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EVOLUTION OF THE ROMANIAN NEARSHORE CURRENTS UNDER THE INFLUENCE OF WEC FARMS

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ABSTRACT

The objective of the present work is to evaluate the influence of two specific wave farms (a Pelamis and a Wave Dragon farm) on the longhsore currents circulation from the Saint George sector, located on the Romanian Black Sea coast. As a first step, the implementation of the two wave farms was made in the SWAN wave model while subsequently these results were further used by the NSSM model to assess the nearshore circulation. Regarding the numerical simulations, several case studies were considered in order to highlight the evolution of the currents between a normal and an extreme situation. In general, it can be mentioned that the parallel orientation of the farms to the coastline seems to be suitable because do not restrict the natural flow of the sediments along the coast, while in some cases a reduction of the currents velocity was noticed, which can be associated both to the local bathymetry and to the wave farm length.

Keywords: Black Sea, Saint George, nearshore currents, wave farm, SURF model

1. INTRODUCTION

It is estimated that on a global level almost 71% of the earth's surface is covered by water areas which are under the influence of complex physical processes. Reported in these areas an important sector of the oceanographic research is focused on the monitorization and simulation of the ocean currents which are important for the drift of water pollutants, global heat transport or marine navigation. On a coastal level, the nearshore currents represents an important factor for the evolution of the shoreline area (accretion or erosion) being influenced by the action of wind, waves and storm conditions.

A suitable way to identify the evolution of various marine parameters is throughout the use of in situ measurements (such as buoys, sonar or current meter) which can only provide information for small areas while on a large scale the spatial distribution of these parameters (wave, wind, currents) can be accurately identified by considering satellite remote sensors or numerical models [1].

As concerning the Black Sea, this is one of the most isolated unit of the World Ocean being located inside the continent. The main features of this basin are: 555,000km^3 for volume, 423,000 km^2 for area and a maximum depth of 2,258 m for the maximum depth. In the northwestern part of the sea the shelf area covers almost 25% of the entire seabed, while on the surface the basin is entirely encircled by mountains such as Pontides or Carpathians. The Danube River represents one of the main sources of fresh water for this basin, which below 70 m presents anoxic conditions with salinity located between 18-22% [2].

The problems associated with the erosion of the Romanian coast have been known for decades and during the last years, several researches highlighted the severity of this process. It was estimated that almost 80ha/year from the coast disappeared into the sea, while for some beach areas the retreat of the shoreline was evaluated to be in the range of 200-240 m (during the last 40 years) [3-5].

Waves can transport energy over the large water areas with minimum loss, which can be finally converted into electricity throughout the wave energy converter (WEC) systems operating in the offshore and nearshore regions. The first WEC device was patented in 1974 and almost 100 different ocean energy technologies have been considered since then, the current market being defined by more than 50 WEC systems which are at various levels of developments [6].

In this context the purpose of the present work is to study the influence of two wave farm projects consisting of Pelamis and Wave Dragon systems onto the nearshore currents from the Romanian Black Sea coast.

2. METHODS AND MATERIALS

Figure 1 presents the Saint George target area, which is located in the northwestern part of the Black Sea in the vicinity of the Danube Delta. The computational domain considered for the numerical simulations performed with the SWAN (Simulating Waves Nearshore) model is presented in Fig. 2, where can be noticed the Pelamis and Wave Dragon farms while in the background is presented the local bathymetry. The area is defined by a rectangle with a length of 16 km on *x* axis (cross shore) and 20 km on y axis (along coast).

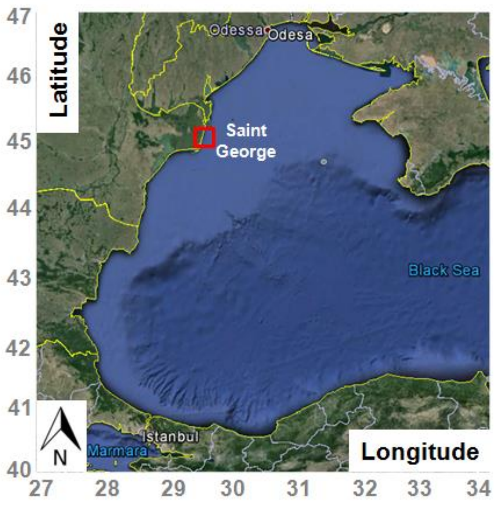

Fig. 1. A general overview of the western part of the Black Sea basin, where the Saint George area is being located

