Local wind regime characterization and modelling for wind energy optimization, applying statistical and geostatistical methods

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Abstract

In wind energy production through wind turbines, one of the elements that have been stated as much relevant to optimize energy production is the knowledge of the local wind regime in the area in which the wind farm is placed. So, it is very important to be able to characterize the above-stated wind regime to, later, model and simulate it from the short term weather forecasting; this simulation should reproduce the best possible different episodes that characterize the wind regime in the area and verify parametric characteristics that allow defining the wind regime.

Wind speed data are analysed to characterize local wind regime (wind speed distribution) and also an analysis of regional and seasonal parameters of local wind regime is done. Also, episodes (gusts) of wind are analysed applying geostatistical techniques (variogram model) and analysis is done characterizing regional and seasonal components. The aim is to analyse wind regime behaviour and show how it can be characterized through variograms that can be classified through typologies, depending on the duration of the episode of wind is short, medium or long.

Keywords: Wind regime, Weibull distribution, variogram model, wind model.

1. INTRODUCTION

To be able to optimize wind energy production, a good knowledge of the wind regime in the area of location of wind turbines is required. The general characteristics of the wind regime and local and seasonal variations influence the production of energy.

There are several studies on the subject that highlights the importance of knowledge of the wind regime for the optimization of wind energy production. In general, a statistical study of the parameters of the wind regime and by those parameters characterizing the local wind is done.

Fig.1. The studied area and the university campus.

In the present work, some advances in the study are done, incorporating a geostatistical analysis to characterize the wind episodes (gusts). This study has allowed characterization of these episodes, classify them and incorporate them into a proposed methodology to simulate wind data series.

The objectives proposed in this paper are the following:

- To study and characterize local wind regime: statistical analysis of data sets of wind (speed and direction).
- Geostatistical study of series of wind data: speed, direction, episodes (gusts).
- Statistical and geostatistical parameters to characterize local wind regime.
- Proposal of a methodology to generate data sets of simulated wind speed.

2. THE DATA SET: STATISTICAL ANALYSIS

The data set used in this work consists in measuring the speed (km/h) and wind direction (degrees) during the years 2005-2009 with an anemometer located on the campus of the Polytechnic University of Catalunya (UPC) in the town of Castelldefels (Barcelona). Measurements have different intervals: a series with 1440 data per day, ie a data per minute and other data series are 1430 hours, ie 34320 data per day, corresponding to intervals of 2.52 seconds. The wind data have been provided by the Institute of Energetic Techniques (INTE) of the Polytechnic University of Catalunya (UPC). Figure 1 shows the area and the university campus.

For each set of data it has been done:

1. Transformation of the wind speed in km/h to m/s.

2. Wind Speed analysis:

- Statistical parameters of each series.
- Histogram of relative frequencies.
- Cumulative relative frequency histogram.
- Relative frequency polygon.
- Cumulative relative frequency polygon.
- Identification of the distribution function and least-squares fitting.

3. Wind direction analysis:

- Statistical analysis
- Graphic characterization.

4. Direction - wind speed analysis:

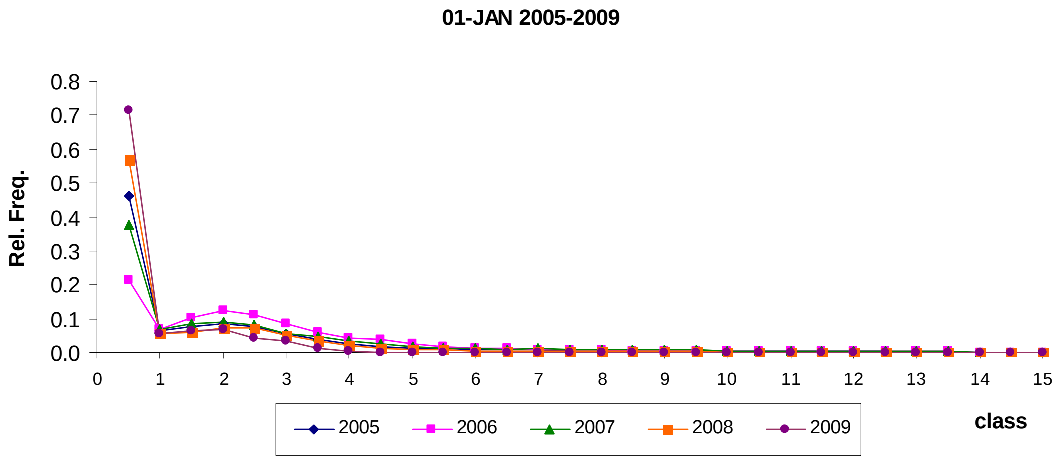
- Diagram direction - speed.

