Validation of the National Solar Radiation Database (NSRDB) (2005–2012)

Preprint

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To be presented at the European PV Solar Energy Conference and Exhibition
Hamburg, Germany
September 14–18, 2015

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Conference Paper
NREL/CP-5D00-64981
September 2015

Contract No. DE-AC36-08GO28308

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ABSTRACT: Publicly accessible, high-quality, long-term, satellite-based solar resource data is foundational and critical to solar technologies to quantify system output predictions and deploy solar energy technologies in grid-tied systems. Solar radiation models have been in development for more than three decades. For many years, the National Renewable Energy Laboratory (NREL) developed and/or updated such models through the National Solar Radiation Data Base (NSRDB). There are two widely used approaches to derive solar resource data from models: (a) an empirical approach that relates ground-based observations to satellite measurements and (b) 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 Physical Solar Model (PSM) developed by NREL in collaboration with the University of Wisconsin and the National Oceanic and Atmospheric Administration (NOAA) computes global horizontal irradiance (GHI) using the visible and infrared channel measurements from the Geostationary Operational Environmental Satellites (GOES) system. PSM uses a two-stage scheme that first retrieves cloud properties and then uses those properties to calculate surface radiation. The cloud properties in PSM are generated using the AVHRR Pathfinder Atmospheres-Extended (PATMOS-x) algorithms [5]. Using the cloud mask from PATMOS-x, and aerosol optical depth (AOD) and precipitable water vapor (PWV) from ancillary sources, the direct normal irradiance (DNI) and GHI are computed for clear-sky conditions using the MMAC model. For cloud scenes identified by the cloud mask, the Satellite Algorithm for Surface Radiation Budget (SASRAB) is used to compute the GHI. The DNI for cloud scenes is then computed using the DISC model [6]. The current NSRDB update has a 4-km x 4-km, 30-minute resolution covering 2005–2012. This paper evaluates the PSM-based NSRDB data set using ground-measured data and provides detailed evaluation statistics. The result of the comparison shows a good correlation between the NSRDB and ground data. Further, an outline of the next version of the NSRDB and future plans for enhancement and improvement are provided. This version is expected to be released in September 2015 and will contain data from 1998–2014.

1 INTRODUCTION

Photovoltaic system performance and concentrating solar power (CSP) 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-measured and/or modeled data, and they are complementary to each other. Ground-measured data is inadequate because there are a very limited number of measurement stations in long-term operation, yet the data are essential to 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 the PSM-based National Solar Radiation Data Base (NSRDB) data set. PSM is a physics-based, satellite-derived solar radiation data set that uses cloud properties from the PATMOS-X algorithms in radiative transfer models to calculate surface radiation. Using the cloud mask to identify clear-sky scenes, the MMAC model is used to compute global horizontal irradiance (GHI) and direct normal irradiance (DNI) for clear skies. To improve the accuracy of clear-sky modeling, the AOD and PWV, which are critical inputs to MMAC, are derived from ancillary information. The AOD is derived using a combination of the MODIS- and MISR-based AOD product that is scaled to ground-based AERONET data. The PWV is derived from the CFSR model through an interpolation to the NSRDB grid. For cloudy skies identified by the cloud mask, the Satellite Algorithm for Surface Radiation Budget (SASRAB) model

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is used to calculate the GHI. The DNI is then calculated from the GHI using the DISC model [6]. Data gaps in the satellite-based product due to various reasons, including issues with the raw satellite data, were filled using a gap-filling algorithm. We used data from two satellites, GOES-East and GOES-West, to cover the whole United States. GOES-West provides observations at the top and middle of the hour. GOES-East, on the other hand, provides observations at 15 minutes and 45 minutes past the hour. The GOES-East solar radiation product was time-shifted to match the GOES-West times.

Previously, SASRAB was used for both clear- and cloudy sky computations. SASRAB demonstrated a low bias under clear-sky conditions, and to correct the bias we implemented a newer generation fast clear-sky radiative transfer model. Three clear-sky models were investigated [1], [2], and [3], and MMAC was chosen as the clear-sky radiative transfer model [7]. The results in this paper were validated using a high-quality, ground-based solar data set obtained from the National Oceanic and Atmospheric Administration's (NOAA's) Surface Radiation (SURFRAD)[1]. Prior to using the ground-based solar data, data quality schemes were applied to detect any data issues due to equipment and operational related errors, unclean instruments, 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 75 degrees. To evaluate the performance of the satellite data relative to the ground-measured data, mean bias error (MBE), mean absolute error (MAE), and root mean square error (RMSE) were used as a basic performance set of measures (eq. 1–3). Clear, cloudy-sky, and all sky conditions were compared. The sky conditions were categorized using the cloud type information derived from the satellite retrievals.

