Renewable Energy 101 (2017) 680–689

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Spatial and temporal variability of wind energy resource and production over the North Western Mediterranean Sea: Sensitivity to air-sea interactions

Hiba Omrani [a], [*], Philippe Drobinski [b], Thomas Arsouze [b], [c], Sophie Bastin [d],
Cindy Lebeaupin-Brossier [e], Sylvain Mailler [b]

[a] *LSCE/IPSL, CNRS and CEA, Université Paris-Saclay, Gif sur Yvette, France*
[b] *LMD/IPSL, CNRS and École Polytechnique, Université Paris-Saclay, Palaiseau, France*
[c] *UME, ENSTA-ParisTech, Université Paris-Saclay, Palaiseau, France*
[d] *LATMOS/IPSL, Laboratoire Atmosphères, Milieux, Observations Spatiales, France*
[e] *Météo-France/CNRM, CNRS/GAME, Toulouse, France*

ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form
13 September 2016
Accepted 15 September 2016

Keywords:
Offshore wind energy
Air-sea coupling
Sensitivity numerical experiment

ABSTRACT

This work assesses the sensitivity of the offshore wind energy density and production to SST biases and air-sea feedbacks along the French and Spanish coast in the North-Western Mediterranean. It makes use of a set of three 20-years simulations from atmosphere stand-alone and atmosphere/ocean coupled models. In this numerical experiment, the effects of SST bias and air-sea feedbacks are isolated without any interference with other sources of error and uncertainty propagation, meaning that the same model and hence the same physics are used, all other things being equal. This study shows that the effects of SST bias or air-sea feedbacks on wind energy density and production estimation can reach up to 10% and 5%, respectively. Especially, accounting for air-sea coupled processes on sub-monthly time scales weakens systematically the energy density and production by 6.5% and 2.4% with respect to the configuration where these effects are neglected. The relative variability over the 20 years of simulation does not exceed 20% so the impact of air-sea feedbacks is very robust in time in terms of wind energy density and production assessment. Uncertainties up to 6.5 and 2.5% in the evaluation of the potential in terms of wind energy density and production potential can have severe consequences on the whole industry by lowering the projects profitability. This study shows that the effects of SST bias and air-sea feedbacks usually extend vertically up to the hub-height but their magnitude depends on the stability of the atmosphere. This study concludes that reducing the SST bias at the lower boundary of numerical atmospheric models and accounting for rapid interactions and feedbacks between the ocean and the atmosphere are key to improve the reliability of offshore wind energy density and production assessment.

1. Introduction

Today, wind energy is one of the most important sustainable energy resources in Europe. It represents the leading source of renewable electricity. In 2013, wind power accounted for 32% (11.2 GW) of newly installed generating power capacity in Europe. This significant deployment of wind energy has been instrumental in reducing greenhouse gas emissions from the power sector. The wind energy plays thus a significant role in the energy transition with respect to the climate policy in Europe.

In 2013, offshore wind power installations represent over 14% of the annual European Union wind energy market, up from 10% in 2012 (EWEA report, 2013). France represents the second largest European offshore wind potential energy, after Great Britain and before Germany. The estimated theoretical offshore wind potential in France is 80 GW over a 10,000 km^2 area considering the actual offshore wind turbine technology. This estimation reaches 140 GW distributed over a 25,000 km^2 area for floating wind turbines which are less dependent on the sea depth and the distance to the coast.

---

[*] Corresponding author.
E-mail address: hiba.omrani@lmd.polytechnique.fr (H. Omrani).

http://dx.doi.org/10.1016/j.renene.2016.09.028

Such potential is favourable to a growing development of offshore wind farms for which an accurate assessment of possible sites is needed.

High quality wind data are a key in the site assessment process to evaluate the wind energy potential, the economic viability, and engineering requirements of offshore energy project sites. Onshore wind energy potential is estimated using data from meteorological masts installed for such purpose during a year or so, or from existing weather station networks operated by national weather services. However, in the offshore environment, the deployment of instrumented masts is both difficult and expensive. As an alternative, near surface wind speed data from spaceborne scatterometers have been used for offshore wind assessment (e.g. QuickSCAT, ERS-NSCAT) [16,17,29,42]. The satellite wind data are not direct wind measurements and they only provide 10-m wind speed with coarse temporal and spatial resolutions. These products are usually not adapted to offshore wind assessment studies which require a higher spatial and temporal resolution data. Remote sensing techniques like Doppler sodars or lidars (e.g. Refs. [2,28,41]) have a strong potential to evaluate the wind potential at a given offshore location but it is still not widely used, and does not allow to map the wind resources over a large region.

Numerical models, such as numerical weather prediction models or regional climate models are convenient tools for onshore wind energy assessment in sparse-data regions (e.g. Refs. [1,14,15]) and have proven to be efficient to overcome the complex issues associated with offshore wind energy assessment (e.g. Refs. [48,49,55]). In particular, the impact of the sea-surface temperature (SST) accuracy on the simulated wind energy resource has been investigated with numerical experiments, showing a sensitivity of several percents of the simulated wind speed and wind energy at hub-height (80–100 m) to SST differences of few degrees (e.g. Ref. [47]). However, the use of such models have mainly been restricted to very short periods of time (typically one year) which limit the investigation of offshore wind variability on longer time scales.

