Annual Solar Irradiance Anomaly Features Over the USA During 1998–2017 Using NSRDB V3

Preprint

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Abstract—**Annual solar irradiance anomalies (or departures from the long-term mean annual value) have a direct impact on various phases of solar energy projects, from prefeasibility studies to technical deployment decisions. Anomalies can happen because of normal climate variability or exceptional weather patterns. This study investigates such anomalies for both global horizontal irradiance (GHI) and direct normal irradiance (DNI) using Version 3 of the National Solar Radiation Database (NSRDB V3) and surface irradiance measurements at eight U.S. locations. At each site, the annual anomaly is analyzed here by evaluating the irradiance deviation from the long-term average for each specific year from 1998–2017. A positive/negative anomaly indicates that the solar resource was higher/lower than the long-term average during that specific year. The results show that in most cases the anomaly is within ±5% for GHI and ±10% for DNI using either ground-based irradiance measurements or modeled data from the NSRDB.**

Keywords—GHI, DNI, Solar Radiation, PV Resource, Anomaly

I. Introduction

Interannual variability in solar irradiance is a challenging issue for the proper design, financing, and operation of solar energy conversion projects. With reference to the long-term annual solar resource, which is used as the basis for all project calculations, any annual deviation (or anomaly) during a specific year can result in generation variability and financial challenges. Hence, understanding and quantifying the time series of annual anomalies at any site is essential for reducing the investment risks for such projects [1], [2], [3]. Solar energy projects tend to depend on a limited solar irradiance data set, such as a typical meteorological year (TMY) and/or a data set that constitutes 1 year to a few years of solar irradiance measurements or modeled information. However, these limited data sets are prone to bias and might underestimate or overestimate the solar resource. This is in part because all weather patterns deviating from the median are excluded by the very design of TMYs [4]. Short measurement time series of, e.g., 1 year could, by chance, correspond to a normal year or an exceptional year, which complicates solar resource assessments. Conversely, extreme weather situations are typically included in longer time series of, e.g., 15–30 years. Therefore, it is imperative to understand the long-term and interannual variability in solar irradiance.

Multiple causes can trigger long-term changes in solar irradiance. Beside the normal stochastic variability in weather patterns, there are relatively regular climate cycles (e.g., the El Niño Southern Oscillation) as well as exceptional events, such as major volcanic eruptions, extended wildfires, or hurricanes [5], [6].

In this study, we investigate the solar irradiance anomalies from ground-based measurement stations and concurrent model predictions from the 20-year National Solar Radiation Database (NSRDB) Version 3 developed by the National Renewable Energy Laboratory [7]. Such 20-year time series can be assumed representative of the "true" local climatology (which is normally considered to be based on 30 years of data [1]).

The NSRDB is a widely used public data set that provides predictions of the three-component solar irradiance data set—i.e., global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI)—as well as related parameters [7]. The operational model used to produce the NSRDB is called the Physical Solar Model. It uses satellite-derived cloud properties and some meteorological inputs to operate the Fast Radiative Model for Satellite Applications (FARMS) [8] and derive irradiance values. The NSRDB disseminates solar irradiance and meteorological data on a 4-km x 4-km and half-hourly spatiotemporal resolution over the Americas between 60°N and 21°S.

II. Method

In this study, the annual anomalies for the 1998–2017 period at seven National Oceanic and Atmospheric Administration Surface Radiation Budget Network (SURFRAD) stations and one station from the University of Oregon's Solar Radiation Measurement Laboratory are compared to those of the corresponding NSRDB pixels (Table 1). Analyzing solar irradiance anomalies using ground observations in conjunction with modeled data from the NSRDB is beneficial to, e.g., validate the reliability of the NSRDB in capturing the "true" annual or long-term anomalies under varied solar climates. For any specific year, the anomalies are evaluated by calculating the percentage irradiance deviation from the *long-term average*—which constitutes the main characteristic of the solar resource at any solar project site. This method is consistent with what was used in earlier studies [2], [3].

