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STUDIES CONCERNING THE COASTAL IMPACT OF AN OFFSHORE WIND FARM OPERATING IN THE VICINITY OF THE DANUBE DELTA

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ABSTRACT

Motivated by the fact that the European offshore industry is continuously expanding, the present work has as main objective to assess the expected coastal impact of a large wind project, which would operate in the vicinity of the Danube Delta. Since the distance to the coastline represents an important aspect for the development of such a project, both from an economical and a technical point of view, three main case studies were taken into accounts, namely: a) wind farm located at 3 km from the shoreline; b) wind farm at 4.5 km; c) wind farm at 6 km. The structure of the wind farm is similar for all scenarios, involving a total of 54 wind turbines distributed along 3 lines (18 systems per line), the distance between each system being around three times the rotor diameter of a typical wind turbine. Based on these outcome of the present work can be mentioned that the results look promising, since they reveal a significant attenuation of the wave energy in the presence of the farm, which indicate that a such project may provide besides renewable energy also an effective coastal protection for all the scenarios taken into account.

Key-Words: *Danube Delta, offshore wind farm, coastal impact, waves, SWAN*

INTRODUCTION

Although the coastal areas cover only 20% of the entire land it is estimated that almost 39% of the population lives within an area of 100 km from the coast. As a consequence, 19% of all land is considered to be directly influenced by the agricultural and the urban activities and 10% is indirectly influenced [1]. In addition, the coastal erosion and sediment transport can be significantly influenced by the action of the wind, waves or coastal currents which could be considered a negative phenomena in the areas where the sediment sources are limited [2]. At this moment, the methods considered for the protection of the beach sectors involve monitoring and applications of various technologies such as: beach nourishment, artificial dunes, seawalls, surge barriers or wetland restoration [3].

None of the current solutions, include renewable energy systems which are gaining momentum, especially in Europe. For the coastal sectors, maybe the best protection can be provided by the wave energy converters (WECs) which seems to significantly reduce the wave energy, especially during the storm events when the erosion processes are more severe [4-6]. The erosion problems corresponding to the Romanian nearshore are already known. They are mainly influenced by the development of the local harbors and also by the shortage of the sediments transported by the Danube river [7]. Since the northwestern part of the Black Sea seems to present more consistent wave and wind conditions, a renewable energy project will be capable to generate electricity, but more important will provide a sheltering area. This type of protection could be considered suitable for protected areas, especially in the vicinity of the Danube Delta, which was included in the UNESCO heritage starting with 1991 [8]. A wind energy project developed in the Romanian coastal environment can become reality in the near future if we take into account that most of the onshore wind parks are going to the sea (Galati, Tulcea and Constanța), from which can be mentioned that in 2012 the project Fantanele-Cogealac was one of the largest [9].

MATERIALS AND METHODS

2.1 Target area and SWAN computational domain

In Figure 1a is presented the target area considered for evaluations, which is located in the vicinity of the Romanian nearshore, more precisely north of the Saint George branch of the Danube. More details regarding the set-up of the numerical models performed with SWAN (Simulating WAves Nearshore) [10] are presented in Figure 1b. The computational area is defined by a rectangle with a size of 12 km x 20 km, where a maximum water depth of 40 m is reported in the lower part of the region. Similar to a wind project, where multiple systems are grouped in a park, for the current work it was considered relevant to simulate the influence of a wind farm were 54 turbines are arranged in three lines oriented parallel with the coast line. In order to estimate the influence of a farm which operates at different distances from the shore, three main configurations were considered. The first one (denoted with W3) is located at a distance of 3 km, being followed by a second scenario (W4.5), where the farm is located at approximately 4.5 km from the shore, while a maximum 6 km was selected for the last case (W6). The towers of the offshore wind turbines were considered in SWAN as obstacles, which are defined by a zero transmission coefficient indicating that no wave will pass through these regions, while the reflection coefficient was set to 0.2.

