WIND RESOURCE ASSESSMENT IN BERLENGAS ISLAND

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Summary

In the most recent years Portugal experienced an accentuated deployment of the wind sector, having recently overcome 2000 MW of wind capacity installed onshore. During 2007 through a public call for wind park grid connection, more 1400 MW were granted, totalling actually 5100 MW to be developed in continental Portugal until 2013, all in onshore projects. To further develop the wind sector in the post-Kyoto period, R&D organizations and developers are studying new opportunities for wind energy investment, namely through the characterization of the offshore resource and the coastal bathymetry. INETI has recently developed an Offshore Wind Atlas which results enabled the preliminary identification of suitable areas for offshore exploitation. In order to calibrate the Atlas results, in 2006 an anemometric station was installed, in Berlengas, an Atlantic rocky island located seven nautical miles west of Peniche city. The quikSCAT wind satellite data and the output from the model's simulations show an excellent agreement with observational values from the Berlenga anemometric station. The high correlation of the wind time series results obtained by the different approaches, lead INETI to initiate a composite methodology to compute offshore wind resource based on satellite data and mesoscale models.

1. Introduction

Portugal is a country characterized by complex orography and moderated mean wind speeds, although in some areas the mean wind speeds surpasses 8 m/s at the standard turbine hub heights. Those areas are mainly situated in the mountainous northern interior and the coastal exposed regions of Continental Portugal. Wind energy developers have already explored most of these sites and as a consequence, 1698 MW of wind capacity was installed until the end of 2006, and about 2000 MW were already operating in the end of September 2007. In the recent years - driven by the wind park developer's ambitious plans - hundreds of anemometric stations were installed and operated during several years, leading to a quite complete knowledge of the wind resource onshore. INETI has contributed for this resource assessment with the operation of, approximately 200 anemometric stations and the development of numerical wind atlases, both for onshore and offshore, and even some long term wind databases (Projects EOLOS I and II) [1, 2]. Within this line of work, Portugal's first Offshore Wind Atlas was developed in 2006 [3, 4] by using mesoscale models (MM5) [5]. Using this Atlas several regions were identified for offshore applications in the Portuguese continent coast. Based on the results obtained from this work, INETI has selected a site with good wind resource – the archipelago of Berlengas, and performed a long term high resolution mesoscale simulation. In this archipelago was also installed a meteorological mast to calibrate the wind resource. Since the archipelago of Berlengas is a natural reserve, INETI had previously asked for a special authorization kindly conceded by the national environmental and maritime authorities in Portugal to install the anemometric mast in the archipelago. The calibration of the wind resource also includes other sets of wind databases, namely the QuikSCAT satellite data to infer from the remote sensing's instruments the offshore resource assessment at the ocean surface for the area under study.

2. Wind Campaign in the Archipelago of Berlengas

2.1 Berlenga Island characteristics

The archipelago of berlengas is composed by three islands, namely, the Berlenga, Estelas and Farilhões, and other very small rocky islands, classified as natural reserve in Portugal. Berlenga island is the most largest island of the archipelago and is located 5.4 miles west-northwest of Cabo Carvoeiro and about 7 nautical miles from the large port of Peniche. With an area of approximately 79 hectares, it can be considered as a “spot” island in the Atlantic Ocean, due to its small dimensions. In what concerns roughness elements, it is characterized by small vegetation mainly due to the occurrence of extremely high wind speeds. The island has no permanent population. During the winter months the climate and sea conditions are very rough and only the lighthouse operators stay there. On the contrary, in the summer months the crystalline waters invite to swimming and scuba diving and the island becomes a desired resort receiving hundreds of visitors among local tourists. In these warm months a small community of fishermen also resides in the south-eastern part of the island. Figure 1, shows the orography pattern of Berlenga Island.

