Variability in global and direct irradiation series generation: scope and limitations

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VARIABILITY IN GLOBAL AND DIRECT IRRADIATION SERIES GENERATION: SCOPE AND LIMITATIONS

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Dr, Solar Thermal Energy Department, National Renewable Energy Centre (CENER). Address: C/ Isaac Newton n 4 - Pabellón de Italia, 41092 Sevilla (Spain). Phone: (+34) 902 25 28 00. Fax: (+34) 954 46 09 07 E-mail: cfernandez@cener.com

Abstract

The synthetic generation of hourly global horizontal irradiation (GHI) series allows the estimation of solar radiation potential by allowing the filling of gaps in records of daily or hourly values. In addition, synthetic generation of GHI can provide an increase of the time resolution of measured (or estimated) GHI series.

Unfortunately, since GHI synthetic generation schemes are based on the use of random numbers, they provide different global irradiation values in each generation. Consequently, synthetic GHI series generated from the same set of initial data can exhibit different annual values. This variation is transferred and amplified in the estimation of direct normal irradiation (DNI) through synthetically generated GHI series.

In this article, generation of a number of artificial series of hourly GHI and DNI is carried out to investigate and quantify their annual variability. Annual values of GHI and DNI generated series are compared with measured ones provided by the Spanish Agency for Meteorology (AEMET) in Madrid, Murcia, Valladolid and Coruña (Spain). The results of this study indicates that synthetic generation of solar irradiation series must be used as a procedure to obtain hourly-frequency series which presents statistical properties consistent to those observed, not as a procedure to predict precise DNI values.

Keywords: resource assessment, global irradiation, direct irradiation, synthetic generation, variability

1. Introduction

To fulfill present needs in concentrating solar power systems, many design and simulation codes demands hourly solar irradiation data. Unfortunately, measured series of solar irradiation are only available for a reduced number of locations. The synthetic generation of hourly solar irradiation series allows the estimation of the solar resource in those locations lacking measurements, the filling of gaps in records of daily or hourly values, or the interpolation of recorded data when the time resolution is too rough. In order to generate hourly values at any location, solar radiation models are used to obtain data having the same statistical properties as the measured series. Such properties include both probabilistic characteristics (average value, variance, probability density function) and sequential characteristics (autocorrelation) [1]. The output of the models approximates the characteristics of the natural solar radiation series as far as possible, and can be used successfully as long-term measured data [2], emulating the natural climatic variability.

Since GHI synthetic generation schemes are based on the use of random numbers, they provide different hourly global irradiation values in each generation. This fact has been previously studied by Fernández-Peruchena et al [3], where annual values of hourly resolution synthetic GHI series generated from the same set of initial measured data were investigated. In this work, the variability in both direct normal irradiation (DNI) and GHI annual values, from synthetic generation of GHI and several global-to-beam conversion models is analyzed. The comparison of measured annual values of GHI and DNI with synthetically generated ones allows the quantification of the goodness of synthetic generation scheme to predict DNI annual values.

2. Methodology

2.1 Generation of daily GHI values

The first algorithm for generating synthetic series is the one proposed by Aguiar [4], which allows the generation of daily clearness index from monthly ones. This model uses Markov transition matrices to break down the monthly mean global radiation into the daily global radiation values, having the same statistical properties as observed time series. Two observations support this method: the probability of occurrence of a daily radiation value is the same for months having the same clearness index; daily radiation values are correlated only with those values observed in consecutive days [4]. Furthermore, the matrices which are used to generate new series are universal. This model is depicted briefly in figure 1 (A).

2.2. Generation of hourly GHI values

The second algorithm for generating synthetic series is the time-dependent autoregressive Gaussian (TAG) model, proposed by Aguiar [1], which provides synthetic sequences of hourly clearness index values by using the daily clearness index as input (see figure 1, B). This method proposes a decomposition of hourly clearness index in two components, one reflecting a tendency and other reflecting randomness.