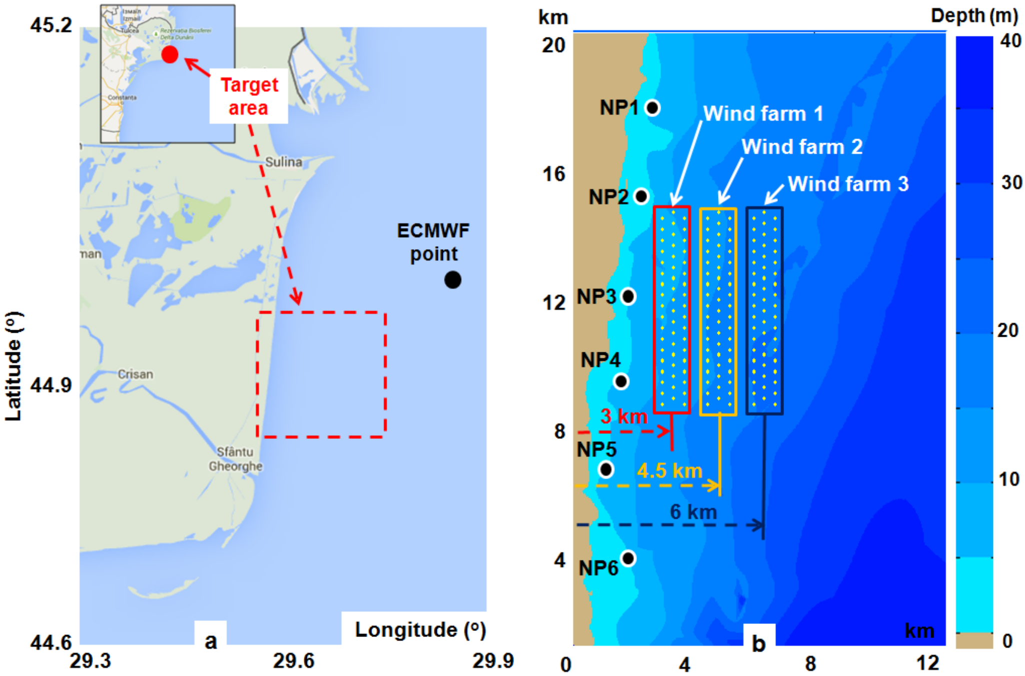

Fig. 1. Definition of the target area and set-up, where: a) overview of the target area; b) SWAN computational domain where can be observed the three case studies taken into account and also the locations of the reference points NP1-NP6

Close to the coastline several reference points (NP1-NP6) were defined. These will be used to identify the variations of the wave characteristics in the presence of the wind farm. In order to run the SWAN simulations, the initial wave conditions were reported to an offshore point (Figure 1a), for which 10-year of reanalysis wave data (2005-2014) coming from the European Centre for Medium-Range Weather Forecasts (ECMWF) were processed. More details about this dataset can be found in the documentation of this program [11, 12]. Besides these, must be mentioned that the SWAN outputs were processed throughout the ISSM (Interface for SWAN and Surf Models) [13, 14].

RESULTS

Based on the wave data reported by the ECMWF point, it was possible to identify some relevant wave patterns, which occur more often in the target area. The first case study can be associated with the summer time (April-September) and it is defined by the following wave height and period: *Hs*=2.5 m; *Tm*=8 s. Moreover, based on some previous studies [4], the wave direction was set to 40° (northeast sector) for all the simulations carried out in the present work. The distribution of the wave fields in the presence of the three wind farms (W3, W4.5 and W6) is presented in Figure 2. At a first analysis, can be observed that for the scenario W3, the sheltering effect seems to be more severe in the vicinity of the shoreline over an area equaltoforearmh the farm length. The influence of the farm is notable for all the scenarios, even in the case when the farm is located at approximately 6 km from the shore, in this case however, the variations being more severe in the ofshore area.

