DIRECT NORMAL IRRADIANCE FOR CSP BASED ON SATELLITE IMAGES OF METEOSAT SECOND GENERATION

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Abstract

We present a method to derive the direct normal irradiance (DNI) from MSG data. For this, we apply the Heliosat method and a new model for the direct fraction of the irradiance. The clear sky irradiance is mainly determined by the aerosol optical depth (AOD) and water vapour content, which are taken from suitable climatologies. The accuracy of satellite derived DNI data has been analyzed for Spanish sites, more sites will be evaluated within the project SESK (Standardisierung der Ertragsprognose Solarthermischer Kraftwerke – standardization of yield prognosis for solar thermal power plants). As for concentrating solar power (CSP) the frequency distribution of DNI is of special importance, special attention is given to correct modeling of this feature.

Keywords: Direct normal irradiance, Meteosat Second Generation, frequency distribution of DNI

1. Introduction

Measurements of the direct normal irradiance (DNI) are needed for the planning of a solar thermal power plant at a given site. Direct solar irradiance is highly variable in space and time. As ground measurements are expensive, such data are rare.

Meteorological satellites operationally scan the Earth's surface and clouds. So we can derive the direct normal irradiance from their data with a good spatial and temporal coverage. Since 2004, the satellites of the new generation MSG provide images of Africa and Europe every 15 minutes with a spatial resolution of approximately 1 km x 1 km at sub-satellite point.

A combination of solar irradiance measurements and various satellite derived products to a site-specific best estimate is presented in [8]. Here, we analyze the quality of satellite derived DNI data.

2. DNI from satellite imagery

The Heliosat method is a technique of determining the global radiation at the ground by using data from a geostationary satellite, see [1]. We use this method in combination with the SOLIS clear sky model and a new beam fraction model [7] to calculate the DNI.

2.1. Heliosat method

The key parameter of the Heliosat method is the cloud index n, which is taken from the satellite measurements and related to the transmissivity of the atmosphere via

$$k^* = 1 - n,$$

where the transmissivity is expressed by the clear sky index k^* defined as the ratio of global irradiance and clear sky irradiance:

$k^* = I_g / I_{clear}$.

The clear sky irradiance must be known for each site. For this purpose we use the SOLIS clear sky model, see sec. 2.2.

2.2. SOLIS clear sky model

The SOLIS clear sky model [2] uses the radiative transfer model libRadtran [3] to calculate input parameters for a fitting function called the modified Lambert–Beer (MLB) relation. For this, only two radiative transfer calculations are needed for a given atmospheric state to get the irradiance for a full day. We use climatologies with monthly averages of AOD [4] and water vapour content [5] as input parameters for SOLIS and get the direct and global irradiance as output.

2.2. Direct model

We propose a new model [7] to calculate direct irradiance as a function of the clear sky index k^* and the direct irradiance at clear sky conditions b_{clear}. An appropriate clear sky model is the basis for this approach, see sec. 2.2.

For cloud events, described by $k^* < (1 - c(\theta))$ (whith $c(\theta)$ is a fit function), an exponentially rising parametrisation b(k*) for the direct irradiance was found empirically. It is given by

$$b(k^*) = b_{clear} \; k^{*P}$$

with P as a fit parameter.

Situations, where $|k^* - 1|$ becomes smaller than $c(\theta)$, are defined as clear sky situations and the parametrisation results in

$$b(k^*) = b_{clear} + (k^*-1)\,\alpha$$

where α is a fit parameter.

If the clear sky index becomes greater than $(1 + c(\theta))$ we assume a special cloudy situation. In this case the global irradiance becomes more than I_{clear} in consequence of an increasing diffuse irradiance by reflection on clouds. The direct irradiance is then parameterised by

$$b(k^*) = b_{clear} \; / \, k^*.$$

In Fig. 1 the beam fraction as a function of clearsky index is given for satellite and ground derived values.