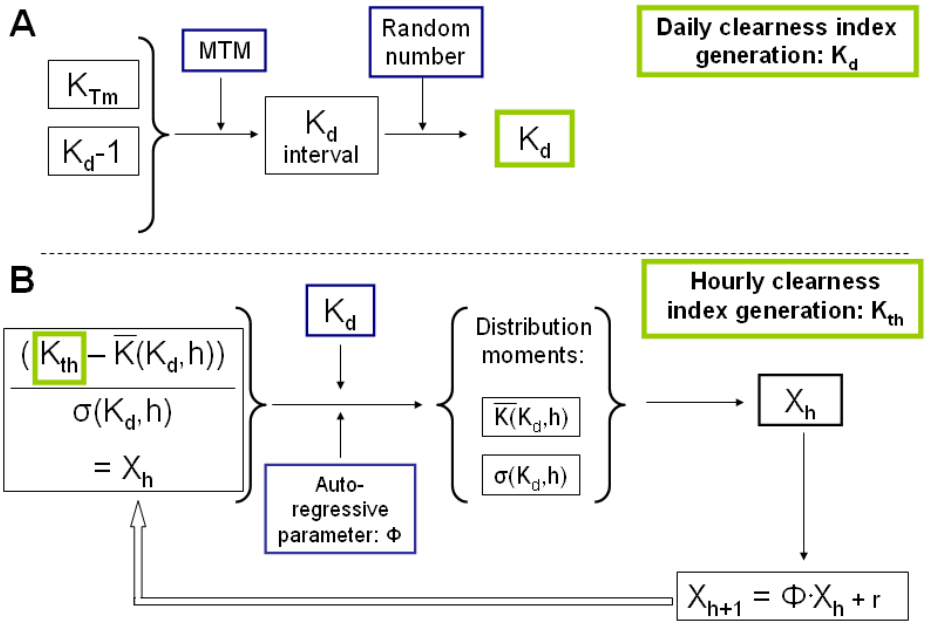

Fig. 1. Generation of synthetic daily sequences of hourly radiation values requiring as input only monthly clearness index.

2.3. Generation of hourly DNI values

The models proposed by Orgill & Hollands, Erbs, Reindl, and Louche (methods are explained in [5]) have been selected for generating hourly DNI values. With the exception of the model from Louche (which estimates direct irradiance values from direct transmittance values), all of the models estimate direct irradiance from the diffuse fraction. These models are detailed in table 1.

Orgill-Hollands		
Kd =	$1.0 - 0.249 \cdot Kt$	$Kt < 0.35$
	$1.577 - 1.84 \cdot Kt$	$0.35 \le Kt \le 0.75$
	0.177	$0.75 < Kt$
Reindl		
Kd =	$1.02 - 0.248 \cdot Kt$	$Kt < 0.3$
	$1.45 - 1.67 \cdot Kt$	$0.3 \le Kt \le 0.78$
	0.147	$0.78 < Kt$
Erbs		
Kd =	$1.0 - 0.09 \cdot Kt$	$Kt < 0.22$
	$0.9511 - 0.1604 \cdot Kt + 4.388 \cdot Kt^2 - 16.638 \cdot Kt^3 + 0.12.336 \cdot Kt^4$	$0.22 \le Kt \le 0.8$
	0.165	$0.8 < Kt$
Louche		
Kb =	$0.002 - 0.059 \cdot Kt + 0.994 \cdot Kt^2 - 5.205 \cdot Kt^3 + 15.307 \cdot Kt^4 - 10.627 \cdot Kt^5$	$Kt > 0$

Table 1. Models used for global-to-beam conversion

2.4. Synthetic generation to reach irradiation values

In general, a great variety of hourly synthetic generated GHI irradiation series from the same daily Kt value can be generated. To illustrate this, let us consider the example depicted in Fig. 2, where two hourly Kt series, having identically daily Kt value, provides different GHI daily values. A similar example can be constructed to show that a given monthly Kt values can provide different daily GHI values.