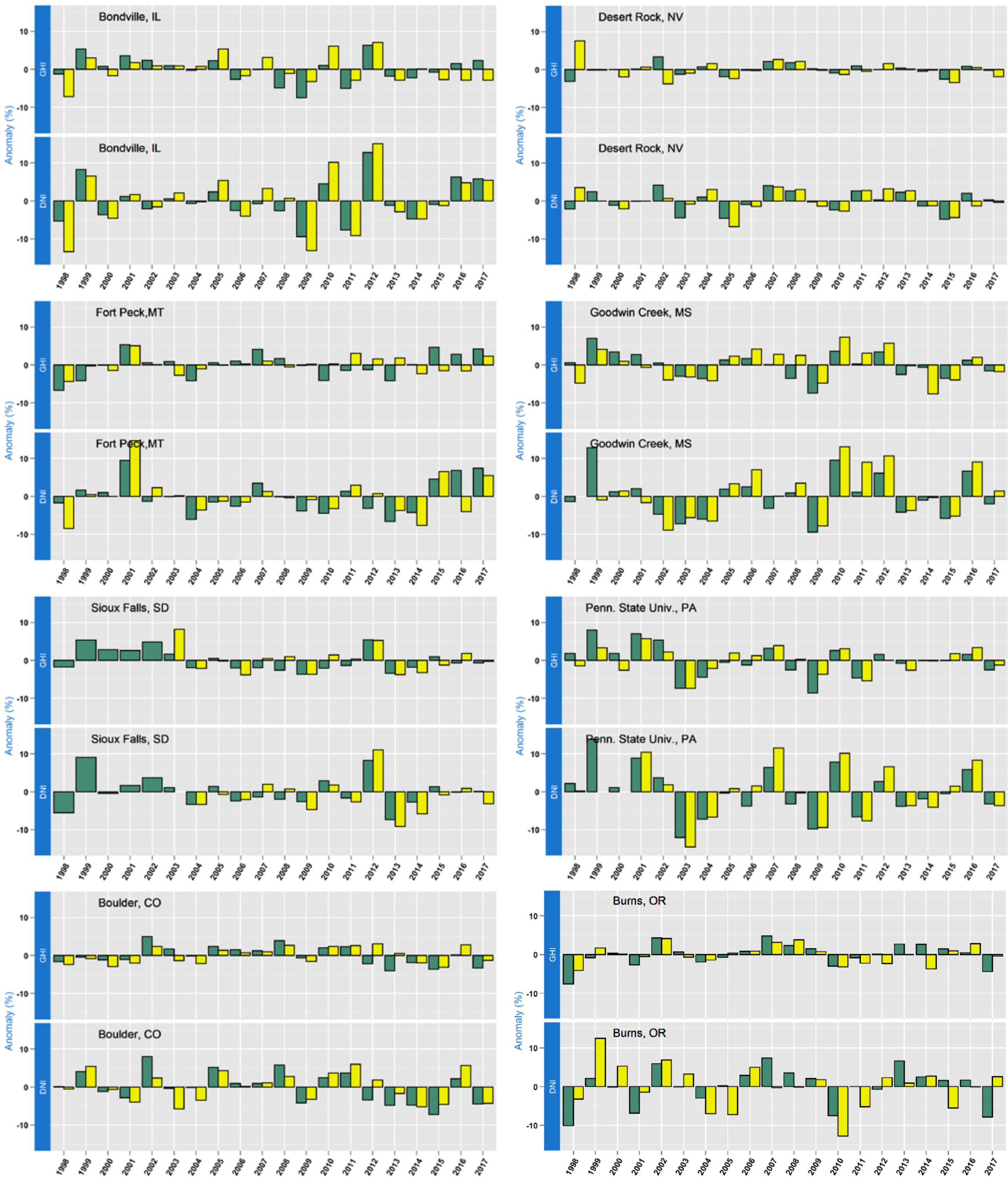

Fig. 1. Percentage annual anomaly of ground measurements (yellow bar) and NSRDB (green bar) for GHI (top row) and DNI (bottom row) at eight locations during the period from 1998–2017 (X-axis).

III. Results

Fig. 1 shows the anomaly time series obtained for each year relative to the 1998–2017 long-term average at the eight test locations (except 2003–2017 at Sioux Falls, SD). In general, the NSRDB and surface measurements capture similar positive or negative deviations as well as their magnitudes. This gives confidence that the NSRDB data are able to accurately predict long-term variability, even though exceptions do occur during some years, when the anomaly magnitudes differ for reasons still unclear. It is anticipated that the NSRDB Version 4, to be released later in 2020, will address some of the remaining sources of discrepancy.