- Identification of the maximum speed for each direction (intervals of 15 deg).
- Identification of the average speed for each direction (intervals of 15 deg).

Figure 2 shows an example of a frequency polygon for the month of January 2006, in (a) the relative frequency polygon and (b) the cumulative relative frequency. For the subsequent mathematical modeling, we have identified the distribution function and fitting numerical values applying the least squares method. Figure 3 shows the fitting result.

The wind direction has been studied by circular diagram of directions, which allows to know for each month the most frequent wind direction. Figure 4 shows the pie chart for the months of January (a) and July (b) for the year 2006.

(a)



(b)

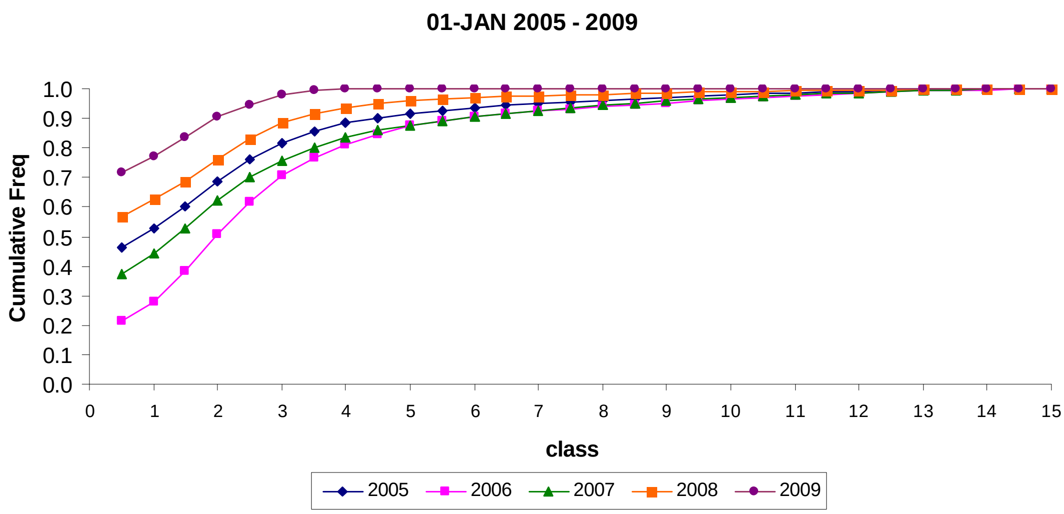


Fig.2. Relative (a) and cumulative (b) frequencies of wind speed series (January)

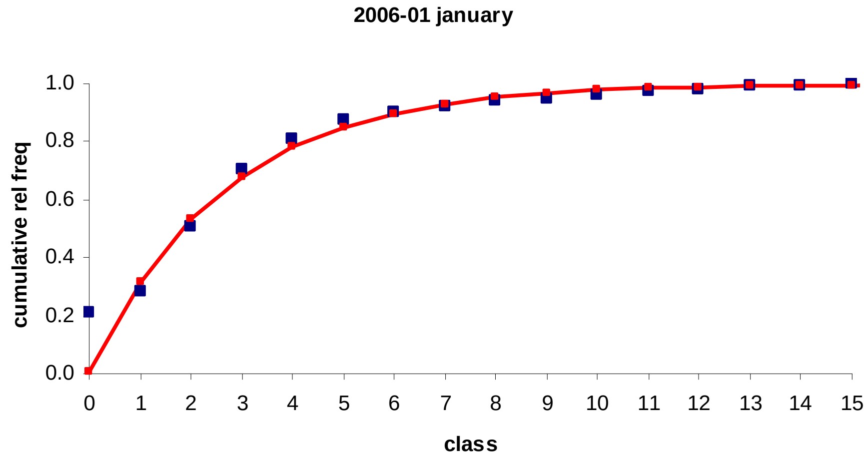
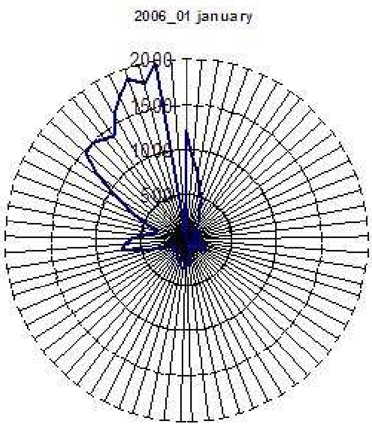


