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WRF wind simulation and wind energy production estimates forced by different reanalyses: Comparison with observed data for Portugal

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HIGHLIGHTS

- Simulated winds and wind energy estimates forced by different reanalysis were evaluated in Portugal.
- ERA-Interim reanalysis is the one that likely provides the most realistic initial and boundary data.
- NCEP-FNL and NCEP-GFS analyses showed better results than the other reanalyses datasets tested.
- New generation reanalysis provide considerable improvement in the near surface wind simulation.
- NCEP-FNL and NCEP-GFS analyses are the best alternatives to ERA-Interim.

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ABSTRACT

The performance of the WRF mesoscale model in the wind simulation and wind energy estimates was assessed and evaluated under different initial and boundary forcing conditions. Due to the continuous evolution and progress in the development of reanalyses datasets, this work aims to compare an older, yet widely used, reanalysis (the NCEP-R2) with three recently released reanalyses datasets that represent the new generation of this type of data (ERA-Interim, NASA-MERRA and NCEP-CFSR). Due to its intensive use in wind energy assessment studies, the NCEP-GFS and NCEP-FNL analysis were also used to drive WRF and its results compared to those of the simulations driven by reanalyses.

Six different WRF simulations were conducted and their results compared to measured wind data collected at thirteen wind measuring stations located in Portugal in areas of high wind energy potential. Based on the analysis and results presented in this work, it can be concluded that the new generation reanalyses are able to provide a considerable improvement in wind simulation when compared to the older reanalyses. Among all the initial and boundary conditions datasets tested here, ERA-Interim reanalysis is the one that likely provides the most realistic initial and boundary data, providing the best estimates of the local wind regimes and potential wind energy production. The NCEP-GFS and NCEP-FNL analyses seem to be the best alternatives to ERA-Interim, showing better results than all the other reanalyses datasets here tested, and can therefore be considered as valid alternatives to ERA-Interim, in particular for cases where reliable forcing data is needed for real-time applications due to its fast availability.

1. Introduction

Due to the current deterioration of the worldwide environment, together with the increasing scarcity and high cost of the conventional energy sources (mainly fossil fuels), renewable energies are currently one of the main areas of research and investment. One of the fastest growing renewable energy sources has been wind power, which is presently one of the main suppliers of electricity in European countries. Portugal has been one of the leading countries in terms of installed onshore wind generating power: in 2011, it ranked 10th worldwide and 5th among European countries in terms of total wind energy installed capacity [1]. In 2010, Portugal was able to achieve an 18% quota of wind-derived energy in the total annual energy consumption, only outranked worldwide by Denmark in this parameter [2]. The exponential growth of worldwide installed wind power, mainly over the last decade, together with the future expansion of the wind energy markets [3] brings new challenges to the wind power industry, namely in what is related to the identification of the most promising sites in terms

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of wind energy potential. Although the use of this renewable energy source has been rapidly increasing worldwide, the lack of reliable measured wind data in several areas of the globe is still hampering the development of new wind energy projects, particularly in developing countries [4].

The wind energetic potential of one given area is traditionally assessed using locally acquired wind measurements and, in order to realistically represent the local wind climatology for wind energy assessment, a minimum of 1 year of measurements needs to be performed. However, the planning, installation and maintenance of wind measuring masts is an expensive endeavor, and if the wind measuring campaign reveals a poor wind energetic potential of the selected site, a considerable amount of investment is irreversibly lost. The need to obtain a preliminary knowledge of the available wind resource at sites with few or no local measurements becomes, therefore, of paramount importance. Due to these needs and limitations, alternative and reliable sources of wind data specifically designed to assess the wind energetic potential of one given area and/or to accurately forecast the wind constitute, nowadays, a very valuable service. One of the most used alternative sources of wind data are numerical weather prediction (NWP) models, capable of deriving wind climatologies at high resolution at the regional scale. In the recent past, mesoscale modeling using NWP codes has been used in several applications in the wind energy field: in the long-term wind climatology characterization of potential sites, in order to quantify the wind variability and representativeness of the local wind measurements to reduce uncertainty in annual energy production estimates; in short-term wind forecasting for wind farms already in operation, in order to correctly balance the electrical grid; and in mapping the average wind resource over large areas, very useful for large scale energy and/or electrical grid planning, to help promoters identify potential sites for wind energy exploitation, for greenfield or early-stage projects [5–13]. Despite the promising results obtained until now with NWP models, the wind simulation (and, particularly, the near-surface wind modeling) is still a major challenge to atmospheric modellers involved in meteorological research and applications, mainly due to the strong interaction between these low-altitude atmospheric flows and the local topography.