This study can therefore be seen as a natural follow-up of these studies, as it investigates not only the effects of SST bias as in Shimada et al. [47] but also the effects of air-sea feedbacks on the spatial pattern of wind energy resource and production, and their temporal variability from seasonal to interannual scales. The study focuses on the North-Western Mediterranean region (Fig. 1) which is a hot spot for offshore wind energy [27]. Indeed, strong offshore and onshore coastal winds can persist for several days in this region. The strongest and most frequent wind is the mistral, which blows from the north/northwest [25]; Guénard et al., 2005, 2006). It occurs when a synoptic northerly flow impinges on the Alpine range. As the flow experiences channeling, it is substantially accelerated and can extend offshore over horizontal ranges exceeding few hundreds of kilometers [46]. The mistral occurs all year long but exhibits a seasonal variability either in speed and direction, or in its spatial distribution. It often blows simultaneously with the tramontane, a companion northwesterly wind channelled in the Aude valley [26]. During summer, the mistral shares its occurrence with the breeze (e.g. Refs. [5,7,23,24]), which can also be channelled in the nearby valleys [6,8] or interact with the mistral [4]. Such frequent and persistent wind systems impact the ocean dynamics with a strong seasonal cycle. During summer, breezes alternate with weak mistral and tramontane over a shallow ocean mixed layer, whereas in winter, the mistral and tramontane bring dry and cold continental air over the sea, inducing strong air-sea interactions with intense heat and momentum exchanges, which cool down the SST and deepen the ocean mixed layer [31–33].

In return, the energy fluxes at the ocean surface and the surface currents can have an effect on the wind field through heat and momentum transfer. How these air-sea feedbacks affect at various time scales the spatial pattern of the wind field, energy potential and production is the question addressed in this study.

Section 2 details the numerical sensitivity experiment. Section 3 discusses the sensitivity of the simulated offshore wind to air-sea interactions and Section 4 evaluates the impact of air-sea interactions on wind energy density and production. Section 5 concludes the study.

2. Experiment set-up

This study is conducted in the framework of two international programs - the Hydrological Cycle in the Mediterranean Experiment (HyMeX) [21] and the Coordinated Downscaling Experiment for the Mediterranean (Med-CORDEX) [44]. For this study, an ensemble of three 20-years regional climate simulations over the Mediterranean region are used (Fig. 1a).

The MORCE (Model of the Regional Coupled Earth system) platform is the framework in which the regional two-way air-sea coupled system (the AORCM) used in this study was developed [22]. The atmospheric model within the MORCE system is the Weather Research and Forecasting (WRF) model of the National Center for Atmospheric Research (NCAR) [50]. The domain covers the Mediterranean basin with a horizontal resolution of 20 km. It has 28 vertical levels using sigma coordinates. The first 1000 m are resolved on eight levels. Initial and lateral conditions are taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-interim reanalysis [19] provided every 6 h with a 0.75° resolution. Moreover, indiscriminate nudging is used to constrain the fields above the planetary boundary layer with a coefficient of 5×10^{-5} s^{-1} for temperature, humidity and velocity components. This reduces chaos between different simulations and allows us to consider that the differences come mostly from the surface differences [36,37,45]. The complete set of physics parametrisations can be found in Lebeaupin Brossier et al. [30].

The ocean model of MORCE is Nucleus for European Modeling of the Ocean (NEMO) [35]. It is used in a regional eddy-resolving Mediterranean configuration MED12 (e.g. Ref. [32]) with a 1/12° horizontal resolution, which represents about 6.5–7 km in the Gulf of Lions. In the vertical, MED12 has 50 stretched z-levels with finer resolution near the surface. The initial conditions for 3D potential temperature and salinity fields are provided by the MODB4 climatology [13] except in the Atlantic zone between 118 W and 5.58 W, where the Levitus et al. [34] climatology is applied. In this area, a 3D relaxation to this monthly climatology is used. River runoff and the Black Sea water input come from a climatology and their freshwater flux is set at the mouths of the 33 main rivers and at the Dardanelles Strait respectively. Smaller river runoffs are summed and set as a homogeneous coastal runoff around the Mediterranean Sea as in Beuvier et al. [12]. Further details on the ocean model parametrisation can be found in Lebeaupin Brossier et al. [30].

The control simulation (CTL) is the downscaling of the ERA-interim reanalyses obtained with WRF alone. For this simulation, the SST is thus prescribed from the same product used in ERA-interim and is updated daily (see Table 1 in Ref. [19]). Despite the ocean response to the regional winds generally occurs over a too small area to be correctly assimilated in the reanalyses (e.g. Ref. [30]), it is generally the numerical set-up used to perform simulations of the wind field. The coupled simulation (CPL) runs with two-way interactive exchanges between the two compartment-models managed by the OASIS coupler version 3