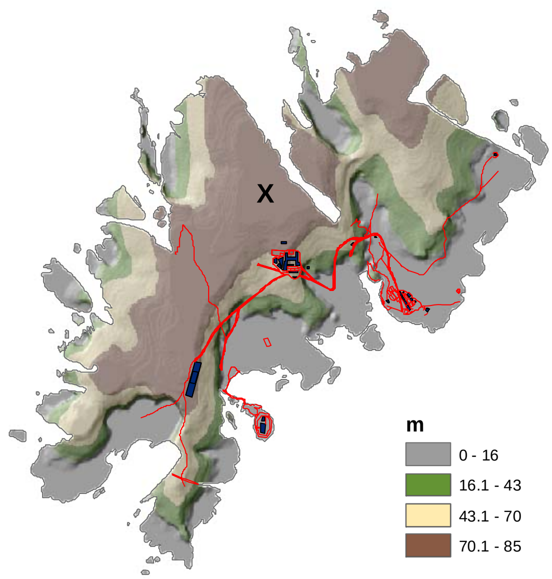


Figure 1 – Orography of the Berlenga Island. Cross mark (X) refers to the anemometric mast location. Red lines represent the trails (small roads)

Observing the behavior of the terrain one can see that the maximum altitude is about 85m height. The orography is characterized by very complex rocky terrain and the pattern is very irregular. Therefore, it is expected that in some sites of the island, a strong wind concentration may occur.

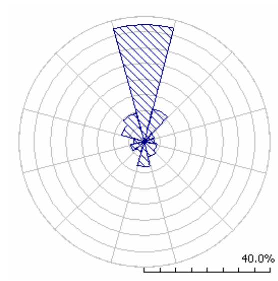
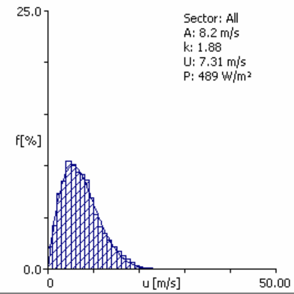
2.2 Wind data and statistics

The mast of Berlenga was installed in November 2006 near the lighthouse (cross mark in figure 1). The anemometric tower has one anemometer and a wind vane both installed at 20m height (in top of the tower) and another anemometer installed at 10m - the meteorological reference height. The collected wind data period considered in this study is from December 2006 to September 2007. The wind statistics computed from the data, as well as the wind rose and weibull distribution are represented in tables 1 and 2.

Table 1 – Wind statistics in Berlenga Island for two measurements heights. Data observed in the period December 2006 to September 2007.

Height M	Velocity. (m/s)	Power Density (W/m2)	Weibull A (m/s)	Weibull k
10	6.73	390	7.7	1.89
20	7.35	489	8.2	1.88

Table 2 – Wind rose and Weibull distribution in Berlenga Island recorded at 20m height. Data computed in the period December 2006 to September 2007.

