PRELIMINARY SIMULATIONS OF COASTAL CURRENTS FROM THE AREA OF CONSTANȚA TO THE BORDER BETWEEN ROMANIA AND BULGARIA

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Abstract. This study is focused on the southern Romanian coast, confined by the city of Constanța (north) and Vama Veche village, at the border with Bulgaria (south). Here the coastal morphology is influenced by nearshore current circulation, disrupted during the last few decades by severe human interventions, such as building groins, jetties and other coastal protection activities. Nevertheless, the dynamics of coastal currents has not been thoroughly studied (or at least the works have not been published) over the past decades. This is why this paper aims to present the preliminary results of a numerical hydrodynamic model applied for coastal currents circulation in the above mentioned study area. All available data concerning the bathymetry of the Black Sea, the boundary conditions and the wind velocity are used in a process based hydrodynamic model. Hydrodynamic simulations provide the calculated surge and coastal current velocity. The simulations took into account two representative periods (February 2006 and June 2006) and the results indicate the large variability of the nearshore currents. Despite this variability, the dominant direction of the currents follows the characteristics of the wind climate of the study zone.

Key words: coastal current, simulation, current velocity, forcing, wind velocity

1. INTRODUCTION

The Romanian Black Sea coastal dynamics is complex due to both water and sediment input from two distributaries (Sulina and Sf. Gheorghe) of the Danube River, and of the strong nearshore currents. The coastal currents circulation and the deposition of the sediments discharged by the Danube are the main factors that influence the morphology of the coast. The Romanian littoral is divided into two units (Fig. 1): the northern unit, in front of the Danube Delta, and the southern unit, from Mamaia Bay to the border with Bulgaria. The boundary between these two units is Cape Midia, with a net boundary in sediment transport given by the Midia Harbor jetties. The jetties, with a length of 5 km offshore, have interrupted the littoral sediment drift originating from the Danube and going southwards. South of the Danube Delta coast, a significant role in controlling directions and velocities of the coastal currents is played by human structures, harbour defence works, coastal protection measures for tourist beaches, artificially designed pocket beaches etc. (Stănică *et al.*, 2007).

The SHYFEM model (Shallow water HYdrodynamic Finite Element Model) (Umgiesser *et al.*, 2004; Umgiesser, 2009), used in the present study, is developed at the Institute of Marine Sciences (ISMAR) in Venice. In order to obtain the offshore boundary conditions for the coastal zone, the model has been applied to the entire Black Sea, but this study is focused on an area along the Romanian (northwestern Black Sea) coast, from Constanța city to the border between Romania and Bulgaria. The paper demonstrates the results of preliminary simulations carried out for two periods: February 2006 and June 2006. A previous study, simulating the sea surface current circulation and sediment transport on the northern part of the Romanian Black Sea coast using the SHYFEM model was made by Tescari *et al.* (2006).

In this context, the main objective of the present study is to investigate distribution of the nearshore sea currents forced by winds, around a large part of the Romanian southern littoral.

2. METHODOLOGY

The SHYFEM model is based on the method of finite elements to solve the hydrodynamic equations in lagoons, coastal seas, estuaries and lakes. The finite elements, together with an effective semi-implicit time resolution algorithm, make this program especially applicable to a complicated geometry and bathymetry. The model has been implemented on the entire Black Sea and it is focused on the southern Romanian coast and Danube delta with a resolution gradually increasing towards the shoreline.

