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Regional wind monitoring system based on multiple sensor networks: A crowdsourcing preliminary test

Agustín Agüera-Pérez [a,b,*], José Carlos Palomares-Salas [a,b], Juan José González de la Rosa [a,b,1], José María Sierra-Fernández [a,b]

[a] Research Group PAIDI-TIC-168: Computational Instrumentation and Industrial Electronics (ICEI), Spain
[b] University of Cádiz, Area of Electronics, EPSA, Av. Ramón Puyol S/N, E-11202 Algeciras, Cádiz, Spain

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ABSTRACT

The availability of updated information of regional wind fields is fundamental for an efficient management and prediction of wind power production. The present paper proposes a regional wind monitoring system based on the integration of different meteorological nets as a direct way to obtain this information. Concretely, we describe a monitoring system for the region of Andalusia supported by 198 stations, able to provide near surface wind field estimations with updating period of 10 min. Each of these stations has different characteristics since they are focused on measuring different environmental parameters, and most of them are below the quality level required by the World Meteorological Organization for wind measurement. Despite this drawback, the proposed monitoring system takes advantage of the high density of measurement points to produce valuable descriptions of the regional wind field. A basic geostatistical model coupled to the system achieves better results than Numerical Weather Prediction models, obtaining RMSE values of 1.52 m/s and 64.9° for speed and directional series respectively. The test confirms the tolerance of this massive monitoring system to data without quality assurance, being an interesting platform to implement crowdsourcing methodologies.

1. Introduction

A basic prerequisite for regional wind energy development and management is the availability of accurate information of the wind conditions in the area. Regional wind estimations have been mainly focused on wind resource assessment, thereby dealing with long-term parameters: mean speed values, Weibull parameters or wind power densities (Omer, 2008; Migoya et al., 2007; Cellura et al., 2008; Waewsak et al., 2013; Masseran et al., 2012). On the contrary, obtaining regional wind distributions at short time scales is a less studied topic with interesting applications on wind farms optimized management, power prediction or load balance. Besides wind energy, this information is also fundamental in fire propagation, particles spread or storm damages.

The achievement of updated estimations of the near-surface wind field is extremely difficult, due to the high temporal and spatial variability inherent to atmospheric processes. Nowadays, this information is mainly obtained by using synthetic data generated by Numerical Weather Prediction (NWP) models, freely provided by some public organizations as National Center for Atmospheric Research (NCAR) or European Centre for Medium-Range Weather Forecasts (ECMWF). These global data are calculated without introducing orographic or local-scale considerations and, thereby, their insertion in real problems is subjected to a refinement process to estimate the near-surface wind field. This process is called 'downscaling'.

Downscaling methodologies can be performed using statistical methods (Salameh et al., 2009), but the usual approaches are based on dynamical considerations. The most extended downscaling models are the PSU/NCAR fifth-generation Mesoscale Model (MM5) (NCAR, 2013) and its successor the Weather Research and Forecasting model (WRF) (NCAR-NCEP, 2013), which calculate the atmospheric dynamics in a regional scale by processing NWP data together with geophysical information.

The general performance of these downscaling models is difficult to evaluate because they are applied in very different contexts—different geophysical frameworks, configurations or validation processes. In order to give an idea of the results associated to these numerical models, we have summarized in

* Corresponding author at: University of Cádiz, Area of Electronics, EPSA, Av. Ramón Puyol S/N, E-11202 Algeciras, Cádiz, Spain. Tel.: +34 956028069; fax: +34 956028001.
E-mail address: agustin.aguera@uca.es (A. Agüera-Pérez).
URL: http://www.uca.es/grupos-inv/TIC168/ (A. Agüera-Pérez).
[1] Main Researcher of the Research Unit PAIDI-TIC-168.

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Table 1
Recent studies: description.

