNI in the NSRDB processing, the DNI values computed using satellite data are cross-checked with surface observations. The surface observations are initially collected at a resolution of 1 minute, but they are then aggregated to match the NSRDB timestamps, averaging the values over each 5-minute interval.

Figure 1 shows the mean bias error (MBE), mean absolute error (MAE), percentage error (PE), absolute percentage error (APE), mean percentage error (MPE), and mean absolute percentage error (MAPE) of the cloudy-sky DNI over 19 surfaces sites. The results indicate that DISC tends to overestimate cloud-sky DNI at all the sites, primarily due to the limitations of the DISC model and the computation of cloudy-sky GHI. However, incorporating FARMS-DNI into the NSRDB processing significantly mitigates this overestimation bias, especially in sites characterized by high occurrences of snow-covered, bright surfaces, such as TBL, SRRL, DRA, and HNX. Furthermore, the use of FARMS-DNI transforms the overestimation of DNI into a minor underestimation at a few sites, resulting in a more balanced bias in the average over all19 sites. The utilization of FARMS-DNI leads to lower MAE and APE values for cloudy-sky DNI compared to using only DISC.

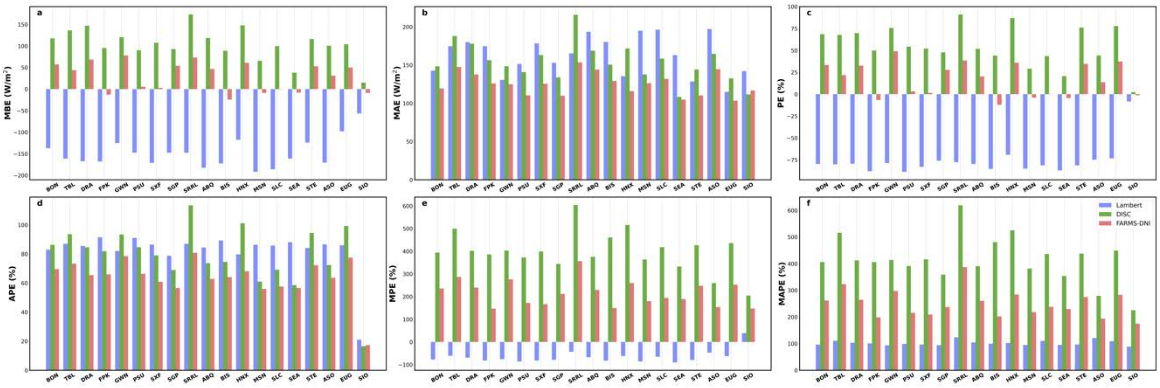

Figure 1. *The error metrics of the cloudy-sky DNI computed by the Lambert law, DISC, and FARMS-DNI.*

Figure 2 demonstrates the error metrics associated with all-sky DNI, which includes both clear-sky and near-clear-sky conditions. The results indicates that FARMS-DNI exhibits superior performance compared to DISC when considering MBE and PE for all-sky DNI calculations. Furthermore, when examining the MAE and APE, the performance of DISC and FARMS-DNI is relatively similar across the 19 surface sites. Considering the enhanced accuracy observed in both cloudy-sky and all-sky conditions, as illustrated in Figs. 1 and 2, the integration of FARMS-DNI into the NSRDB algorithm is anticipated to result in improved DNI data quality.

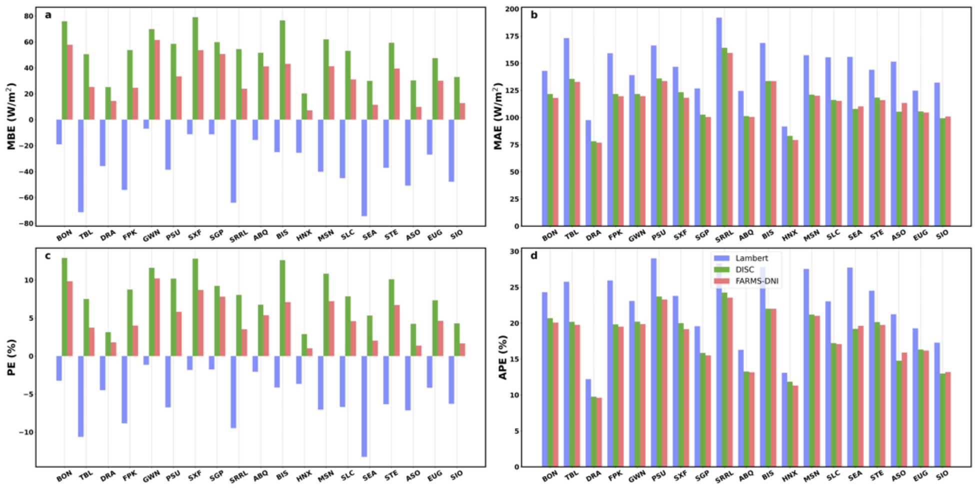

Figure 2. *The error metrics of the all-sky DNI computed by the Lambert law, DISC, and FARMS-DNI.*

Data availability statement

Data are available on request.

Author contributions

Conceptualization, Y.X., M.S, and Y.L.; Methodology, Y.X., M.S., and Y.L.; Investigation, Y.X., and J.Y.; Writing - original draft, Y.X.; Writing – review & editing, Y.X.; Funding acquisition, M.S; Resources, G.B.,B.B., and A.H.

Competing interests

The authors declare that they have no competing interests.

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