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THE MODELLING OF HYDRODYNAMIC PROCESSES OFF THE COAST OF ROMANIAN MARITIME PORTS

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I dedicate the present work to my family, to my parents. They have always supported me, totally and unconditionally, and their patience was infinite.

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CONTENTS OF THE DOCTORAL THESIS ABSTRACT

A SYNTHESIS OF THE CHAPTERS IN THE PRESENT DOCTORAL DISSERTATION ______ *4*

CHAPTER I INTRODUCTION ______ *4*

The underlying motivation for my research topic ______ **4**

The research objectives of my doctoral reserch ______ **4**

Research methodology used in the present study ______ **5**

The structure of the dissertation ______ **6**

CHAPTER 2 THE PHYSICAL AND GEOGRAPHICAL ENVIRONMENT OF ROMANIA'S MARINE COASTAL AREA ______ *8*

CHAPTER 3 THEORETICAL ELEMENTS PERTAINING TO THE HYDRODYNAMICS OF THE MARINE/COASTAL AREA ______ *9*

CHAPTER 4 MODELING / SIMULATION METHODS OF HYDRODYNAMIC PROCESSES IN THE MARITIME PORTS AND IN THEIR NEAR AREAS ______ *10*

CHAPTER 5 RESULTS VALIDATION OF HYDRODYNAMIC MODELS ______ *19*

CHAPTER 6 MARITIME RISK ANALYSIS ______ *25*

CHAPTER 7 - CONCLUSIONS ______ *26*

Personal contribution to the field of research ______ **27**

Future research directions ______ **28**

SELECTIVE BIBLIOGRAPHY ______ *30*

ANNEX 1 - LIST OF PAPERS ______ *34*

ANNEX II - PARTICIPATION IN RESEARCH PROJECTS ______ *38*

A SYNTHESIS OF THE CHAPTERS IN THE PRESENT DOCTORAL DISSERTATION

CHAPTER I INTRODUCTION

The underlying motivation for my research topic

The issue of navigation safety off the coast and especially off the coast of the maritime ports is a highly relevant one. Accordingly, there is a special concern on the part of an appreciable number of categories of managers and/or researchers to go deeper into the present issue from a theoretical point of view and process the ever-growing volume of data obtained fromn specific observations and measurements. Accordingly, national and international bodies have been founded, capable of elaborating and implementing marine hydrological monitoring programs. The eventuial aim of such programs is the provision of oceanographic forecasts linked to the control of maritime navigation.Calculation methods included in such monitoring programs, together with the related numerical modelling systems, may lead up to the structuring of a real and efficient decision-making system.

A decision needs to be madewith respect to making a refuge area available for an endangered vessel. In order to achieve that, certain aspects need to be known, pertaining to the state of navigability of the vesel, the nature and condition of the cargo, of the supplies, of the fuels and the dangerous cargo on board the ship. The location and the characteristics of the refuge area will also have to be taken into account, as well the estimated distance and manoeuvering time to the refuge area. No less important to that effect are the number of persons and/or rescuers on board but also the human factors, that including the panic caused by the endangered vessel.

For such a refuge area to meet the above-mentioned demands, the acquaintance with and the delineation of the most proper shelter area are required, given that the western shore of the Black Sea is exposed to the action of sea agitation factors. The coastal area and, implicitly, the area of the ports are the manifestation domain of the complex dynamic processes studeied as an outcome of the interaction between the sea, the land and the atmosphere. In the present doctoral dissertation, the coastal area will be approached from the viewpoint of its hyrodynamic processes. Also, the coastal area will be described in keeping with its characteristic elements and parameters, with the clear purpose of structuring the underlying geometrical model for the numerical modelling of the processes we have studied closely.

The research objectives of my doctoral reserch

The eventual aim of the present doctoaral research study is the optimization of portuary operations and the safety of coastal navigation during exceptional navigation events. Accordingly, shelter areas were identified and therefore the maritime risk areas, though simulations and forecasts provided by the application of numerical, high-precision hydrodynamic models. In order for that aim to be met, the gradual fulfillemnt of a series of objectives is required. The respective gradual fulfilment will eventually enable researchers to structure a methodology which is typical for the management of emergency situations, in the case of exceptional storms occurring in the north-western basin of the Black Sea.

The first objective pertains to making sense of the hydrodynamics in the area of portuary basins/waters, so that the structuring of a conceptual model can be achieved, which is mandatory when it comes to applying the numerical hydrodynamic models.