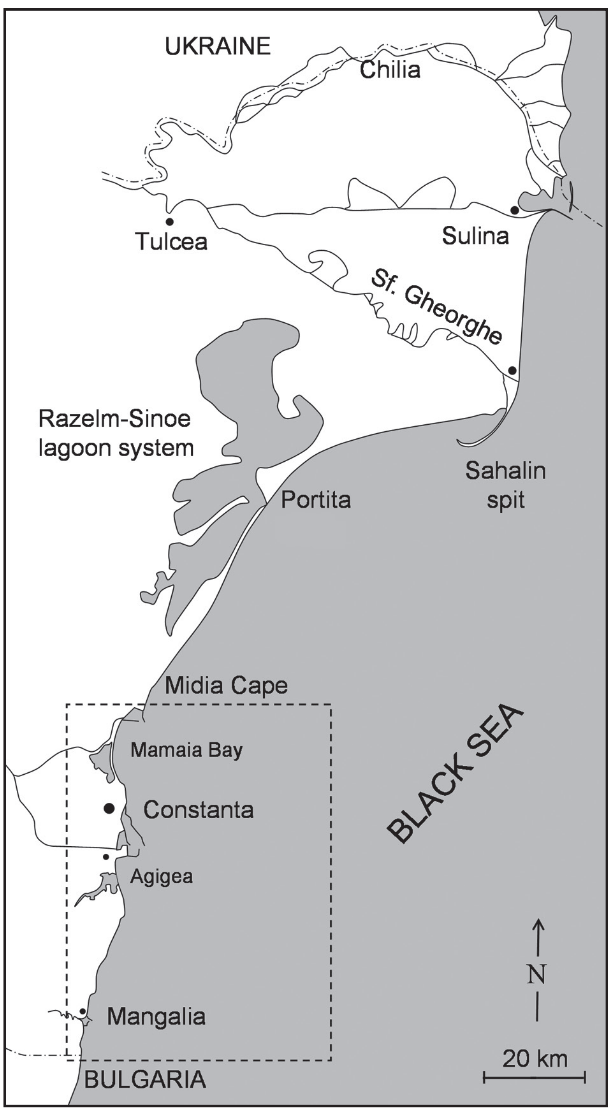

Fig. 1 Location of the study zone

Equations

The model solves the shallow water equations for different vertical layers, providing a 3D representation of the system hydrodynamics. The water column is divided into L layers. The number of a layer l goes from 1 to L, 1 being the surface layer and L the bottom layer. The layer thicknesses can be set by the user and are constant, except for the surface layer, which involves the variation due to the water level ζ. The shallow water equations are:

$$\frac{dU_l}{dt} - fV_l + h_l\left[g\frac{\partial \zeta}{\partial x} + \frac{g}{\rho_0}\frac{\partial}{\partial x}\int_{-H_l}^{\zeta}\rho' dz + \frac{1}{\rho_0}\frac{\partial p_a}{\partial x}\right] - \frac{1}{\rho_0}\left(\tau_x^{l-1} - \tau_x^{l}\right) - A_H \Delta U_l = 0$$

$$\frac{dV_l}{dt} + fU_l + h_l\left[g\frac{\partial \zeta}{\partial y} + \frac{g}{\rho_0}\frac{\partial}{\partial y}\int_{-H_l}^{\zeta}\rho' dz + \frac{1}{\rho_0}\frac{\partial p_a}{\partial y}\right] - \frac{1}{\rho_0}\left(\tau_y^{l-1} - \tau_y^{l}\right) - A_H \Delta V_l = 0$$

$$\frac{\partial \zeta}{\partial t} + \sum_l \frac{\partial U_l}{\partial x} + \sum_l \frac{\partial V_l}{\partial y} = 0$$

where ζ is the water level [L], $U_l = h_l u_l$ and $V_l = h_l v_l$ are the vertically-integrated velocities (total transports) for the layer l [LT^{-1}], t is the time [T]; g is the gravity acceleration [LT^{-2}], p is the atmospheric pressure at the mean sea level [$ML^{-1}T^{-2}$]; ρ_0 is the undisturbed water density [ML^{-3}]; ρ' is the water density [ML^{-3}]; p_a is the air pressure; h_l is the depth of the layer l [L]; f is the variable Coriolis parameter [T^{-1}]; τ_x^l and τ_y^l, τ_x^{l-1} and τ_y^{l-1} are the stress components at the lower interface of the layers l and $l-1$ [$ML^{-1}T^{-2}$]; AH is the horizontal diffusion parameter [L^2T^{-1}].

