Renewable Energy 101 (2017) 347–355

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Identification of clear days from solar irradiance observations using a new method based on the wavelet transform

D. Djafer [a, *], A. Irbah [b], M. Zaiani [a]

[a] Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Devellopement des Energies Renouvelables, CDER, 47133, Ghardaïa, Algeria
[b] Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), CNRS: UMR8190 – Université Paris VI – Pierre et Marie Curie – Université de Versailles Saint-Quentin-en-Yvelines – INSU, 78280, Guyancourt, France

ARTICLE INFO

Article history:
Received 28 February 2016
Received in revised form
19 July 2016
Accepted 12 August 2016

Keywords:
Solar radiation
Turbidity parameters
Clearness index
Wavelet transform

ABSTRACT

A new method using the wavelet transform properties is developed to determine clear days of solar irradiance. These days are needed to model the solar radiation and to compare the existing empirical models. We use this method to process four years of global solar irradiation data collected at the Research Unit of Applied Renewable Energies at Ghardaïa city in Algeria. We also determine clear days from this data set using a standard method based on the clearness index criteria. The results show that the two methods give different numbers of clear days. The effect of this difference is analyzed by computing the Global Solar Radiation (GSR) with the Iqbal C model but also by the estimation of turbidity parameters using for that a innovative approach. We find that some significant differences are observed in the GSR modeling leading to bad estimation of turbidity parameters. We conclude that using our method is therefore more efficient since it is not dependent of the site and observations.

1. Introduction

Solar radiation passing through the Earth atmosphere keeps useful information on the medium. The solar flux is attenuated by scattering, air mass, clouds, aerosols and various reflections. Physical models that explain the solar flux and its temporal variations measured on the ground are of great importance to know the atmosphere state when observing, especially to know the components that are responsible of flux fluctuations. The analysis of these fluctuations is a passive way to probe the atmosphere in contrast to the use of specific instruments such as lidars and radars. Observations during clear days allow detecting certain atmospheric constituents such as aerosols and track their evolution, which may impact Earth's radiative budget and the climate. Clear day observations are also required for models to derive and predict solar irradiance especially where it cannot be measured. These models are needed to obtain the correct design and output of solar power plants in case of clear sky conditions. This accrued interest comes from the huge investments in solar applications in most of countries where the radiative solar resources need to be accurately characterized either measured or modeled. Validating candidate models for this kind of task is an essential step in the process to provide analysts with sufficient background information on their detailed performance. Several works studying and comparing broad band irradiance models are reported in the literature [12]. These models with high-performance and good accuracy are, as previously mentioned, of great interest for clear sky conditions. To assess the performance and improve the validation of such models it is necessary to have clear sky situations i.e. data free of noise and cloudy periods, to obtain valid performance results [12].

The commonly used tool to characterize sky conditions (classification of day types) over a particular site is the clearness index k_t [2,3,14,16–18,22,23,23,26,30]. On a clear day, the atmosphere causes a reduction of the extraterrestrial solar input by about 30% and to nearly 90% in a very turbid (cloudy) day. k_t ranging values depend from one author to the other. Alves et al. [2] reported that a cloudy sky corresponds to $0<k_t<0.3$, a partially cloudy sky to $0.3 \le k_t \le 0.65$ and a clear sky to $0.65<k_t<1$. The last definition was also adopted by Gueymard [18]. Following Bendt et al. [4], clear sky is when $0.5 \le k_t \le 0.85$, greater than 0.5 for Ahmed et al. [1] and greater or equal than 0.7 for Molineaux et al. [24], Li and Lam [19], Li et al. [20] and Eftimie [11]. For Iqbal [15], a clear sky is defined when k_t ranges between 0.7 and 0.9 while Reindl et al. [29] proposed k_t>0.6. The clear sky of most tropical regions for Ndilemeni et al.

* Corresponding author.
E-mail addresses: djdjafer@gmail.com (D. Djafer), air@latmos.ipsl.fr (A. Irbah), zaianimo@gmail.com (M. Zaiani).

http://dx.doi.org/10.1016/j.renene.2016.08.038
0960-1481/

[25] corresponds for $0.68 \leq k_t \leq 0.75$. The choice of k_t interval values is also different from one site to another according to Mellit et al. [23]. In addition it varies also from day to day and from month to month as stated by Serban [31] and Ahmed et al. [1]. We see clearly that there is no unique limit value of k_t neither a direct method for its determination. Therefore, its choice may be controversial to discriminate between clear and turbid days. A bad value will affect the number of clear and turbid days by not selecting the good days. Consequently, the performance of modeling and analysis of solar irradiance data may highly be k_t dependent. For this raison, the problem of k_t choice is first considered in the present work proposing a method that easily separate clear and cloudy periods. This uses the wavelet transform properties that automatically computes a threshold value to discriminate between clear and turbid days. It is chosen according to the noise level and cloud signature present in the recorded data of solar irradiance. First, we present the algorithm based on the k_t mean value of the clearness index to distinguish between a clear and a non clear day. Then, we introduce the wavelet transform method that we compare with the k_t mean one considering the number of clear days obtained from five years of data recorded at Ghardaïa city in Algeria [8]. Finally, we base our comparison on the errors induced onto the GSR (Global Solar Radiation) model and in the estimation of turbidity parameters.

