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Hybridizing the fifth generation mesoscale model with artificial neural networks for short-term wind speed prediction

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ABSTRACT

This paper presents the hybridization of the fifth generation mesoscale model (MM5) with neural networks in order to tackle a problem of short-term wind speed prediction. The mean hourly wind speed forecast at wind turbines in a wind park is an important parameter used to predict the total power production of the park. Our model for short-term wind speed forecast integrates a global numerical weather prediction model and observations at different heights (using atmospheric soundings) as initial and boundary conditions for the MM5 model. Then, the outputs of this model are processed using a neural network to obtain the wind speed forecast in specific points of the wind park. In the experiments carried out, we present some results of wind speed forecasting in a wind park located at the south-east of Spain. The results are encouraging, and show that our hybrid MM5-neural network approach is able to obtain good short-term predictions of wind speed at specific points.

1. Introduction

With the World in almost permanent energy crisis, the use of alternative sources of energy is becoming an important point to mitigate the impact of petroleum's high prices in developed countries. Wind power is nowadays one of the predominant alternative sources of energy, representing about 10% of the energy consumption in Europe, and over 15% in countries such as Germany, Spain or the USA [1].

One of the problems of wind power is that the continuous and chaotic fluctuations of the wind make very difficult to forecast the power that will be produced in a wind park. This can cause difficulties in the energy transportation and power balance of the network, so a good forecasting of the power that will be produced is crucial for the management of the wind park. Specifically, in the case of Spain, the national entity for the power transport (Red Eléctrica, an organization depending on the Spanish government), imposes the power forecast in wind parks, and penalizes the production of much more power that forecasted by the park. On the other hand, if the park produces less power than expected, the revenue of the wind park's owner company diminishes. Thus, the accurate forecast of the power produced in the short-time horizon, is capital in the management of wind parks. There are different possibilities to face the problem of short-term power prediction from the current wind speed: first, good results can be obtained using straight predictions over the power produced in the park, given several measures of the wind in different points of the park for example. Another possibility is to forecast the wind in each wind turbine of the park, and then convert to power by means of the wind power curve. The latter approach is used in the context of wind park management, since it allows to model the power production with the park working at a given percentage (for example, what will be the power production when only half of the wind turbines are in operation, or if we stop 5 wind turbines, etc.). This is the approach we will use in this paper. In order to apply it, we need a good quality short-time wind speed prediction: a forecasting system which considers both the actual wind data and the underlying wind dynamics [2].

In general, the wind speed forecast problem can be tackled from two different points of view: first, wind speed forecasts using past wind data, and second, wind speed forecast using meteorological models of the wind dynamics. The first approach has been applied in different works in the literature [2–14]. This approach is popular mainly because it is easy to obtain reliable data in wind parks, which may be analyzed with different statistical models such as autoregressive models (ARMA, ARIMA) [15,16], neural networks

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[17], support vector machines [3], etc. These analyses provide good results to estimate mean monthly or superior (quarterly, annual) wind speed, though in some cases have been applied to short-term wind speed prediction [15]. However, in most of the cases, in short-term forecasts (mean daily or even mean hourly wind speed forecasts), the importance of atmospheric dynamic is decisive, so a good forecast must include meteorological models [18–21]. Meteorological models work by approximately solving the set of physical equations which govern the behavior of the dynamics and thermodynamics of the atmosphere. They can be classified into global models, which take into account global variables and interactions and provide low resolution forecasts, mesoscale models, which, in some cases, can be integrated up to a resolution limit about 1 km × 1 km, and local models, with higher resolution. An example of short-term wind prediction using physical models is described in the works by Landberg [19,20], who used the High Resolution Limited Area Model (HIRLAM) of the Danish Meteorological Institute. In a different approach, Alexaidis et al. [18] reported the possibility of including the output of global physical meteorological models with neural networks and autoregressive models, though they show that the neural computation approach provides better results than the autoregressive models.

In this paper we propose the hybridization of a mesoscale model (MM5) [24,25] with neural networks to obtain a robust system for the wind speed forecast in short-time horizons, at wind parks. Specifically, we use the predictions of a global forecasting model (Global Forecasting System from the National Center for Environmental Prediction, USA) [23], and some local data from atmospheric soundings as initial and boundary conditions for the MM5 model. The MM5 model performs a physical downscaling of the data from the global model to obtain a prediction of the wind speed in a smaller area. The output of the MM5 model, together with other variables, is then processed by a neural network in order to accurately predict the wind speed in each wind turbine of the park. In the experimental part of this paper we apply our hybrid system in the wind speed forecast of a wind park located in Spain, obtaining positive results.