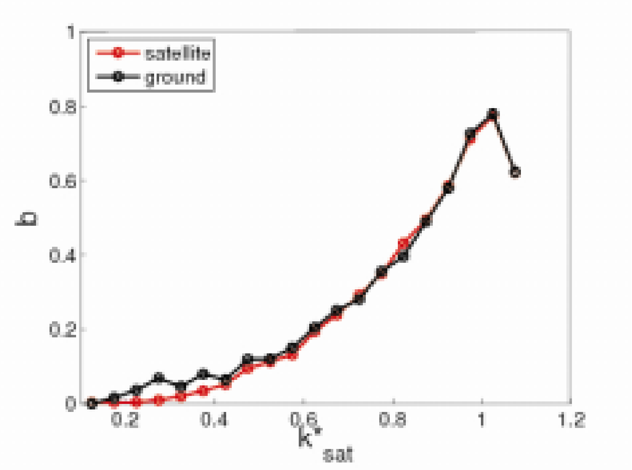

Fig. 1: Distribution of direct irradiance fraction once determined from satellite data and once evaluated from ground data versus the clearsky index.

3. Analysis and results

3.1. Meteorological data base

The accuracy of the proposed method to derive DNI was evaluated for the year 2005 for six stations of the Spanish Meteorological Service INM, namely Santander (43.49°N,3.80°W), Oviedo (43.35°N, 5.87°W), A Coruna (43.37°N, 8.42°W), Valladolid (41.65°N, 4.77°W), Murcia (38.00°N, 1.17°W) and Madrid (40.45°N, 3.27°W). Moreover, the SESK partner Epuron started a measurement campain of DNI in Spain, the two sites CA1 and CO1 are used for the analysis in section 3.2.

3.2. Bias and root mean square deviaiton

The evaluation was performed for all hourly values with the sun above horizon. Special focus of the evaluation was on the accuracy of yearly sums and on the investigation of frequency distributions of the time series, see figure 1, as these are relevant for yield estimates. Beside this, the relative bias (rBIAS) and the relative root mean square deviation (rRMSD) are used for quantitative comparisons.

In Table 1 the accuracy information is given on different time scales which are relevant for solar energy applications. The deviation of annual satellite derived irradiance sums from the respective ground measured sums is between −2% and 4.5% for GHI and between −2% and 8.5% for DNI.

	GHI	**DNI**
Hourly mean	335 W/m²	366 W/m²
rRMSD hourly	14.5%	31.1%
rRMSD daily	7.5%	18.5%
rRMSD monthly	3.6%	6.3%
rBIAS	1.5%	1.1%

Table 1. Accuracy of satellite derived global horizontal irradiance (GHI) and direct normal irradiance (DNI) for different time scales.

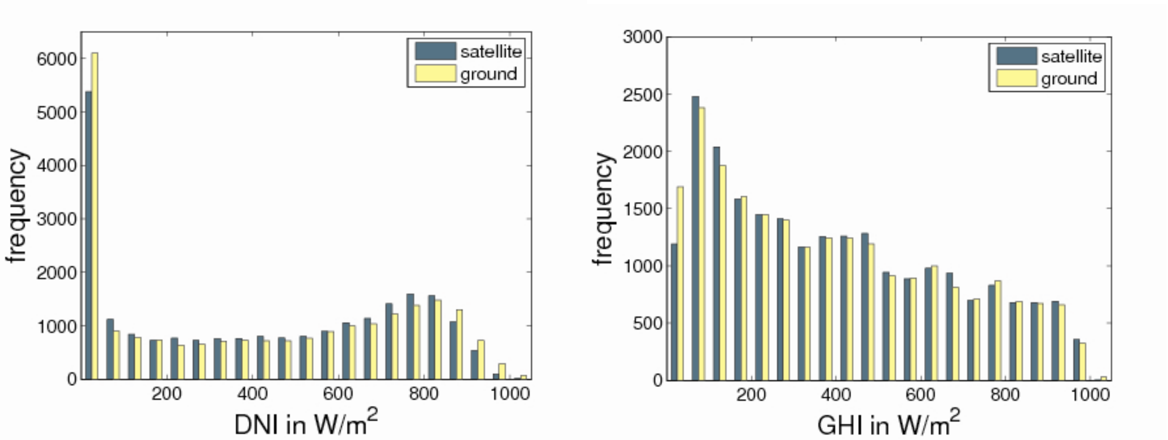

Fig. 2. Frequency distribution of calculated and measured direct normal irradiance (left) and of global irradiance (right) for the 6 Spanish INM stations.

3.2 Matching the frequency distribution

CSP systems usually have a non-linear response to incoming irradiation. So not only the long term average but also the distribution of the irradiance will have an important effect on the energy production. Figure 2 displays the frequency distribution of calculated and measured DNI and GHI for the Spanish INM stations; a fairly good agreement is achieved. In Fig. 3 it is shown that this does not hold for all sites: While satellite derived DNI for the stations CA1 and CO1 show a similar bias, when compared to ground measurements, their frequency distributions are not similar. Here, work has to be done within the framework of the project SESK.