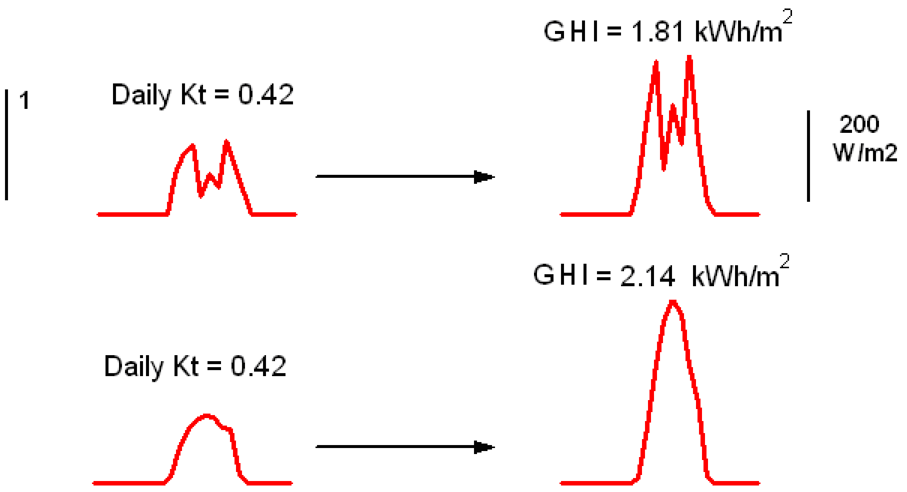

Fig. 2. Two hourly Kt series, having identically daily Kt value, provides different GHI daily values

To investigate the variability of annual irradiation values generated and their relation to measured values, a number of generations up to reach the measured irradiation values have been carried out. .

Fig. 3 shows a schematic view of the procedure. Monthly clearness index (K_{TM}) values, calculated from monthly GHI values measured in the locations investigated, allow the generation of daily and hourly Kt values. A variability of 3% or less between generated and measured K_{TM} is imposed. Once obtained an annual synthetic GHI series (hourly resolution), DNI hourly series are generated using the methods explained above. A difference of 3% between generated and measured annual DNI values (red dashed lines) can also be imposed (not used in this work). 200 synthetic generations in each investigated location have been carried out.

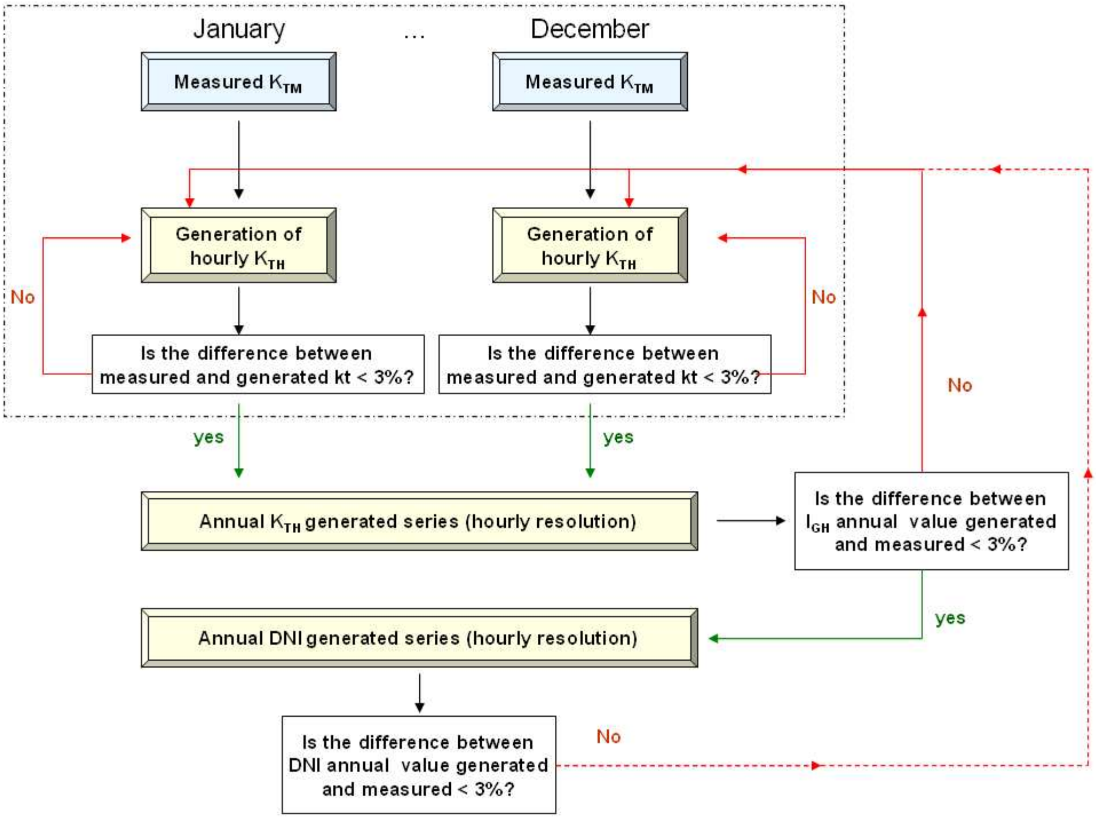

Fig. 3. GHI and DNI synthetic generation procedure.