The second objective refers to the hydrodynamic models, which are appropriate for the marine conditions in the coastal area, characterized by a specific hydrodynamic state. In order to achieve that, the evaluation of the existing pool of data is required as well as a comparative analysis of the IT program packages assocciated with the numerical models. Such an evaluation will be conducted in keeping with the programs' scope and accessibility, as well as according to the accuracy with which the hydrodynamic processes typical for the small and medium-depth marine areas are described in their entire complexity. Also required is a set of numerically solved mathematical equations.

The third objective of the present research specifically targets the activity proper, that of the modelling of hydrodynamic processes associated with the area of the maritime ports under extrme weather conditions reported for the western shore of the Black Sea. The clear purpose of such an undertaking is the identification of shelter areas and/or the maritime risk areas. The fulflilment of this objective aslo entailed the indentification of maximum, values, that is impact values of the wind, wave and current parameters, typical for the coastal/portuary area. The values were included in the multiannual data sets(mentioned in Chapter 4) but thy were also collected as a resukt of a series of in situ measurements we made on the premises of the port of Constanta and the adjacent areas, with the purpose of validating thre results of the hydrodynamic models.

Research methodology used in the present study

In terms of research methodology, we used the spectral numerical models designed for the study of the transformation of waves in the portuary waters and their adjacent areas. By the same token, we used numerical hydrodynamic models with a finite element, which we deemed appropriate for the study of the dynamics of currents. Broadly speaking, our approach of the general research area is obvioulsy a multidisciplinary one, all the more so as the research area is specifically linked to the mechanics of the fluids and with marine hydrodynamics, in particular.

The MOHID hydrodynamic model, used for the study of marine currents, the SWAN spectral model, used for the modelling of waves propagation processes in portuary waters, as well as the BOUSS 2D model, used for the transformation of waves nearby the shore, allow for subsequent developments that can in turn be used as a basis for the ellaboration of various services, which at present underlie the interconnected informatics systems, with specific applicability to the field of maritime transport, but also to the emerging field of the MSP/Maritime Spatial Planning, a fully growing field and Europan and international level.

The results we obtained as part of the simulations, using a numerical model, of the marine and coastal currents, as well as the results of the impact the currents have, jointly with the waves, on the transition area of the Romanian Black Sea coast and especially off the coast of Constanta Port have been analyzed comparatively, in order to be validated by in situ and satellite measurements, specific for the Earth Observation domain. The collection of data required for the validation of the circulation model has been carried with a Doppler effect currentmeter, as part of a hydrological measurements expedition conducted in the port of Constanta and the adjacent areas. The data required for the validation of the hydrodynamic model were provided by the marine geo-hazards warning system, EMSO EUXINUS, which is property of the GeoEcoMar Institute.

Also, instruments were used, specific for the GIS system, in order to create the necessary framework for the generation of the calculation grid/network for the hydrodymanic models that were used.

The conclusion of the present study is that a deeper research process is needed, of the numerical /theoretical approach, as well as of the approach related to filed measurements and oservation activities, for an accurate knowlwdge of hydrodynamic processes, given the considerable variability fo the parameters involved.

The structure of the dissertation

In oder to conduct the studies related to the modelling applications, quite comprehensive data are required, with a spatial and temporal coverage, as well as the documentation of engineering activities, for the coastal modelling. That entails focusing on two key aspects of hydrodynamic modelling. The former pertains to the demonstration of the way numerical models can be applied to facilitate the understanding of regional and local coastal processes, with the purpose of carrying a predictive evaluation of the wave-current regimen and the response of the shore/portuary structures to the various influence configurations of marine agitation factors.

The latter aspect is correlated to the selection of the manner in which those hydrodynamic models can be used to create an intergrated management framework for coastal navigation. Such an aspect can also be extrapolated to the coastal erosion control projects, within a framework which is specific to the Marine Spatial Planning, in keeping with Directive 2014/89/EU, pertaining to the structuring of a framework for the creation of a maritime area, „ a process by means of which the authorities of the respective EU member state analyze and organize human activities around marine areas, with the clear pupose of fulfilling ecological, economic and social objectives.

In the present work, models that are specific for the hydrodynamics of sea waves and currents have been numerically solved, through automated calucation methods. These models have been applied according to various regional and local scales, ranging from the scale of the entire Black Sea basin to the scale of the Romanian shelf, to the mesoscale (over 100 kilometers), to the local-scale coastal applications, of zozens of kilometers and even five kilometers.

The present doctoral research study has been structured in seven chapters. The study seeks to identify and analyze the complex hydrodynamic processes that are active off the coast of maritime ports, in certain, specific circumstances of the marine agitation regimen. Alo, these processes han have an impact on costal navigation.