The Pelamis farm consist of 46 WEC systems distributed on a two line configuration, each system being defined as an obstacle with a length of 190m and a distance of 150m (on x and y direction). For this simulation the transmission coefficient of Pelamis was set to 0.5 which means that only 50% of the waves will be transmitted on the contact with these obstacles [7]. For the Wave Dragon farm a number of 18 systems were considered, which are characterized by a length of 300m and a distance of 190m between the two WEC lines. A 25 m interval was considered between each system in a line, while a transmission coefficient of 0.68 was set for the present simulations [8].

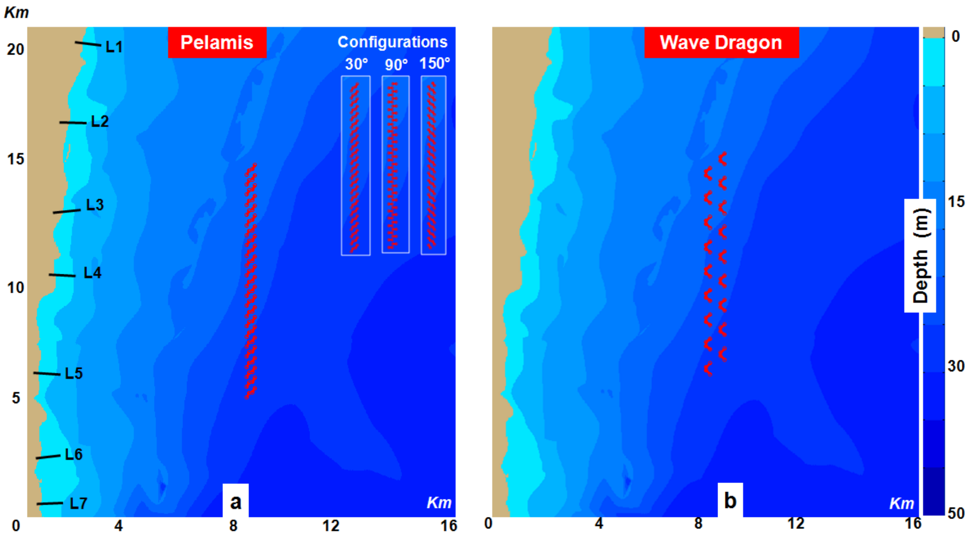

Fig. 2: Computational domain of the Saint George target area, where in the background is presented the local bathymetry. The figures correspond to: a) Pelamis farm (46 WEC systems); b) Wave Dragon farm (18 WEC systems)

Several case studies were identified based on the results presented in Zanopol et al, 2014 [4] which reveal the following situations:
- CS1: Tm=3.5s; Hs=0.94m (average conditions);
- CS2: Tm=5.3s; Hs=2.5m (energetic conditions);
- CS3: Tm=9.2s; Hs=6.3m (storm conditions).

In order to provide a complete overview of the nearshore currents evolution along the coastline, three main wave directions were considered as input in the SWAN model, namely: a) northeast - 30^o; b) east - 90^o; c) southeast - 150^o.

The numerical simulations were performed throughout the ISSM interface [9] which combines the SWAN model (wave simulations) with NSSM (Navy Standard Surf Model) for evaluating the longshore currents. As was previously mentioned in the SWAN model was defined the computational domain (Fig. 2) and the WEC systems were modeled as obstacles, and in this way was possible to simulate the local wave conditions in the presence of the Pelamis and Wave Dragon farms.

Based on these results, the Surf or Navy Standard Surf Model [10] can evaluate the longshore currents distribution along a cross shore profiles based on the following equation:

$$\tau_y^r + \rho \frac{\partial}{\partial x}[\mu h \frac{\partial V}{\partial x}] - \left\langle \tau_y^b \right\rangle + \left\langle \tau_y^w \right\rangle = 0 \quad (1)$$

where τ_y^r represents the longshore directed radiation stress due to the incident waves, the second term represents the horizontal mixing term due to cross-shore gradients in the longshore current velocity, τ_y^b is the wave averaged bottom stress while τ_y^w indicates the long-shore wind stress. Since the NSSM is a 1D model, it is important to mention the following limitations: a) the directional wave spectra is narrow-banded in frequency and direction; b) the current depth is uniform; c) the bathymetric lines are considered straight and parallel.