3. Description of data used

One year of hourly solar irradiation data recorded by the Spanish Agency for Meteorology (AEMET) in four meteorological stations localized in different cities distributed through Spain were selected to carry out the comparison. Data quality has been both visually inspected and analyzed according BSRN (Baseline Surface Radiation Network) recommended tests. Only those months recorded with 2 or less invalid days have been considered.

Station	Latitude	Longitude	Annual GHI (kWh/m^2)	Annual DNI (kWh/m^2)
Coruña	43.37 N	-8.42 W	1405.1	1341.5
Madrid	40.45 N	-3.72 W	1601.0	1792.0
Murcia	38.00 N	-1.17 W	1634.3	1615.9
Valladolid	41.65 N	-4.77 W	1628.9	1799.0

Table 2. Meteorological stations selected from Spanish National Institute of Meteorology

4. Results

4.1 Variability in GHI synthetic generation

Distributions of difference between annual GHI values measured and generated for the investigated locations are shown in Fig. 4 (A). Distributions show different properties as a function of the location: while the one calculated in Valladolid is nearly symmetrical, the distributions calculated in Murcia and Coruña shows marked asymmetry. Moreover, mean values of distributions calculated in Madrid and Valladolid (-0.14) are closer to zero than those calculated in Coruña and Murcia (1.07 and -0.79 respectively), being standard deviation similar in every cases (~1.4) (table 3).

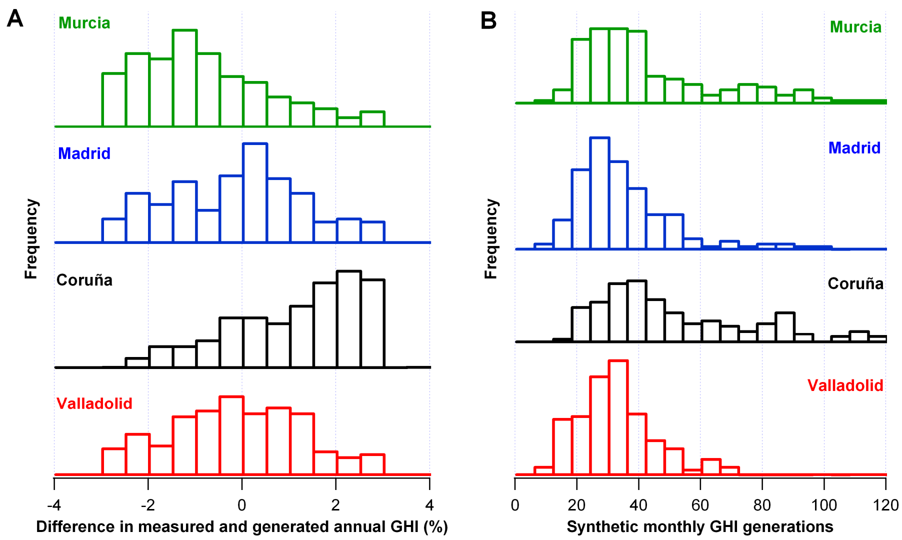

Fig. 4. (A) Difference between measured and generated annual GHI values for each location investigated. (B) Number of synthetic monthly generations to achieve hourly GHI series for each location investigated.

	Mean (%)	Standard deviation (%)
Coruña	1.07385	1.4045
Madrid	-0.139771	1.43667
Murcia	-0.789463	1.41134
Valladolid	-0.142604	1.41157

Table 3. Mean values and standard deviation for difference in measured and generated annual GHI.

Fig. 4 (B) shows, for each location investigated, the distributions of the number of synthetic generations required to achieve measured monthly Kt value with synthetically generated hourly kt values. Distributions calculated in Madrid and Valladolid decrease faster than those calculated in Murcia and Coruña. These results suggest a better behaviour of the synthetic generation models as a function of the location investigated.

4.2 Variability in DNI synthetic generation

Fig. 5 shows distributions of difference (%) between annual DNI values measured in the locations and those generated from synthetically generated GHI values.

