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Assessing mesoscale wind simulations in different environments

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ABSTRACT

An adequate simulation of the wind in the near surface marine environment is important for a large range of applications, including energy assessments. In this work, wind speed simulated by different models is evaluated through comparison with observational data. Three experiments using two open mesoscale models (MM5 and WRF) under different types of simulation mode were considered together with two institutional meteorological models (IFS and Aladin). Observational data measured over land in meteorological stations, in the near coast by marine buoys and in the open sea by altimetry, were used for the comparisons. Results show that although IFS is the model with the best results, the three experiments using WRF and MM5 are also of good quality, especially in the coast and open ocean.

The added value of using a mesoscale model over global, lower resolution ones, usually used as driver, is investigated for the different environments (land, coast and open ocean) and the three experiments. Using the Brier skill score, it is found that there is added value in the case of simulations over land and in the coast, but not for the open ocean.

1. Introduction

An adequate simulation and prediction of the near-surface marine wind is a subject of utmost importance not only for the scientific community but also for a broad spectrum of areas including offshore renewable energy. In fact, the increase of energy demand and the high growing rate of the European wind sector are some of the factors that motivate the search of a reliable and accurate prediction of the onshore and offshore wind resources. In recent years, numerical weather prediction models have been used in wind assessment studies (Heikkila et al., 2011; Carvalho et al., 2014) although some of the studies conducted so far use only data from meteorological weather stations. If the use of this data has several limitations over land, as the sparse location of the stations and only useful locally, over the ocean, in situ observations are even sparser. On the other hand, satellite scatterometers are an alternative to in situ observations (Bentamy and Croize-Fillon, 2014), although they offer records with irregular measurements in space and time (Menendez et al., 2014). Models represent a better tool for assessing wind resources instead of in-situ data and/or satellite measurements. Nevertheless, a combination of both would be the solution that would lead to better coverage and higher spatial and temporal resolution wind fields. Significant advances have been witnessed in the development of mesoscale models. A wide range of parameterization schemes have been implemented in mesoscale models along with improvements in the model resolution, turning them into powerful weather tools in different research areas (Goswami and Baruah, 2012).

Aside from these improvements it is still a challenge to determine the most appropriate model configuration for a specific area, especially due to the fact that the models are often very sensitive to the choice of parameterizations and the best combination for one region is not necessarily applicable to another and different models have different proper combinations. Physical and dynamical parameterizations and terrain resolution have to be combined in different ways and sensitive studies have to be performed in order to obtain the most appropriate model configuration (Awan et al., 2011).

There is a wide variety of products, obtained from model simulations, from global forecasts to reanalysis data sets that can be used to evaluate and characterize the marine wind regimes. Some are freely available, others only available for the scientific community, and yet others are produced and used only within national or international meteorological institutes. Freely available data is usually of coarse resolution, not allowing an accurate description when complex orography and/or coastlines are present. This is one of the cases where mesoscale meteorological models can be useful. But, even in open sea, it is assumed that high-resolution models will provide better representation of processes as fronts or mesoscale disturbances (Denis et al., 2002). Several authors have produced dynamical downscaled hindcast data sets, using mesoscale model with the purpose of obtaining added value regarding the

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larger scale model (Weisse, and Feser, 2003, Castro et al., 2005; Sotillo et al., 2005; Ratsimandresy, et al., 2008). Nevertheless, this added value is higher for some meteorological parameters than for others, and for surface wind it depends on whether simulations are made for open-ocean or for costal domains (Feser et al., 2011). A regional study for the North Seas (Reistad et al., 2011), based on the downscaling of the ERA-40 reanalysis, has been recently produced, homogeneous only until 2002. This study showed a considerable gain in accuracy in the high-resolution downscaled data, both in wave heights and in surface wind speeds, when compared with the original ERA-40. Lowe et al. (2010) downscaled GCM winds with a regional climate model (RCM) and used them to force a wave model.

Several studies have investigated whether a mesoscale atmospheric simulation can add value to near surface wind fields simulated at a larger scale. Some examples of the assessment of the added value in dynamically downscaled near surface wind fields can be found in Winterfeldt and Weisse (2009) and papers herein. In their work, the authors evaluate wind simulations in coastal areas and in the open ocean obtained from dynamically downscaling the NCEP/NCAR reanalysis using the REMO model. Rife and Davis (2005) address the same question but regarding wind forecasts, over land, produced by MM5, using nested domains. Feser et al. (2011) discuss the added valued in regional climate models compared with global model data. More recently, Menendez et al. (2014) produced a high-resolution sea wind hindcast using the WRF model over the Mediterranean Sea.

