# SIMULATION ON MARINE CURRENTS AT MIDIA CAPE-CONSTANTA AREA USING COMPUTATIONAL FLUID DYNAMICS METHOD

by

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Original scientific paper
https://doi.org/10.2298/TSCI170508247B

*The work involves assessing of the marine current regime in the north west of the Black Sea, Midia Cape-Constanta area. The area of interest is chosen due its existing features, using marine currents data (direction and speed) within the CFD to determine the distribution of velocities and pressures. The study on the distribution of velocities and pressures, according to local hydro-meteorological characteristic elements, can be used for identifying the risk areas for navigation and existing hydro-technical construction industry. Modelling results using the CFD analysis shows the currents velocity values, pressures and turbulences of the investigated marine region. The model can be used in the analysis and the coastline changes as well as in risk assessment for hydraulic structures. Additional parameters into the model, such as the sea wave characteristics, aim to provide an indication of the potential hydro-dynamic power that is available at a determined location of interest.*

Key words: *CFD, marine currents, navigation, western black sea, potential hydro-dynamic power*

## Introduction

Black Sea is a semi-enclosed basin with an area of 423.000 km$^2$, and a volume of 534.000 km$^3$. The maximum depth is 2206 m, with an average of 1 to 240 m [1]. The basin is bounded by the parallels 40°55'N and 46°37'N, and the meridians 27°27'E and 41°47'E. Maximum length W-E is 1130 km, and the maximum width by the direction N-S is 530 km [2]. It can be observed a stratification of the water layers in Black Sea, due the absence of vertical currents, the salinity increases with depth to 22.33 PSU [3]. Due to the absence of vertical currents and strong water stratification, the concentration in oxygen is reduced by depth and as result is settled an anoxic environment from 150-180 m depth [4].

The observations made on current speed using radio buoys indicate a maximum average speed of approx. 40-50 cm/s, increasing to over 80 to 10 cm/s. Observations shown that the

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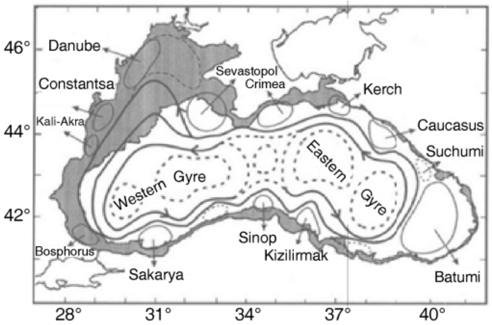


**Figure 1. Circulation of enhanced vortex in the Black Sea based on revised altimetry data analyses, source: http:/www.ims.metu.edu.tr/cv /oguz/circulation.htm (image retrieved in April 20th 2017)**

vertical currents are almost uniform until the water depth reaches up to 150 m [5]. The edge of continental shelf situated between the north-western shelf, and deep water area has an increased variability on the current direction. Variability of dynamic topography (elevation of the sea surface) can have amplitude of 10-15 cm, and the speed at mesoscale surface currents reach 50 cm/s (fig. 1).

The southern sector of Romanian Black Sea coast, between Midia Cape and Vama Veche have structural and morphological characteristics of the Dobrogea plateau. The shore is alveolar type with cliffs up to a height of 35 m which are interrupted by old estuary of the rivers, closed in coastal inlets and behind them forms the river-sea (Techirghiol, Costinesti) or lagoons (Tasaul, Ovidiu). At the base of the cliffs and coastal inlets the beaches have formed. Natural factors which determine the coastal dynamics comprise of two categories: meteorological and climatic. From meteorological factors the wind is the most important which act in two ways: directly, due the action of drifting sand on the emerged beach and indirectly, reflected by formation of waves and marine currents and temporal variation of the sea level. In the Black Sea region, according to [6] the climate change effect on the last period was characterized by an increase on the air temperature multiannual mean from 11.6 °C (before 1998) to 12.7 °C (after 1998) at Constanta, Romania meteorological station.