The total transports U and V are defined as:

$$U = \sum_{l=1}^{L} U_l$$

$$V = \sum_{l=1}^{L} V_l$$

The stress components between the water layers are given by:

$$\tau_x^l = \frac{\rho_0 \nu \partial u_l}{\partial x}$$

$$\tau_y^l = \frac{\rho_0 \nu \partial v_l}{\partial y}$$

with ν the vertical eddy viscosity [L^2T^{-1}]. The shear stress at the air-water surface is given by the empirical formula of Smith and Banke:

$$\tau_{xs} = \rho_a C_D u_w \sqrt{u_w^2 + v_w^2}$$

$$\tau_{ys} = \rho_a C_D v_w \sqrt{u_w^2 + v_w^2}$$

with u_w and v_w the two components of the wind, ρ_a the air density [ML^{-3}], and C_D the drag coefficient [-]:

$$C_D = 0.001\left(0.63 + 0.066\sqrt{u_w^2 + v_w^2}\right) \quad [-]$$

The stress at the bottom is specified by the following formulas:

$$\tau_{xb} = \rho_0 C_B u_L \sqrt{u_L^2 + v_L^2}$$

$$\tau_{yb} = \rho_0 C_B v_L \sqrt{u_L^2 + v_L^2}$$

where ρ_0 is the water density, CB is the bottom drag coefficient [-] and u_L and v_L the two components of the velocity at the bottom layer [LT^{-1}]. The drag coefficient of the water is set to 0.0025.

The transports are directly dependent on the time, but also through the space variables U_l $(x(t), y(t), t)$ and V_l $(x(t), y(t), t)$. As a consequence, the total time derivatives contain the advection of the velocities that are non-linear terms.

Computational grid

The computational grid is defined by nodes and triangular elements. The model uses a staggered grid, which means that the water level is specified in the nodes, while the velocities are specified in the element centers. The depth of the basin is specified in each element.

Using the finite elements technique allows us to significantly increase the grid resolution only in some parts of the domain. In those parts where the dynamics does not vary too much, or in the parts far from the study area, the resolution can be kept lower. In this case, the resolution is increased on the Romanian coast (Fig. 2). The mean distance between nodes is about 20 km, where the resolution is coarser, and about 50 m near the Romanian coast. The open boundary conditions are specified at the Bosphorus Strait, near Istanbul.

The Danube River discharges into the Black Sea through three distributaries - Sf. Gheorghe, Sulina and Chilia. The Chilia distributary forms a secondary delta, which is the only part of the Danube Delta still prograding. For each distributary the mean discharges were imposed. The total Danube discharge is 6300 m^3/s, of the same order of magnitude as in Panin and Jipa (2002). The water discharge distribution for each distributary is: Chilia 58%, Sulina 19% and Sfantu Gheorghe 23% (Bondar and Panin, 2001). Other discharge values introduced in the model represent the rivers Dnepr, Dnestr and South Bug, as found in Yankovsky *et al.* (2004).

The coastline is specified by the coordinates of points situated in representative areas. In order to facilitate computations, the grid was designed with a higher resolution in the areas of interest, such as Bosphorus Straits (for the water exchanges) and coastal zone, and with a coarser resolution for the other parts of the Black Sea.

The coastline used for the simulations is a merge of the Romanian coastline provided by GEOECOMAR, a coarser coastline of the Black Sea provided by NOAA (http://rimmer.ngdc.noaa.gov/mgg/coast/getcoast.html), and a coastline extracted from Google Earth (http://earth.google.com/).

The bathymetry near the Romanian coast (Fig. 3) was provided by GEOECOMAR, while for the other parts of the Black Sea the data were obtained from the NOAA free on-line service (http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html).

Meteorological data

The model simulates the formation of sea currents and the surge induced by meteorological forcing. The astronomic tide is not considered since the Black Sea is almost tideless and tide has rather low values for the Romanian coast (about 7 - 11 cm). Moreover the interaction with waves is not considered at this stage of the study.

As in any simulation effort, the quality of results is strongly affected by the quality of the forcing data. These must cover the whole domain of the grid and have a spatial resolution of at least six hours for a good resolution of the real currents.