The ground-based observations were available at a 1-minute resolution, whereas the satellite-based results were every 30 minutes for 4-km resolution pixels [8]. The ground data was averaged to 30 minutes centered at the satellite time stamp to account for spatial scales of the satellite. This particular averaging time was chosen to match the satellite time interval.

$$MBE(W/m^2) = \frac{1}{n}\sum_{i=1}^{n}(I_{satellite} - I_{Measured}) \quad (1)$$

$$MAE(W/m^2) = \frac{1}{n}\sum_{i=1}^{n}|I_{satellite} - I_{Measured}| \quad (2)$$

$$RMSE(W/m^2) = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(I_{satellite} - I_{Measured})^2\right)} \quad (3)$$

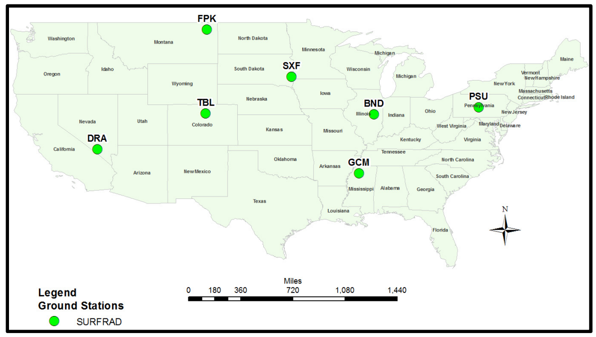

Figure 1: SURFRAD stations included in the analysis

3 RESULTS AND DISCUSSION

The spatial and temporal differences between the ground-measured and satellite-derived data sets were analyzed (Table 1). The ground measurements were averaged to half-hourly values centered at the satellite time stamp. This served two purposes: (a) to convert a point measurement to a representation of a finite area covered by a satellite pixel and (b) 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.

The following figures and Table 1 show the bias and scatter of the differences when the ground-measured data was compared to the NSRDB satellite-derived data. The results demonstrate that the clear-sky condition showed better statistical correlation and less bias than the cloudy condition. However, the direct normal irradiance (DNI) difference between the measured and NSRDB data set was much higher than the global horizontal irradiance (GHI), especially under cloudy-sky conditions.

[1] www.srrb.noaa.gov/surfrad/sitepage.html

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Table 1: Average statistical differences (2005–2012) of correlation (R), MBE (W/m^2), MAE (W/m^2), and RMSE (W/m^2) between the measured and satellite irradiance data under various sky conditions.

Sky Condition	Statistics	TBL		DRA		GCM		PSU		BON		FPK		SXF	
		GHI	DNI	GHI	DNI	GHI	DNI	GHI	DNI	GHI	DNI	GHI	DNI	GHI	DNI
All	MBE	-21	-53	2	-7	27	39	14	36	8	16	-4	5	4	18
	MAE	85	174	48	100	67	120	78	139	63	122	63	127	59	113
	RMSE	133	261	84	182	105	181	120	209	98	183	97	197	93	176
	R square	0.76	0.56	0.9	0.67	0.86	0.73	0.79	0.65	0.86	0.72	0.84	0.69	0.87	0.76
Clear	MBE	18	3	19	14	38	37	31	31	22	3	26	29	22	15
	MAE	23	55	23	41	42	104	39	118	31	107	29	71	29	87
	RMSE	40	96	37	77	71	155	68	170	53	148	45	116	47	132
	R square	0.97	0.37	0.98	0.56	0.93	0.38	0.93	0.3	0.96	0.3	0.97	0.37	0.96	0.3
Cloudy	MBE	-37	-76	-34	-53	14	40	5	39	-2	26	-22	-9	-10	20
	MAE	112	223	102	227	94	139	98	150	86	133	84	161	83	134
	RMSE	156	305	139	302	133	205	139	227	121	204	117	233	117	205
	R square	0.66	0.34	0.7	0.23	0.74	0.45	0.68	0.36	0.75	0.47	0.72	0.41	0.74	0.5