For north-western part of Black Sea, marine currents are differentiated into: drift currents (wind-related), density currents (in the pre-deltaic marine area), and inertia currents (after a relative fall in the impulse force), but also local circulation cells induced by the configuration of the coastline or by various hydro-technical structures designed for port activities or coastline defences [7].

In the Black Sea riparian countries, and not only, by the necessity for a better observation of the ecosystems, as well as developing, were implemented some forecasting system of the physical parameters (temperature, salinity, currents). In this respect was designed some mathematical models types.

– Princeton model and adapting it for the existing conditions, and others own-developed-models of the Black Sea research institutions [8, 9]. At the same time, along with the circulation model or independently, there are other types of models: waves model [10-12], ecosystem model [13, 14], and the oil spill model [15]. During 2002-2005 has been developed the 1998 version of the princeton ocean model (POM), for the entire Black Sea basin, in collaboration with specialists from the Institute of Volcanology in Bologna, Italy [16], and from 2004-2006, in cooperation with the Marine Hydrophysical Institute, Ukraine (FP7: ARENA, ASCABOS and MyOcean projects), a regional model based on the same POM – version OzPOM, for the western area of the Black Sea [17]. The 2016 model version for the Black Sea basin, with the grid step varies from 150 m in the coastal zone to 4.6 km in the main basin, can reproduce the large-scale Black Sea circulation and submesoscale variations in the coastal currents [18].
– Shallow water hydro-dynamic finite element model (SHYFEM), a 3-D hydro-dynamic model developed at CNR-ISMAR of Venice, Italy [19-23], which solves the hydro-dynamic

Shallow water equations. The equations used by the model are the hydro-dynamic equations in the Shallow water approximation, derived from the momentum and mass conservation equations, simplified with the incompressibility condition and the hydrostatic approximation [24].

## Data and methods

Research methods of currents applied are mainly of the two types.

– Direct survey by means of mobile current-meter devices or to bed-fixed acoustic doppler current profiler (ADCP) aimed to record, at daily intervals, the velocity and direction of marine current at various depths.

*In-situ* data for marine currents were obtained using ADCP on-board R/V *Catuneanu* of Maritime Hydrographic Directorate by NIMRD oceanographers, during February 2010. The results of the measured marine currents vectors ($u$ – horizontal velocity and $v$ – vertical velocity) were analysed in this paper and the graphical method were performed using the specialized program: Golden Software – Surfer, fig. 2.

– Indirect assessment in terms of the current dependency (geostrophic relation) on surface pressure variability through horizontal currents. The approach is similar to the meteorological one, where atmospheric pressure applies to wind field mapping. In both cases, of winds and currents, the geostrophic velocity is parallel to the pressure contours of the mapping and of inverse proportionality to their spacing (distances). The assessment is made for relative values of velocity to a reference sea water depth; the absolute velocity may be obtained when measurements of current velocities are also performed at the reference depth.

To determine predominant directions and variations in velocities in the western Black Sea shelf (28.61-30.49 E and 43.74-44.5 N), long-time series (1998-2012) of marine currents components were downloaded and analysed from the Black Sea circulation model of Marine Hydrophysical Institute, city of Sevastopol [25].

From the distribution of mediated currents extracted from the general circulation Black Sea model, for the period 1992-2012 [25], it follows that on the continental shelf of the Black Sea, in the Danube Mouths area, a predominant direction from north to south is predominant. Generally, currents in this area, are spreading in fan shape and their speed decreases rapidly. After entering the sea, the currents are influenced by littoral currents and by the river water flow. The north to south current flows towards the coastal zone (near shore) on the entire depth with speeds ranging