The meteorological data used in this work were provided by the European Centre of Medium-Range Weather Forecasts

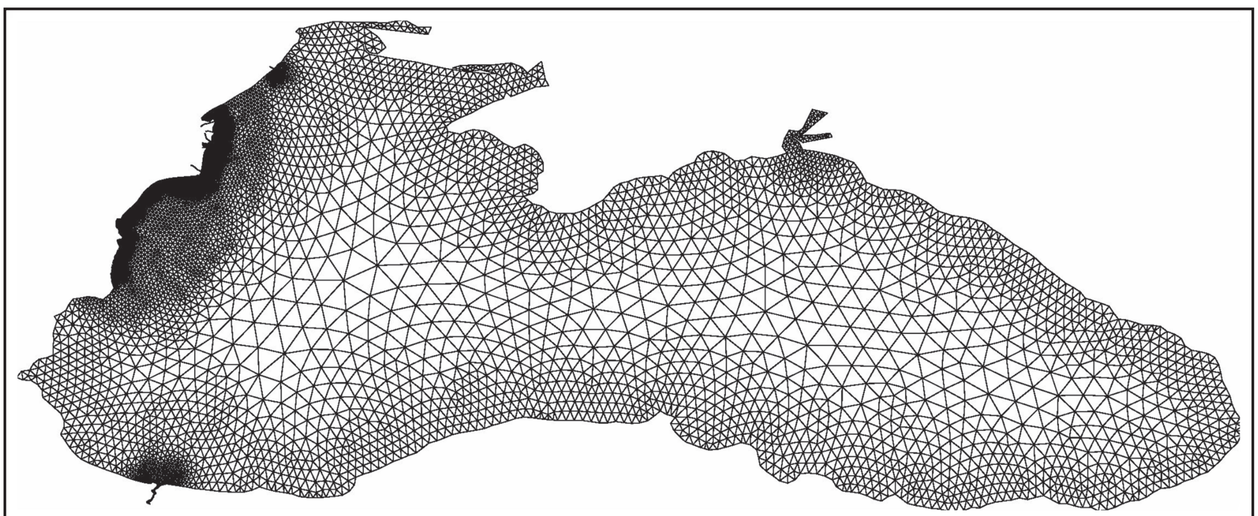

Fig. 2 Computational grid of the Black Sea

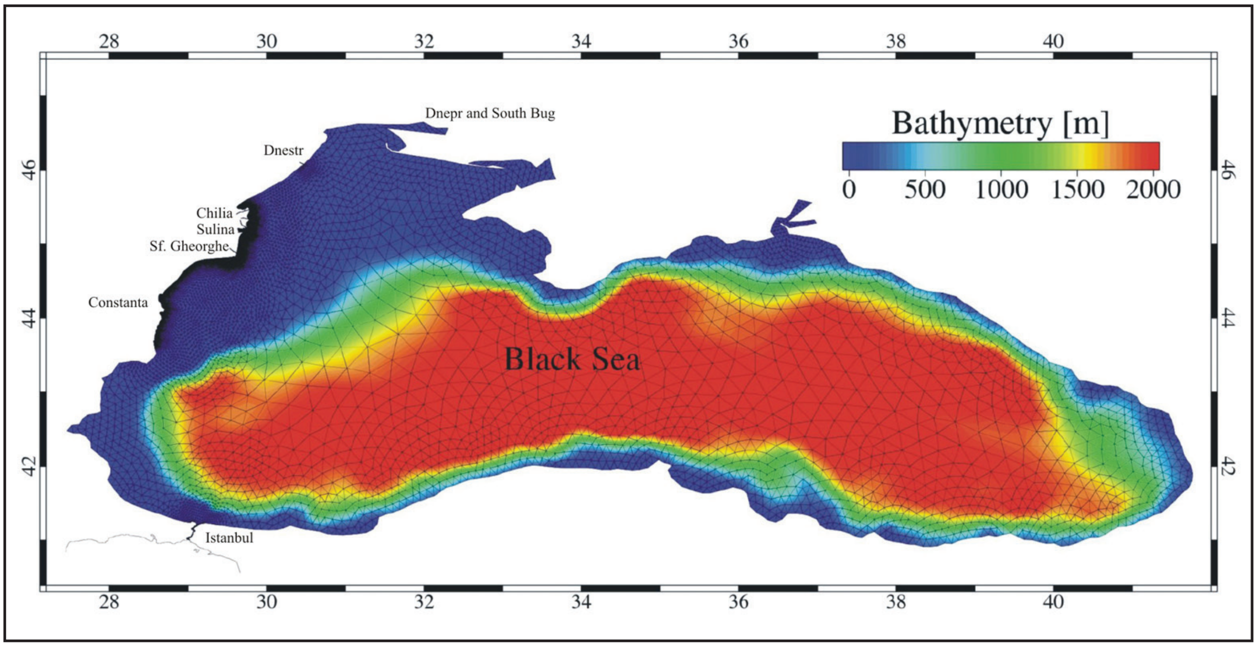

Fig. 3 Bathymetry used by the computational grid

(ECMWF), and the quality of their analysis fields has been tested in numerous works, including the Romanian coast (Kuroki *et al.*, 2006). The fields represent the two components of wind velocity (*u* and *v*) at 10 m from the sea surface, and the atmospheric pressure at the mean sea level. The resolution is 0.5 degree in latitude and longitude, while the temporal step is 6 hours. The simulations were made for February and June 2006 due to the following causes: February is a typical winter month, with strong winds and storms, while June is characteristic for the fair weather season. The year was selected for practical reasons, as the data were already available from that period.

3. RESULTS

The simulations presented here were made for two periods: February 1 to 28, 2006 and June 1 to 30, 2006. A spin-up time of 1 month, for the whole period of February 2006, has been used to reach a correct initial state for the results. This period is very short to reach a plausible initial state for the entire basin, but it is long enough to obtain a comprehensive situation of the wind-driven coastal currents in the shallow sea part and to provide a preliminary description of the dynamics on the southern part of the Romanian coast.

The results presented hereafter are for the Romanian Black Sea coast between Constanța city and the border between Romania and Bulgaria. The surge and the current velocity at a certain moment are influenced by the wind conditions occurring some hours or days before.