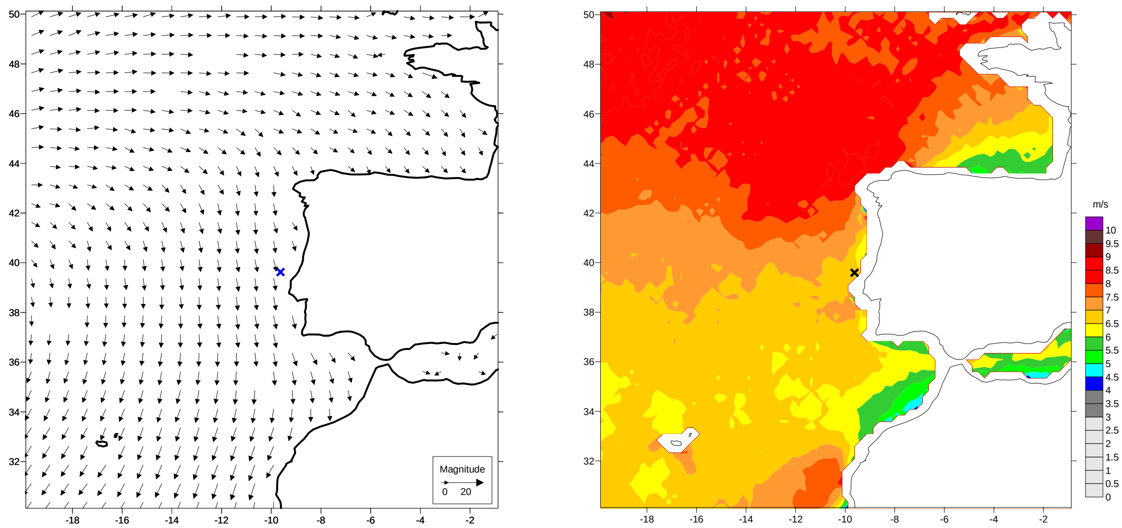
Wind Rose	Weibull distribution
	

By analyzing Tables 1 and 2 one can see the behavior of the recorded atmospheric pattern. The wind blows mainly from the North sector. This is very consistent with data collected in other coastal meteorological wind stations, since the winds are mainly, drifted away by the permanent presence of the large atmospheric high pressure system, known by Azores's High near the country during the whole year. The mean wind speed in the period under study at h=20m is 7.35m/s, a rather high value. This fact leads to the conclusion that the wind speed and weibull distribution processed from local data constitute a good source for the offshore resource assessment in the vicinity of Berlenga Island. Therefore, the archipelago of Berlengas can be considered as a very suitable site for spreading wind turbines (for microgeneration or multimegawatt wind parks) as well as the traditional offshore wind turbines in the area around the islands, since the bathymetry between the archipelago and the Continent is in the order of 40m depth. However, for the last case the observed wind data must be collected at appropriate heights, such as 80m or higher, according to the offshore wind turbine manufacturers. In the near future, it is expected the installation of a LiDAR instrument in Berlengas Island to infer the local vertical wind profile up to 150m height.

3. Wind Resource from QuikSCAT

3.1 QuikSCAT SeaWinds data

Offshore wind resource assessment can nowadays be reasonably derived from special remote sensing instruments capable to "measure" the ocean wave heights and infer from that, the mean surface wind field powered by large/local scale atmospheric motions (e.g. Highs and Lows), responsible for triggering waves in the ocean. The knowledge of such wind field information is indeed a valuable database for offshore purposes, although the majority of these databases aren't yet available freeware to public and scientific communities. Contrarily to this tendency, the Jet Propulsion Laboratory (JPL) from NASA maintains since 1999, a daily wind ocean database entirely collected from satellite, known by QuikSCAT SeaWinds satellite data. The QuikSCAT satellite maintains his helio-synchronous orbit around the whole globe tracking twice a day, the same local point in the ocean with a "footprint" resolution of 0.25ºX0.25º. More details about QuikSCAT can be found in [6]. In this work, the wind was extracted for an area covering the latitudes and longitudes between 30ºN and 50º N and 20ºW and 1ºW (WGS84 coordinate system) for the same period as the one of Berlenga's anemometric mast. In figure 2 (a) and (b) are shown the surface wind speed and wind vectors, processed for the mentioned area.



(a) (b)

Figure 2 – Spatial distribution of (a) mean wind field and (b) mean surface wind speed gathered from QuikSCAT satellite, between December 2006 and September 2007. Cross marked in both images reveals approximately the location of Berlenga island.

Observing the spatial distribution of the mean wind field (figure 2a) one can see the presence of the Azores high pressure system near the coastal area of Continental Portugal, where the winds come from the north sector. The mean surface wind speed at cross marked point (figure 2b) is between 6.5 and 7.0 m/s interval. These results are very consistent and similar to the ones obtained with the observational campaign in Berlengas, according the results presented in table 1.

For the cross marked points in figures 2a and 2b, it was also processed a time series of wind data to be plotted against observational data recorded in Berlengas. Figures 3 and 4 show these time series where one can see an excellent agreement between both wind speed and wind direction values. The correlation factor is rather high, 90.2%.