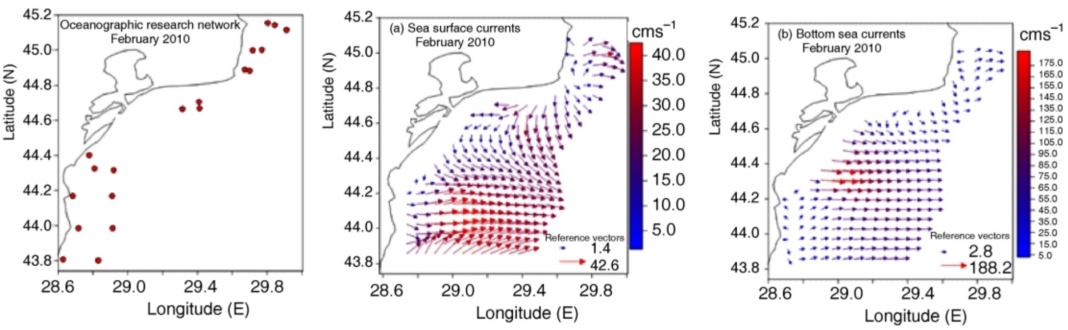


**Figure 2. Marine currents distribution in february 2010 in the western part of the Black Sea's continental shelf**

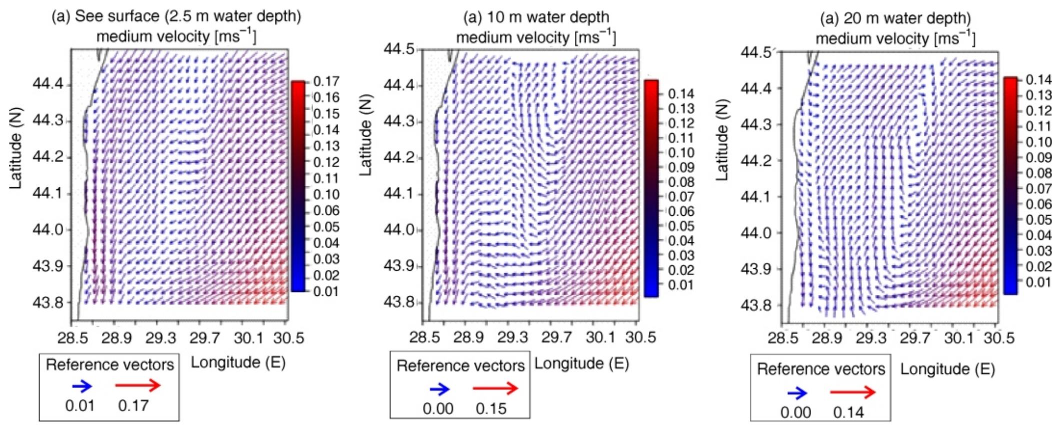


**Figure 3. Scalar mediated of the current velocity and direction (1992-2012) distribution along the Romanian Black Sea shelf, model data [25]**

between 0.2 m/s (on the surface) and of 0.4 m/s (10 m water depth) [26]. In the southern region of the western Black Sea coast, due to the shoreline orientation, at 20 m water depth, the south-east and north are the prevailing currents. On the surface, the sea currents have velocities ranging between 0.2 m/s (the north-south direction in the shallow waters), and 0.6 m/s (in the offshore area with predominant north-western and northern direction), fig. 3(a).

Black Sea due to the strong stratification, the magnitude of the velocity (the speed) decreases from a maximum at the surface until the bottom (were at the great depths it dissipates). The direction also shifts slightly to the right with the layers. This process is called the Ekman spiral in [26]. Currents velocities at the 10 m and 20 m water depth, follow the Ekman layer, with speeds ranging from 0.1 to 0.14 m/s on the entire western shelf, fig. 3(a)-3(c). At the junction of the shallow waters currents and offshore water masses driven by the Black Sea mainstream (RIM current), in deep layers anticyclonic eddies are formed, fig. 3(b) and 3(c).

– The undertaken analysis underlying the selected model validation, such as CFD.

The ANSYS CFX software, which is part of ANSYS software package, allows the study of: the fluid dynamics by CFD analysis, the equations of motion and presentation of results. ANSYS software is available at [27] with dedicated licence for Mircea cel Batran Naval Academy, Constanta, Romania [27].

The model was developed in Naval Academy Hydroacoustic Laboratory based on ANSYS licensed software.