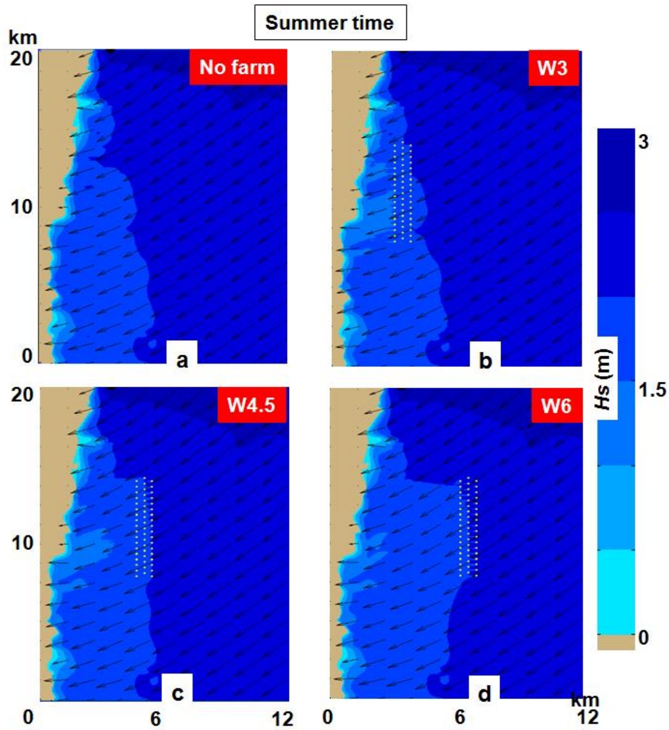

Fig. 2. The expected impact of the wind farm on the wave fields reported for the summer time, where: a) no farm; b) W3 scenario; c) W4.5 scenario and d) W6 scenario

Figure 3 illustrates the variation of the main wave characteristics reflected by the NP points. Regarding the *Hs* parameter, can be observed that the wind farms induce some variation of the wave heights, which it seems to be more significant in the case of the W3 scenario near the point NP3. The maximum variations are observed in the vicinity of NP4, regardless the scenario considered, with the mention that the wind farm W6 seems to have a higher impact on the wave conditions reported in the lower part of the target area.

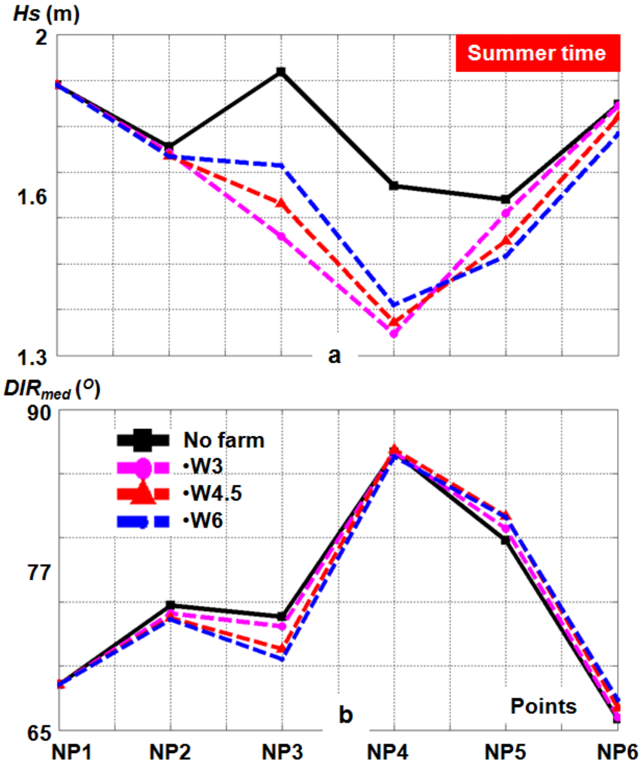

Fig. 3. The influence of the offshore wind farms during the summer time, reported for: a) *Hs* (m) parameter; *Dir* (º) parameter

Figure 4 presents the distribution of wave fields during the winter time, which was considered from October to March the associated wave conditions being defined by: *Hs*=4; *Tm*=10.