2. The clearness index method to select clear and turbid days

The clearness index is usually used to determine the clear days to perform model comparison and other studies. It was introduced by Liu and Jordan [22] as a parameter that accounts for stochastic property conditions for a given site [27]. Interval values for the clearness index are used to separate clear and turbid days (see Section 1). They change however from one site to another leading to misinterpretation of the results especially when authors are comparing and studying the clear sky empirical models. We develop then an algorithm based on the instantaneous clearness index to determine automatically complete clear days from a huge data set. The different steps of the algorithm are as follows:

1. Selection of global solar radiation records of a given day where the Sun elevation is greater than 10°. This restriction is due to the thin haze in the early morning or late afternoon that may be present. This may lead to consider clear days as not, if any.
2. Calculation of the instantaneous clearness index k_t. It is defined over time t between sunrise and sunset as the ratio between the terrestrial global solar radiation G on a horizontal surface and the extraterrestrial one G_0. Its mathematical expression is:

$$k_t = \frac{G}{G_0} \tag{1}$$

G_0 in W/m^2 is given by Ref. [10]:

$$G_0 = I_{sc}*\left[1 + 0.033\cos\left(\frac{360N}{365}\right)\right] \times [\cos(\phi)\cos(\delta)\cos(\omega) + \sin(\phi)\sin(\delta)] \tag{2}$$

where $I_{sc} = 1367\ \mathrm{W/m^2}$ is the solar constant and N the day number in the year (N = 1 is the first and N = 365 the last day in the year). ϕ, δ, ω are respectively the latitude of the location, the solar declination angle and the hour angle at Sun rise in degrees.

The data used in this work were collected at the Unit of Applied Research in Renewable Energy (Ghardaïa, Algeria) between (2005–2008). The instruments and methods of the data collection are described in detail in Djafer and Irbah [8]. The key to know is that the three components of solar radiation are recorded every 5 min since 2004 together with the temperature and humidity. The instruments that measure the direct, the global and the diffuse solar radiation components are from *EKO instruments* (http://eko-eu.com/). They are usually cleaned two or three times per week according to the weather conditions. They are also calibrated each three years at the meteorological station of Tamanrasset (latitude = +22.78°, longitude = +5.51°, altitude = 1270 m) where the solar irradiance is measured since 1970. The histograms of the instantaneous clearness values obtained with these data are shown in Fig. 1. Each histogram in the figure is computed over one year for the period 2005 to 2008. The values of

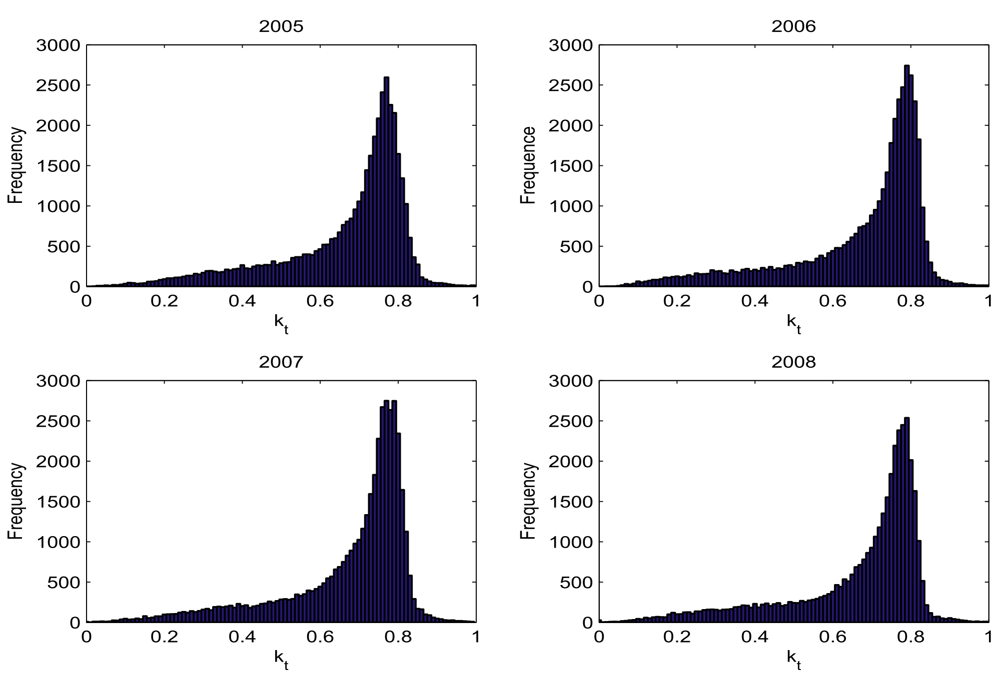

Fig. 1. Histogram of the instantaneous clearness index k_t for each year.