STANDARDIZING AND BENCHMARKING OF MODELED DNI DATA PRODUCTS

Richard Meyer[1], Chris Gueymard[2] and Pierre Ineichen[3]

[1] Suntrace GmbH. Address: Brandstwiete 46, 20457 Hamburg, Germany. Phone: (+49) 40 767 9638 0 E-mail: r.meyer@suntrace.de

[2] Solar Consulting Services, P.O. Box 392, Colebrook, NH 03576, USA

[3] University Genève, Battelle Bat D-7 rte de Drize, CH-1227 Carouge, Switzerland

1. Introduction

Direct normal irradiance (DNI) is the 'fuel' of concentrating solar power (CSP) systems. The intensity and distribution of DNI are dominating factors for the design and performance of CSP plants. Due to the significant short-term and long-term variability in DNI, CSP analysts must obtain DNI data time series—not just mean annual averages. It has been shown that a relatively accurate annual value might be predicted by satellite-based models, but with large errors in monthly values [1]. Using probabilistic performance simulations, which also take the uncertainty of many technical parameters into account, it has been shown that the uncertainty and variability in annual DNI at a site is the single greatest cause of uncertainty when predicting the energy production of a CSP plant [2]. In addition to the need for verifiable accuracy in monthly-average DNI, realistic performance simulations of a CSP installation depend on reliable time-series of DNI and ancillary meteorological variables, such as temperature. Many simulation tools use only a synthetic year (referred to as TMY). To avoid power output prediction errors of typically ≈ 10 %, such TMY data sets must well represent the hourly frequency distribution of DNI [3], but this is not always the case. Moreover, it appears that larger errors may occur, if satellite-derived data time resolutions with better than one hour are used, even though this is necessary to simulate transient behavior of CSP plants. As the characteristics of DNI time series have a strong impact on the design and financing of large solar plants, it is necessary to quantify the accuracy of such data products under various aspects, from the long-term average down to sub-hourly time-steps.

The validation of available satellite-derived DNI data is currently insufficient, due in part to the lack of measurement sites with good-quality data, particularly over regions with large CSP potential but insufficient infrastructure. Validation exercises take time and must be done by experts and, hence, require sufficient financial resources. So far, such resources have been scarce in general. The CSP industry, which would directly benefit from such studies, prefers to install weather stations at the specific sites, where CSP projects are planned. The data collected by these stations would be essential for validation studies, but is most often inaccessible since it is proprietary. Often, the only existing validation is done by the data producers themselves, which is against best practices for due diligence processes. Recently, Šúri et al. [4] inter-compared several satellite-derived DNI datasets. This study only covered Europe and used the average of all data sets as the reference instead of ground-based measurements.

As the CSP industry gets more mature, it urgently needs an in-depth analysis of the currently available satellite-derived data sets. Ideally, validation studies should be performed by independent experts with various data sets, using reference measurements that have not been used by the data providers to train or calibrate their model. (This common practice makes their resulting databases of apparent high performance when compared to the training data.)

For the above reasons, the Executive Committee of SolarPACES decided to fund a research project to benchmark the various satellite-derived DNI data sets that would agree to participate. This paper reports about the first phase of this project. It gives an overview of current satellite-derived DNI products, and suitable DNI measurements for validation and benchmarking. It proposes a methodology to benchmark existing (or future) modeled DNI data, and offers some examples of a larger international benchmarking action, now under preparation.

2. Overview of available satellite-derived DNI time series data for CSP

Several different satellite-derived DNI products are now available. NASA-SSE, NREL-CSR, NREL-SUNY or Satel-Light are examples of public-domain data sources. SoDa/HelioClim and DLR-Solemi offer free data to some extent only. Data from other providers, such as Focus Solar, GeoModel/solargis, EnMetSol, IrSOLaV, s2m or 3TIER, are of a commercial nature, and are reportedly based on better radiative models and input data. It has to be shown whether this translates into higher-accuracy DNI results.

In principle, DNI can also be calculated from numerical weather models. Usually such models are used for forecasting purposes, but they can also be run in re-analysis mode to create long historic time series. Since the industry has requested that such kind of data be analyzed too, it has been decided to open up the planned benchmarking study to such products, which do not directly use satellite-based cloud data as input.

3. Worldwide DNI-measurement sites for benchmarking of satellite data

The reference for the benchmarking of model-derived data shall be high-quality solar radiation measurements, such as those from the BSRN network. Many other sources of measured data are contemplated, including stations equipped with rotating shadowband radiometers. Most generally only stations with good track record of calibration, maintenance and quality control should be considered. To qualify for the benchmarking effort, each measurement station will have to pass a quality check. The benchmarking shall focus on the 'sun belt' region, meaning latitudes between -45 and +45°, and a mean daily DNI above 5 kWh/m^2. Under these constraints, a total of two dozen potential reference stations have been identified so far.

4. Methodology for benchmarking and application to test data sets

Various statistical parameters are proposed to quantify performance. The mean bias (MB) and the root mean square deviation (RMSD) are very popular. They can be calculated for each site and various time steps. It is shown that the RMSD decreases almost logarithmically when time resolution increases from 15 minutes up to yearly values. This behavior is found to be similar for the various sites and data sets, albeit steeper for sites that are more affected by convective clouds. The Kolmogorov-Smirnov-Integral (KSI) provides a way to characterize how well short-term fluctuations in DNI are reproduced by the modeled data sets [5]. KSI summarizes in a single value how well modeled time series fit the measured reference, and is therefore a desirable performance indicator [3]. Detailed statistical results using four modeled datasets will be presented.

More detailed tests are necessary to satisfy the industry needs. For instance, low-sun conditions are associated with low DNI and increased shading issues, and are therefore rarely utilizable for CSP operation. Such time periods can be advantageously filtered out, thus tailoring the benchmarking process to provide performance results optimized for CSP applications.

4. Conclusions and outlook

In recent years, many new DNI-measurement stations have been installed worldwide. Quality improves, data records get longer, while satellite data are now offered in 15-min time steps in addition to the conventional hourly frequency. In principle, it could become possible to obtain time-series at higher frequency. In the future it is expected that detailed CSP performance simulations will be done with 1- to 10-min time steps.

New DNI products are currently being developed. Especially for Europe, Africa and the Middle East, the Meteosat Second Generation satellite is now able to provide the necessary inputs to radiative models at 15-min time intervals. A preliminary validation at a limited amount of sites is under way, using four satellite-derived hourly DNI products. Significant deviations are obtained, confirming the importance of this study.

Several powerful statistical indicators will be proposed and used to characterize the performance of DNI time-series for CSP applications. An advanced methodology will be used to inter-compare measurements and modeled time-series. An international workshop on DNI benchmarking is foreseen for spring 2012. All interested data providers will be invited to deliver their data time-series at various time resolutions, for either public or private measurement sites. More providers of measured data (public and private) for sites within the sun-belt would also be an essential asset in this research study.

References

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