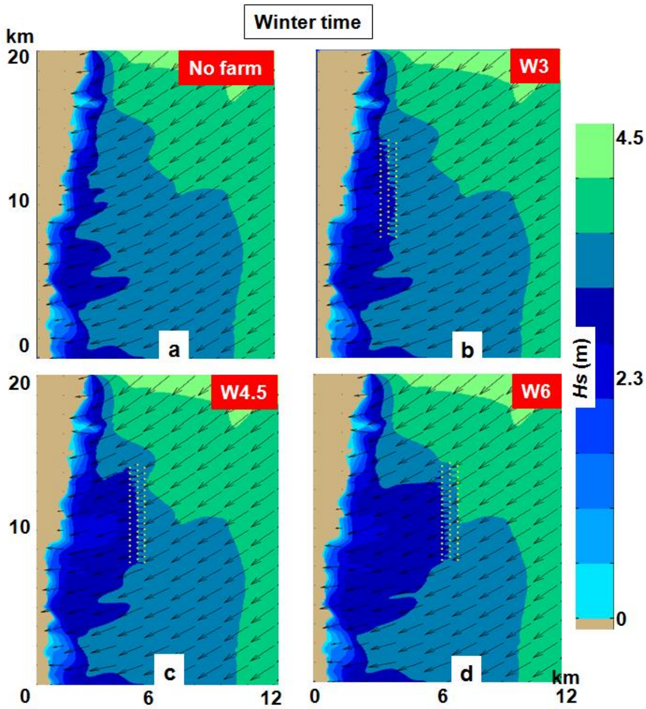

Fig. 4. The expected impact of the wind farm on the wave fields reported for the winter time, where: a) no farm; b) W3 scenario; c) W4.5 scenario and d) W6 scenario

From these simulations can be observed that the sheltered area located between the farm and the shoreline is highlighted more clear, being concentrated mainly in the lower part of the target area, as can be noticed in the case of the wind farms W4.5 and W6, respectively. For the last two cases, the *Hs* waves can be reduced from 4.5 m to 2.5 m in the vicinity of the farms, being reported also some spots where the waves may report significant wave heights of about 2 m. A detailed investigation of the main wave parameters is also presented in Figure 5 according to the results indicated by the NP points.

Compared to the previous study, the directional pattern remains the same, while the *Hs* values tend to increase from the upper to the lower part of the target area. The variations between the scenarios are quite small, being reported more significant values in the vicinity of the points NP3 and NP4, with 2.26 m and 2.19 m, respectively. In the case of the wave directions the following values are reported: NP1-73.16^o (all the scenarios); NP3-78.45^o (no farm), 75.4^o -W6 scenario; NP6-69.64^o (all the scenarios).

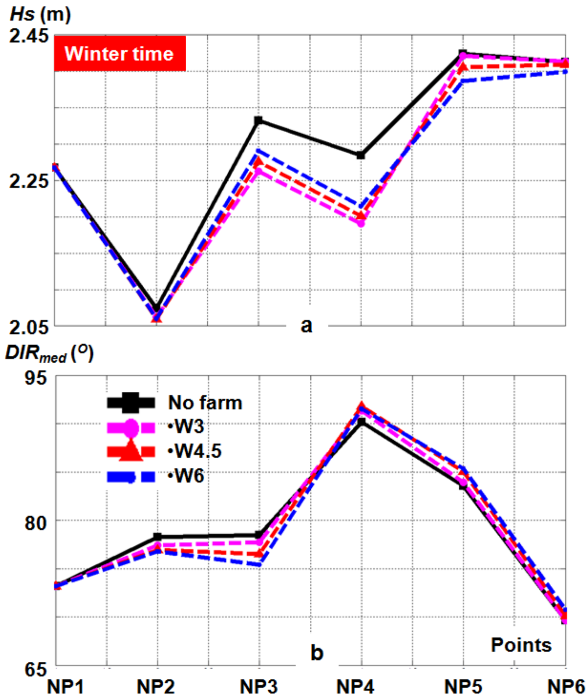

Fig. 5. The influence of the offshore wind farms during the winter time, reported for: a) *Hs* (m) parameter; *Dir* (°) parameter

A similar analysis is performed in Figure 6, considering this time a scenario which involves extreme conditions (*Hs*-15 m; *Tm*-16 s) specific to a storm event reported in the vicinity of the Romanian nearshore. This time can be observed that the impact of the wind farm is notable only for the wave fields located behind the farm, while close to the coastline the local wave fields seems to report no variations. This aspect is confirmed by the nearshore points NP (Figure 7), which reveals more important variations for the *Dir* parameter, the scenario W3 indicating a similar distribution as in the case of the wind farm located at approximately 6 km from the shore.