In order to identify the evolution of the longshore currents in the vicinity of the coastline, seven reference lines (denoted from L1 to L7) were defined, more details regarding their positions being provided in Fig. 2.

3. RESULTS AND DISCUSSION

Figure 3 presents the evolution of the longshore currents for the case study CS1 indicated by the reference lines L1-L7. Based on these results is possible to notice that when the waves are coming from the northeast sector the nershore currents can report negative values, which mean that the main flow direction will be from north to south. For this direction the presence of the two wave farm does not influence the local currents fields which are characterized by a maximum value of 0.87 m/s along the line L1, being followed by the line L7 with 0.57 m/s.

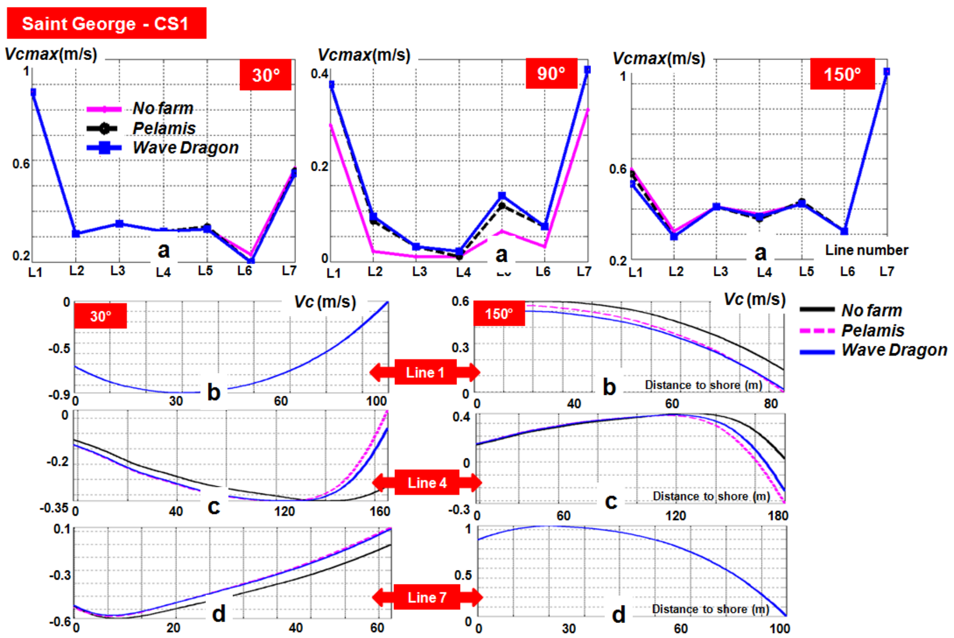

Fig. 3. Evolution of the nearshore currents in the presence of the wave farms for the case study CS1, considering the influence of the waves coming from northeast, east and southeast. The results are indicated in terms of the: a) *Vcmax* evolution along the reference lines; b) *Vc* variation along the profile L1; c) *Vc* variation along the profile L4; d) *Vc* variation along the profile L7

When the waves are entering in the target area from east the line L1 reveal negative values, while the reference lines L2, L3, L4 and L6 indicate values close to zero. The presence of the two wave farms can increase the currents velocity in the extremity of the target area (line L1 and L7) with a maximum 0.08m/s. In the case of the southeast waves, the Wave Dragon farm can reduce the velocity of the currents from 0.56 m/s to 0.5 m/s along the line L1, while the rest of the points do not reveal any significant changes although a maximum of 0.95 m/s can be mentioned for the line L7.

Going from average to more energetic conditions, Figure 4 presents the evolution of the longshore currents for the case study CS2. Can be noticed that much higher values are being observed in the extremity of the target area where a maximum of 1.15 m/s is reported by the line L1 (northeast waves), which is followed by L7 with 0.93 m/s (southeast waves). The reference lines L2, L3, L4 and L6 reveal values close to zero of the local currents fields when the waves are coming from the eastern sector. As a tendency, in the presence of the WEC systems the line L5 indicate an increase of the current velocity (with 0.1m/s) in the case of the east waves, while the line L1 report a reverse trend for the southeast waves (a decrease with 0.12 m/s).