Fig.3. Least squares fitted Weibull model for cumulative frequency (2006, January)

(a)



(b)

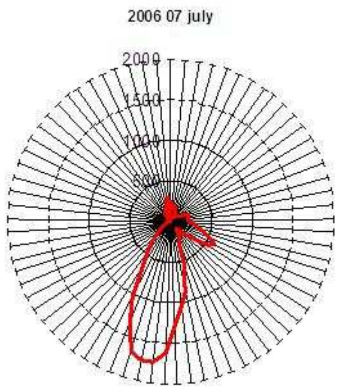
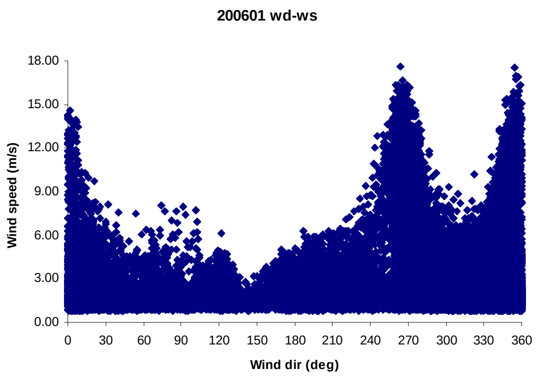


Fig.4. Example of wind direction analysis (2006, January (a) and July (b))

(a)



(b)

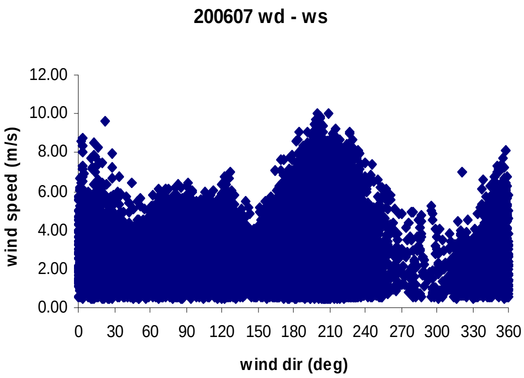
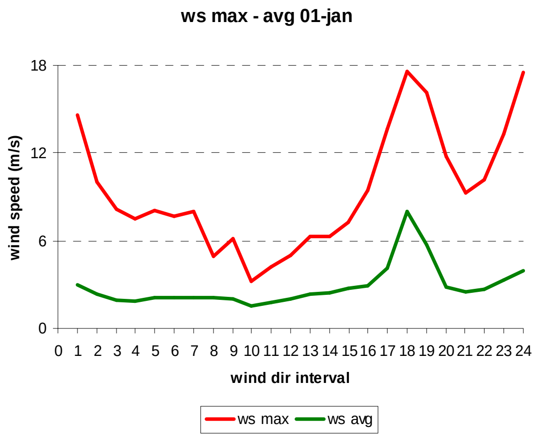


Fig.5. Example of wind direction – wind speed scatterplot (2006, January (a) and July (b)).

In order to relate wind speed and direction, the scatterplot formed by the abscissa (direction) and ordinate (speed) at the points where the velocity is not zero is represented for each month of the series. It is understood that zero velocity corresponds to no wind direction. Figure 5 shows two of such scatterplots, corresponding to 2006 January (a) and July (b). From these scatter diagrams, we have characterized direction-wind speed regime by two functions: the average and maximum, obtaining functions as are represented in Figure 6, for the year 2006 January (a) and July (b).

Another element essential to characterize the wind regime is the so called turbulence factor (TF) of wind speed, defined as the ratio of standard deviation and the mean in a certain range. Figure 7 shows the graphical representation of the turbulence factor for January (a) and July (b) of 2006, calculated at intervals of 15 degrees.