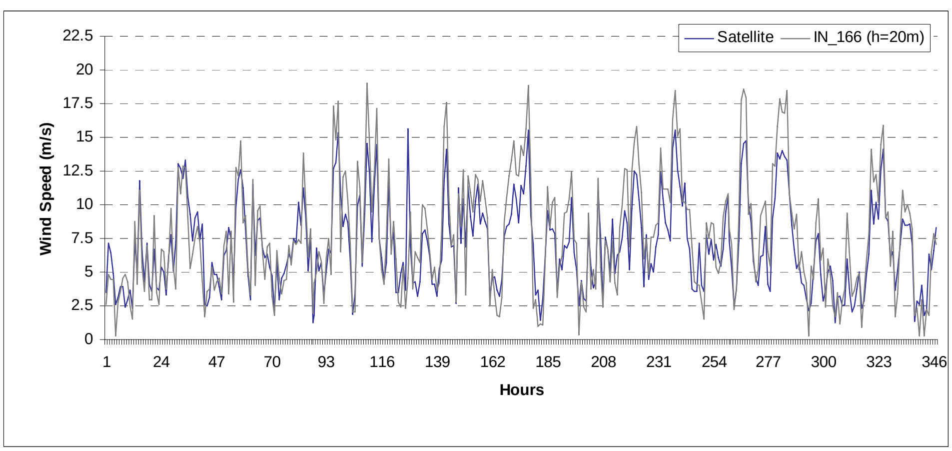


Figure 3 – Wind speed time series data between observational (IN_166 meteorological mast in Berlengas at h=20m) and quikSCAT data

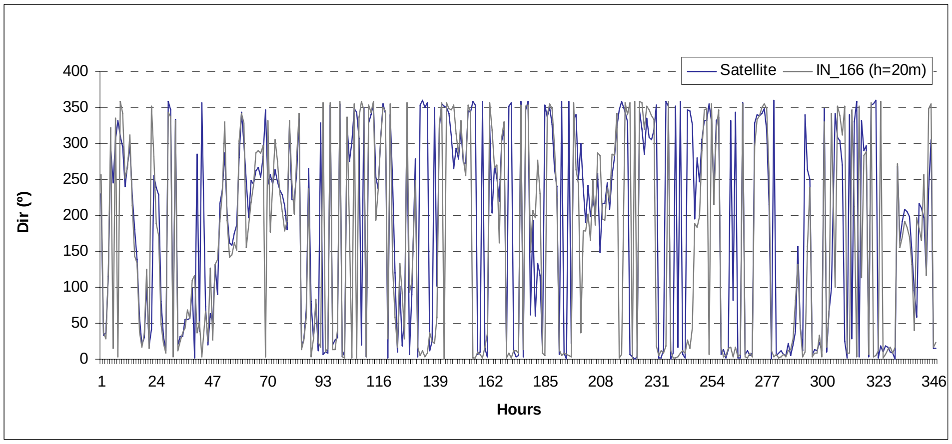


Figure 4 – Wind direction time series between observational (IN_166 meteorological mast in Berlengas at h=20m) and quikSCAT data.

It is clear from figure 3 that wind speed inferred from QuickSCAT can't represent the observed maximum wind speed along time, which it's a first indicator that Berlengas Island suffers some kind of wind concentration phenomena, probably associated with the irregularity of the island. Figure 4 shows an excellent agreement between wind direction values.

Based on the presented results, the QuikSCAT wind data can be used as a reasonable tool to perform wind resource assessment studies for offshore exploitation near Berlengas, although it must be pointed out the very poorly sets of available data for each day (about two or three values per day) can not be enough to represent the frequency of coastal phenomena like sea-breezes and turbulence/stratification, among others. Besides this, these sets of data can be useable in statistical studies to overcome some lacks of observational data or used for ingesting local or regional atmospheric simulations with specific models.

4. Wind Resource from MM5 model

4.1 Set of numerical simulation

In order to deal with turbulence and atmospheric stratification phenomena due to the influence of coastal regions of Portugal, a numerical simulation in the vicinity of Berlengas Island was made in this work by making a high resolution (1X1km) long term simulation with the popular atmospheric MM5 model. Basically, the MM5 is a regional atmospheric model capable to simulate local thermal or shearing phenomena (e.g. sea-breeze circulations) among others in a *sigma* [7] coordinate grid which follows the terrain. For this study, a period of, approximately, 10 months of continuous meteorological data (from December 2006 up to September 2007) gathered from Reanalysis [8] data from NCAR/NCEP's mass storage systems, was ingested into MM5 in intervals of 6h. The same data was used to make grid nudging to prevent some drifts between the Reanalysis data and the numerical solution.