Chapter one presents the rationale underlying the research topic which was selected, the aims of the study, as well as the research methodology. Chapter one also provides an overview of hydrological activity endeavours carried for Romania’s sea and shore area.

Chapter two provides the overall description of the Black Sea basin, of the physical/geographical environment of Romania's marine/coastal area, as well as the maritime ports. Aloso presented in Chapter two, in detail, are the general climate regimen and the prevailing winds; also, an analysis is provided of the sea level variability on the shore.

Chapter three outlines the theoretical elements pertaining to the marine/coastal hydrodynamic.s Notions of fluids dynamics and cinematics have been presented, the main categories of marine currents, elements of wave theory, as well as the applicability domain of these theories. Chapter three also presents modern measurement and observation metods of wave parameters and the circulation of water masses in the areas of interest, which are sigificant with respect to the variability of hydrodynamic priocesses.

Chapter four provides a presentation of several theoretical notions of hydrodynamic processes numerical modelling, the types of models that were used, as well as the modular structure and the governing equations of the MOHID hydrodynamic model. The maon stages in the development of a numerical model have also been presented, the structure of the simulations plan, the extreme conditions, the applicability domains. To that effect, the MOHID hydrodynamic model was presented, applied for the Constanta area beginning 2013, in the processing version carried on a PC-type calculation system. The implementation of the model was completed in late 2017, in an operational forecasting system, iSWIM (http://iswim.rmri.ro). The system can be accessed on a server, through a web mapping IT system. (WebMappingSistem/WMS).

Waves propagation simulations have been carried, on the premises of Constanta port, using the SWAN (Simulating WAves Nearshore) model, included in the MOHID STUDIO programming package, which allows for simulations to be conducted on various spatial and temporal scales. SWAN was chosen as an alternative to the WAM model, with mesoscale-level applications.

Also, a phase model has been applied, simulating the composition and transformation of waves of the model's selected geometrical domain. Such a model used for the solution of a wave's progression phases is the waves model developed following the Boussineq approximations, being integrated as a numerical application, inserted in SMS (Surface Water Modeling System), as BOUSS2D. The model has been used for the numerical application on the propagation of storm waves for the Constanta and Midia maritime ports. Because of the influence storm waves can have on the waters in the portuary areas, phenomena are likely to occur, associated to the undertow waves or the vertical waves.

Chapter five includes the validation operations of hydrodynamic models in the port of Constanta through field measurements made using the ADCP Doppler currentmeter, along a route including the Tomis harbour, the area of the harbour's waterway, the access mouth to the harbour and berth zero, concurrently with data obtained through remote observation methods – through satellite remote sensing.

Chapter six presents basic concepts on the evaluation of risks for maritime ports, as well as notions pertaining to maritime risk management in the case of exceptional hydro-meteorological events.

Chapter seven presents the conclusions of the present research, as wel las the author's own contributions ot the field. Also presented are the lines of future research, based on the results obtained as part of the doctoral research stage.

CHAPTER 2 THE PHYSICAL AND GEOGRAPHICAL ENVIRONMENT OF ROMANIA'S MARINE COASTAL AREA

Chapter two provides a synthetic presentation of the main data and parameters, characteristic for the marine and coastal hydro-meteorological regimen. The data have been processed based on the available sets of data, provided by several oceanographic centers at regional, European and international level. The results we obtained are convergent with the trends we identified in reference works in the field, for the Black Sea area. Wind data have been analyzed, provided by the Mangalia and Constanta stations, over 1965 and 2000. We noticed that the highest-frequency winds are those blowing from the west, with a reported 17% frequency in Constanta and a frequency of 20.3% reported for Mangalia, during the cold season.

Chapter two also presents relevant elements on the position and layout of Romania's maritime ports, that including enlargement stages of the port structures, the layout of the berths and that of the portuary basins.