(a)



(b)

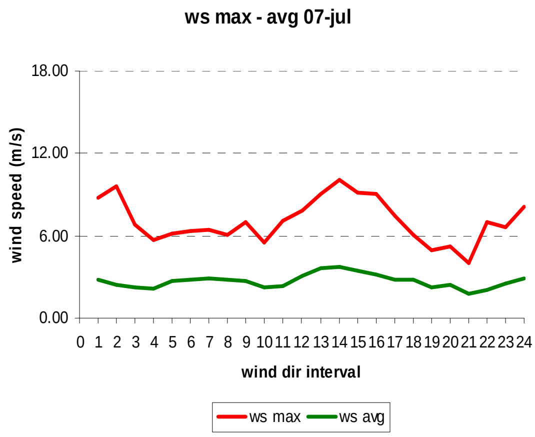
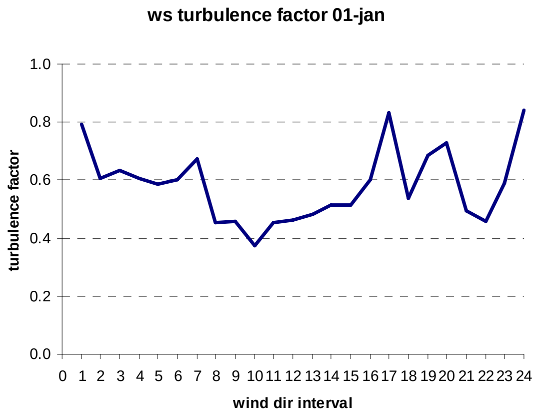


Fig.6. Example of direction-wind regime functions (2006, January (a) and July (b))

(a)



(b)

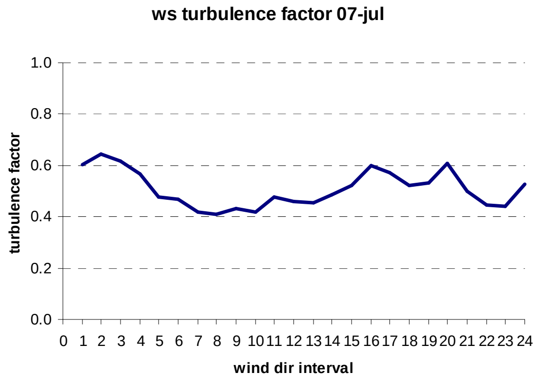


Fig.7. Example of turbulence factor of wind speed (2006, January (a) and July (b))

3. THE DATA SET: GEOSTATISTICAL ANALYSIS

We consider that a gust of wind is the set of consecutive values of wind different of zero, or with less than 30 inserted zeros (i.e. the distance between a gust and the following one is a set of 30 zeros). However there are some exceptions: the program used to analyze data (Variowin) can work with a maximum of 1400 data. So, when longer gusts have been found (gusts lasting for more than 23 hours) they have been split into two subsets, generally with a 10-15 zeros interruption.

