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Reconstruction of long-term direct solar irradiance data series using a model based on the Cloud Modification Factor

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ABSTRACT

This paper develops a semi-empirical model to calculate direct solar shortwave irradiance on a horizontal surface for any cloudiness condition. The model is based on radiative transfer simulations combined with empirical relationships; it makes use of the global solar irradiance, experimentally measured in most of the radiometric stations, and the Cloud Modification Factor (CMF). A dataset of irradiance from eight Spanish locations is used to tune the model parameters and a part of the data is used to validate the model. By using long-term series of experimental global irradiance data, the corresponding long-term direct irradiances are reconstructed for each location using the proposed model. An evaluation of the model performance is carried out for different solar zenith angles. Following, monthly averages of the hourly data were calculated from the reconstructed values. A high correlation is found when compared with the corresponding measured values. To make use of the obtained results, a characterization of the typical climatic values of the solar direct irradiance in Spain is carried out. The results provide representative values of solar direct radiation and show the availability of this solar resource in the studied areas.

1. Introduction

Solar energy is the most abundant energy resource on earth, being the solar energy reaching the earth surface in an hour about the same as the amount of energy consumed by all human in one year [1]. The yearly average values of effective solar shortwave (280–3000 nm) irradiance reaching the earth's surface ranges from about 0.06 kW/m^2 at the highest latitudes to 0.25 kW/m^2 at low latitudes; those numbers indicate that the technical potential of solar energy is the biggest and in most regions of the world is many times greater than current total primary energy consumption in those regions [2].

Solar radiation is an essential input variable to many models in multitude of process that affect to our ordinary live as the analysis of atmospheric properties [3], modelling solar radiation maps in specific areas of the world [4], operational crop growth monitoring systems [5], studies of climatic trends [6,7], design and predict the performance of solar energy devices [8,9], among others. In this context, solar radiation data are required at locations where this wide range of applications has to be used, being recommendable the availability of long-term data series of solar radiation in each study case [10].

To answer questions adequately about efficiency of the renewable facilities it is necessary to have proper insight in the potential availability of the natural resource as energy varies over time and between locations [11]. Therefore, the efficiency of solar plants depends highly on the knowledge of the magnitude and variability of the solar resource (the incoming solar radiation) in each geographical point chosen for its installation. Related to this point, this work is focused in the solar resource evaluation referred in this case to the direct component of the solar irradiance whose knowledge is requested in many solar energy applications [12].

While global radiation is usually measured in most of the radiometric stations, it is not the same for its components. By one side, diffuse and direct radiation are not measured in all stations, and if they are, there is no extensive data series unless exceptions. The direct normal irradiation is found to require many more years

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to stabilize to its long-term “climatological” value than global irradiation [13]. Therefore, in the case of this magnitude, numerous years of data are required in order to establish a typical behaviour of the solar resources for energy applications. To overcome the lack of experimental data, mathematical models to estimate solar radiation are necessary [14]. The main objective of this work is to develop a model to calculate direct irradiance in order to reconstruct long-term direct irradiance series. This model uses the global radiation, usually available in the radiometric stations, and the Cloud Modification Factor (CMF). A scheme based also on similar parameters, clear sky global irradiance and cloud coverage, in that case, the hourly Cloud Fractional Coverage (CFC) obtained from the satellite data can be found in Ref. [15] where several simple empirical models are tested to estimate global irradiance in Romania. Early works that applied methods to retrieve the direct component from the global solar irradiance (also called splitting models) are those by Maxwell [16] and Perez et al. [17] who used time series of global irradiance to calculate several insolation parameters as input to models. By other hand, a recompilation of splitting models to calculate diffuse radiation can be found in Ridley et al. [18].

The proposed model in this paper is semi-empirical and contains a theoretical part to obtain clear-sky synthetic irradiances and other part with adjustable coefficients; the different steps of this model described in the following sections can be easily adapted for any geographical area.

In order to formulate and validate the model, experimental data from eight locations in Spain have been taken. The work was motivated by the need to carry out characterizations of the solar resource by means of long-term data series of direct radiation in areas where there is no availability of such measurements. Reconstructed series are based in long-term series of global radiation measurements provided by the National Meteorological Agency from the Spanish government.

This paper is structured as follows: Section 2 presents the locations, instruments and data used in the work. The development and performance of the direct reconstruction model is given in Section 3. The analysis of the reconstructed series in the eight Spanish locations is discussed in Section 4, and, finally, the main conclusions are summarized in Section 5.