The MM5 model was run with version 3.7.3 updated in what concerns to the formulation of the atmospheric physics, presenting the advantage of being a freeware model constantly improved by it's users in universities and research institutes all over the world. For the study here presented, the MM5 model was configured with six one-way nested domains with resolutions of 81km, 27km, 9km, 3km, 1km and 0.33km (still under simulation). Parameterization schemes were previously selected by making a couple of simple control simulations to improve the minimization differences between observed and simulated wind speed values as well as wind direction values. Parameterization schemes like MRF (PBL), RRTM (radiation), BETTS MILLER (cumulus) MIX PHASE (microphysics) and NOAH soil model (4 levels used from reanalysis data: 10, 40, 100 and 200 cm) were chosen since wind data simulated work better in agreement with observed wind data. Figure 5 shows the high resolution domain (1X1km) used for resource offshore assessment in Berlenga Island and table 2 shows the grid point dimensions as well as the spatial resolution and the model time step for all six one-way nested domains.

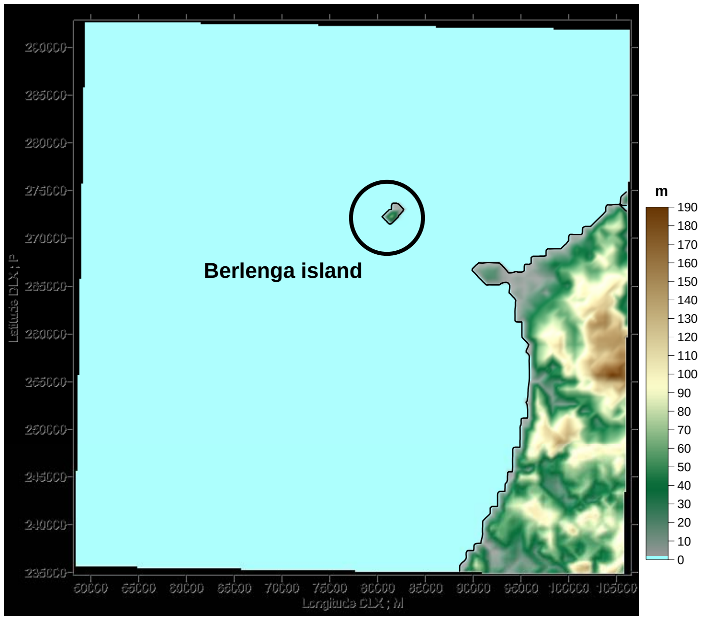


Figure 5 – High resolution MM5 orography domain (1X1km) in the vicinity of the Berlenga Island.

Table 2 – Domain dimensions and time step of model's simulations.

Domain	**Grid dimensions ny×nx×nσ**	**Spatial resolution**	**Model Step (s)**
D1	28×28×32	81 km	240
D2	40×40×32	27 km	81
D3	52×55×32	9 km	27
D4	55×52×32	3 km	9
D5	76×76×32	1 km	3
D6	91×91×32	0.33 km	1

MM5 was configured to produce the outputs every hour. Following the same line of work, it was processed a wind time series of values from the model results. Figures 6 and 7 represent the behavior of MM5 simulation with observational measurements. The correlation factor between time series is 82.1% at 1km resolution. From figure 6, it is clear that MM5 model captures very well the atmospheric phenomena with time scales larger than 1hr, although they can't represent the observed maximum values in Berlengas Island. This is mainly due to the discretization of the Berlengas orography ingested into the model previously extrapolated to 1x1km resolution. A domain model with a resolution of 0.33kmx0.33km is currently being simulated with specific orography and roughness gently provided from the local Peniche authorities in order to improve the description of the terrain and the behavior of the strong wind speed concentrations around the Island. Figure 7 shows the excellent agreement of the wind field derived from the model. In figure 8 it the spatial wind speed and wind field from the outputs of MM5 were processed for 20m height. Again the sector north is clearly evidenced by the regional model.

