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Performance of empirical models for diffuse fraction in Uruguay

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ABSTRACT

Knowledge of diffuse solar radiation is required for the estimation of global irradiation on inclined surfaces or for estimating DNI for CSP applications. Since diffuse irradiance data is comparatively scarce relative to global horizontal irradiance (GHI) data, several methods are used to estimate the diffuse component of GHI. These methods have a local component and most of them have been developed using data recorded in the northern hemisphere, where long-term reliable measurements of diffuse irradiance are available. This work considers ten models for hourly diffuse irradiation and evaluates their performance, both in their original and locally adjusted versions, against data recorded at five sites from a subtropical-temperate zone in the southern part of South America (latitudes between 30°S and 35°S). The raw data has been quality-assessed by using a set of seven sequential filters which preserve the natural spread of the data while removing unphysical data points. The local adjustment and performance evaluation are done using random-sampling cross-validation techniques on an ensemble. The best estimates result from locally adjusted multiple-predictor models, some of which can estimate hourly diffuse fraction with uncertainty of 18% of the mean.

1. Introduction

The diffuse component (DHI) of the solar radiation reaching the ground is the result of several interactions between the incident solar (beam) radiation and the atmosphere. These processes can be described by physical models provided enough information on the current composition of the local atmosphere (i.e. aerosol type and density, water vapor column, Ozone column, among others) are available (Gueymard, 2007). This detailed information is recorded at a few specialized ground measuring sites, such as those from Aeronet (http://aeronet.gsfc.nasa.gov/).

The separation of the beam and diffuse components of GHI is required before estimating direct normal irradiance (DNI) or global irradiance on inclined surfaces. Recent efforts in solar resource assessment in Uruguay have emphasized the characterization and modeling of GHI on several time scales (Abal, 2010; Alonso Suárez et al., 2011, 2012), but there is little information available on diffuse radiation for this region. DHI is comparatively hard to measure accurately over long periods of time, so most available data sets include only GHI. A simple way to do this separation is to use phenomenological approaches, based on estimating DHI from a small set of easily measured or calculated predictor variables. These models refer to a definite time scale (typically an hour, a day or a month) and usually relate the diffuse fraction (the fraction of global horizontal irradiance (GHI) which is diffuse) to the clearness index and eventually other variables. They are not universal and several comparisons of their performance at different locations have been reported (Gueymard and Ruiz-Arias, 2016; Dervishi and Mahdavi, 2012; Li, 2011; Tapakis et al., 2014; Jacovides, 2006; Raichijk and Taddei, 2012).

Since the final uncertainties in solar resource estimation correlate with financial risks in utility-scale projects, a reasonable knowledge of the uncertainties in each step of the calculations is important for the assessment of the performance of solar energy conversion technologies (Gueymard, 2009). The uncertainty of a diffuse-fraction model will depend on the degree of climatic similarity between the data sets used to develop the model and the climate in which it is being evaluated. Localized assessments are necessary both to select the best model and to characterize its uncertainty.

The diffuse fraction is not a function of clearness index alone. Proposals with additional variables (Li, 2011; Reindl et al., 1990, 2010; Ruiz-Arias, 2010; Skartveit et al., 1998) may have lower uncertainties in diffuse fraction estimates at the expense of higher complexity. Gueymard and Ruiz-Arias have recently compared the performance of 140 diffuse fraction models published in the

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Nomenclature

Symbol	
GHI	global horizontal irradiance (W m^{-2})
DHI	diffuse horizontal irradiance (W m^{-2})
DNI	beam or direct normal irradiance (W m^{-2})
I_h	global horizontal hourly irradiation (Wh m^{-2})
I_{dh}	diffuse horizontal hourly irradiation (Wh m^{-2})
I_{bh}	beam horizontal hourly irradiation (Wh m^{-2})
f_d	hourly diffuse fraction $= I_{dh}/I_h$
I_{0h}	extraterrestrial hourly horizontal irradiation (Wh m^{-2})
k_t	hourly clearness index $= I_h/I_{0h}$
θ_z	solar zenith angle (rad)
α_s	solar altitude angle (rad)
δ	solar declination angle (rad)
ϕ	latitude (rad)
I_{dc}	clear-sky diffuse hourly horizontal irradiation (Wh m^{-2})
I_{bc}	clear-sky beam hourly irradiation (Wh m^{-2})
I_c	clear-sky global horizontal irradiation (Wh m^{-2})
I_{sc}	hourly solar constant = 1367 (Wh m^{-2})
ϵ	eccentricity of the earth's orbit
m	air mass
T_L	Linke Turbidity at $m = 2$
δ_R	Rayleigh optical thickness
T_{rd}	diffuse transmittance function
F_{da}	diffuse angular function
H_{0h}	extraterrestrial daily irradiation $= \sum_{day} I_{0h}$ (MJ m^{-2})
H_h	global daily horizontal irradiation $= \sum_{day} I_h$ (MJ m^{-2})
K_T	daily clearness index $= H_h/H_{0h}$
ω_s	sunset hour angle (rad)
H_{dh}	diffuse daily horizontal irradiation $= \sum_{day} I_{dh}$ (MJ m^{-2})
F_d	daily diffuse fraction
$\overline{H}_{0h}$	monthly mean extraterrestrial daily irradiation (MJ m^{-2})
$\overline{H}_h$	monthly mean global daily horizontal irradiation (MJ m^{-2})
$\overline{K}_T$	monthly mean clearness index $= \overline{H}_h/\overline{H}_{0h}$
$\overline{H}_{dh}$	monthly mean diffuse daily horizontal irradiation (MJ m^{-2})
$\bar{F}_d$	monthly mean diffuse fraction $= \overline{H}_{dh}/\overline{H}_h$

