USING WRF TO GENERATE HIGH RESOLUTION OFFSHORE WIND CLIMATOLOGIES

Markel GARCÍA-DÍEZ[1,2], Jesús FERNÁNDEZ[2], Lluís FITA[3]
Melisa MENÉNDEZ[4], Fernando J. MÉNDEZ[4], José Manuel GUTIÉRREZ[1]
[1]*Instituto de Física de Cantabria (IFCA-CSIC), Universidad de Cantabria, Santander (Spain)*
[2]*Dept. Applied Mathematics and Comp. Sci., Universidad de Cantabria, Santander (Spain)*
[3]*Climate Change Research Center, University of New South Wales, Sydney (Australia)*
[4] *Environmental Hydraulic Institute, Universidad de Cantabria, Santander (Spain)*
garciadm@unican.es

ABSTRACT

Recently, the demand of gridded wind datasets over sea areas has increased due to the ongoing development of offshore wind farms. Currently available reanalysis datasets do not have enough resolution to deal with complex coastlines and coastal topography, and these do interact with the winds and meteorological systems well into the open sea. Here we present the main characteristics of a high resolution wind climatology that has been produced using the Weather Research and Forecasting model to downscale the ERA-INTERIM reanalysis. The simulations were carried out in a domain covering the Mediterranean basin and most of Europe, and thus areas with different wind regimes. The model has been kept close to the driving reanalysis by restarting it daily, as this running mode provided better results than nudging techniques. Results show that WRF is able to produce realistic offshore wind climatologies, probabilistic wind distributions and annual cycle. It also reproduces well-known regional winds remarkably well.

Key words: WRF, wind, downscaling, offshore, wind farms, numerical modelling.

1. INTRODUCTION

The recent developments in offshore wind energy have increased the interest in gridded datasets of offshore surface wind. These can be used to find the optimum location for the wind farms, solving the problem of the limited availability of observations. Other uses of these datasets include research in ocean waves, currents and dock engineering. Global reanalysis datasets can provide wind fields for long periods, but lack resolution to take into account the important effects of the coastline and the topography in the winds. Thus, limited area models can be used to obtain higher resolution datasets with physical consistency, performing the so-called dynamical downscaling.

The growing demand of comprehensive surface wind gridded databases contrasts with the relatively scarce literature related to this topic. Sotillo et al. (2005) downscaled the NCEP-NCAR reanalysis to 0.44º resolution using the REMO model over Europe. The comparison with observations showed that the regional model was clearly improving the wind fields in the regions close to the continent, and also the extreme wind thresholds. Weisse et al. (2009) produced several datasets of atmosphere, waves and tide surges using REMO and other models, focusing in northern Europe. Winterfeldt et al. (2011) showed the added value of these simulations with respect to the reanalysis by comparing them with satellite data from QuikSCAT. Again, the added value was concentrated near the continents, while the downscaled winds were slightly worse over the oceans. This points to the importance of optimizing the technique used to keep the regional model close to the synoptic situation that really occurred day by day. Sotillo et al (2005) used spectral nudging (von Storch et al., 2000). An equivalent result was found by Winterfeldt & Weisse (2009) using buoy data over the North Sea.

In this study our goal is to show how the WRF model can be used to produce high resolution wind datasets, with the advantages of being an open source, state-of-art, non-hydrostatic model, that can deal with mesoscale phenomena. The study is focused on the Mediterranean Sea, which is a highly complex area to model. Because of its complicated orography, coastline, and convective weather regimes, mesoscale phenomena play a very important role in many regions of the Mediterranean sea, so these higher resolution simulations are expected to add more value compared with the existing reanalysis.