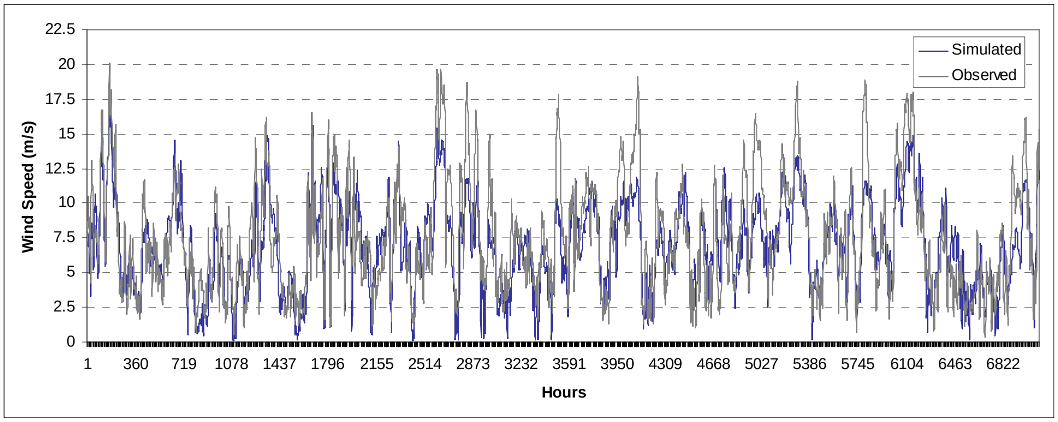


Figure 6 – Wind speed MM5 1km (h=20m) vs Berlenga mast measurements.

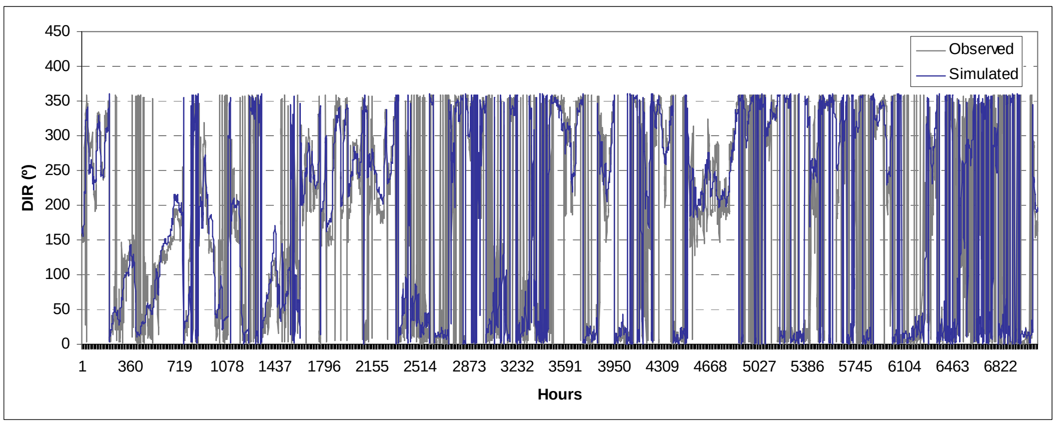


Figure 7 – Direction MM5 1km (h=20m) vs Berlenga mast measurements.

