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Offshore wind energy resource simulation forced by different reanalyses: Comparison with observed data in the Iberian Peninsula

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HIGHLIGHTS

- Simulated offshore winds were forced by different reanalysis and analysis.
- New generation reanalysis are able to improve offshore wind simulation.
- ERA-Interim driven simulation showed the lowest wind temporal variability errors.
- NCEP-R2 provide the most accurate offshore wind energy production estimates.
- NCEP-FNL and NCEP-GFS can be seen as valid alternatives to traditional reanalyses.

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ABSTRACT

Due to the increasing interest in the prospection of potential sites for the installation of offshore wind farms, it becomes important to extend the tests presented on Carvalho et al. (2014) to offshore areas. For that, the WRF model was used to conduct ocean surface wind simulations forced by different initial and boundary conditions (NCEP-R2, ERA-Interim, NCEP-CFSR, NASA-MERRA, NCEP-FNL and NCEP-GFS) aiming to assess which one of these datasets provides the most accurate ocean surface wind simulation and offshore wind energy estimates. Six near surface wind simulations were performed, each one of them forced by a different initial and boundary dataset. Results were evaluated using data collected at five buoys that measure the wind in the Iberian Peninsula region (Galician coast and Gulf of Cádiz).

The results show that the simulation driven with ERA-Interim reanalysis provided the lowest errors in terms of offshore wind temporal variability. NCEP-R2 driven simulation showed the lowest offshore wind speed bias, mean wind speed and offshore wind energy production estimates. However, it was the one with the highest errors related to the wind temporal variability. The simulations driven with the NCEP-FNL and NCEP-GFS analyses products also showed interesting results, better than the NCEP-CFSR and NASA-MERRA reanalyses.

Based on the results presented in this work and in Carvalho et al. (2014), ERA-Interim reanalysis likely provide the most accurate initial and boundary data to force near-surface wind simulations for the offshore and onshore areas. However, for offshore sites the NCEP-R2 reanalysis seem to provide the most accurate estimation of the potential wind energy production, fact that is of great importance for the wind energy industry. Furthermore, the NCEP-GFS and NCEP-FNL analyses can be considered as valid alternatives to ERA-Interim and NCEP-R2, in particular for cases where reliable forcing data is needed for real-time applications due to their fast availability.

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1. Introduction

The present study is based on the previous work of [1], in which the performance of the WRF mesoscale model in the wind and potential wind energy production simulation was assessed and evaluated under different initial and boundary forcing conditions:

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the older, yet widely used, NCEP-R2 reanalysis; three new generation reanalyses, ERA-Interim, NASA-MERRA and NCEP-CFSR; and also the NCEP-GFS and NCEP-FNL analysis, also considered in that work due to its recurrent use in wind energy assessment studies. That study only focused only on onshore sites located in continental Portugal. However, in the recent past there has been an increasing interest in wind energy derived from offshore sites due to their higher energy potential production, as a consequence of the steadier and higher near-surface wind speeds present in ocean areas. Offshore wind energy is an emerging energy sector with a high growth potential [2], supported by ambitious plans to promote offshore wind energy penetration to be carried out by Europe, China, Japan, Korea and USA [3,4]. Although offshore wind energy generation is presently more expensive and technologically more challenging to implement than onshore one, it is becoming increasingly difficult to find in Europe new attractive and suitable areas for the implementation of onshore wind farms [5]. Therefore, offshore wind energy is expected to constitute a significant part of the future wind-derived power and, in the near future, an increase in the proliferation of offshore wind energy farms is expected in order to mitigate greenhouse gas emissions together with the need to reduce the energetic dependency on fossil fuels [6]. Recent directives and targets defined by the European Union (EU) are clearly supporting the use of renewable sources on energy production, with the latest EU directive 2009/28/EC setting the target to 20% of the total energy consumption to be derived from renewable sources until 2020 [7,8]. Furthermore, the Iberian Peninsula is presently one of the areas with the highest percentage of installed onshore wind power per capita worldwide due to its attractive wind conditions, which combined its large coastal line makes this area a promising one for the future installation of offshore wind farms.

