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Investigation on the stochastic nature of the solar radiation process

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Abstract

A detailed investigation of the variability of solar radiation can be proven useful towards more efficient and sustainable design of renewable resources systems. In this context, we analyze observations from Athens, Greece and we investigate the marginal distribution of the solar radiation process at a daily and hourly step, the long-term behavior based on the annual scale of the process, as well as the double periodicity (diurnal-seasonal) of the process. Finally, we apply a parsimonious double-cyclostationary stochastic model to generate hourly synthetic time series preserving the marginal statistical characteristics, the double periodicity and the dependence structure of the process.

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Keywords: synthetic hourly solar radiation; Kumaraswamy distribution; Hurst parameter; double periodicity

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1. Introduction

Several studies have been conducted to investigate the stochastic simulation of solar radiation for the purpose of renewable energy simulation and management. For example, in the analysis of [1] the Beta distribution is suggested

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for the modelling of hourly solar radiation recorded in Algiers. However, little research has been done in comparing different marginal distributions for the process of the hourly solar radiation. Here, we aim at investigating the marginal distribution for each month at an hourly step (24 hours for 12 months) fitting two of the most suitable distributions for this process. Preliminary analyses in a monthly scale (with a daily step) showed that popular distributions used in geophysics (such as Gamma, Pareto, Lognormal, Pearson etc.), that were fitted through the open-software Hydrognomon (hydrognomon.org), could not adequately fit the right tail of the empirical distribution. This can be explained considering that the solar irradiation process is left and right bounded. Although the left boundary is close to zero, the right boundary varies at a seasonal scale. Therefore, distributions like Gamma and Pareto, although they may exhibit a good fit (based on the Kolmogorov–Smirnov test), they should not be applied for the solar irradiation, since they are not right bounded.

After analysing both scales, hourly and daily, we conclude that the Kumaraswamy distribution [2] describes adequately well the observed distributions of diurnal and monthly solar irradiation and also exhibits certain technical advantages in model building and simulation, as discussed in Section 5.

2. Data

The study area is located in Athens, Greece. We analyze more than 12 year of hourly time series of solar irradiance, that is equivalent to more than 102,920 hours (Fig. 1a) and daily data spanning more than 25 years (Fig. 1b). Hourly data are obtained from the Hydrological Observatory of Athens (http://hoa.ntua.gr/) and daily data from the NASA SSE -Surface meteorology Solar Energy- (http://www.soda-pro.com/web-services/radiation/nasa-sse). From the 288 hourly time series (24 hours × 12 months) we only consider the 170 time series of records of good quality and with a mean solar radiation much larger than zero, i.e. excluding night hours.

a

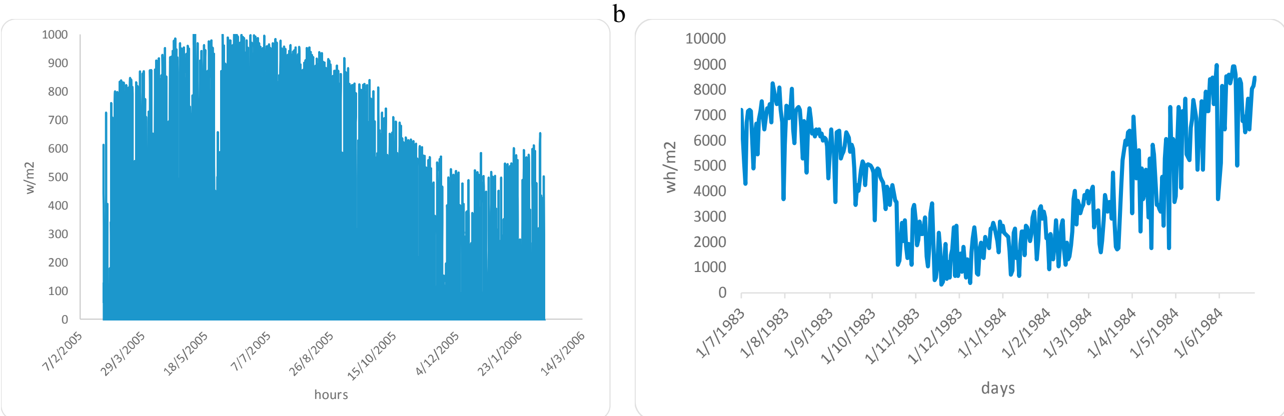

Fig.1. (a) One year of hourly time series of solar irradiance (Athens); (b) One year of daily time series of solar irradiation (Athens).

3. Marginal distribution

3.1 Double periodicity

One of the most common characteristic of atmospheric processes, such as the solar radiation process (Fig. 2), is the double periodicity, i.e., the diurnal and seasonal variation of the process. Therefore, for a robust generation of a synthetic time series we have to analyze the hourly and monthly statistical characteristic of solar radiation (such as the double periodic statistical mean and standard deviation).