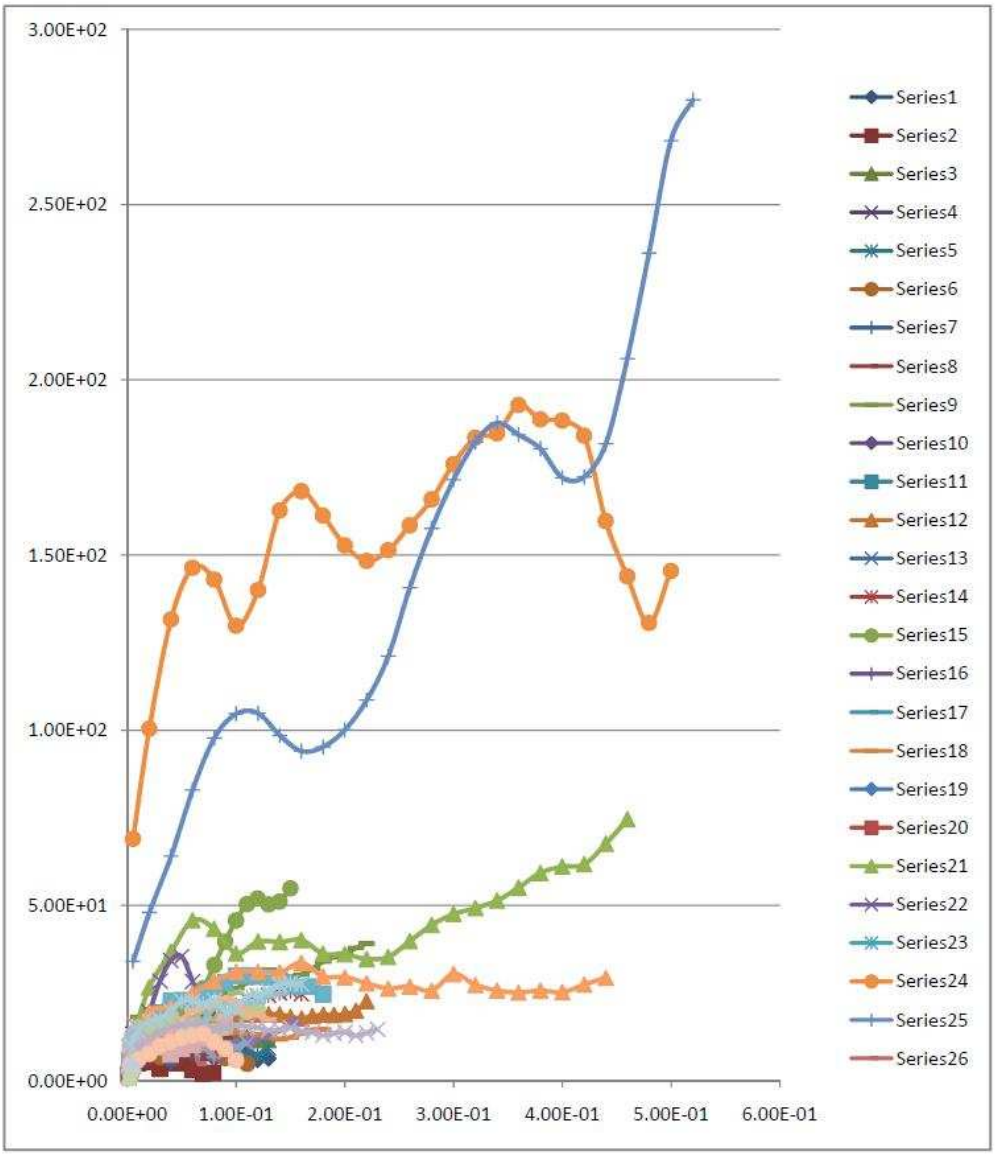


Fig.8. Example of monthly variograms (2007, July).

The variogram nugget represents the variance at the origin, that is, the variance among values separated 1 minute. It includes instrumental error and turbulence. As all data have been collected with the same anemometer, we can guess that nugget is associated to wind turbulence, and this analysis is related with turbulence factor defined before.

The variogram sill stands for long distance variance. Then it represents wind variability inside a gust. So, we think it can be a means to distinguish between zonal and convective wind.

In Figure 8 is shown an example of monthly variograms, corresponding to July 2007.

4. PROPOSAL OF A WIND SPEED MODEL SIMULATION

One of the main objectives of this study was to develop a methodology to generate data for wind speed, in order to carry out simulations in the optimization of wind energy production. This section briefly describes the model and some results.

Model input.
It is used as base information to predict wind speed and direction for the next day. This information takes the form: month of year, day of the month, expected direction of the wind, expected intensity of the wind (Beaufort scale). This information is implemented with the statistical and geostatistical analysis of wind in the area, as described in previous sections.

Model parameters.
Monthly wind regime: month, day, direction-velocity diagram, expected events, turbulence factor, type of series (0, stationary; one, growing, -1, decreasing).

Model output.
It generates a piecewise function at intervals of amplitude 10 seconds, ie 6 intervals per minute and 360 intervals per hour. This piecewise function is generated according to the criteria of the type of series (stationary, increasing or decreasing) in 1 minute. Random values are generated according to a uniform distribution that takes into account the factor of turbulence. Generated values are added to the constant in each interval. This methodology generates a series of simulated values of wind speed. Each wind speed value is associated to a direction that is assumed constant in each interval of 10 seconds. In a text file there are listed the values of time, direction and wind speed simulated.

Figures 9-13 show some results. Figure 9 shows an example of a step function in two consecutive intervals of 1 minute. Figure 10 shows an example of simulated values generated by a uniform distribution in two intervals of 1 minute. Figure 11 shows the sum of the step function with the previous simulated in two 1-minute intervals. Figure 12 shows the comparison between simulated results and real wind speed data in two 1-minute intervals. Finally, figure 13 shows the above values jointly represented.

