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Estimating the offshore wind resources of the State of Ceará in Brazil

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ABSTRACT

The onshore wind power is consolidated; the challenge is to reach the same level of maturity for offshore exploitation. Brazil has no offshore wind power plants and there are few studies in this direction. This paper aims to estimate the offshore wind resources in the State of Ceará, in Brazil. The investigation uses a mesoscale atmospheric computer model, the Regional Atmospheric Modeling System (RAMS), with horizontal resolution of 2 km, which estimates the offshore average wind speed, average wind direction, power density and turbulence taking into account the bathymetry data and navigation routes along the coast of Ceará. The wind potential was evaluated in three representative periods, La Niña, El Niño and Neutral year, analyzing the dry and rainy season for each period. The results indicate an average wind speed above 8 m/s and power density above 720 W/m^2 no matter the period evaluated, in the dry season. The predominant wind direction in the observed dry periods was from East to West and the turbulence intensity is smaller during dry season of El Niño. Besides, the bathymetry of the State of Ceará is shallow and the large ships route is far beyond the coast, offering no danger to future endeavors.

1. Introduction

Wind power generation has established itself over the years in the market as one of the cleanest electricity generation technologies. However, issues related to aesthetic, in special, has elicited reaction not in favor of onshore wind power plants in some parts of the world. The offshore wind facilities have then emerged as an alternative.

The distinct advantages of offshore wind power are easier transportation logistics, use of wind turbines of higher capacity, lower noise and visual impacts, better wind conditions, amongst others [1].

The lower roughness at the sea surface positively affects the Atmospheric Boundary Layer, also known as the Planetary Boundary Layer (PBL) that is the lowest part of the atmosphere, directly influenced by its contact with the surface of the planet. The PBL depth varies broadly and a tropical PBL could grow to 1 and 2 km depth [2].

The development of offshore wind power is, in many regions of the world, hindered by the lack of good quality information on the extent, characteristics and distribution of offshore wind energy resources [3].

The wind power in Brazil is growing and expected to reach 22 GW of installed capacity, 11.8% of the electricity matrix, in 2023 [4]. The South and in special the Northeast of Brazil are the regions with the greatest potential of wind power.

A study accomplished by the National Institute for Space Research (INPE) revealed that the potential for wind power generation at the Brazilian coast is about 3500 GW, ten times higher than onshore [5].

An investigation performed on the offshore wind energy resources in southeastern Brazil found that the average wind power is of 102 GW at a distance of 50 m from the coast, in the location between 28° S and 33° S [6]. Such results indicate that the offshore wind resources in Brazil, close to the coastal cities where concentrates the highest population density in the country, are promising and have great potential to complement the Brazilian electricity matrix.

Abbreviations: (RAMS), Regional Atmospheric Modeling System; (PBL), Planetary Boundary Layer; (PC), personal computer; (NCEP), National Centers for Environmental Prediction; (MBE), Mean Bias Error; (TI), turbulence intensity.

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The State of Ceará, in the Northeast of Brazil, has so far an onshore wind atlas, published in 2001. The atlas gives the wind resources at 50 m and 70 m above ground level, based on data set from 33 anemometric stations scattered over the state, at heights between 10 m and 50 m above ground, assessed by WindMAP software.

This paper aims to present the assessment results of the offshore wind resources along the seacoast of the State of Ceará with 543 km length of coastal line. The potential is estimated at 100 m above ground level, including the seacoast as well as about half of the onshore territory of the State. The assessment is based on the Regional Atmospheric Modeling System (RAMS) model to estimate the wind speed, power density, wind direction and wind turbulence. The bathymetry data and navigation routes along the coast are also taken into consideration.

The remainder of this paper is organized as follows. Section 2 gives an overview on the RAMS mesoscale model, the simulation tool applied for estimation of the offshore wind potential. Section 3 describes the methodology used in the research and the software parameter settings and Section 4 presents the validation of the results. Section 5 gives the offshore wind potential of the State of Ceará through maps of wind speed, wind direction power density, turbulence intensity and bathymetry. The conclusions are presented in Section 6, and additional results outlined in the Appendix with final remarks.

2. Regional atmospheric mesoscale model system – RAMS

RAMS is a versatile numerical code, developed at Colorado State University, often used for simulating mesoscale and large scale atmospheric systems. This model has multiple options of numerical schemes and physical parameterization that makes it possible to be useful in a broad spectrum of applications, with horizontal resolution of 2 km–2000 km [7–9].

