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The Uncertainty of the HelioClim-3 DNI Data Under Moroccan Climate

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Abstract. The purpose of this study is to evaluate the uncertainty of the DNI satellite-derived data from HelioClim-3 against those measured at ground level by calculating the classical statistical performance indicators for different time resolutions (hourly, daily and monthly). Correlations between the errors and the Aerosol optical depth (AOD) data measured by an AERONET sun photometer station at the University of Oujda were performed. Results show that the DNI data derived from Helioclim-3 can be considered as acceptable for satellite data with an RMSE of 19.7 % and a bias of 7.9 % for the hourly data. HelioClim-3 systematically over-estimates the daily DNI sums for the investigated site. The correlation to AOD at 550 nm can only be one of the reasons for the deviation. Corrections or site adaptation could help to increase the accuracy of the data base for that pixel.

INTRODUCTION

For Concentrating Solar Power (CSP) the most important parameter that has to be taken into consideration is the Direct Normal Irradiance (DNI). DNI is the leading meteorological parameter to be used in the resource assessment of potential CSP sites. Having a DNI database with high accuracy, high time resolution and covering a long-time period is crucial. The Middle East and North African region (MENA) is a target area for solar [10,11]; however, the DNI measurements at ground level are scarce. That's why researchers and engineers usually use data from different satellite databases for their simulations and investigations.

Even though, satellite databases can offer long DNI time coverage, they have relatively low accuracy especially in these arid regions because of the presence of Aerosols that affect the derivation of DNI from satellite data [1]. The objective of this paper is to make a comparative study between the DNI values calculated by Helioclim-3 and measured at ground level in Oujda city (Eastern Morocco), in order to assess the uncertainty of the Helioclim-3 DNI dataset for the Oujda site. The *HelioClim-3* algorithm has been developed by Mines Paristech

METHODOLOGY

Irradiance Data

In order to obtain a good evaluation of the irradiance data estimated by satellite, at least 9-12 months of data measured at ground level with high accuracy instruments is required [2]. In this paper, the DNI data is measured using the first class Kipp&Zonen CHP1 pyrheliometer installed on a solar tracker at the roof top of the University of Oujda (latitude 34.65°, longitude -1.90°, altitude 617 m) in the framework of the enerMENA project [3].

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The irradiance sensors are cleaned on daily basis and they are calibrated regularly. The data is thoroughly quality controlled on a regular basis following the procedures described in [9]. The measurement period is January 2012 until December 2013.

Statistical Performance Indicators

As mentioned above, the irradiance data accuracy is very important since they are used as a reference for the resource assessment and in the analysis of the electrical and economical outputs of a solar plant at a given site. Even if the satellite derived data are widely used for this purpose, however, they have an error range that should be evaluated and corrected if possible. For the correction or the site adaptation many techniques exists, some of which are summarized in [2]. The purpose of this study is to evaluate the performance of the DNI data from *HelioClim-3* data base under the climate of Morocco.

The most commonly used performance indicators to assess the accuracy of a solar radiation data set or model are the mean bias error (MBE), root mean square error (RMSE), normalized root mean square error (NRMSE), test statistic (TS), and the Standard deviation (σ) [4]. In what follows, definitions of these values are given where N represents the number of observations. D_s^i, D_g^i are the ith DNI value extracted from *HelioClim-3* and measured at ground level, respectively. While, $\overline{D_s^i}$, $\overline{D_g^i}$ represent the mean values of the observations defined previously.

The MBE represents the arithmetic average of the error and it gives a measure of bias of the overall model. A positive MBE represents an over-estimation of DNI by the satellite data and a negative MBE an under-estimation of the measured value. However, a MBE equal to zero doesn't necessarily mean that the model is without error.

$$MBE = \frac{1}{N}\sum_{i=1}^{i=N}(D_s^i - D_g^i) \tag{1}$$

The RMSE offers information on the short-term performance of the satellite data set by making a term by term comparison of the actual deviation between the data measured at ground level and that extracted from satellite models. This indicator is always positive and the ideal value is zero. However, the presence of few high errors can significantly increase the RMSE value.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{i=N}(D_s^i - D_g^i)^2} \tag{2}$$

The NRMSE is calculated by dividing the RMSE by the average value of the measured values. This indicator is a relative error and can provide information on the long term performance of the model.

$$NRMSE = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{i=N}(D_s^i - D_g^i)^2}}{\frac{1}{N}\sum_{i=1}^{i=N}\overline{D_g^i}} \tag{3}$$