Table 1
Indicative table showing the characteristics of the database-values: latitude, longitude, altitude and the periods with available measurements of global and direct irradiance for each location.

Location	Latitude (°)	Longitude (°)	Altitude (m)	Available period of global measurements	Available period of direct measurements
A Coruña	43.37	−8.42	58	11/1/1985–31/12/2011	–
San Sebastián	43.31	−2.04	251	12/4/1983–31/12/2011	–
Valladolid	41.65	−4.77	735	1/3/1991–31/12/2011	1/8/1999–31/12/2012
Tortosa	40.82	0.49	44	1/1/1980–31/12/2011	–
Madrid	40.45	−3.72	664	1/7/1973–31/12/2011	5/5/1977–31/12/2012
Cáceres	39.47	−6.34	394	1/1/1983–31/12/2011	12/10/1999–31/12/2012
Ciudad Real	38.99	−3.92	628	1/3/1983–31/12/2011	–
Murcia	38.00	−1.17	61	1/4/1984–31/12/2011	1/5/1988–31/12/2012

2. Places and instrumentation

Experimental data used in this work consist of hourly global and direct irradiance measurements on a horizontal surface recorded from 5:00 h to 20:00 h (time expressed in True Solar Time) and provided by the National Meteorological Agency (AEMet) for different locations in Spain. These locations were eight and their characteristics are given in Fig. 1 and Table 1. They were selected for the present study due to the availability of data and because they cover different geographical Spanish zones as can be observed in Fig. 1. In addition, the choice of sites was conditioned for the requirement to have large irradiance data series and these are not available for all AEMet stations. Table 1 shows the name of the locations, their geographical characteristics (altitude, longitude and altitude) and the period of years managed for each one. The climate conditions are varied. Inner areas in Spain (Valladolid, Madrid, Caceres and Ciudad Real) have

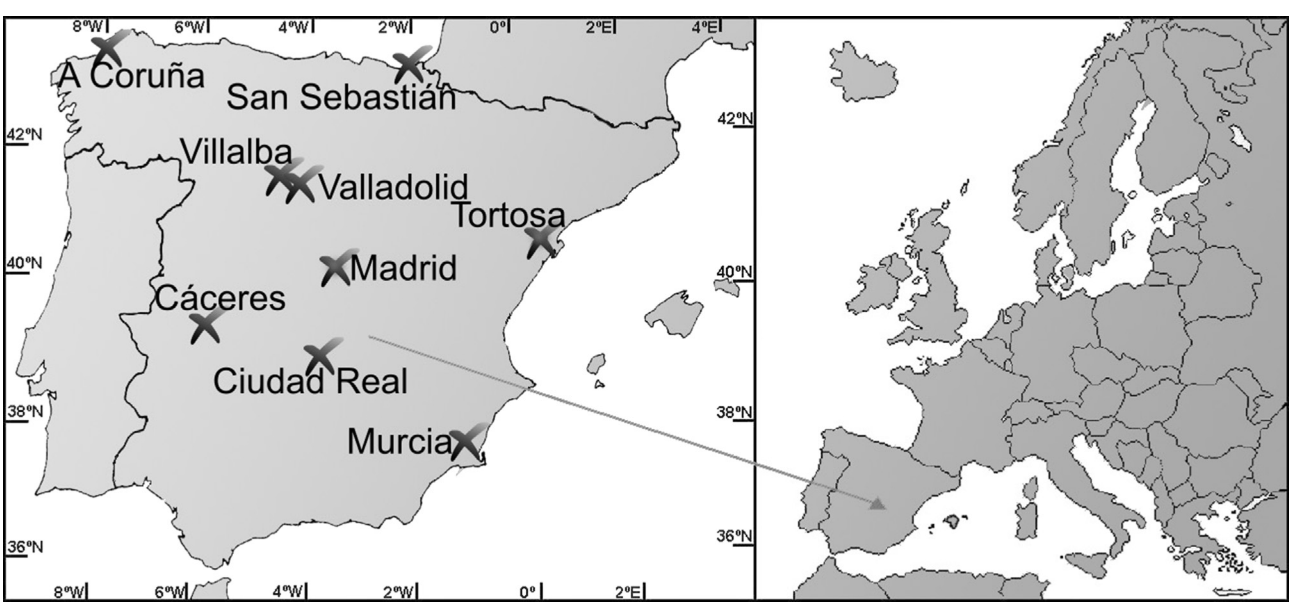

Fig. 1. Locations of AEMet radiometric stations.