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# Application of stochastic methods to double cyclostationary processes for hourly wind speed simulation

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**Abstract**

In this paper, we present a methodology to analyze processes of double cyclostationarity (e.g. daily and seasonal). This method preserves the marginal characteristics as well as the dependence structure of a process (through the use of climacogram). It consists of a normalization scheme with two periodicities. Furthermore, we apply it to a meteorological station in Greece and construct a stochastic model capable of preserving the Hurst-Kolmogorov behaviour. Finally, we produce synthetic time-series (based on aggregated Markovian processes) for the purpose of wind speed and energy production simulation (based on a proposed industrial wind turbine).

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*Keywords:* hourly wind speed; double cyclostationarity; stochastic modelling; Hurst-Kolmogorov dynamics; climacogram; uncertainty-bias; wind turbine

## 1. Introduction

Several methods exist for dealing with processes of single periodicity, with most of them preserving the marginal characteristics of the process and assuming a short-range dependence structure (cf. [1]). However, neglecting a possible long-range dependence, i.e. Hurst-Kolmogorov (HK) behaviour, could lead to unrealistic predictions and wind load situations, causing some impact on the energy production and management of renewable sources. Here,

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we focus on the stochastic nature of wind speed in an hourly scale. The most challenging problem of wind speed simulation is the internal periodicities (e.g. daily and seasonal cycle), a common characteristic of hydrometeorological processes. In this paper, we apply the methodology presented in [1], which involves the analysis of a monthly-scale process, but with preserving both daily and seasonal periodicity. Particularly, assuming that the process has a double cyclostationarity, we first normalize each cyclostationary variable, using a scheme of double periodicity with three parameters. Then, we analyze the stochastic structure of the wind process and we construct a model based on the climacogram, a stochastic tool with many advantages in stochastic interpretation and model building [2,3]. Additionally, we produce synthetic time-series for the purpose of wind speed and energy production simulation (based on a proposed industrial wind turbine). Finally, we apply the methodology to the meteorological station of Larissa (www.hnms.gr) in the area of Thessaly (Greece), with latitude 22.417$^{o}$, longitude 39.633$^{o}$ and elevation +74 m. This is one of the older stations in Greece and includes up to 75 years of measurements in an hourly scale. Its marginal mean wind speed is estimated as 1.7 m/s and its standard deviation as 2.71 m/s (for more information see in [2]).

In the next section, we describe the normalization method, we show how to analyze the stochastic structure of a normalized process and how to generate synthetic time-series based on aggregated Markovian processes. Finally, we produce a one week hourly wind speed time-series (that preserves the marginal characteristics as well as the dependence structure of the examined process) and we estimate the hypothetically produced energy from a wind turbine. Note that underlined symbols denote random variables and the overline symbol (^) denotes estimation.

## 2. Stochastic analysis of the wind speed process

### 2.1. Cyclostationarity

One of the most common characteristics of hydrometeorological processes (in a sub-climatic scale) is the double periodicity, i.e. the continuous change of the process' statistical properties in both daily and seasonal scales. Several techniques have been developed to model this behaviour (a brief description can be seen in [1]). However, most of them can capture the marginal characteristics of the process assuming a short-range dependence structure between daily and seasonal variables. A method to model a single periodicity with any type of internal dependence structure is presented in [1], where the process is assumed to be cyclostationary in seasonal scale (e.g. monthly scale). The main feature of this method is the application of a normalization scheme (derived from the principle of maximum entropy) to all seasonal variables, capturing in this way both the marginal properties as well as the dependence structure of the process (zero values are excluded from the analysis since the wind process cannot exhibit zero speeds). Here, we apply this scheme but with also including the daily periodicity since we are interested in sub-daily (e.g. hourly) scale simulation. The normalization scheme is the following:

$$\underline{Z} = \operatorname{sign}\left(\frac{\underline{X}-\mu_c}{\sigma_c}\right)\sqrt{\left(1+\frac{1}{g_c}\right)\ln\left(1+g_c\left(\frac{\underline{X}-\mu_c}{\sigma_c}\right)^2\right)} \quad (1)$$

where $\underline{Z}$~N(0,1) is the transformed process of $\underline{X}$, $\mu_c$ and $\sigma_c$ are the mean and standard deviation for each cyclostationary variable (i.e. one for each hour and month), and $g_c$ is a parameter related to the distribution tail of the cyclostationary process.

From Fig. 1, we observe that the cyclostationary mean value of the process can be well described by a periodic exponential function for the daily scale and with a simple cosine function for the monthly scale (performance of these models to the Larissa station can be also seen in [2]). Also, we observe that the standard deviation can be well modeled by two simple periodic functions and that $g_c$ significantly varies only within the daily scale and thus, can be described by a single cosine function:

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