The wave direction is gradually increasing from 91.6° (NP1) reaching in point NP4 a value of 108.1°, while a severe variation of the direction occurs until the values reach a minimum of 85.6°. On an opposite side, the *Hs* parameter gradually increases from 2.35 m (NP1), going through 2.54 m in NP3 and finally reaching 2.78 m in NP6.

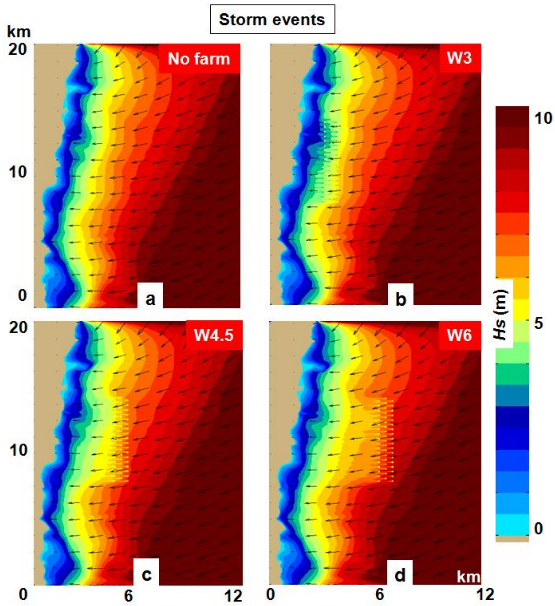

Fig. 6. The expected impact of the wind farm on the wave fields reported during a storm event, where: a) no farm; b) W3 scenario; c) W4.5 scenario and d) W6 scenario

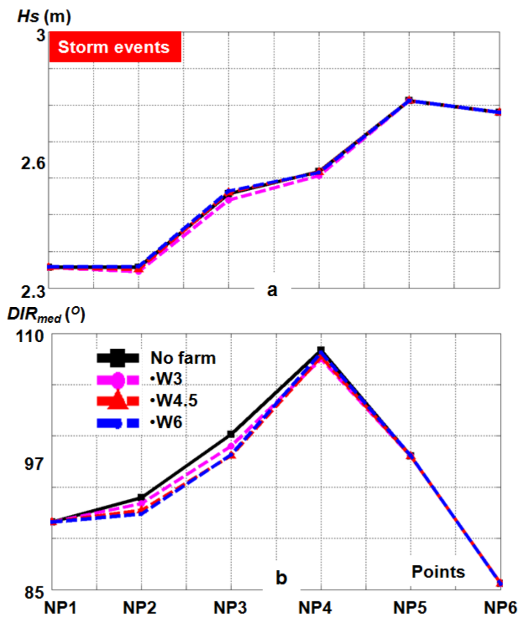

Fig. 7. The influence of the offshore wind farms during a storm event, reported for: a) *Hs* (m) parameter; *Dir* (°) parameter

CONCLUSIONS

A general assessment of the wave conditions in the presence of several wind farms operating in the vicinity of the Romanian nearshore was carried out in the present work. The wind farm configuration is the same, the only changes in the case studies was the distance from the shore, which was gradually adjusted to 3 km, 4.5 km and 6 km, respectively. Based on the reanalysis wave data provided by the European Centre for Medium-Range Weather Forecasts, it was possible to identify the most relevant seasonal patterns of this area, in order to set-up the numerical simulations performed with the SWAN wave model. Based on these results, it was observed that each wind farm may reduce the wave conditions of the offshore area, fact which could be considered beneficial, since the wave energy reaching the shoreline will be significantly reduced. Regarding the extreme conditions, it was noticed that the NP-points present no variation, which may be related to the fact that the incoming wave fields could regenerate quicker after they pass through the wind farm.

Finally, can be mentioned that the results look interesting, since they indicate that even a wind project may reduce the wave heights to a certain degree, with the mention that the shielding effect could be more pronounced in the case of a hybrid wind-wave farm.

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