TABLE I. Locations Used in This Study During 1998–2017 (except 2003–2017 at Sioux Falls)

Station	State	Code	Latitude (°)	Longitude (°)
Bondville	IL	BON	40.052	-88.373
Boulder	CO	TBL	40.125	-105.237
Desert Rock	NV	DRA	36.624	-116.019
Fort Peck	MT	FPK	48.308	-105.102
Goodwin Creek	MS	GWN	34.255	-89.873
Penn. State Univ.	PA	PSU	40.720	-77.931
Sioux Falls	SD	SXF	43.734	-96.623
Burns	OR	BURNS	43.520	-119.020

Interestingly, the 1998–2017 period was not affected by major volcanic eruptions, contrary to earlier periods when such eruptions (from, e.g., El Chichon or Pinatubo) had a profound impact [9].

Another observation is that the anomaly values are higher for DNI than for GHI, which could be expected because DNI is more sensitive to cloudiness and aerosols than GHI. This also substantiates previous studies [9], [10]. Remarkably, some years are characterized by DNI anomalies reaching or even exceeding 10% (Fig.1), despite the absence of significant interference from volcanic activity. Although it can be hypothesized that annual variations in cloudiness are the prominent factor here, large-scale variations in atmospheric aerosol load also constitute a known source of interannual variability [9].

Desert Rock, Nevada, demonstrates relatively less anomaly for most years than other locations. This can be explained by the low cloudiness and aerosol load. Conversely, stations with larger impacts from both clouds and aerosols—such as Bondville, Illinois, and Goodwin Creek, Mississippi—are characterized by higher DNI anomalies.

In Fig. 2, a hypothetical time series is constructed in a non-chronological order to identify the nominal period of record required to estimate the long-term "climatological" average at a given location. The method used in Fig. 2 is similar to that in [2], except for the number of years and the period considered. Fig. 2 is based on a 20-year period (1998–2017), whereas Figs. 7–10 in [2] covered 23–28 years (depending on station), including years affected by the two major volcanic eruptions of El Chichon and Pinatubo. To construct Fig. 2, the observations and model predictions are sorted from the worst years showing the largest anomalies to the best years with smaller anomalies. This exemplifies the extreme cases when the period of irradiance record could, by chance, start during a very good year (maximum positive deviation) or during a very bad year (maximum negative deviation) relative to the long-term "climatological" average.

As shown in Fig. 2, the selected 20-year period appears stable compared to the longer and different period used in [2], even though the latter's extremes were severely impacted by volcanic eruptions—especially in the case of the DNI's anomalies. This result suggests that each year of irradiance data is essentially independent from previous years, as stated in [11] and that the anomalies could also be dependent on location in relation to the area's climate conditions. At Desert Rock, for example, clear-sky conditions are most frequent. The low overall cloudiness and aerosol loads induce less variability than at the Penn State location, which is significantly cloudier and hazier.

During the due-diligence phase of the deployment of photovoltaic (PV) plants or other solar technologies, these findings provide an estimate of the minimum length of irradiance records that is required to accurately assess their performance. Based on the limited number of sites investigated here, it is possible to recommend a minimum period of 5 years to correctly characterize the solar resource of PV plants, considering a ±5% possible error in the long-term average GHI. To reach a more conservative risk of error of only ±1%, a 10-year period would be necessary.