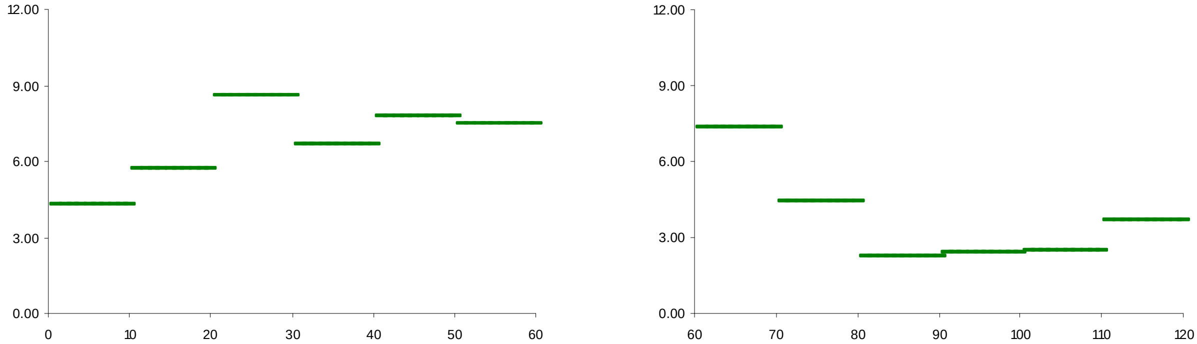


Fig.9. Example of piecewise function generated in two periods of one minute.

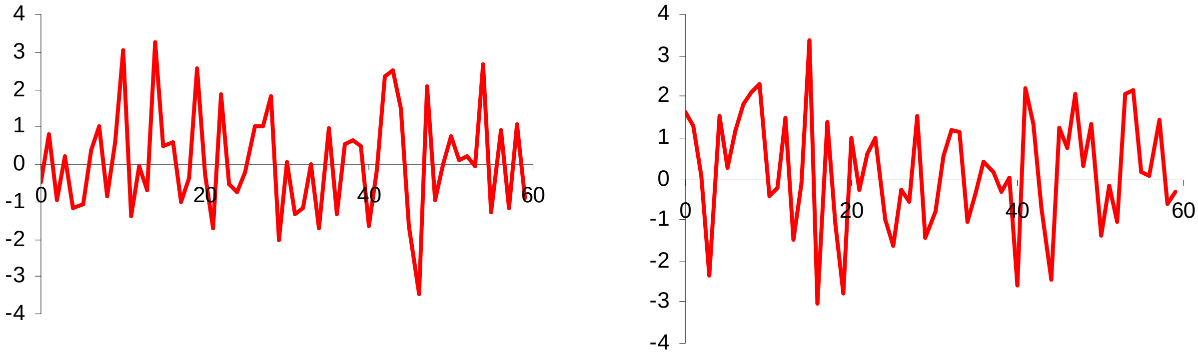


Fig.10. Example of uniform generated simulated values in two periods of one minute.

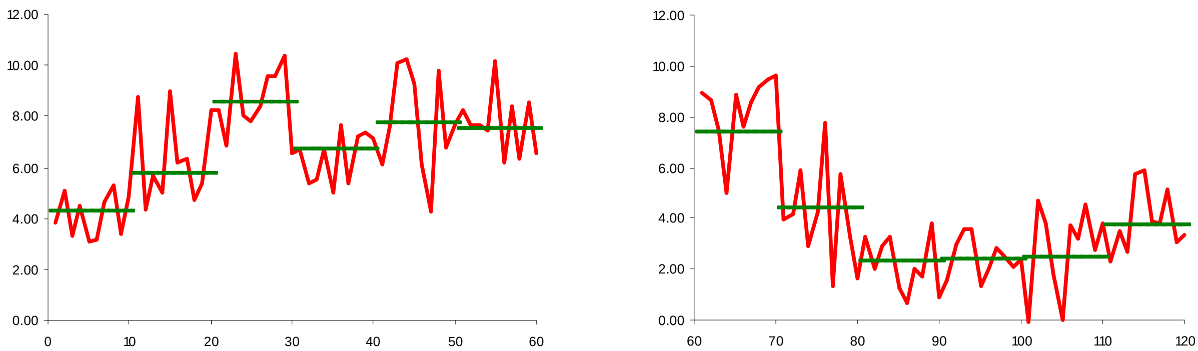


Fig.11. Example of addition of piecewise function and uniform generated values in two periods of one minute.