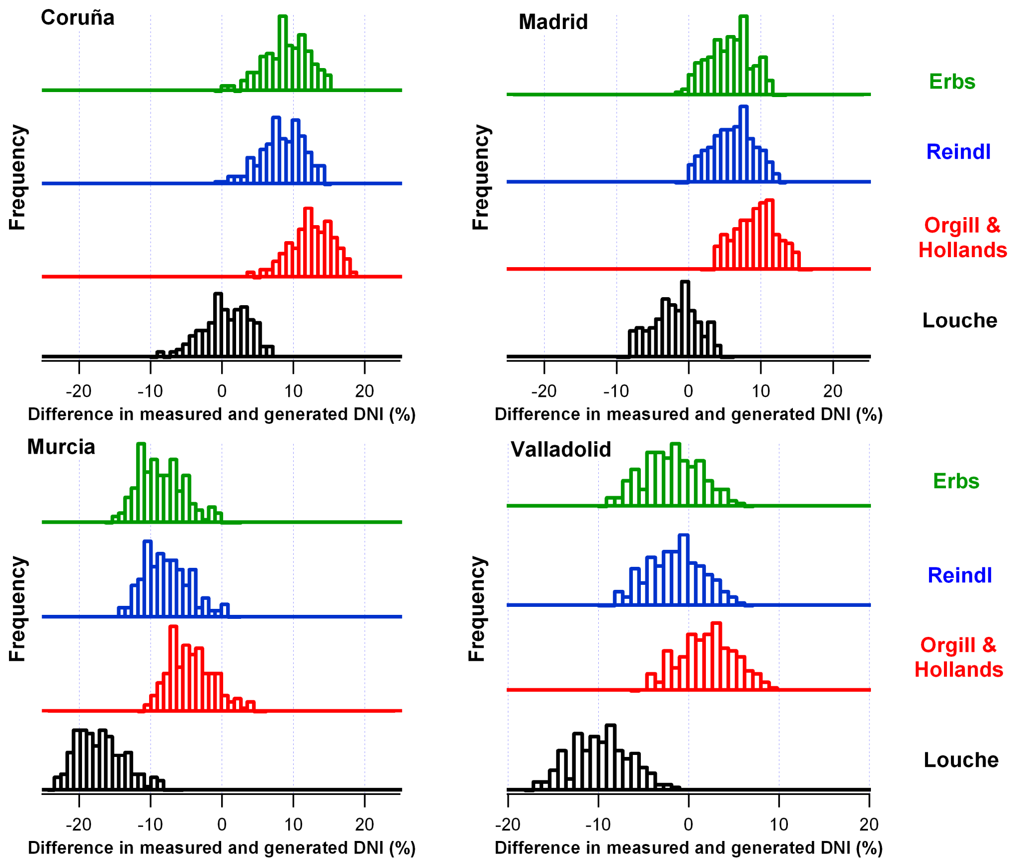

Fig. 5. Difference between measured and generated annual DNI values for each location investigated.

In general, Louche's model provides the lower annual DNI values, and O&H's model provides values slightly higher than those obtained by Reindl's and Erbs' models.

The goodness of each model depends on the location investigated. For example, in Coruña and Madrid, the best results are achieved with Louche's model, while the other models overestimate DNI annual value. In Valladolid, Reindl's model provides the best results, while Louche's model underestimates (~10%). Moreover, DNI distributions in each location show similar symmetry and dispersions (~3%) (Table 4).

	Mean				Standard deviation			
	Erbs	Reindl	O&H	Louche	Erbs	Reindl	O&H	Louche
Coruña	8.65488	8.08224	12.1539	0.121434	3.33672	3.25045	3.14645	3.42907
Madrid	5.4462	5.85599	9.10117	-2.1409	3.10077	3.04359	2.95279	3.22581
Murcia	-8.4829	-7.7794	-4.3757	-17.0305	3.5136	3.42268	3.37631	3.6428
Valladolid	-2.0209	-1.6322	1.91785	-9.8781	3.33422	3.23956	3.19198	3.44769

Table 4. Mean values and standard deviation for difference in measured and generated annual DNI.

Fig 6 shows scatter plots of differences in measured and generated annual DNI values vs differences in measured and generated annual GHI values for each location and model investigated. For each location and model, it is appreciated a linear relation between those variables, with similar dispersion and slope, and different position. Erbs' and Reindl's models show similar values, slightly lower than those provided by O&H's model and higher than those provided by Louche's model. Moreover, dispersion is lower in Valladolid and Madrid stations.

