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Heuristic correction of wind speed mesoscale models simulations for wind farms prospecting and micrositing

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ABSTRACT

The distribution of surface-level wind speeds over a given area is important information that is related to several processes in wind farm prospecting, design and micrositing. This information is often obtained from simulations using mesoscale models that take variables from global models as starting points. Improved outputs from mesoscale models can lead to reduced error compared to real wind speeds in the study area if in situ wind speed measurements are available. In this paper, we present several techniques to correct surface wind speed simulations from mesoscale models using data from measuring stations in wind farms. Specifically, we propose different heuristic corrections of the outputs from mesoscale models by means of surface fitting between the Weibull parameters of the wind speed series (from the mesoscale model) and those from the measuring stations (real wind speed) in the wind farm. The proposed methodology has direct applications in wind farm design, site prospection and micrositing. The good performance of our method is evident in the more accurate surface wind speeds obtained from mesoscale models in two wind farm prospection sites in Spain, where several measuring towers are installed.

1. Introduction

Wind farm prospection is a complex process that involves a number of preliminary studies. These prospection studies include the analysis and estimation of wind resources in the area, evaluation of possible problems with wind turbine installation, estimation of the cost of installation and wind farm exploitation and several environmental and impact studies (Kaiser and Snyder, 2013; Soleimanzadeh et al., 2013; Bishop and Stock, 2010; Porté-Agel et al., 2011; Zhang et al., 2012; Chen et al., 2013; Tegou et al., 2010). The substantial economical investments involved in this process make it extremely important that the preliminary analyses ensure optimal placement of the wind farm (Kim et al., 2013; Al-Yahyai et al., 2012). These analyses usually start with wind speed modeling in the study area from different perspectives. First, wind speed trends are assessed to check whether they are maintained (or even increased) over the years. Second, it is important to know the geographical wind speed distribution in the study area. Finally, a complete study of surface wind speeds in the study area is needed to carry out effective micrositing of the wind turbines. Effective micrositing allows the profit from the wind farm to be maximized. Usually, this wind farm prospection process starts with the installation of a set of measuring towers in the zone to collect wind speed data during a period of time long enough to perform the different studies involved in the process.

To obtain the wind speed trend over several years, regression methods are usually applied. The objective is to extend the series of wind speed measurements back to previous years. This process can also be used to obtain long-term wind speed estimates, which will help to support the suitability of the area when it is presented to investors. There are many works in the literature devoted to the introduction of regression techniques for this problem (Mabel and Fernández, 2008; Goh et al., 2006; Mohandes et al., 2004; Karioniotakis and Nogaret, 1996; Cadenas and Rivera, 2007; Bilgili et al., 2007). The problem can also be addressed by using indirect measurements to estimate the wind speed, mainly by reanalyzing data or proxies such as synoptic pressure patterns (Carro-Calvo et al., 2011, 2012). In contrast, CFD simulations are usually carried out to determine the specific geographical distribution of surface wind speeds over the area of study, but in large, complex areas, simulations by mesoscale models provide better results (Badger et al., 2011) and are quite often employed.

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The methods that use mesoscale models are discretized by a grid of points defined over the study area. The wind speed distribution is calculated over this grid by means of the mesoscale model, which is often initialized from global-scale model outputs that are updated with local information and/or parameterizations. The main problem with this approach is that mesoscale models can produce wind speed data with some drift due to the characteristics of the model, such as its resolution and the discretization process. Therefore, it is important to incorporate different corrections to the models to obtain surface wind fields as similar to the real wind measurements as possible.

Recently, two works have proposed statistical correction of the surface wind speed from a mesoscale model obtained using measuring stations (Nawri et al., 2012a, 2012b). In those papers, a statistical correction of the geostrophic monthly wind speed is carried out through linear transformation of the mesoscale model data in a grid for Iceland. The rescaling factor and the offset in the correction are determined at measuring stations by comparing the model with measurements. The values of the rescaling factor and offset are then interpolated in the model grid through distance-weighted horizontal averaging. These works did not propose applications to wind farm prospecting but aimed to improve wind speed field analysis for Iceland in the scope of meteorological analysis of the area. The idea, however, can be exported to wind farm prospection in a direct way, which is the objective of our work. Thus, in this paper we propose the statistical correction of mesoscale models to estimate the geographical distribution of surface wind speeds for wind farm prospection. We introduce several novelties with respect to the model in Nawri et al. (2012a, 2012b). First, instead of managing a complete wind speed series at each point of the grid, we address probability distributions. We consider the parameters of a Weibull distribution at each point of the grid (representing the wind speed at that point) obtained from the mesoscale model. We also consider that the measured wind speed follows a Weibull distribution, so the Weibull parameters of the measuring stations are used to modify the mesoscale models. A heuristic approach that carries out a rescaling of the Weibull parameters at each grid point, depending on the distance to the different measuring towers in the wind farm, is proposed. We also show the performance of an evolutionary strategy to select the best parameters for the heuristic search. We discuss the performance of the proposed approach by means of different experiments in two wind farm prospection sites in Spain, where several measuring towers are available to show the appropriateness of our approach.