The CFD analysis relates to the numerical calculation of fluid-flow and is based on the Navier-Stokes equations that characterize the flow of a single phase of any fluid. By eliminating terms that describe the viscosity, the equation is simplified, obtaining Euler's equations. Simplification of Euler equations by excluding the terms that describes the vortices, leads to potential equations (irrational). These equations can be easily linearized, and achieve the potential linearized equations.

The Navier-Stokes PDE are discretized into algebraic system of equations. All algebraic equations are numerically solved to obtain the solutions that are presented in CFD post, fig. 4.

As is presented in fig. 4, the main steps of a CFD analysis are:

– Identifying the problem and pre-processing (defining the purpose of modelling, identification of the field to be shaped, designing and creating the network of cells).

– Execute iterative calculation (input, calculation and monitoring solutions).
– Post-processing (results examination, review the model if necessary).

To perform the calculation, it is necessary to define the corresponding geometry for the analysis of fluid domain and to create the grid or mesh (2-D surface).

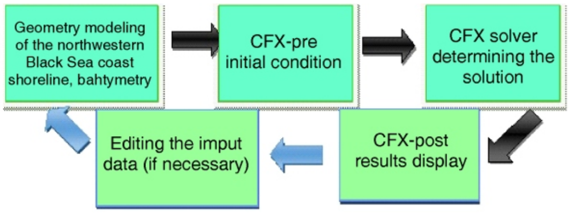


**Figure 4. The ANSYS CFX computational model diagram**

Flow modelling are based on the Navier-Stokes equation and additional conditions given by the type of chosen model, using direct numerical simulation (DNS).

Navier-Stokes equations were the target of software developers. In the late of the 80's had appeared the first programs that solves Navier-Stokes equations for 2-D flow.

The more rigorous set of equations that characterizes the flow is the Navier-Stokes equations:

$$\bar{F} \quad \frac{1}{\rho} \quad p \quad \frac{\eta}{\rho}\Delta\bar{v} \quad \frac{\nu}{3} \quad ( \quad \bar{v}) \quad \frac{\mathrm{d}\bar{v}}{\mathrm{d}t} \tag{1}$$

An accurate characterization of a completely turbulent flow, where parameters such as velocity and pressure are functions of time and space, is realizable only by DNS. Navier-Stokes equations can be solved directly with super-computers that are using advanced numerical techniques which may properly characterize and even at small-scale turbulent flow (boundary-layer).

## Results and discussion

The study area is shown on the Romanian official chart – 1.050.02- From Tuzla Cape to Midia, with approval of Romanian Maritime Hydrographic Directorate, fig. 5(a). By digitizing the nautical chart, it was defined the fluid domain for CFD, fig. 5(b), for studying the interaction of the north-south marine current using the coastline shape of the Midia Cape and bathymetry data.

**Figure 5(a), The study area Midia Cape-Constanta**

The CFD simulation for fluid domain, between Midia Cape-Constanta coastline and corresponding distance for 20 m bathymetric, gives the pressure generated by a marine current, generally from north-south direction, fig. 6(a), which interacts with the profile of coastline. The simulation does not consider the blue area on the right side of the figure, because that result comes from limiting the domain of CFD analysis. High pressure areas are the areas close to the coastline where the local pressure is distributed on the elements present: dikes, dams or variations in the depth of the seabed.

The simulation for $v_i$ horizontal velocity, fig. 6(b), in the assumption of an undisturbed horizon for $z = 2.5$ m, for a marine current from north-south direction that are interacting with the coastline profile. The results indicate a reduced influence of the current in the surrounding shore areas, corresponding to the

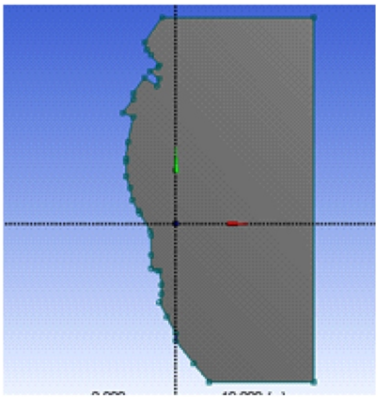

**Figure 5(b). The CDF ansys simulation**

measured current shown in fig. 3. The value of $v_i/v_o$ is used to determine the speed of the CFD simulation, relative to the current velocity input. In the areas, close to the coastline, shown in blue, the velocities are reduced due to the interaction with shoreline and the seabed, with 75% less than input velocity (0.2 m/s value) for fluid domain.