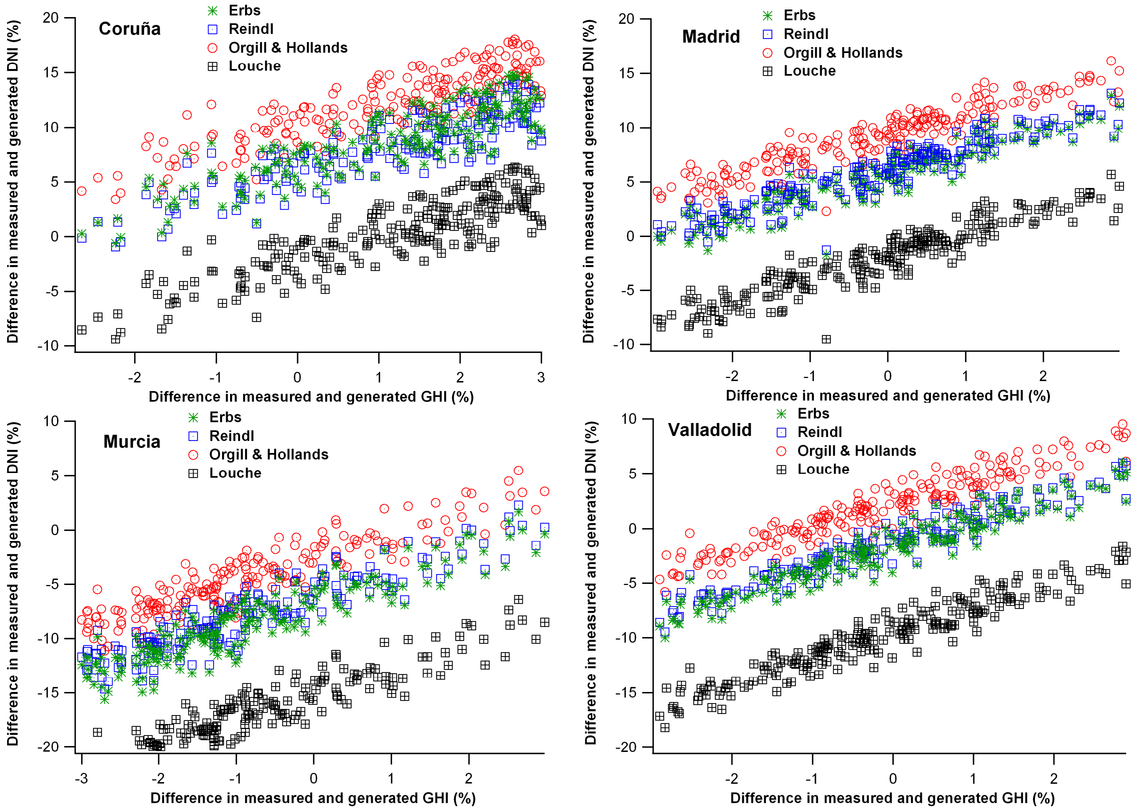

Fig. 6. Scatter plots of differences in measured and generated DNI vs differences in measured and generated GHI for each location and model investigated.

5. Conclusions

Synthetic generation has been tested in order to evaluate the goodness of fit between measured and simulated data. Input data are measured monthly GHI values, from which hourly values of GHI and DNI during one year are calculated. Measured and calculated annual values of both G_h and DNI are compared.

The goodness of GHI synthetic generation models used in this work depends on the location investigated, showing a slightly overestimation in Coruña and underestimation in Murcia.

The models proposed by Orgill & Hollands, Erbs, Reindl, and Louche have been selected for generating hourly DNI values. Louche's model provides the lowest annual DNI values, and O&H's model provides values slightly higher than those obtained by Reindl and Erbs' models. Differences in measured and generated DNI vs differences in measured and generated GHI for each location and model investigated are linearly related, with similar dispersion and slope, and different position for each model and location.

The results of this study indicates that synthetic generation of solar irradiation series must be used as a procedure to obtain high-frequency series which present statistical properties consistent to those observed, not as a procedure to predict precise DNI values. As DNI has been calculated in this work through kt-kd models, variability found in GHI synthetic generation is transferred and amplified to the DNI synthetic generation.

Acknowledgements

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