One of the main issues still hampering the evolution of offshore wind farms projects is the severe lack of measured wind data over ocean areas, due to the technical challenges and associated high costs of conducting wind measuring campaigns in the ocean. Even when such measurements do exist (buoys deployed on ocean areas, satellites, onboard ships, vessels, etc.), they are not representative of the local ocean wind regimes over a medium/large spatial area or temporal period: measured wind data from buoys and ships is normally collected inside a limited spatial and time window, while wind observations taken by satellites typically suffer from low and insufficient spatial and temporal resolutions together with considerable data gaps [9–12]. Under these circumstances it becomes clear the need to obtain a preliminary assessment of the available offshore wind energy production potential at a given site, in which numerical weather prediction (NWP) models can be of great value by providing high resolution and gap-free wind data. The use of NWP models as a source of wind data for offshore wind energy applications has been growing in the recent past, and several authors investigated the accuracy of NWP models ocean wind simulations by comparing its results to measured winds, obtaining fairly satisfactory and promising results [13–20]. Despite the promising performances of NWP models on offshore winds simulation, coastal winds still remain a modelling challenge when compared to typical open sea and onshore winds due to the fact that they are strongly influenced by the local topography, discontinuity between land and sea roughness and also by thermal gradients resulting from land-sea temperature differences [21]. Therefore, continuous research on how to improve and optimize NWP offshore wind simulation is paramount.

Considering that one of the main possible sources of error of NWP modelling is the choice of the initial and boundary conditions that drive the simulations [1,22], it becomes mandatory to extend the tests and analyzes performed in [1] to offshore areas, in order to aid the identification of the most promising sites in terms of offshore wind energy production potential. Similarly to was what performed in that work, six different ocean near-surface wind speed and direction simulations were performed with the WRF model, each one of which using a different dataset as initial and boundary conditions: the older, but still widely used first generation reanalysis NCEP-R2 [23]; the new generation reanalyses ERA-Interim [24], NASA-MERRA [25] and NCEP-CFSR [26]; and also the NCEP-GFS and NCEP-FNL analyses. Although these two last datasets are analyses and not reanalyses, it was decided to include them in this work due to its intensive use in the wind energy industry. These six datasets are currently the only available initial and boundary conditions data sources that are freely available, are up-to-date and are available for the area under scope in this study. Summarized information about these datasets is depicted in Table 1, and a more detailed description and discussion about these datasets can be found in [1].

In the published literature only [9] tested the use of several reanalyses in NWP offshore wind simulation, but only focusing on three datasets (NCEP-R2, ERA-Interim and NCEP-CFSR), and this work can also be seen as an update of that study. As aforementioned, [1] evaluates the use of the reanalyses and analyses under study in this work but for onshore wind simulation. Although no other studies were found that evaluate the use of these, or others, reanalyses and/or analyses products on NWP offshore wind simulation, it is worth referencing studies that evaluated the use of older generation reanalyses on NWP onshore wind simulation [27], or that compare these (and/or other) sets of reanalyses not as initial and boundary conditions in NWP models but the reanalyses datasets themselves [28–32]. In all these studies was concluded that ERA-Interim is the dataset that, either provides the most accurate NWP wind simulation, or is the product with wind data closest to measurements. The main reason provided by the authors for this better performance of ERA-Interim was its four-dimensional variational analysis (4D-Var) assimilation system of observed data, which constitutes a major advantage and allows better results when compared to other reanalyses that use three-dimensional variational (3D-Var) analysis in the assimilation of meteorological data measurements.

Considering this lack of published literature focusing on the evaluation of all the new generation reanalyses (and plus two more analyses datasets) in the NWP offshore wind simulation, this work can constitute a reference and provide solid baselines for future studies regarding offshore wind energy assessment studies. Moreover, this work combined with combined with [1] constitutes a complete and solid analysis and testing on the use of all reanalyses and analyses datasets presently available in the near-surface wind modelling, providing important guidelines for future onshore and offshore wind energy modelling applications.

2. Methodology and data

The observed wind data used in this work was collected by five buoys moored offshore the Galician northern and western coast and the Gulf of Cádiz. The buoys are operated and maintained by the Spanish Agency Puertos del Estado (www.puertos.es), and their locations are depicted in Fig. 1, together with the innermost simulation domain shaded in gray. Wind measurements taken over the period January to December 2008 were selected, and the choice of this period was related to measured data availability and quality criteria. Table 2 depicts the geographical coordinates of the buoys used in this work, together with information regarding their distance to the coast.

Typically, near-surface ocean winds are referred at 10 m above sea level (a.s.l.). The buoys considered in this study collect their measurements at 3 m a.s.l. Therefore, it becomes necessary to

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