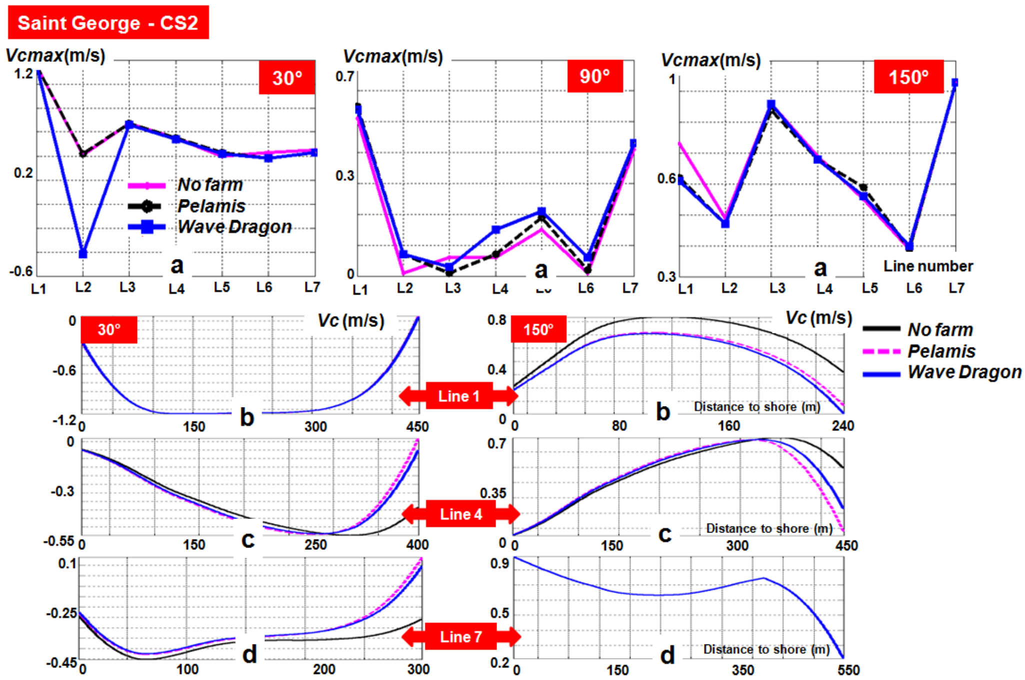

Fig. 4. Evolution of the nearshore currents in the presence of the wave farms for the case study CS2, considering the influence of the waves coming from northeast, east and southeast. The results are indicated in terms of:
a) *Vcmax* evolution along the reference lines;
b) *Vc* variation along the profile L1;
c) *Vc* variation along the profile L4;
d) *Vc* variation along the profile L7

Figure 5 presents a similar analysis of the nearshore currents, reported this time for the case study CS3. When the waves are coming from northeast the line L3 reveals a significant increase of the current velocity from 0.7 m/s to 0.88 m/s in the presence of the wave farm, while a similar evolution can be mentioned for the line L4 (much lower values). For the east waves, the line L1 reveals values close to zero, while L2 and L3 indicate a decrease of currents velocity from 0.48 m/s to 0.19 m/s and from 0.62 m/s to 0.51 m/s, respectively. Much higher values are being reported for the southeast waves which constantly reports velocity close to 1m/s, with the exception of the line L6 located in the lower part of the target area where a maximum of 0.5 m/s is reported.