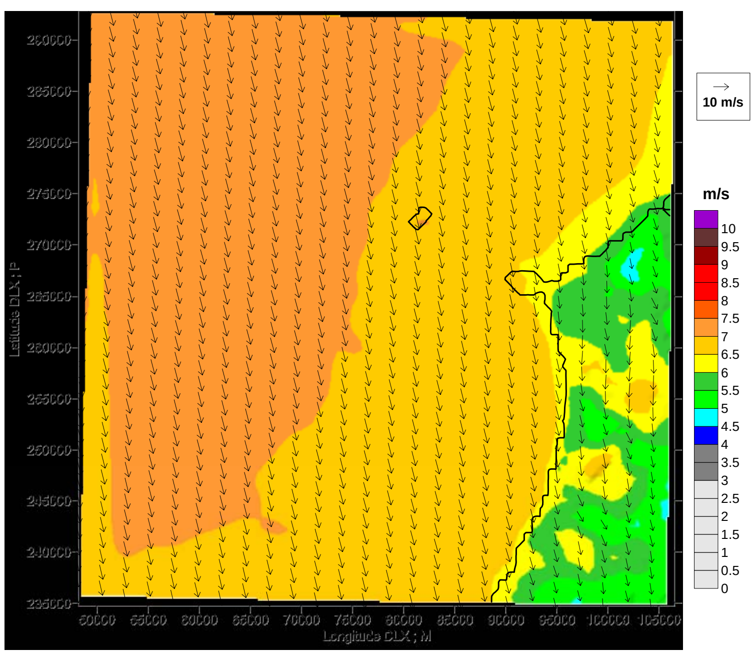
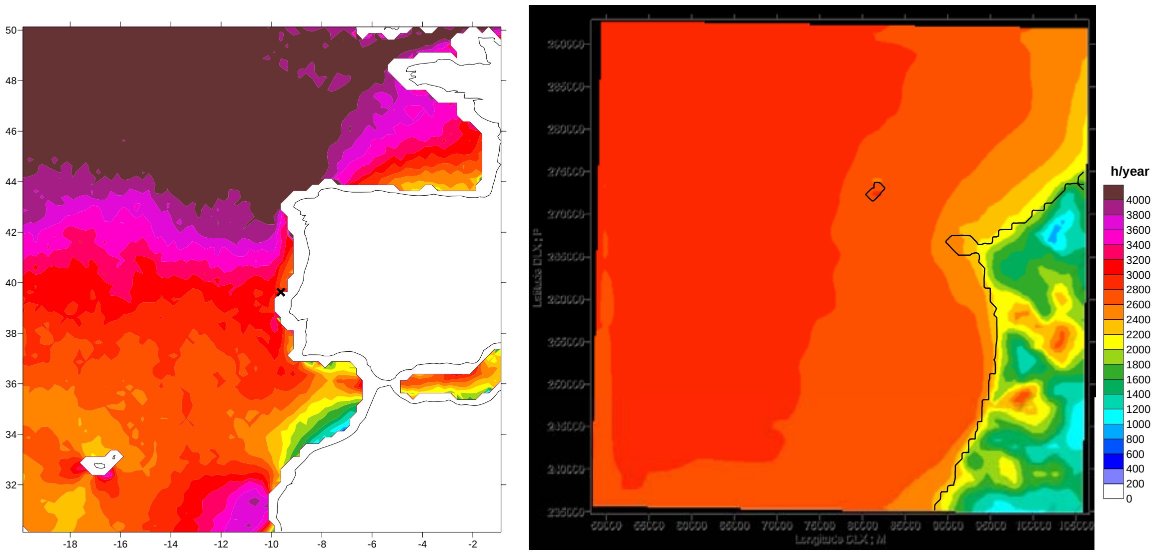


Figure 8 – Wind speed and wind field simulated with MM5 for 20m height.

4. Wind power production

Based on the results from QuikSCAT and MM5 mesoscale simulations, it was computed in this work a preliminary estimate of wind power production (h/year) for the whole region around the archipelago of Berlengas, based on the characteristics of a standard 1500kW wind offshore turbine. Results are presented in figures 9a and 9b). In the case of QuikSCAT data, the wind power production shown in figure 9a was processed for the surface of ocean height while MM5 simulations (at 1X1km) were processed for 20m height (figure 9b).



(a) (b)

Figure 9 – Spatial distribution of wind power production expressed in hours per year for (a) QuikSCAT data and (b) MM5 1x1km simulation, h=20m. The wind turbine model used corresponds to a conventional 1500 kW offshore wind turbine. Cross marked in figure 9a reveal the location of Berlenga Island.