literature (Gueymard and Ruiz-Arias, 2016). They used minute-based data from 54 research-class stations distributed over four climatic regions of the globe (only one of them is located less than 1000 km from the area of interest in this paper) and characterized the regional performance of each model. An important conclusion is that no current separation model is truly "universal", in the sense to have consistent accuracy over large climatic zones. In fact, the diffuse fraction reflects the typical composition of the local atmosphere, which may be influenced by (natural or man-made) phenomena affecting the water content or aerosol type and density at a specific region. Thus, diffuse fraction estimation is a problem with an important local component.

Phenomenological separation models should be adjusted to local data to remove most of their bias and significantly reduce related uncertainties. However, these models are frequently used as universal due to the absence of reliable local information on their performance. Many models for diffuse fraction have been derived from DHI data taken at locations in the northern hemisphere, some of them at locations near densely populated areas, where these kind of measurements first became available. These models may not perform as well in locations with different characteristics, as previously noted for Australia by Boland et al. (2008).

In this work, controlled-quality local diffuse irradiation data from five low-altitude sites with southern latitudes (between 30°S and 35°S) is used to evaluate the performance of ten well-known hourly diffuse-fraction models. A strong filtering procedure is applied to the hourly data. For each model, both the original version and a locally adjusted version are evaluated against independent data using a standard cross-validation technique. Two frequently used models for daily and monthly average diffuse fraction are also evaluated and locally adjusted. Information is provided on the best way to estimate diffuse fraction for this and similar geographical regions on an hourly, daily and monthly basis. More importantly, the uncertainty associated to each estimation procedure is characterized, so that it may be accounted for in engineering calculations for solar energy projects.

The paper is organized as follows. In Section 2, the solar radiation database, the typical uncertainty for each site and the filters applied on the raw data are discussed. In Section 3, hourly diffuse fraction models are briefly described and evaluated against local data. In Section 4, all hourly models are adjusted to local data and re-evaluated on a per-site basis using several common statistical indicators. A global adjusted version of each model is defined and evaluated. In Section 5, the data is reduced to daily totals and two daily and monthly average models for diffuse fraction are implemented, locally adjusted and evaluated. Finally, In Section 6 our conclusions are summarized.

2. Ground data

The data used in this work consists of simultaneous data sets for hourly global and diffuse horizontal irradiation from five sites located in a sub-tropical temperate zone of the south-eastern part of South America with homogeneous climatic characteristics shown in Fig. 1. The area has a marked seasonality, no significant

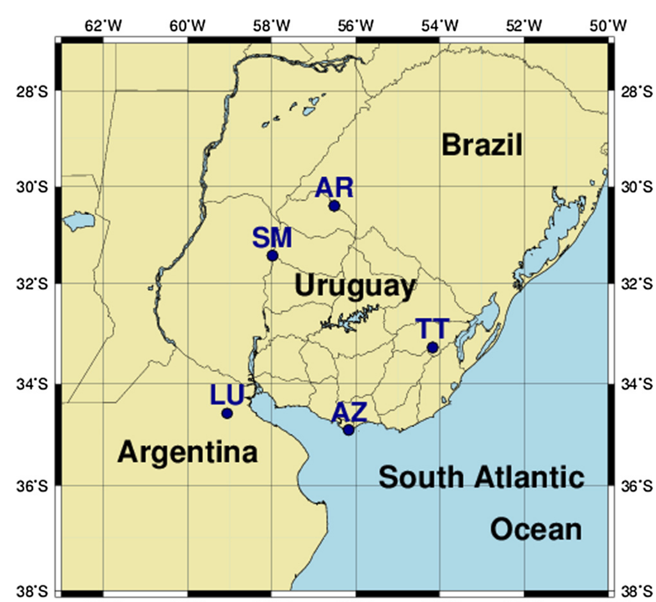

Fig. 1. Location of the measuring stations considered in this work. Other details are provided in Table 1.