The main goal of this work is to contribute to the evaluation of the added value of using high-resolution models to simulate marine wind fields that could be used for wind energy assessments such as in Salvação et al. (2013, 2014). For that purpose three numerical experiments are performed using the MM5 and the WRF mesoscale models in a two-way nesting scheme. Comparison of the wind fields for the driving models and the wind fields produced at the two different domains resolution with observations on land, near the coast and in the open sea is performed. Also, an assessment of how these open source models behave when compared with models run by national and international meteorological institutes is made. For that purpose the wind simulations produced by the limited area numerical model Aire Limitée Adaptation Dynamique Développement International (ALADIN) that is used by the Portuguese Meteorological Institute and by the Integrated Forecasting System model (IFS) that runs in the European Center for Medium Range Weather Forecast (ECMWF) were also evaluated using the same methodology and observational data and results of this statistical evaluation are compared with equivalent results obtained from MM5 and WRF.

Due to the interaction of large and small length scale forcing, the wind speed is difficult to forecast. To accurately simulate the wind speed at a given location, the models need to accurately forecast the movement and strength of synoptic systems, and the local influence of topography. The wind speed characterization is usually made through the use of in situ measurements but most of the times the network of meteorological stations is not dense enough to characterize the wind field of a region. Typically, meteorological weather stations are installed inland at specific locations, usually with high density population, and provide measures of wind only at specific heights, usually 10 m. Single measurements will only allow the determination of the magnitude and direction of the wind in that location and may not be representative of the wind regime over a larger area. So, in order to characterize the wind speed field, the results from model simulations can be interpolated to specific points of interest. Interpolation can, however, be less accurate when the characteristics of the landscape are not uniform or not properly represented in the meteorological model. Depending on the space-temporal scale chosen for the model, the different physical processes are more or less important, so the choice of the correct parameterization of the model becomes crucial. Different types of simulations depending on the desired spatial resolution of the results, the number of meteorological stations and the complexity of the landscape should be taken into account in order to improve the model results (Morales et al., 2012).

For the stated reasons, the correct choice of the parameterizations and the use of high-resolution topography, when available, are crucial. The WRF, one of the models considered in this work, is very sensitive to the change of parameterization schemes (Gallus and Pfeifer, 2008). The version used in this study (version 3.2.1) includes a set of physics options sufficient to allow simulations at various situations and grid sizes. Sensitivity studies performed for Portugal have showed that the parameterization schemes set MM5, YSU, and Noah regarding the boundary layer, Surface Layer Planetary boundary layer and land surface model, respectively, produce the most accurate results for wind (Carvalho et al., 2012). Nevertheless every region has its own optimal parameterization scheme and different combinations should be tested for each case study.

The quality of the wind speed forecasts has also an important effect in wave modeling (Teixeira et al., 1995; Holthuijsen, et al., 1996; Tolman et al., 2005; Ardhuin et al., 2007). As the wind field is used as input to wave models, it is of great interest to improve the quality of the input winds in order to improve the wave models forecasts (Rusu et al., 2009). An operational forecasting system has been implemented by Guedes Soares et al. (2011) for the Portuguese coast and runs automatically since 2008.This system produces 4 day forecasts of wind fields and wave parameters using the mesoscale atmospheric models MM5 forced by Global Forecasting System (GFS) output available online and the wave models WAM and SWAN. In the present work, the forecasts for the 10 m wind speed produced by MM5 are compared against the ones produced by the WRF model. The same physical and dynamical parameterizations are used for MM5 and WRF models and the period of the simulation is the whole year of 2011. In order to determine the accuracy of the simulations performed by the different models, the results were compared with in situ measures of wind speeds from meteorological inland stations and offshore buoys. To access the impact of using higher resolution input data a second WRF simulation is performed, forced with the ERA-INTERIM data with 0.75° of resolution (Simmons et al., 2006). The physical parameterizations used are the same for the two WRF simulations. A statistical analysis was carried out for all simulations.

2. Data and methods

In order to evaluate the performance of the different models, implemented in different environments, observations are needed. Observational data from different sources have been used: (1) wind magnitude measured by anemometers in meteorological stations over land in Portugal and over the Spanish region of Galicia; (2) wind magnitude measured near the coast by marine buoys and (3) wind magnitude measured at open sea using altimetry.

Other sources of data that were also used in this work were global forecasting models ran by national and international meteorological centers and a reanalysis data set.

2.1. Observational data

The inland observational data includes wind magnitude measured at 14 meteorological stations in Portugal (data provided by the Portuguese Institute for the Sea and the Atmosphere, hereafter IPMA) and 4 meteorological stations in the Spanish region of Galicia (data obtained from the Meteogalicia website). Wind