This application tool is used by the Ceará Foundation for Meteorology and Water Resources (FUNCEME) and has proven suitable for weather forecasting, with high skill scores. It is a parallel distributed model that runs on a cluster of PC using distributed processing.

RAMS model uses prognostic and diagnostic models based on a set of hydrostatic and non-hydrostatic compressible equations of dynamics and thermodynamics of the atmosphere, plus conservation equations that includes: energy conservation, mass conservation (continuity equation), conservation of momentum (Navier–Stokes), water conservation, and the equation of state of ideal gas [8]. The microphysics is of volume, but explicit, with schemes of one or two moments, with seven distinct classes of hydrometeors: cloud water, rainwater, ice crystals, snow, aggregates, graupel and hail [10].

The application of the RAMS modelling system to predict the wind power generation in Northeastern Brazil, particularly in Ceará, has provided good results [11,12]. In this investigation, the RAMS model version 6 is used for estimation of the offshore wind resources in Ceará, Brazil.

3. Offshore wind evaluation methodology

The methodology applied for wind mapping depicted in Fig. 1 is based on RAMS model. The input data source is from the daily forecast provided by the National Centers for Environmental Prediction (NCEP). Access to NCEP grids over the Internet provides the initial and boundary conditions required to run the regional model.

The mesoscale model RAMS has the ability of grid nesting to provide high spatial resolution. For the purpose of this investigation, three nested grids were considered: the larger grid covers part

Fig. 1. Diagram of the methodology used in mesoscale.

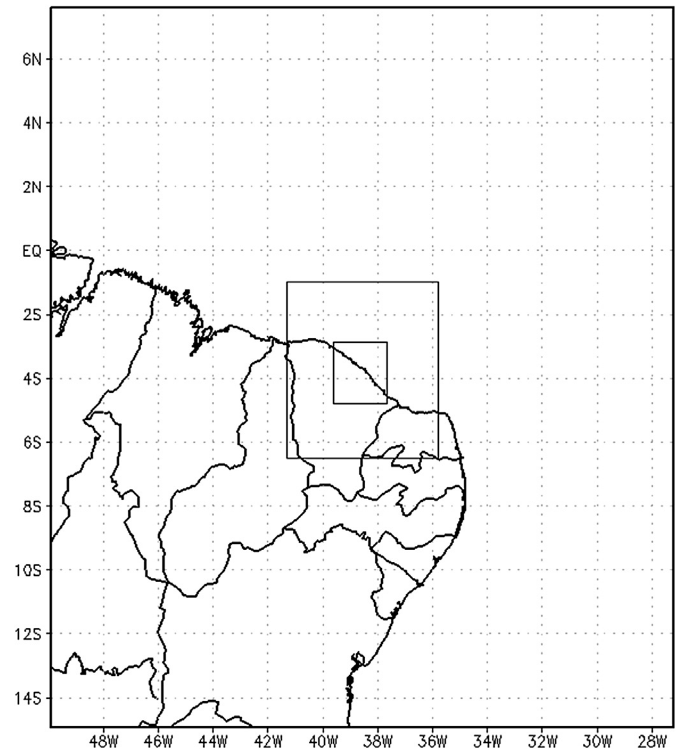

Fig. 2. Boundaries of the three nested grids.

of the Northeast region of Brazil; the second one encompasses most of the State of Ceará; and the higher resolution grid encompasses the entire coast of Ceará as shown in Fig. 2.

Table 1 shows the grid configurations as horizontal resolution, grid points, initial vertical resolution, vertical levels, rate of vertical enlargement and maximum vertical spacing.

The spacing of 2 km for grid 3 was selected taking into consideration a trade-off between data storage requirements and processing time against the atmospheric events able to be viewed by the simulation rounds of interest. The grid resolution of 2 km has therefore considered the computational effort and the effects of the atmospheric forces of mesoscale where sea breeze as well as land breeze are very active.

The model parameterizations include Kain-Fritsch scheme for convection, Mellor and Yamada for turbulence, and Harrington for radiation. The Kain-Fritsch scheme is a parameterization of mass

Table 1
Grids setting adopted.

Parameter	Grid 1	Grid 2	Grid 3
Spacing x	24 km	6 km	2 km
Spacing y	24 km	6 km	2 km
Grid points x	108	122	239
Grid points y	108	122	239
Initial spacing z	20 m	20 m	20 m
Vertical levels	51	51	51