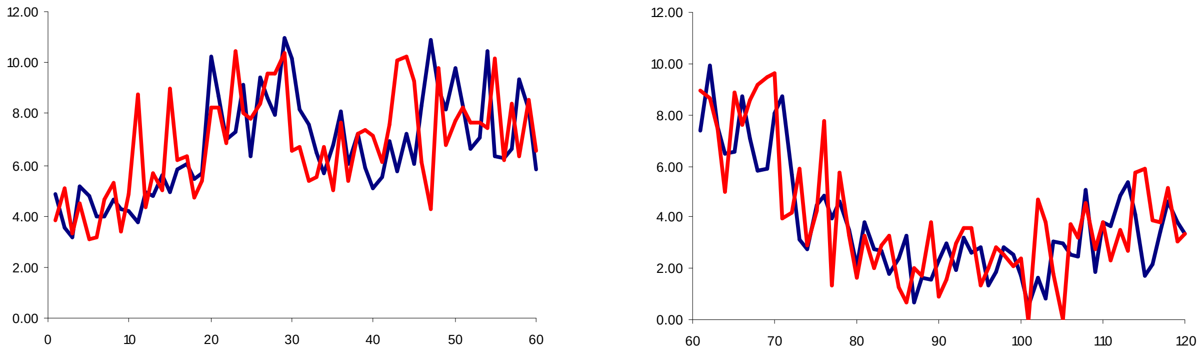


Fig.12. Simulated values of wind speed compared to wind speed data in two periods of one minute.

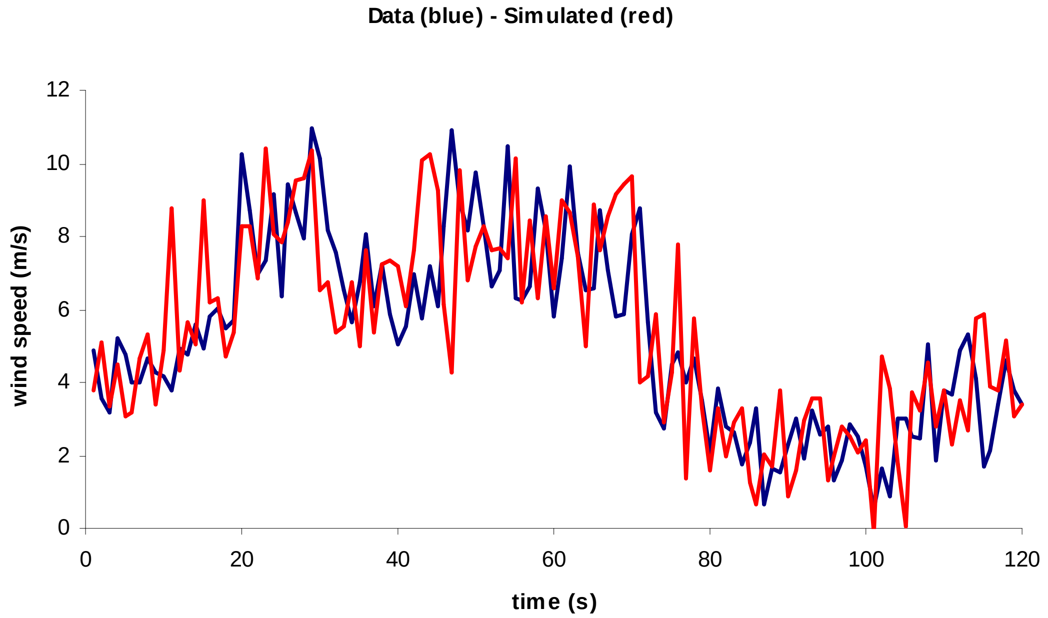


Fig.13. Simulated values of wind speed compared to wind speed data in a period of two minutes.

5. CONCLUSIONS

The main conclusions of this work can be stated as follows:

1. Adequate wind speed and direction statistical parameters are useful for wind speed series analysis and characterization.

2. Geostatistical techniques are useful for wind episodes characterization.

3. Model performed is appropriate for simulated wind speed series generation.

4. Model performed is useful for wind energy optimization.

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ACKNOWLEDGEMENTS

Departament de Matemàtica Aplicada III and E.T.S. Eng. de Camins, Canals i Ports de Barcelona (Universitat Politècnica de Catalunya), for its economic support for attending the IAMG'2010 conference.

This research has been supported by the Spanish Ministry of Science and Innovation under the project ENE2007-67033-C03-01.