The TS is a widely used test to assess whether the satellite irradiance data are significantly different from the measured values or not. The smaller the TS value the more accurate is the satellite dataset.

$$TS = \sqrt{\frac{(N-1)MBE^2}{(RMSE^2 - MBE^2)}} \tag{4}$$

The standard deviation σ represents the difference between the irradiance data measured by satellite and that calculated at ground level. This indicator is always positive and the ideal value is zero.

$$\sigma = \sqrt{\frac{N(RMSE^2 - MBE^2)}{(N-1)}} \tag{5}$$

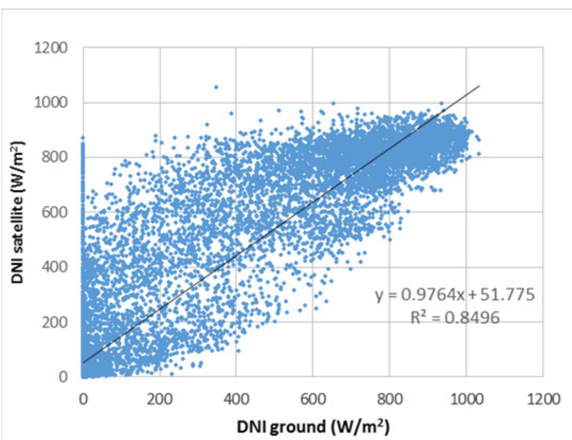
All those indicators are calculated for different scenarios and gathered in Table1 in the next paragraph.

RESULTS AND DISCUSSION

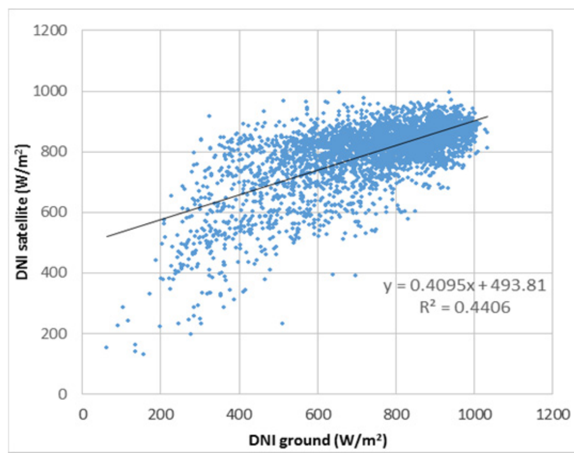
Solar resource community widely agreed to only include day time values in the comparison of satellite and ground data sets in order to avoid shading and sensor cosine response errors at low solar angles [5]. Daytime here corresponds to periods in which the solar zenith angle is below 80^o. In this paper, the statistical indicators were calculated for both cases (day time and 24 h).

Before discussing the performance indicators, direct comparisons of the two data sets are performed to get a general idea on the agreement between the DNI values derived from *HelioClim-3* and those measured at ground level. For this purpose, the hourly (24h data and the day time data) daily and monthly data, are plotted in a scatterplot in figure1. A perfect match between the satellite and the ground DNI data would occur if the blue markers are on the black line. This is not the case in any of the graphs. The data agree better if only day time data is included. Furthermore, the agreement between the data increases when the time resolution decreases. Another comparison technique is to analyze the frequency and the cumulative distribution function (CDF) for both data sets. Figure 2 represents the frequency distribution of the hourly data and Figure 3 represents the CDF of the 1h day time values, as well as the daily averages of both data sets.

From the first look we can say that the DNI from HelioClim-3 is higher than that measured at ground level. This is confirmed by the positive MBE values calculated with and without the daytime filter (Table 1).



(a)



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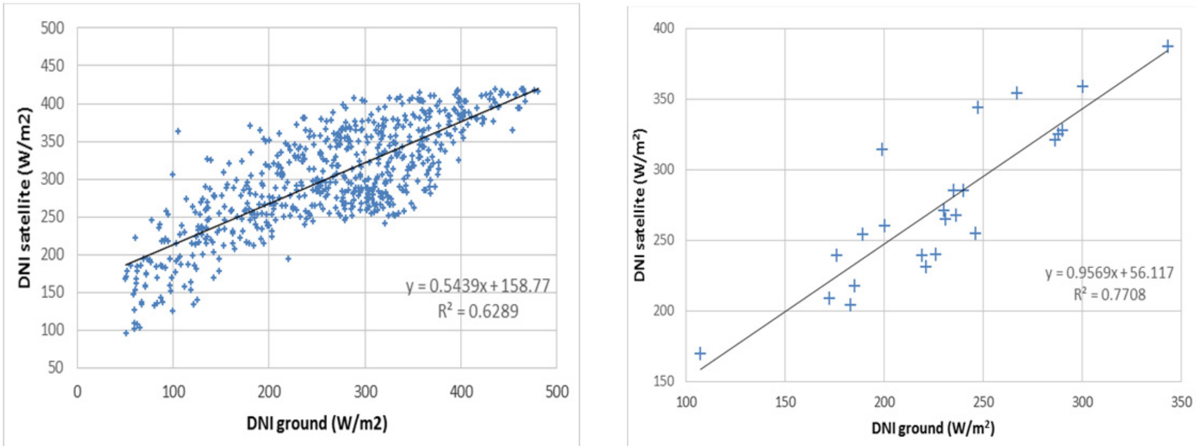