The rest of the paper has the following structure: in the next section we present in detail the hybrid system proposed, describing the global model used, the first downscaling carried out (physical downscaling), with the MM5 model and the structure of the artificial neural network used to perform the final statistical downscaling. Section 3 presents the experiments carried out to evaluate the performance of our approach. The short-term (48 h horizon) wind speed forecast in a wind park with 33 wind turbines, located at the south-east of Spain is considered. Section 4 gives some final remarks for concluding the paper.

2. Description of the proposed hybrid system

This paper proposes a hybrid system for short-term wind speed prediction, mixing weather forecasting models and artificial intelligent devices such as neural networks. Fig. 1 shows an outline of the system. It starts from a global weather forecast model whose outputs will be used as initial condition for the MM5 model. Two different downscaling processes are then considered, the first one applying the MM5 model, and the second one a statistical downscaling, using a neural network. In the following sections we describe in detail the model proposed.

2.1. Global and mesoscale predictions for short-term wind speed forecasting

The process of short-term wind speed forecast based on mesoscale predictions requires several steps and the use of data from national and international weather forecasting institutions around the world. Specifically, the initial conditions of the MM5 model are obtained from one global prediction model: the Global Forecasting System (GFS) maintained by to the National Center for Environmental Prediction (USA) [23]. The data from this global prediction system are freely available on the Internet.

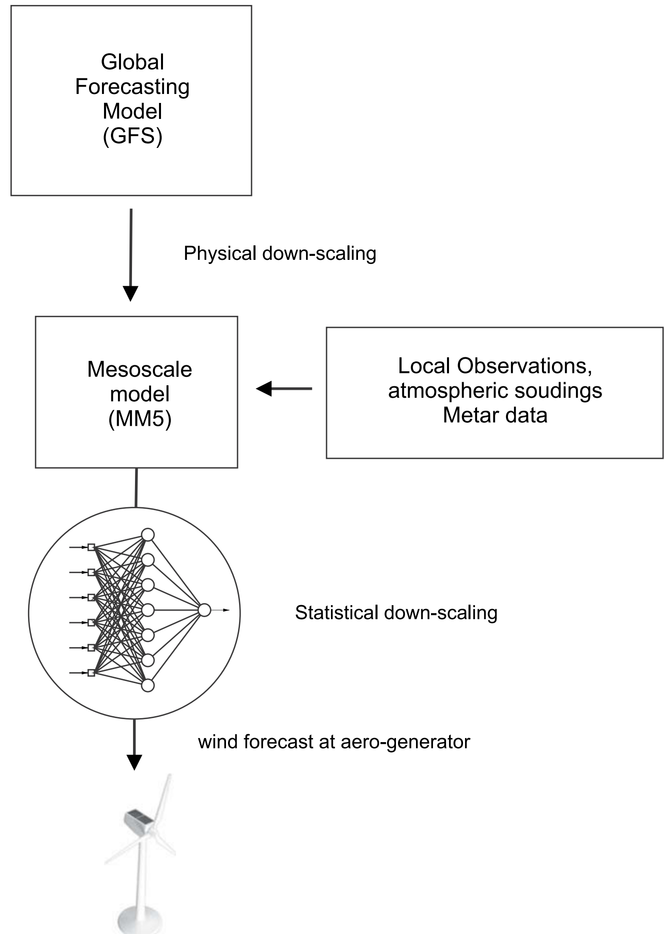

Fig. 1. Outline of the hybrid system for short-term wind speed forecasting.

This global prediction system produces meteorological information for future times at given positions and altitudes, considering as horizontal domain the entire Earth. In order to do this, the model solves the Navier–Stokes equations, which govern the behavior of the dynamics and thermodynamics of the atmosphere. This model provides a set of atmospheric variables such as pressure (P), temperature (T), geopotential height (gph) and, of course, wind speed and direction (v). In general, these variables are solved for a given number of levels in height, which vary between 1000 hPa and 10 hPa. In addition, the global model also provides these basic variables at a level of 10 m over the ground. Regarding the spacial resolution of the model, the global forecasts are given in a grid $1^\circ \times 1^\circ$. Recall that one degree in longitude is about 78 km (at 45° of latitude) and one degree in longitude is equivalent to 111 km.

The data from the global prediction system considered are complemented with data from atmospheric soundings, using aerostatic balloons. We use data from cities at the Iberian Peninsula: Gibraltar, Madrid, Murcia, Palma de Mallorca, Santander and Zaragoza. In addition, we can also include *metar* data in our system. Metar are surface data measured in the 39 airports of the Iberian Peninsula and the Balear Islands, each 30 min. Variables included in metar data are pressure, temperature, wind speed and direction, among others. We use metar measures at 00:00, 3:00, and 6:00 (times at which there are available data from the GFS model). Table 1