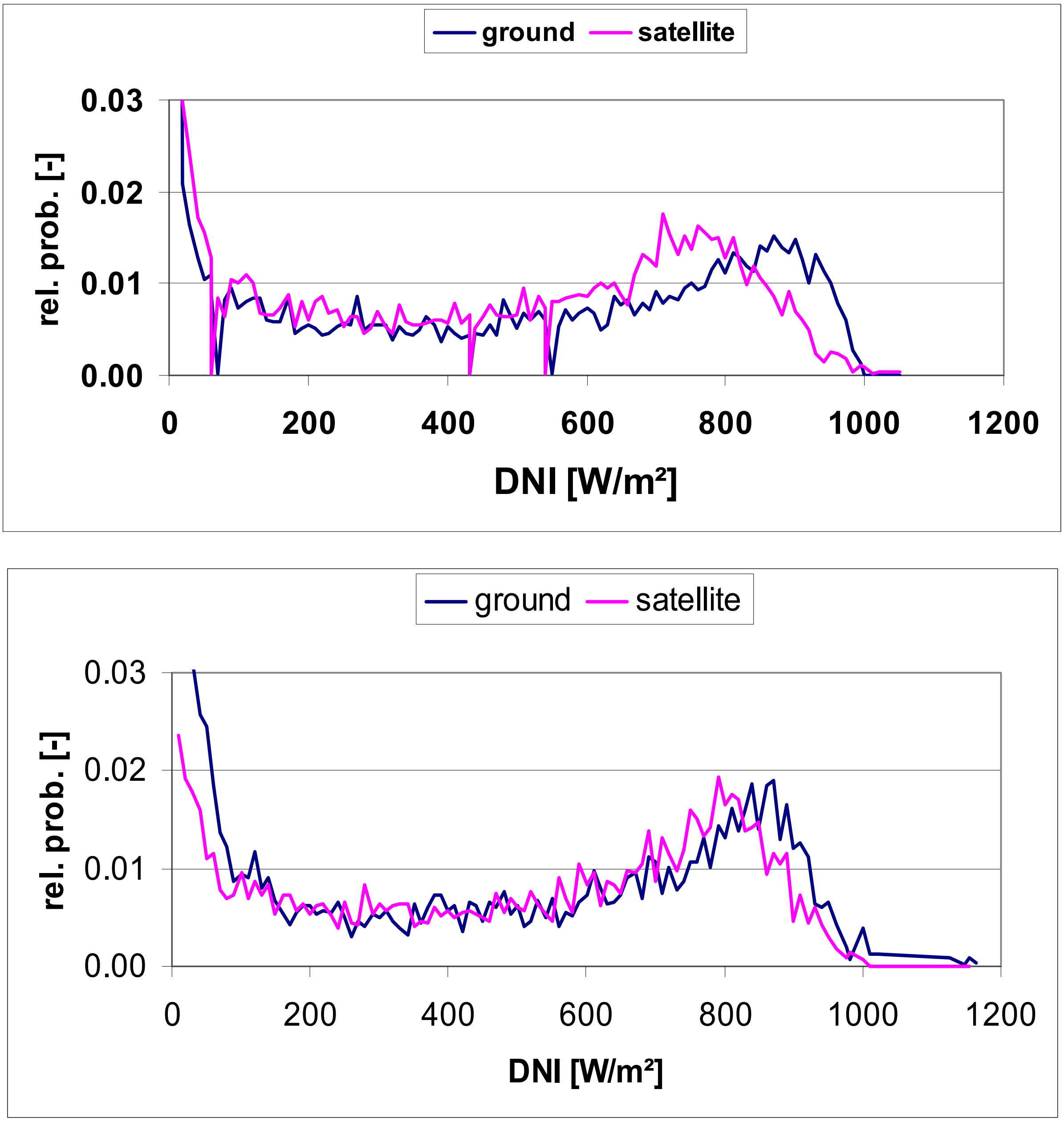

Fig. 3. Frequency distribution of calculated and measured direct normal irradiance for two Spanish Epuron stations CA1 (upper image) CO1 (lower image).

4. Conclusion

While global irradiance time series is well represented by satellite derived data, this is also true for the bias of DNI but does not hold for the frequency distribution of DNI. Here, work has to be done within the project SESK.

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