(c) (d)

FIGURE 1. Correlation between the DNI data measured at ground level and derived from HelioClim-3 (a) 24h data, (b), day time values, (c) daily averages, (d), Monthly averages.

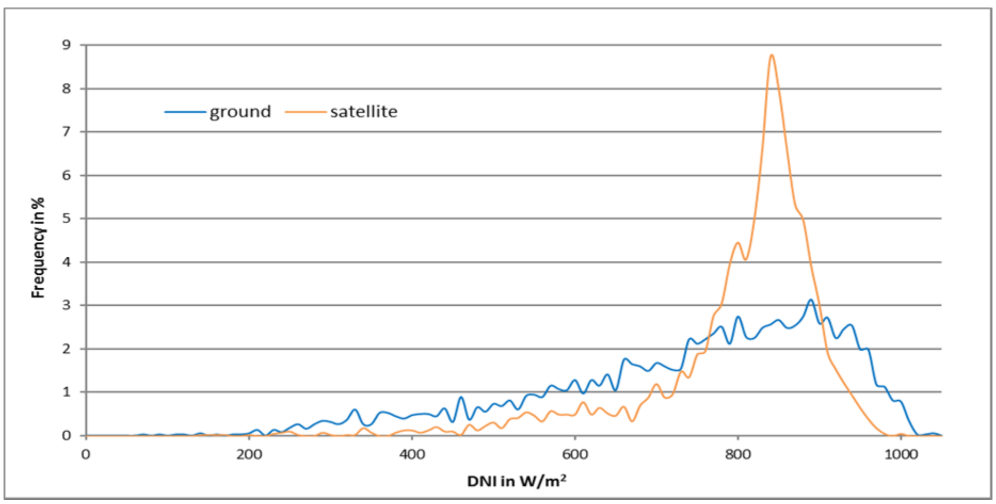
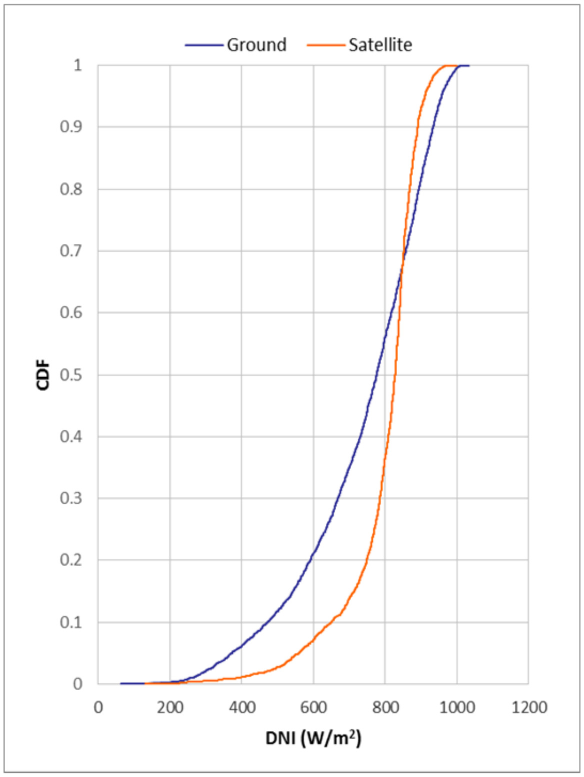
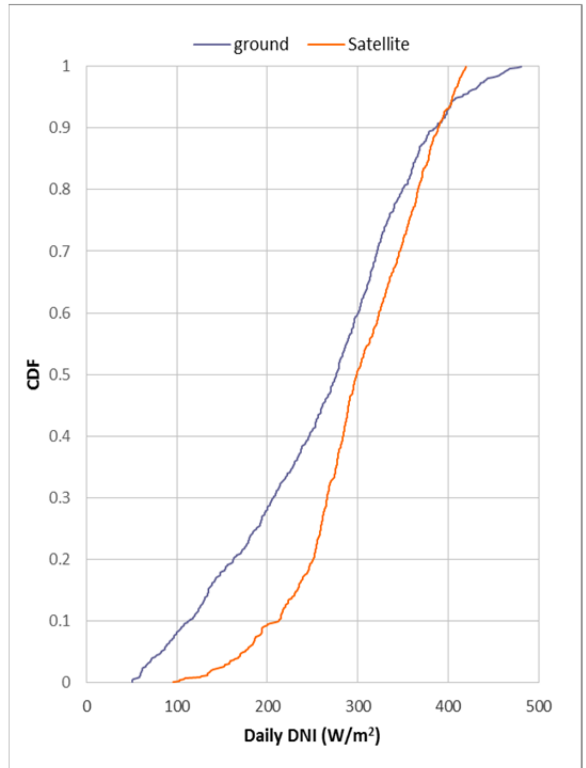