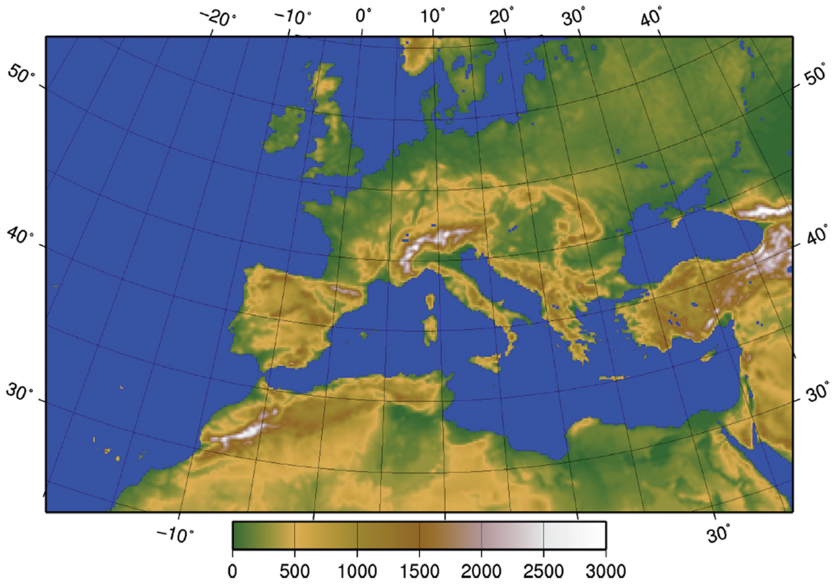

FIG. 1: *Domain of the simulations.*

2. DATA AND METHODS

The model used is WRF-ARW version 3.1.1 (Skamarock et al., 2008), which is a non-hydrostatic limited area model (LAM). WRF has become popular since it is a freely available open source model that offers a large amount of state-of -the-art physical parametrizations and other options. The domain used (Figure 1) covers Europe with 15 km resolution. The configuration used in this case was obtained from a set of sensitivity tests that were compared with buoy and satellite data (Menendez et al. 2012). Two datasets were produced. One, labelled I15, was nested in the ERA-INTERIM reanalysis (Dee et al., 2011) with 15 km of resolution. To cover a longer period, another dataset, labelled N20, was produced, this one nested in NCEP-NCAR reanalysis (Kalnay et al., 1996) with 30 km resolution. Details about the configuration can be found at Table 1, while Table 2 summarizes the set of parametrization schemes that where chosen. For simplicity, in this work only results from I15 are shown.

	I15	N30
Horizontal resolution (km)	15	30
Projection	Lambert conformal	Lambert conformal
Number of eta levels	39	39
Time step (seg)	90	180
Data frequency (h)	1	1
Period covered	1989-2009	1949-2009

TABLE 1: *Configuration of the model.*

In the sensitivity experiment mentioned the running mode was also tested between continuous (without nudging, with spectral nudging and with grid nudging) and re-forecast. The re-forecast running mode was found to be the more accurate, and was the one used for generating the full dataset.

PARAMETRIZATION SCHEME	DESCRIPTION
Convection	Grell-Devenyi (Grell & Devenyi, 2002)
Surface Layer	MM5 (Hong et al., 2006)
Planetary Boundary Layer	Yonsei University Scheme (Hong et al., 2006)
Short wave radiation	Dudhia (Dudhia, 1989)
Long wave radiation	RRTM (Mlawer et al., 1997)
Microphysics	WRF-SM5 (Hong et al., 2004)
Land-surface model	Noah (Chen & Dudhia, 2001)

TABLE 2: *Parametrization schemes*

The re-forecast mode used consists in performing daily simulations starting at 6 UTC and running for 36 hours. Afterwards, individual simulations are concatenated to form a pseudo-continuous dataset, discarding the first 12 hours of each one as spin-up (see the diagram in Figure 2). Lenderink et al. (2009) and Hu et al. (2010) used this technique before with good results.

The running mode chosen leads to a large number of independent simulations that need to be configured, run and post-processed. This task was performed with WRF4G (Fernández-Quiruelas et al. 2012), which is a software developed to handle large typical experiments in meteorology and climatology in distributed computational resources.

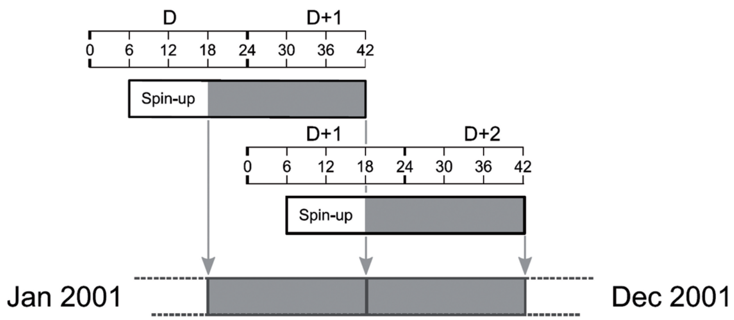

FIG. 2: *Schematic representation of the reforecast running mode used.*

The observational wind data used are from a buoy located at Cabo Vilano (Figure 3), that belongs to the REDEXT Spanish network of offshore buoys. The frequency of the data is hourly, and the anemometer is 3 m above the sea surface. A simple power law of the marine wind profile has been used to interpolate it to 10 m, to keep consistency with the model.