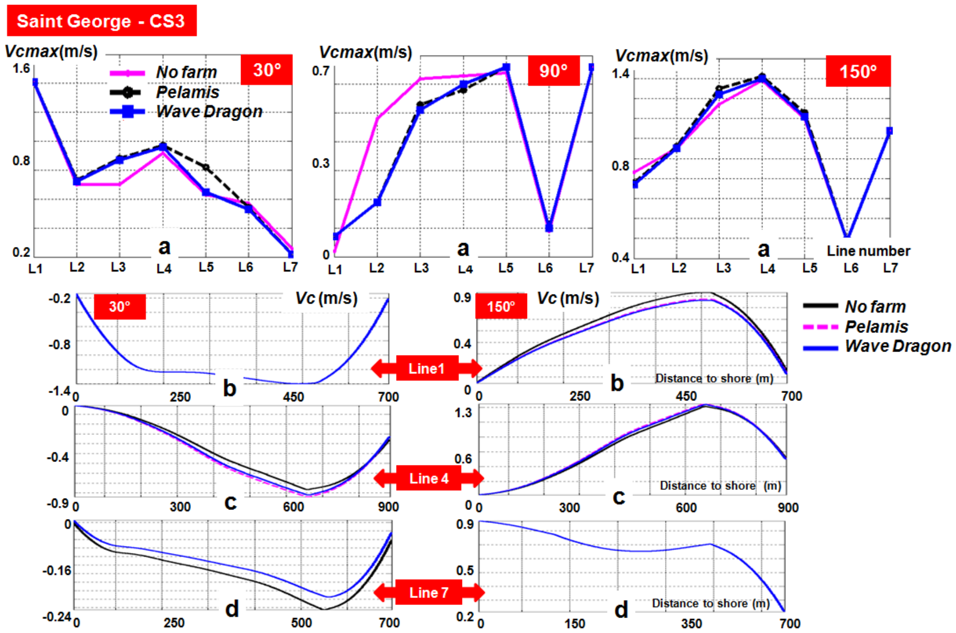

Fig. 5. Evolution of the nearshore currents in the presence of the wave farms for the case study CS3, considering the influence of the waves coming from northeast, east and southeast. The results are indicated in terms of:
a) *Vcmax* evolution along the reference lines;
b) *Vc* variation along the profile L1;
c) *Vc* variation along the profile L4;
d) *Vc* variation along the profile L7

Regarding the profile of the longshore currents reported for the case study CS1 (Fig. 3) can be noticed that much higher values are being reported in the offshore area for the line L4 and L7 and also that the line L7 presents a profile length of 60m (northeast waves) compared to line L4 which is defined by 180m (southeast waves). In general can be observed small differences between the considered scenarios (no farm, Wave Dragon and Pelamis farm), with the mention that for the offshore area the line L4 (southeast waves) reveal a decrease of the currents velocity under the influence of the WEC systems.

For the case study CS2 (Fig. 4) the currents profiles also reveal much higher values in the offshore area, with the exception of the line L7 (northeast waves) which in the vicinity of the coastline present a value of 0.9 m/s. In the case of the northeast waves, the presence of the two wave farms can significantly reduce the currents flow, but only in the offshore area at a distance of 300-400 m from the coastline. A similar evolution can be observed in the case of the southeast waves in the proximity of the lines L1 and L4, respectively.

4. CONCLUSIONS

The objective of the present work is to evaluate the coastal impact of a Pelamis and Wave Dragon farm that would operate in the Romanian nearshore. The target area considered for the present studies is located in the vicinity of the Danube Delta, more precisely in the Saint George sector which is a dynamical environment since the local coastline configuration is constantly modified by the combined action of the wind, wave and coastal currents.

Throughout the ISSM interface, it was possible to simulate the influence of various WEC system types on the longshore currents velocity from this region. In general, small differences were noticed between the impact provided by the Pelamis and the Wave Dragon farms, which suggest that both systems could successfully operate in this part of the Black Sea since they do not restrict the pattern of the nearshore currents.

A detailed investigation of the nearshore currents was performed only for the profiles reported for the waves coming from the northeast and southeast sectors (reported to the nautical system), since the longshore currents are generated by the incoming waves reaching the shoreline on a oblique angle. Considering the results indicated by these profiles it can be mentioned that the presence of the WEC system seems to be more significant in the offshore area, while in the shallow water area (close to the coastline) the dissipative effects are dominant.

The results presented in this work can be considered interesting since they suggest that a wave farm aligned parallel to the coastline can be considered suitable for the coastal protection since do not restrict the longshore currents velocity, while in terms of the WEC type selection both Pelamis and Wave Dragon converter can be considered appropriate for the coastal protection.

ACKNOLEDGMENTS

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