FIGURE 2. Frequency distribution of the hourly data derived from HelioClim-3 and measured at ground level.



(a)



(b)

FIGURE 3. Cumulative Distribution Function (CDF) of the DNI values measured at ground level and derived from HelioClim-3 (a) Hourly values for zenith angles < 80°, (b), daily average values.

Indeed, for the hourly data the NMBE equals 20 % and 7.9 % for the hourly DNI in the case of 24 h and at a zenith angle less than 80^{o} (day time) respectively. Regarding the daily averages, the *HelioClim-3* DNI data have a bias of 15.1 %.

TABLE 1. Statistical evaluation of different performance indicators

	MBE(W/m^2)	NMBE %	RMSE(W/m^2)	NRMSE%	TS	R^2	σ
Hourly data (24h)	46.4	20.2	143.4	62.4	45.2	0.85	62.4
Hourly data (day time)	58.4	7.9	145.5	19.7	27.1	0.45	19.7
Daily averages	39.5	15.1	73.7	28.2	16	0.63	28.2
Weekly averages	64.4	20.2	62.7	27.3	11.3	0.73	27.3
Monthly averages	46.2	20.1	53	23.1	8.5	0.77	23.2

The NRMSE of the hourly data equal 62.4 % and 19.7 % for the 24 h and day time values respectively, while the NRMSE for the DNI daily average values equals 28.2 %.

With those values we can assume that the *HelioClim-3* DNI values have a good accuracy in the range of the satellite measurements, but it's not good enough for sufficiently precise feasibility studies of CSP projects. Therefore, they have to be corrected to increase their accuracy. Different correction/site adaptation techniques are available in the literature [6,7], but this not the objective of the current study.

Since our field of study is characterized by high aerosols concentration [12,13], we will investigate the impact of this parameter on the error of the HelioClim-3 DNI values. For this purpose, the daily Aerosol Optical Depth (AOD) data measured using an AERONET sun photometer installed at the University of Oujda are used for the whole experiment period (2012-2013). This dataset was compared with α, that is defined as the daily average DNI from HelioClim-3 divided by the daily average DNI measured at ground level.

Figure 4 shows a weak correlation between the AOD at 550 nm and α. Knowing the fact that HelioClim-3 over-estimates the DNI it seems reasonable that, for high AOD values α tends to be higher and for low AOD α is mostly lower.