At this stage, we focused on the vertically-integrated currents on the whole water column.

1. Simulation for February 2006

From February 1 to 5, the wind blows with low velocity from various directions. The current velocities increase to 30 cm/s on February 2. The anticyclone currents are formed and the surge is very low, not exceeding 3 cm.

Starting from February 5 in the afternoon, the wind blows mainly from N, with an increased velocity, resulting in increased current velocities that reach 35 cm/s in the southern part near the shore. The main current directions are from NE, while the surge reaches 8 to 10 cm near the shore.

Wind velocity decreases on February 7 in the afternoon and keeps low values, generally lower than 5 m/s until February 16 in the morning. The wind blows from W or NW until February 9 in the morning, then from S on February 9, again from W on February 10. It is suggested that the eddy from February 11, at 12.00 (Fig. 4) was probably formed because of these varying wind directions.

Starting from February 11, the wind blows mainly from N. The current velocities may reach values lower than 30 cm/s near the shore, when the wind blows from S, and 35 cm/s south, close to Constanța Harbor, when the wind blows from W. Their directions are mainly from N and NE (Fig. 5). The surge may reach 10 cm near the shore.

The wind changes its direction on February 16, originating from S. On February 17 in the morning, the wind starts to blow from W or SW. The main current direction changes towards S. On February 18, the zone with current velocity higher than 35 cm/s, initially located close to Constanța Harbor, extended along the shore, while the surge reached 12 cm near the shore.