For the simulation of the vertical velocities $w_i$, fig. 6(c), using the same hypothesis (undisturbed horizon for $z$ = 2.5 m, for a marine current from north-south direction that are interacting with the coastline profile). The results of simulation show the values of vertical velocities between 0.19 to 0.22 m/s values. The vertical velocity variation in the studied area occurs at values below 95% to 110% of velocities for the input current see the colour legend in fig. 6(b). The red area indicates the possibility of developing maximum vertical velocity.

In the simulation of the turbulence $T_i$, fig. 6(d), occurring in the field of CFD simulation for the same approach (undisturbed horizon for $z$ = 2.5 m, for a marine current from north-south direction that are interacting with the coastline profile). In the simulation results it is shown the distinct areas with turbulence intensity values of percentage between 5% and 35%, see the colour legend of fig. 6(d). The result indicates the possibility of occurrence in the red zone of a highly turbulent fluid flow up to 35%.

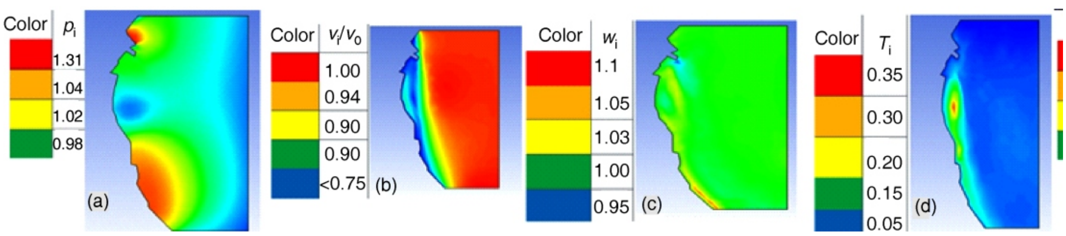


**Figure 6. The CFD simulation for Midia Cape-Constanta area, where X= longitude E and Y= latitude N; (a) pressures within the simulation, (b) horizontal velocities in CFD simulation, (c) vertical velocities in CFD simulation, (d) turbulence in CFD simulation**

## Conclusions

The CFD method can be used for analysis of interactions between marine currents, sea shores and sea bottom to help understand fluid dynamics of the area. It is the first time when Romanian authors are used a mixed method based on real marine current measurements and the CFD simulation for the study of and marine current interaction with sea shores and sea bottom for Midia Cape to Constanta, at the depth up to 20 m.

In contrast to the conventional methods, the mixed analysis shows more clearly the velocity values, pressures and turbulences of the investigated marine and can be used in the analysis and the coastline changes and assessment of risk for hydraulic structures.

A correct assessment of risk areas for navigation and hydrotechnical constructive industry can be performed using DNS method. The CFD simulation highlighted such areas – presented in red within this work allowing for a development of small scale mathematical models based on linear wave theory.

The next objective is to compare theoretical and experimental achieved work by using CFD tool as output to derive the hydro-dynamic force leading to an updated analysis of sea energy (mechanical and thermal energy) for user-defined areas.

## Nomenclature

$\overline{F}$ – the force per unit mass
$p$ – pressure, [dbar]
$v$ – the velocity of the fluid, [$ms^{-1}$]

*Greek symbols*

$\eta$ – dynamic viscosity, [Pa s]
$\rho$ – density of the fluid, [$kgcm^{-3}$]
$\nu$ – kinematic viscosity, [$m^2s^{-1}$]

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Paper submitted: May 18, 2017
Paper revised: July 10, 2017
Paper accepted: December 7, 2017