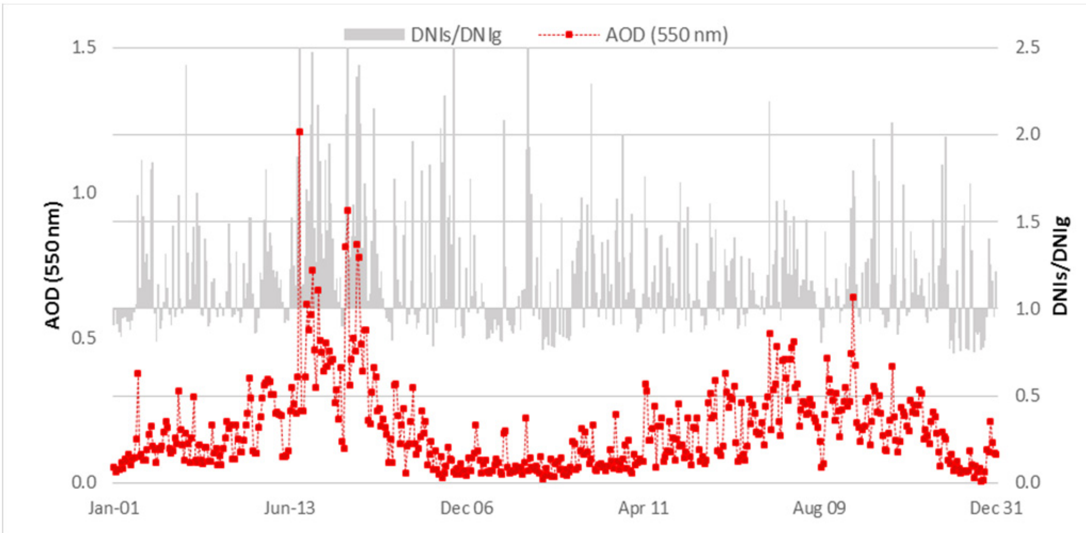


FIGURE 4. Fraction between daily average values of the DNI measured at ground and from satellite (α) and the AOD at 550 nm.

The coefficient of determination, $R^2 = 0.37$ between α and AOD at 550 nm, is relatively small, see figure 5. That means that aerosols alone are not sufficient to explain the deviation of satellite determined DNI from the ground measured DNI in Morocco. In fact, according to [8], aerosols are classified as the second most important parameter affecting the solar irradiance derivation after the cloud cover index. To quantify the deviation between satellite and ground measurement, the RMSE and the MBE of each month are shown in Figure 6.

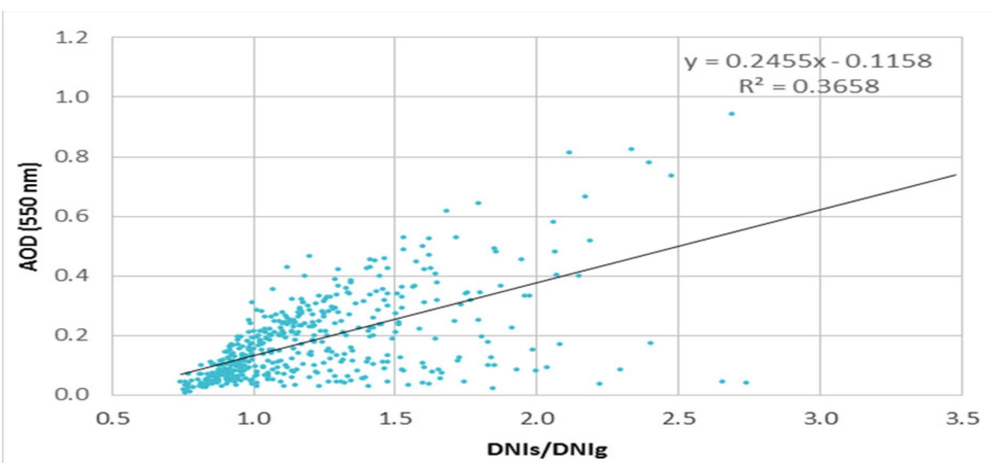
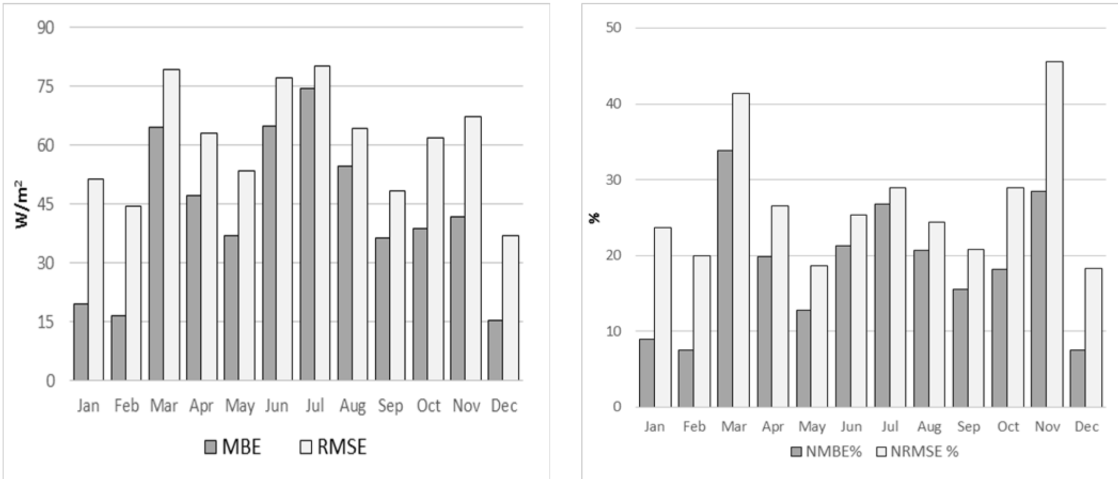


FIGURE 5. Correlation between the daily average values of α and the AOD at 550nm.