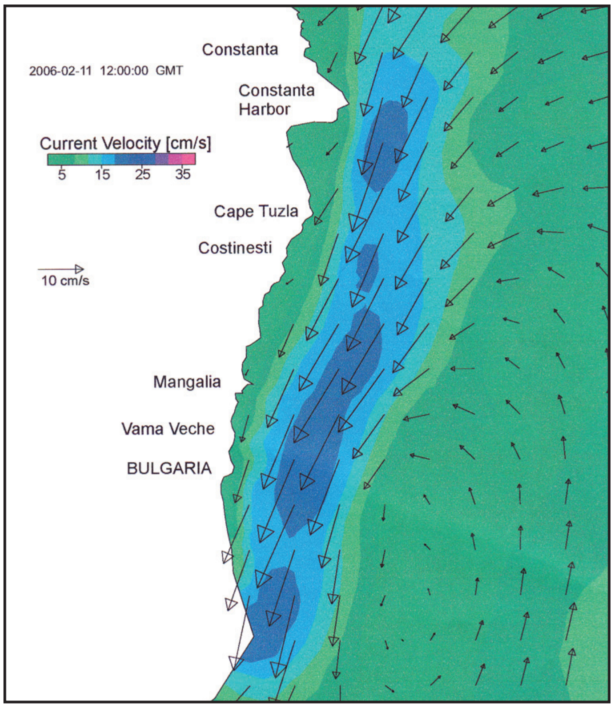

Fig. 4 Current velocity on February 11, 12.00

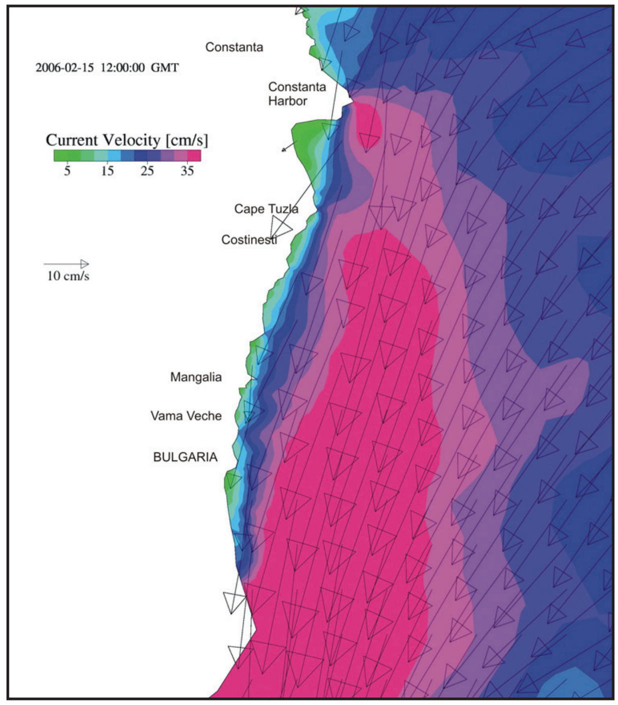

Fig. 5 Current velocity on February 15, 12.00

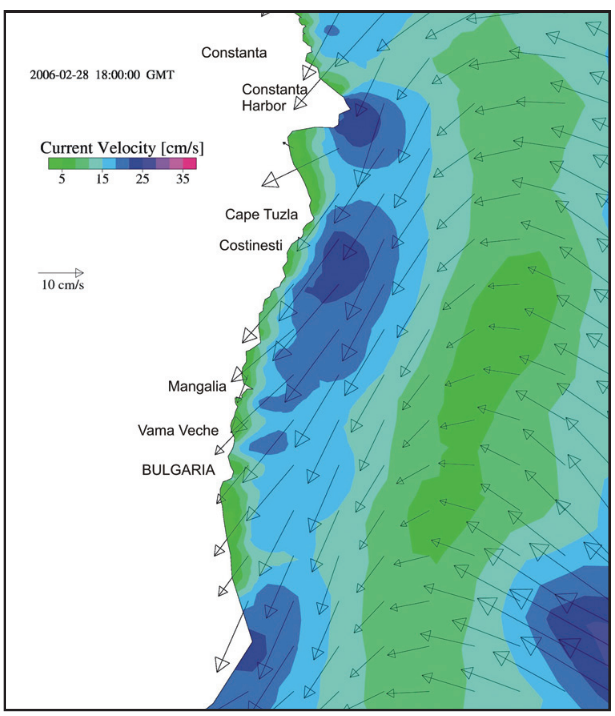

Fig. 6 Current velocity on February 28, 18:00

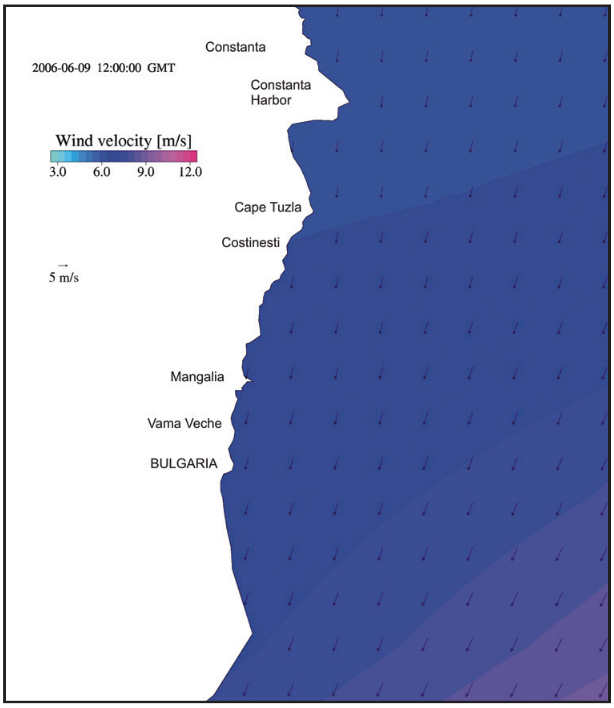

Fig. 7 Wind velocity on June 9, 12.00

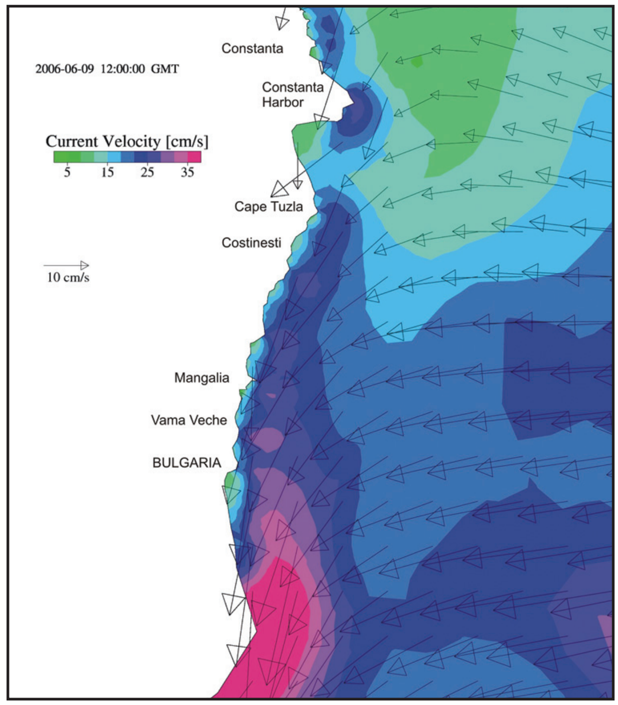

Fig. 8 Current velocity on June 9, 12.00

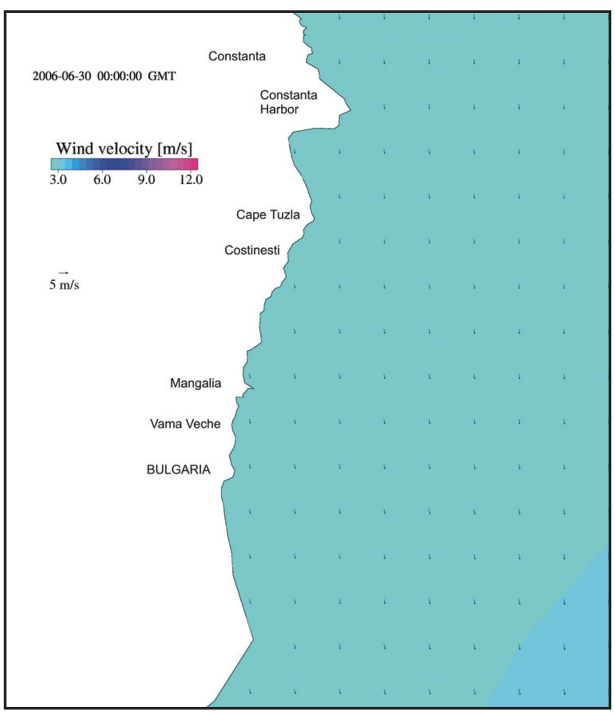

Fig. 9 Wind velocity on June 30, 0:00

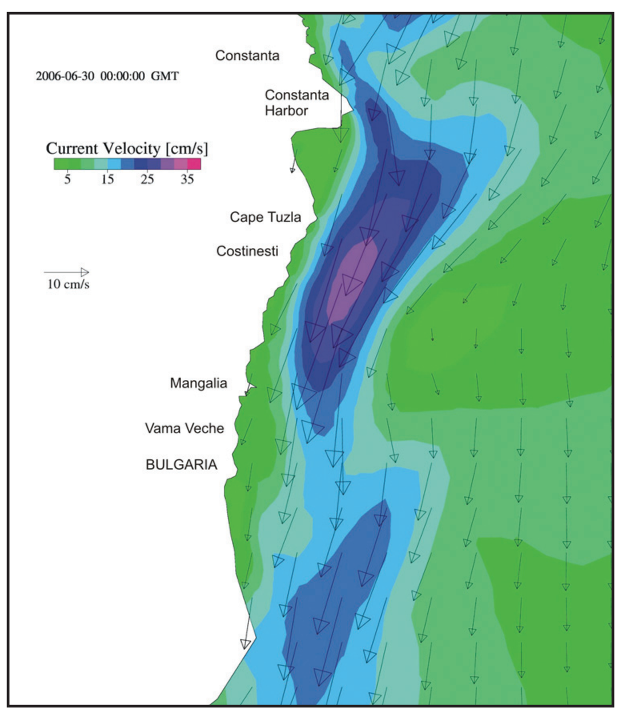

Fig. 10 Current velocity on June 30, 0:00

From February 19 to 22 the wind blowing from S, with relatively lower velocity, determines lower current velocities close to the shore, changing current directions and surge up to 10 cm.

The small anticyclone currents may occur after intervals with low wind velocity, usually less than 5 m/s, and changes in the wind direction.

The wind blowing from NW with increasing velocity, influences the simulated current velocity, which starting from February 24, reaches more than 35 cm/s near the coast, to the border with Bulgaria.

The wind blowing from E determines increasing surge at the end of February. Figure 6 shows the modelled current velocity at the end of the simulation.

The results of the simulation for February 2006 are in agreement to the predominant wind and wave directions discussed by Dan *et al.* (2007), which are from northeastern directions, in particular over the wintertime.