As shown in Figure 3, under clear-sky conditions in all seven SURFRAD stations, the GHI comparison appeared to be close to the 1:1 line; however, the NSRDB data set demonstrated a slight positive bias, which indicates that the surface measurements were slightly lower than the NSRDB data set. Under cloudy conditions, as might be expected, the GHI comparison demonstrated relatively higher scatter and lower correlation, and this is mainly because a satellite pixel represents a nominal 4-km by 4-km area, whereas a ground-based station represents only a small area above the measuring station. As clouds pass by, it appears that these spatial differences contributed to the higher differences. Further, for the DNI comparison, the spatial differences under cloudy conditions were exacerbated, because the ground-measuring radiometer has an approximate five-degree field of view, but the satellite DNI represents the 4-km by 4-km area.

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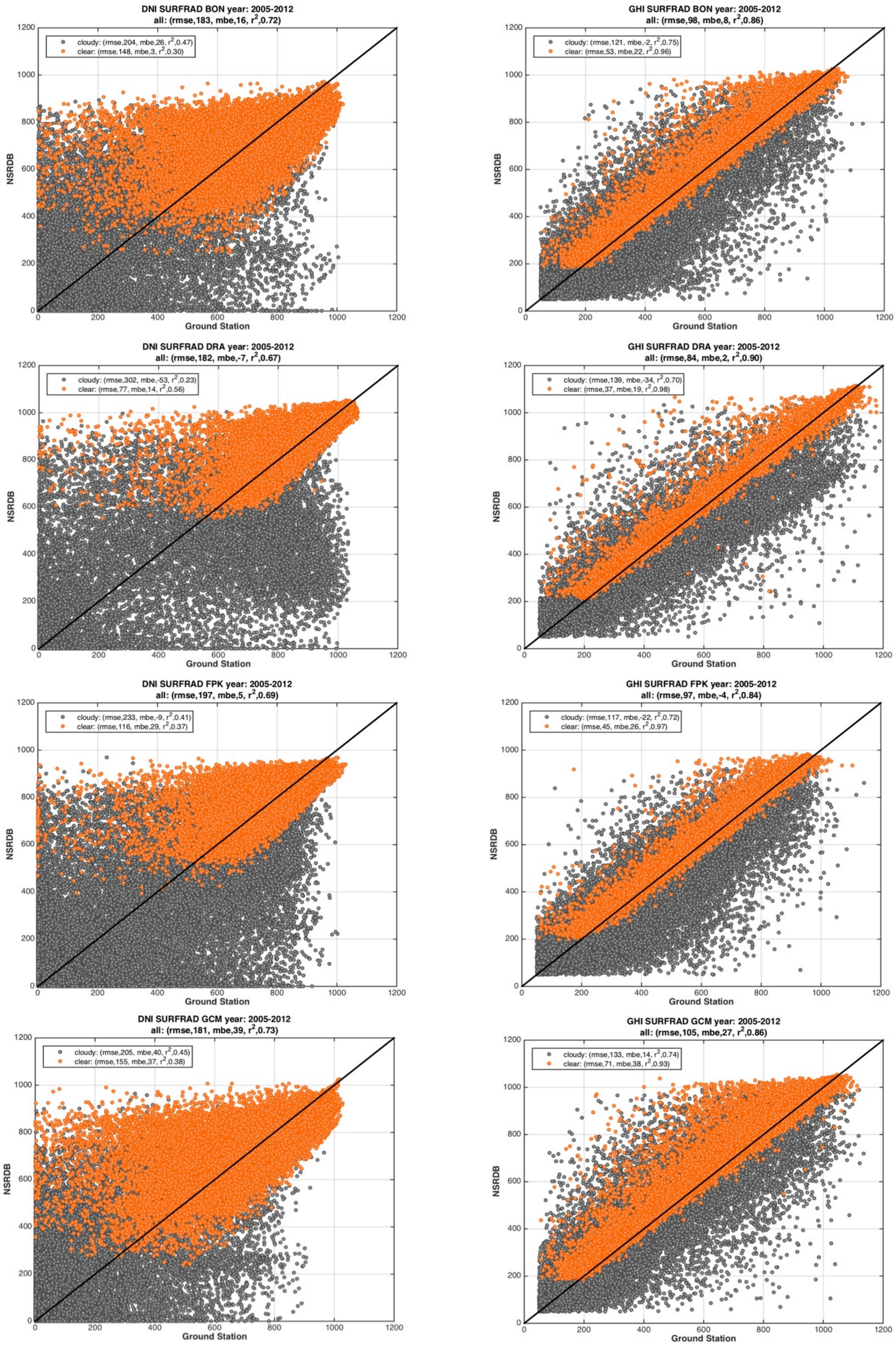