The highest NRMSE and NMBE errors were measured in March and November, presumably due to the higher presence of clouds. Those are also the months with the lowest DNI monthly sums measured at ground level. Future work will focus on including the cloud frequency to understand the parameters that influence the DNI data extracted from satellite images and aim to correct the *HelioClim-3* DNI data accordingly.



(a) (b)

FIGURE 6. Monthly RMSE and MBE as absolute values in W/m^2 (a) and in relative units in %.

A scatterplot of α versus the sun elevation angle in hourly time resolution is shown in figure 7. It shows that the *HelioClim-3* overestimates the DNI for angles greater than 20 or 25 W/m^2. Oftentimes the overestimation is substantial with α well above 1.5, which corresponds to an error of 50 %. For smaller elevation angles, the satellite derived DNI most frequently underestimates the ground measured DNI. This result can be useful for determining the reasons for the deviation of *HelioClim-3* DNI measurement from the ground measured DNI.

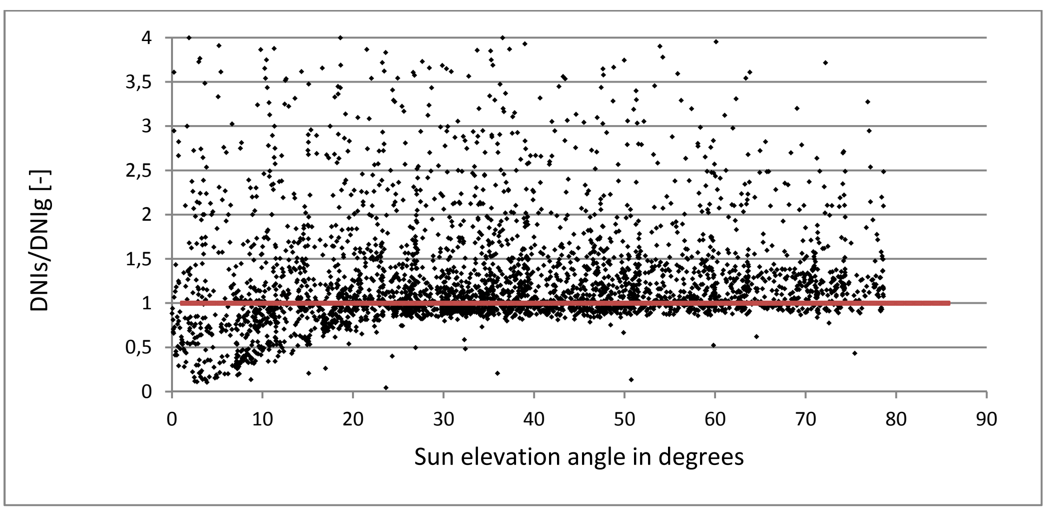


FIGURE 7. Ratio of DNIs and DNIg in hourly time resolution plotted against the sun elevation angle at the time of measurement. The line at α=1 has been inserted as an orientation.

CONCLUSION

High accuracy DNI data are required to precisely assess the solar resource of a target region and the potential economic outputs of a CSP plant at a candidate site. Satellite derived solar irradiance data may deviate substantially from ground measurements. This affects the feasibility and the bankability of a CSP project.

In this study, the accuracy of the DNI data derived from HelioClim-3 was compared to the high precision DNI dataset measured at ground level at the University of Oujda (Eastern Morocco). The most common statistical performance parameters are presented for a 2-year dataset (2012-2013). Furthermore, correlations between the AOD at 550 nm and α, the quotient of satellite and ground DNI were conducted. Results show that HelioClim-3 model over-estimates DNI but the deviation is in the range of typical satellite model deviations with an RMSE of 19.7 % and a bias of 7.9 %. Especially the morning and evening hours show greater deviations between satellite and ground data. Moreover, the correlation between α and the AOD is weak, thus it can be concluded that aerosols are not the only factor that influence the DNI data extracted from satellite images. Further analysis need to be conducted to understand the source of error and to correct or adapt the data from HelioClim-3 to Moroccan climate.

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