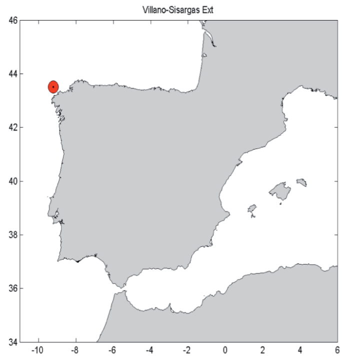

FIG. 3: *Location of the Vilano buoy used for valitadion.*

3. RESULTS

3.1 Validation

Figure 4 shows a scatterplot comparing observations from the buoy of Cabo Vilano with the nearest gridpoint of I15. Also a quantile-quantile plot is plotted over the scatterplot, using the quantiles of the Gumbel distribution, to emphasize the extremes. Some scores (bias, RMSD, SI) are also shown. The simulated wind closely follows the observed distribution, as the quantile-quantile plot is a straight diagonal. Also the scores have reasonable values. For the highest wind values a deviation is found, but in those quantiles the values are very scarce, and the result is not significant.

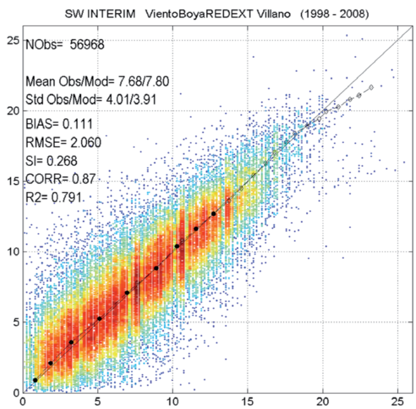

FIG. 4: *Scatterplot comparing observations from the Vilano buoy with the nearest gridpoint of I15.*

3.2 Climatology

Figure 5 shows the seasonal averages of offshore wind speed of the forcing field (ERA-INTERIM) and I15. The original land-sea masks of both WRF and ERA-INTERIM have been used to show the differences. The most relevant differences are the regional wind maxima caused by straits and mountain ranges close to the coast. Examples are the strait of Gibraltar (which is closed in ERA-INTERIM), the strait of Bonifacio (between Corsica and Sardinia) and others. The influence of the Canary Islands in the trade winds can also be clearly distinguished.

Over the areas far away from land, mainly the Northwest corner of the domain, WRF and ERA-INTERIM are in agreement in the four seasons, both in the spatial patterns and in the intensity. As the reanalysis use data assimilation and are a revised and reliable dataset, this reinforces the credibility of the regional model. Nevertheless, WRF seems to be producing generally stronger winds over the Mediterranean Sea. This is especially noticeable in SON.

As an example of an extreme wind event, Figure 6 shows maps for the 2001-11-11 at 00 UTC, 18 hours after initiating the model. On this day a strong cyclogenesis took place in the western Mediterranean, becoming one of the worst storms ever recorded in that region. Although WRF and ERA-INTERIM are very coincident in the location of the center of the storm, notable differences can be observed between the wind fields. These are fundamentally caused by the islands that ERA-INTERIM is not resolving, specially the Balearic Islands. In WRF simulation the wind maximum is located south of the island of Ibiza, reaching an intensity of 25-30 m s^{-1}. In contrast, the most intense winds in ERA-INTERIM only reach 21-24 m s^{-1}, and the maximum is located north of Mallorca. WRF is also generating stronger winds over the Gulfs of Leon and Geneva, and over the Adriatic Sea.