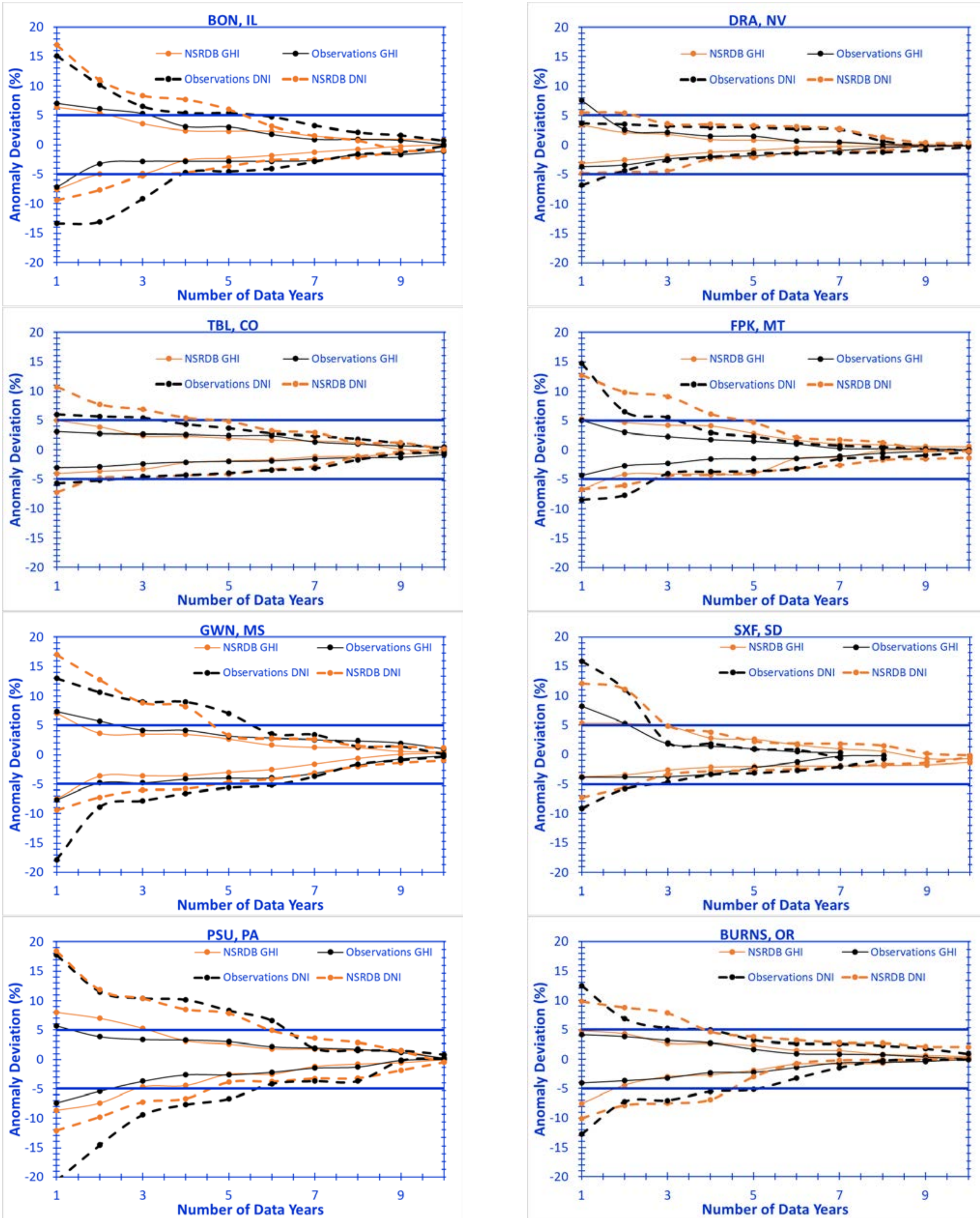

Fig. 2. Number of years required to stabilize GHI and DNI for the eight locations using NSRDB (orange) and observation data (black). The blue line represents the ±5% range. A period of 20 years of the NSRDB and observation data is assumed to represent the "true" climatological average.

IV. Conclusion

Solar irradiance anomalies from one year to the next is an important source of uncertainty for solar energy projects, which in turn can cause financial risks for these projects. This study used the latest version of the NSRDB and surface measurements at eight U.S. stations to capture the solar irradiance anomalies during the period from 1998–2017. In most years at all locations, the results show deviations of up to approximately ±5% for GHI and ±10% for DNI.

The present findings have clarified what the minimum period of irradiance records should be to correctly characterize the solar resource of PV plants. Assuming that the eight stations considered here are representative of the general situation, at least over the United States, a minimum period of 5 years is recommended to approach the long-term average GHI within ±5%. In contrast, a 10-year period appears necessary to reach a more conservative risk of error of only ±1%.

The results in this study demonstrate the importance of analyzing and understanding the long-term variability in solar irradiance, which has a direct impact on solar energy projects, such as prefeasibility studies or estimating the system performance of PV power plants.

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