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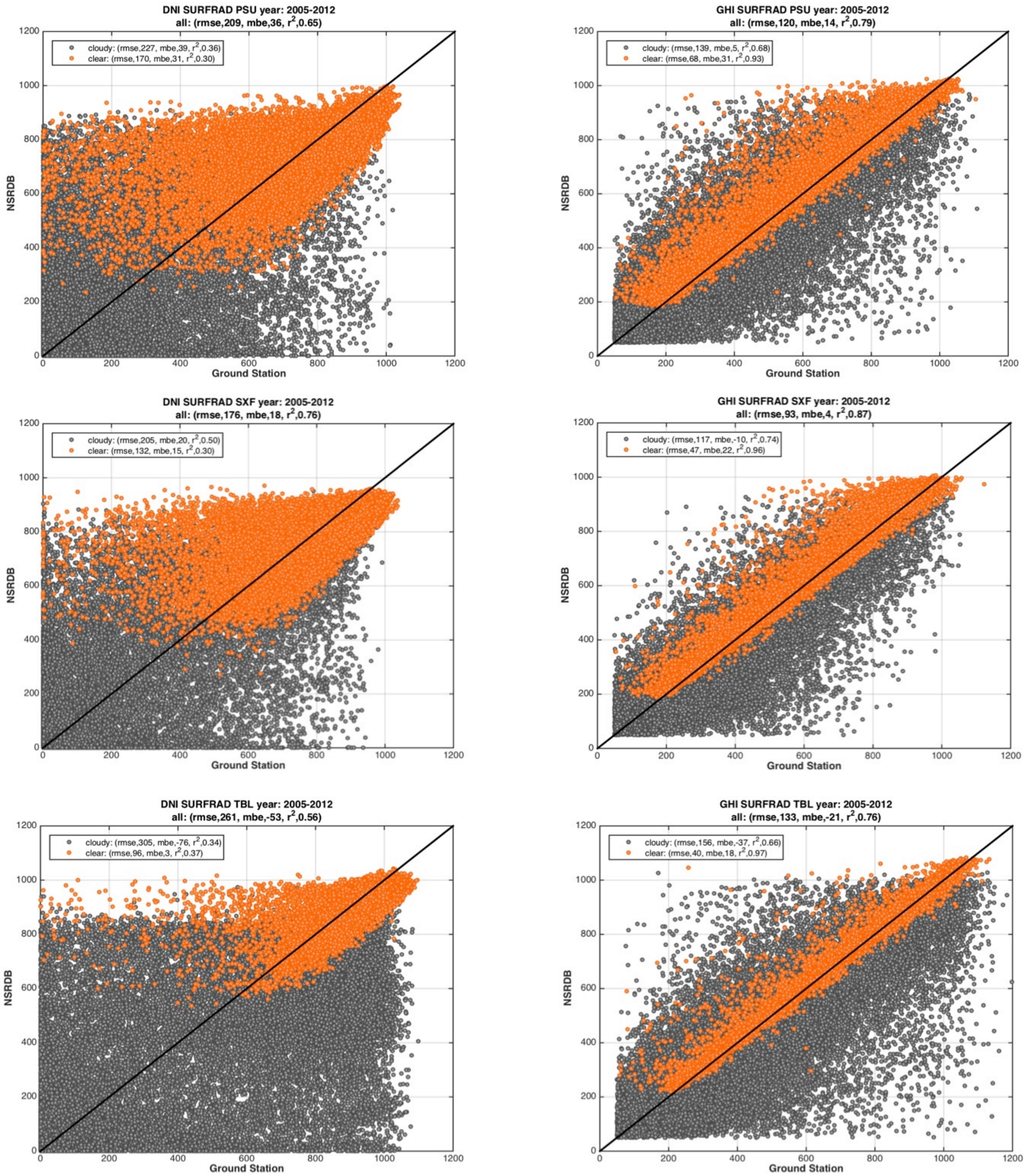

Figure 3: Half-hourly irradiance comparison in W/m^2 for all SURFRAD stations for years 2005–2012. (Left) DNI comparison of the NSRDB to the ground-measured data set. (Right) The same comparison but for GHI.