The simulated current velocities may still have high values after the decrease in intensity of strong winds. This happens because there is a delay between the wind forcing and its effect on the coastal current.

2. Simulation for June 2006

In the first part of the month the currents are very irregular, due to the continuous change in wind direction. On June 8, a strong wind from NE began to blow for about one day (Fig. 7). This causes a strong coastal current. As presented in Figure 8, the velocity of the coastal currents increases near the prominences of the coast, reaching values higher than 30 cm/s. Then, the wind velocities were lower till the end of the month and no significant events happened. As a consequence, the current velocities reach higher values. One can notice that, as wind directions changed, the current directions followed more or less the same tendency with a delay from 18 hours to 1 day.

At the end of June 2006 the predominant wind direction was from NE. A constant current with the same direction is noticed in the simulation. The coastal current runs few kilometres from the coast and reaches values of about 25 – 30 cm/s, even after the corresponding wind cease (Figs. 9 and 10).

As discussed by Dan *et al.* (2009), the NE winds occur mostly in the wintertime, causing waves with the same direction. Both during winter and summer, S winds and waves can also occur, but less frequently.

4. CONCLUSIONS

Simulations with the complex numerical model SHYFEM were carried out for the sector of the Romanian Black Sea coast between Constanța city and the border with Bulgaria, in order to obtain a regional view on the coastal currents.

The main result of the present study is a complete spatial distribution of the major fields for the nearshore sea currents covering two representative periods of time.

As expected, the simulations for February 2006 (storm season) demonstrate how strong wind influences the velocity and direction of the coastal currents, which might lead to storms, when blowing from N or NNE directions.

The simulations for June 2006 (fair weather season) show that the current direction strongly varies, depending on both wind forcing and coastal morphology. The coastal currents run a few kilometres offshore and they typically accelerate near capes or promontories.

Even though it may seem obvious for both periods of time, the current fields actually show a lower variability than the wind fields. This is due to the higher inertia of the water than the air masses.

Further simulations will be also performed in more specific zones to study the local dynamics and including as well as data collected during recent field surveys.

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