The rest of the paper is structured as follows: the following section presents the problem definition, including the notation used and the objective functions considered. Section 3 discusses the different heuristics proposed in this work for the mesoscale model correction. Section 4 shows the performance of the heuristics in grid data obtained from measuring towers located in two different wind farms in Spain, one with a statistically significant number of measuring towers installed and the other with a reduced number of towers available. Comparative results are discussed in both cases. Section 5 closes the paper by giving some final conclusions and remarks.

2. Problem definition

To define the problem, we consider a grid $M \times N$ in a prospective area under study for the installation of a wind farm. In each node of the grid, we consider a wind speed series obtained from a given mesoscale physical model, Ξ. Because the treatment of large wind speed series in each grid node is complex, we make the assumption that each wind speed series follows a Weibull probability distribution:

$$f(v; A, k) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} e^{-(v/A)^k} \tag{1}$$

where v is the wind speed value (variable), A is the scale parameter of the distribution and k is its shape parameter. So each point in the grid keeps values of A and k to model the complete wind speed series.

Let $\mathcal{G}$ be an $M \times N$ grid with the wind speed measures from the mesoscale model. The wind speed series in the grid can be represented by using two matrices: $\mathcal{G}_A$ with values of the Weibull distribution of each grid node (parameter A), and another matrix $\mathcal{G}_k$ with values of parameter k. In addition, let $\mathcal{T} = \{t_i\},\ i = 1, \ldots, K$, be the set of K measuring towers installed on the studied area, which gives a set of real wind speed measurements. We also represent the wind speed in each measuring tower t using the Weibull distribution, i.e., a value t_{A_i} for the parameter A and a value t_{k_i} for the parameter k (Fig. 1).

The aim of the problem is to obtain two different $M \times N$ matrices, $\mathcal{S}_A$ and $\mathcal{S}_k$ that contain modified values of the mesoscale model. The modification is carried out by using information describing the real wind speed values obtained from the measuring towers in a way that minimizes a given error function (e_A or e_k, depending on the Weibull parameter to be modified), defined by the following equations:

$$e_A^{\mathcal{S}} = \frac{1}{K^*} \sum_{i=1}^{K^*} |A(t_i) - \mathcal{S}_A(t_i)| \tag{2}$$

$$e_k^{\mathcal{S}} = \frac{1}{K^*} \sum_{i=1}^{K^*} |k(t_i) - \mathcal{S}_k(t_i)| \tag{3}$$

where $A(t_i)$ and $k(t_i)$ stand for the real values of the Weibull parameters that represent wind speed series measured at tower t_i (values of A and k, respectively), K stands for the total number of towers in the wind farm and K^* stands for the number of towers selected to train or test the results. $\mathcal{S}_A(t_i)$ and $\mathcal{S}_k(t_i)$ stand for the value of the modified mesoscale model wind speed series Weibull parameter at the point where tower i is installed. Note that if the modification process of the mesoscale model is performed correctly, the values of $e_A^{\mathcal{S}}$ and $e_k^{\mathcal{S}}$ should be better than the values of the original mesoscale model $e_A^{\mathcal{G}}$ and $e_k^{\mathcal{G}}$ (non-corrected values), defined as follows:

$$e_A^{\mathcal{G}} = \frac{1}{K^*} \sum_{i=1}^{K^*} |A(t_i) - \mathcal{G}_A(t_i)| \tag{4}$$

$$e_k^{\mathcal{G}} = \frac{1}{K^*} \sum_{i=1}^{K^*} |k(t_i) - \mathcal{G}_k(t_i)| \tag{5}$$

Fig. 2 shows an example of a distribution of measures. Grid points with data from the mesoscale model are represented by red crosses. The location of the measuring towers is represented by blue circles. Note that the measuring towers do not coincide with any point in the mesoscale model grid, so at this point we cannot calculate Eqs. (4) and (5). A transformation from discrete to continuous values is therefore needed to extend the values of the mesoscale model to the points where the measuring towers are located. There are several possible ways to do this transformation from discrete to continuous values, and the study in this paper is general, so any transformation procedure can be applied. In this work, we use a surface fitting procedure that is able to construct accurate 2D surface models from scattered (discrete) data by means of a software tool available from MatLab, *gridfit* (D'Errico, 2006).

3. Proposed heuristics for mesoscale model correction

The mesoscale model with measured data can be applied in different ways. First, we propose a constructive heuristic to carry out this correction. Second, we introduce an evolutionary strategy to refine the search for the best modification of the A and k surfaces in terms of the values of the measuring towers.