4 FUTURE PLANS AND OUTLINE OF THE NEW NSRDB RELEASE

The National Renewable Energy Laboratory (NREL) has developed a new radiative transfer model to replace SASRAB and further improve the accuracy and efficiency of the simulation of solar radiation under cloudy-sky conditions. This new parametrized radiative transfer model will be implemented in the upcoming NSRDB data set release, which will cover the years from 1998 to 2014. NREL also developed a new website (http://nsrdb.nrel.gov) to disseminate the resource data. The website has improved user interface with functionality to host the new gridded and historical data set. Users have an option to download a point or an area (polygon) with specific attributes and a time range. The data set will be released by the end of September 2015. The NSRDB covers the United States, part of Canada, Central America, and part of South America (Figure 4). The three solar resources attributes—GHI, DNI and DHI—are included in the data set along with many other meteorological parameters, such as temperature, relative humidity, and wind speed.

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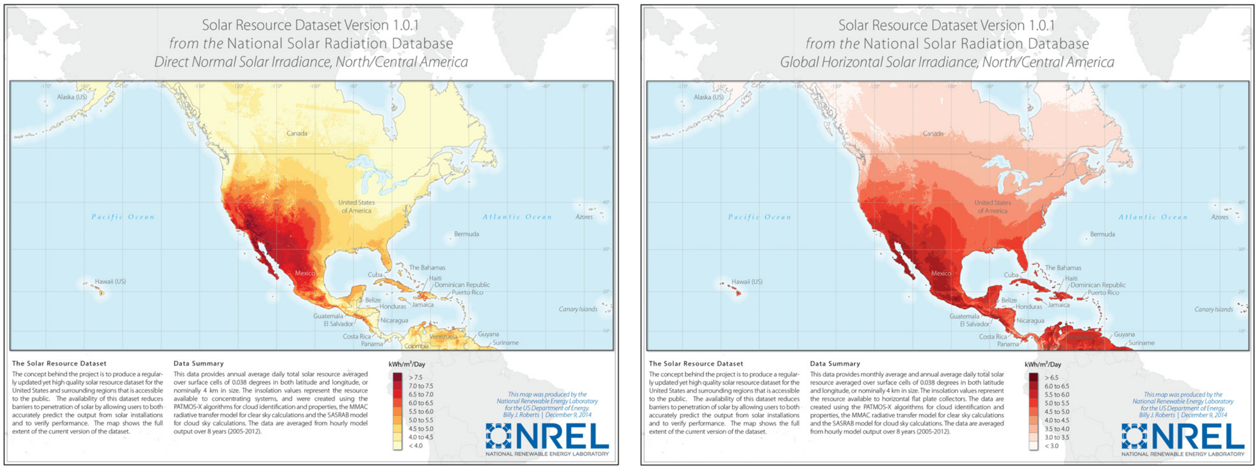

Figure 4: Example of current gridded NSRDB product for 2010. (Left) DNI. (Right) GHI.

4 SUMMARY

Improved satellite-based models are essential to understand system efficiencies of solar renewable installations. Further, to finance these installations through a financial system, banks will need assurances that these systems will produce the energy predicted through performance models. Failing to meet the minimum energy performance requirements can result in large financial penalties that require expensive risk-mitigation measures. Therefore, refining the NSRDB satellite-derived data will benefit renewable energy installations and reduce the expense associated with mitigating performance risks. This paper validated the improvement of the PSM model, which applied the MMAC model with accurate input parameters such as AOD and PWV to compute GHI and DNI for clear skies. Under cloudy conditions, the DISC model was used to compute DNI. Overall, significant improvement in GHI and DNI was seen compared to the original SASRAB product for all ground-based stations [4], [7], [9]. This data set will deliver a location-specific and reliable time-series solar resource data set that will benefit CSP and photovoltaic projects.

5 ACKNOWLEDGEMENTS AND DISCLAIMER

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. 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.

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