Case	Ref.	Area (km^2)	Terrain	Period	Time resolution	Validation	h	Source	Model
1 2	Al-Yahyai et al. (2012)	212,000	80% Flat	1 year	1 h	6 Stat	10 m	ECMWF	HRM COSMO
3	Muscarella et al. (2011)	15,000	Flat	10 days	1 h	8 Stat	10 m	NCEP	WRF 2.2
4 5	Zhang et al. (2011)	9,900,000	Varied	6 months 2 months	6 h	358 Stat	10 m	NCEP-FNL GFS	MM5
6	Liu et al. (2011)	1200	Medium	2 days	10 min	[a]274 Stat	80 m	NCAR	WRF-LES
7 8 9	Cheng et al. (2012)	42,000	90% Flat	12 days	1 h	26 Stat	10 m	NCEP	MM5 WRF Ensemble
10	Carvalho et al. (2012a)	200	Varied	1 month	10 min	3 Stat	60 m	NCAR	WRF(YSU Noah)
11 12 13	Carvalho et al. (2012b)	200,000	Sea	1 year	6 h	5 Bouys	10 m	NCEP-R2 ERA-Interim NCEP-CFSR	–
14 15 16 17	Cheng et al. (2013)	300	Medium	2 days (in winter) 2 days (in summer)	15 min	[a]273 Stat	80 m	GFS	WRF(YSU Noah) WRF(MYNN3) WRF(Lin KF) WRF(WDM6)
18 19	Miglietta et al. (2013)	160,000	Sea	2 snapshots	1 h	SR	10 m	ECMWF	WRF(YSU) WRF(MYJ)
20	Hernández-Ceballos et al. (2013)	30,000	Flat	6 days	1 h	5 Stat	10 m	NCEP	WRF 2.1.2

[a] Anemometric data from wind turbines.

Tables 1 and 2 some recent works which specifically tested the accuracy of the simulated wind fields[2] (Al-Yahyai et al., 2012; Muscarella et al., 2011; Zhang et al., 2011; Liu et al., 2011; Cheng et al., 2012, 2013; Carvalho et al., 2012a, 2012b; Miglietta et al., 2013; Hernández-Ceballos et al., 2013). Table 1 shows the contexts associated to these studies and Table 2 shows the results obtained in each case. This information will be used to contextualize the results obtained in this paper. Among all these cases, Case #20 will receive special attention because, as well as showing the best statistics, it also deals with a part of the area and weather stations used in the present work allowing direct comparisons of results.

As shown, NWP models represent the main way to generate short-term wind information. Obtaining wind fields from real data acquired at weather stations involves additional problems, mainly related to the reduced number of reliable data source points. This is because most of the weather stations do not fulfill the strict locational and instrumental requirements suggested by World Meteorological Organization to measure the wind properly (WMO, 2008). In fact, if WMO criteria are considered, the number of measurement points available over a studied area is strongly reduced (see Burlando et al., 2009; Castino et al., 2003 for two illustrative examples). In these conditions, the inference of regional wind distributions via interpolation of real measurements involves high uncertainties, specially in complex terrains.

On the other hand, despite their individual unreliability and thanks to their abundance, it has been demonstrated that basic stations can provide interesting wind information when processed together (Agüera-Pérez et al., 2012; Palomares-Salas et al., 2013). Located in forests, farms and cities, these basic stations form a representative set of the different surface conditions expected in a zone. Furthermore, surface meteorological nets are generally automatized, i.e., registers are periodically acquired and transmitted to a control center providing updated information, friendly to computational processing.

The integration of all these surface stations under a regional monitoring system could provide refreshed snapshots of the regional near-surface wind conditions. On this basis, techniques for the effective inference of quasi-real-time wind fields could be developed. Moreover, the inclusion of new stations would be simple and results should be benefited by this increase of data sources. In this sense, this regional wind monitoring system could take advantage of the eclosion of wind data from amateur observers available in web sites (see Meteoclimatic as an example Meteoclimatic, 2013). This could be a first step for implementing crowdsourcing[3] techniques in wind simulation.

This paper is focused on checking the potential of a regional wind monitoring system supported by a high number of surface stations, regardless of their quality assurance. Section 2 analyzes the raw data provided by these stations, presenting a method to generate a coherent information supply. Section 3 describes the tests, models and validation processes to assess the system's performance. Finally, the results and conclusions are presented in Sections 4 and 5, respectively.

2. Wind data

2.1. Meteorological nets and stations

Wind data have been acquired by five nets of meteorological stations managed by three public institutions: Environmental

[2] The information must be considered as an approximation to these works. Acronyms, models and data sources are briefly described in Appendix A. In order to show this information in a compact way, we give averaged values when results are offered in different points or periods. We have supposed a hub height of 80 m. In the cases of Al-Yahyai et al. (2012) results are estimated from graphs.

[3] According to the integrated definition of crowdsourcing proposed in Estellés-Arolas and de Guevara (2012).