It is evident from both figures 9a and 9b the strong evidence of the wind power offshore production (h/year) estimated for the entirely region of Berlengas Island. Indicated values from QuikSCAT data and MM5 simulations are within the interval between 2200 up to 2800 h/year. In fact, taking into account the local bathymetry that is always less or around 40m depth in whole area up to the continent, makes this area as a very attractive place to make offshore exploitation with conventional offshore wind turbine systems or even using micro-generation turbine systems for auto sustainable purposes. Since the wind power production was computed only in the surface (QuikSCAT data) and 20m height (MM5) we can expect a better resource assessment for heights greater than 20m, such as the turbine's hub height, according to the offshore wind turbine manufactures. However, for this case, a collected wind campaign must be performed at these heights to evaluate the regional or local model simulation results. For the case of Berlengas Island, it is expected the installation of a LiDAR/SoDAR instrument to infer the vertical wind profile up to 150m height for model validation and therefore, produce wind power estimates at these heights, for some reference offshore turbine models.

4. Conclusions

In this work it was presented the wind resource evaluation around the archipelago of Berlengas located in the Atlantic Ocean, located about seven nautical miles from the west corner of continent. Preliminary offshore studies conducted by INETI have indicated the existence of some coastal areas in Continental Portugal with good potential for offshore exploitation such as the area around the archipelago of Berlengas. This place has also a favourable bathymetry depth for installing traditional offshore wind turbines, since is more or less 40m depth. facing this preliminary results, INETI installed in the Berlengas Island – the largest island of the archipelago of Berlengas, an anemometric mast with two wind speed sensors (10m and 20m height) and one wind vane sensor at 20m height to evaluate the wind resource. The observational data used in this study covers the period between December 2006 (start of campaign) and September 2007.

In order to evaluate the wind resource in the archipelago of Berlengas it were also used other wind data sets for the same observational period, such as the QuikSCAT satellite data and the Reanalysis data from NCAR's mass storage systems to provide boundary data to be ingested into the MM5 regional atmospheric model.

The results obtained via numerical simulations with MM5 model at 1x1km or from QuikSCAT inferred wind data, shown an excellent agreement with observational values, being for that, suitable tools to be used for wind resource offshore assessment, although the results exclusively used from QuikSCAT data can not represent the desired frequency of occurrence of the typical coastal phenomena like sea-breezes and turbulence/stratification among others since they are responsible for the behaviour of the wind field near coastal regions, once the satellite "footprint" track only covers the area under study about two/three times per day.

On the other hand, the MM5 mesoscale model at 1x1km resolution did not represent well the strongest maximum wind speed concentrations observed in the Berlengas Island due, probably, to the discretization of the orography of the Island at these resolutions, since the island is mainly formed by very irregular orography. However a domain model with higher resolution of 0.33kmx0.33km is currently being simulated with specific orography and roughness gently provided from the local Peniche authorities in order to improve the description of these strong wind speed concentrations around the Island. Therefore, the model can, in the future be considered an indispensable tool to perform wind resource assessment and also wind and power forecasting for the whole archipelago of Berlengas.

With both wind data sets (QuikSCAT and MM5) it was generated an estimate for the wind power production expected to the region under study, using the characteristics of a traditional offshore wind turbine with 1500KW. The results clearly indicate expected values ranging from 2200 up to 2800h/year at the surface and at 20m height. Therefore this area is very suitable to make offshore exploitation once it's expected better resource assessment near the turbine's hub height.

The results obtained in this work lead INETI to develop a future methodology to compute wind resource for offshore purposes evolving the ingestion of QuikSCAT data and observational wind data in the MM5 mesoscale model and composite the results with higher resolution local models, such as the CALMET/CALPUFF [9] or WAsP [10] models also ingested with observational wind data, and then, apply these methodology to other coastal regions of Continental Portugal. Following this thematic, an European project in Berlengas Island is about to start, contemplating more wind and vane instruments installed at 60m or higher, more satellite source data (e.g. SAR) and also the behaviour of the wind vertical profile inferred from LiDAR/SoDAR instrument to be installed in Berlengas Island in order to accurate the methodology to be developed. INETI is also expecting to provide, in a near future, a real wind power forecasting system for Berlengas Island.

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