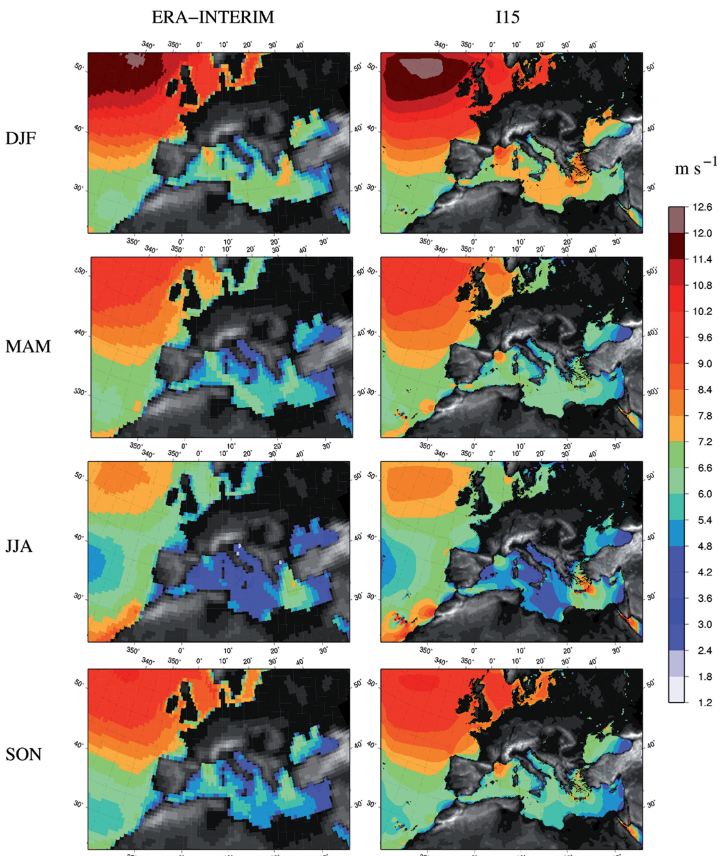

FIG. 5: *Mean wind speed for the 4 seasons, for ERA-INTERIM at 0.7º resolution (left) and I15 (right). The base period is 1989-2009.*

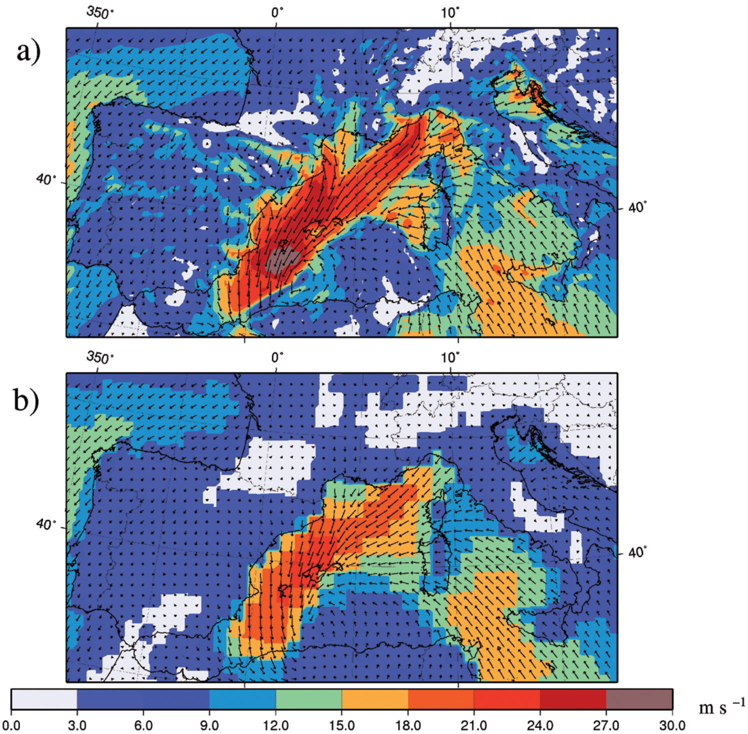

FIG. 6: *Wind velocity and wind vectors at 00 UTC of 2001-11-11 for a) I15 and for b) ERA-INTERIM.*

4. CONCLUSIONS

The offshore wind dataset I15 produced with WRF shows a significant improvement respect to the ERA-INTERIM reanalysis, with much more detail especially in straights and coastal areas close to mountain ranges. The well-known regional winds present in the Mediterranean Sea are successfully represented. The resolved islands and topographical barriers have a large impact in the wind field of an extreme event. The results of the sensitivity studies carried out to decide the model configuration, as well as a more detailed validation of both I15 and N30 datasets has been submitted to Climate Dynamics (Menendez et al., 2012).

Aknowledgements

The authors would like to thank "Puertos del Estado" (Spanish National Ports and Harbour Authority) for providing the information from the instrumental observation networks and the European Center of Medium Range Forecast for providing the ERA-INTERIM data . This paper is a contribution to the financed projects by the Spanish government CORWES (CGL2010-22158-C02-01), WRF4G (CGL2010-22158-C02-01), EXTREMBLES (CGL2010-21869), C3E (200800050084091), iMar21 (CTM201015009) and MARUCA (E17/08), and was partially funded by projects 'MAREN' (Atlantic Area Transnational Programme) and 'CoCoNet' (FP7-OCEAN-2011).

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