One of the most critical issues regarding mesoscale NWP modeling is the initial and boundary conditions that are fed into the model. Typically, for wind energy assessment and wind simulation studies, initial and boundary data are obtained through reanalysis datasets, which provide all the atmospheric information needed by the models to perform their simulations. Reanalysis are gridded datasets that combine data obtained from global circulation models (GCM's) with measured data, providing a synthesis of the available worldwide observations in the context of a physical model [14]. The first generation of reanalyses comprised three datasets: the NCEP-R1 [15], produced and released by the National Centres for Environmental Prediction (NCEP); the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-40 reanalysis [16]; and the Japanese Meteorological Agency JRA-25 reanalysis [17]. Due to several problems reported for the NCEP-R1, a second version known as the NCEP-R2 [18] was released by NCEP in order to correct the detected problems. NCEP-R2 is still processed up to the present in near real-time, which is a unique feature among these first generation reanalyses, considering that ERA-40 was discontinued in 2001 and the JRA-25 in 2004. Recently, a new generation of reanalyses has been produced and released, namely: the new ECMWF reanalysis (ERA Interim, described in [19]), the NCEP Climate Forecast System Reanalysis (NCEP-CFSR, described in [20]) and NASA's Modern Era Retrospective Analysis for Research and Applications (NASA-MERRA, described in [21]). This new generation of reanalyses is expected to provide a significant progress, due to advances in operational weather forecasting and also from previous reanalyses improvement efforts [22]. However, in mesoscale wind modeling applied to wind energy potential assessment it is common to find studies which use two analyses datasets provided by NCEP: the NCEP Global Forecast System (NCEP-GFS) and the NCEP Final Analysis (NCEP-FNL). Although these two analyses datasets differ from the traditional reanalyses, as will be detailed further on, it was decided to include them in this work due to its use in the wind power industry.

In summary, NCEP-R2, ERA-Interim, NCEP-CFSR, NASA-MERRA, NCEP-FNL and NCEP-GFS are currently the only available initial and boundary conditions datasets that are freely and publicly available, continue up-to-date and include the geographical area under scope in this study. Summarized information about these datasets is shown in Table 1.

The main differences between them can be condensed as follows: NCEP-R2 has the coarsest horizontal and vertical resolutions of the six considered datasets, assimilating only a limited amount of satellite observations; ERA-Interim is the latest global reanalysis produced in Europe and, in opposition to the other considered reanalyses, they include a four-dimensional variational analysis, 4D-var [23,24] assimilation method; NCEP-CFSR is the only dataset that makes use of a coupled atmosphere–ocean–sea ice-land model and both in ERA-Interim and NCEP-CFSR a variational bias correction method is employed, which allows a significant improvement and correction of biases related to satellite radiances. Although NCEP-R2 and NCEP-CFSR were produced by the same institution, the last one brought significant improvements to the traditional NCEP-R2, namely a higher resolution model (actually, the highest resolution among the reanalyses used in this study) and increased use of satellite observations in its assimilation process. As for the NASA-MERRA reanalysis, the GEOS model (version 5) and data assimilation system are used [25]. Its 3D-Var data assimilation system includes the implementation of flow-dependent, anisotropic and inhomogeneous background error covariances, described in [26,27]. Another innovation in this product is the implementation of a nudging technique that allows a smooth transition from the model states toward the observed state, the Incremental Analysis Update [25,28]. As for the NCEP-FNL and NCEP-GFS, which consist in analyses and not reanalyses, the major differences between them and reanalysis data are: the amount of observational data assimilated, where the reanalyses datasets typically consider a higher volume of measured and observed data; the availability of the data, where the NCEP-FNL and NCEP-GFS data is available usually within a day (or even in the same day) of the present date while reanalysis datasets are available only a few days/months after; the homogeneity of the analyses, where the advantage of the reanalyses is that the same model physics, parameterizations, etc., are used for the entire dataset produced, while the NCEP-FNL and NCEP-GFS data are subject to whatever the operational configuration is at any given period that can cause some inconsistencies over time (to see an example of how the model setup has changed over time, please consult <http://www.emc.ncep.noaa.gov/gmb/STATS/html/model_changes.html>). NCEP-FNL and NCEP-GFS share practically all of their characteristics, including the atmospheric model and its configuration. The main differences between these two analyses are: NCEP-FNL assimilates a higher amount of measured data than NCEP-GFS, since it runs 3 h past synoptic time when more observational data is available; NCEP-GFS, although containing less observation data assimilated, it has a much finer spatial and vertical resolution (Table 1).

Considering that this new generation of reanalyses is recent, only the study performed by Carvalho et al. [6] compared the use of the reanalyses considered in this work in terms of their use as initial and boundary data in NWP models for wind simulation. However, that work was focused on offshore winds alone, and