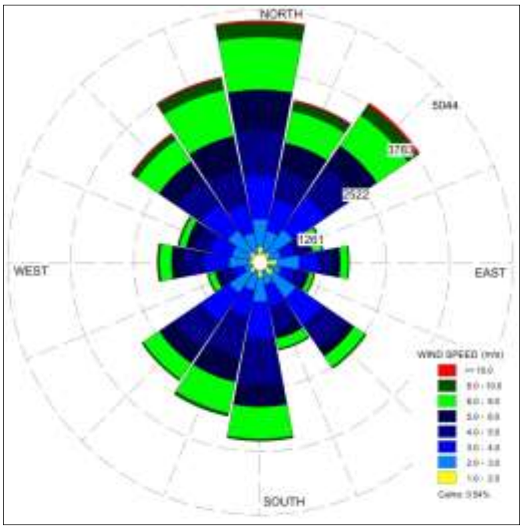

Fig. 2.1. Wind rose: Frequencies and average speeds of coastal winds data recorded by the weather station at Constanta station, for the period 2007 - 2012

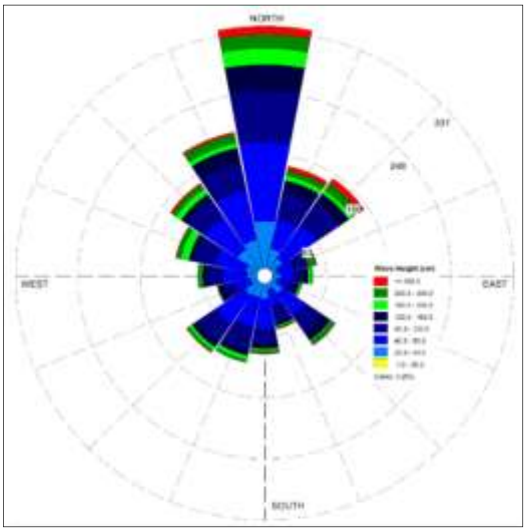

Fig. 2.2. The wave rose, data recorded by the weather station at Gloria maritime platform for the period 2007 - 2012

CHAPTER 3 THEORETICAL ELEMENTS PERTAINING TO THE HYDRODYNAMICS OF THE MARINE/COASTAL AREA

Chapter three provides theoretical elements of fluids cinematics and dynamics, the regimen of marine currents, as well as elements of wave theory. Also described is a series of modern measurement methods for marine currents and wave parameters.

Theoretical elements for the regimen of marine currents were also presented, as well as the types of currents. Also presented in Chapter three were water masses circulation models. Two types of velocity can be detected in fluid mechanics: the trajectory-based velocity of a moving water particle, or the drift velocity (The Lagrange method) and the water velocity reported for a static position (The Euler method). Both methods have been described in Chapter three. Based on these two mathematical methods, several measurement methods have been created, for marine currents. Of these, the most frequently-used are the coastal radars, the satellites or water current meters with the Doppler effect.

The general regimen of the currents off the coast of the Romanian seas shore has been described. It was correlated with marine and coastal measuremeent methods, based on the two mathematical principles mentioned above. In order to make direct high-resolution spatial measurements, both horizontally and in-depth, for the marine circulation in the north-western area of the sea, the equipment was used, to determine the currents' vertical profile, based on the Doppler effect. The equipment had the capacity to operate in a static position, and/or during the navigation of a vessel/boat.

With respect to our approaching the aspects related to waves theory, presented in Chapter three were a wave's morphometric elements and the regimen of marine agitation. Also presented in this chapter were the applicability domains for certain wave theories, but also theoretical elements on the vertical waves, correlated with the resonance of portuary basins. The final part of Chapter four provides several modern methods for the measurement and observation of wave parameters.

Fig.3.1. EMSO-EUXINUS geohazard warning system

Fig. 3.2. Mounting of the ADCP WH600 on a non-magnetic metallic structure, in a wide station

CHAPTER 4 MODELING / SIMULATION METHODS OF HYDRODYNAMIC PROCESSES IN THE MARITIME PORTS AND IN THEIR NEAR AREAS

Chapter four provides a presentation of several theoretical notions of hydrodynamic processes numerical modelling, the types of models that were used, as well as the modular structure and the governing equations of the MOHID hydrodynamic model. To that effect, the MOHID hydrodynamic model was presented, applied for the Constanta area beginning 2013, in the processing version carried on a PC-type calculation system. The implementation of the model was completed in late 2017, in an operational forecasting system, iSWIM (http://iswim.rmri.ro). The system can be accessed on a server, through a web mapping IT system. (WebMappingSistem/WMS).

The hydrodynamics module of the MOHID model solves the primitive continuity and impulse equations for the sea surface elevation and the 3D velocity field for incompressible fluids, in orthogonal horizontal coordinates and generic vertical coordinates, assuming a hydrostatic equilibrium and a Boussinesq approximation. The moment and mass equations are:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{4.1}$$

$$\frac{\partial u_1}{\partial t} + \frac{\partial (u_j u_1)}{\partial x_j} = -f u_2 - g\frac{\rho_\eta}{\rho_0}\frac{\partial \eta}{\partial x_1} - \frac{1}{\rho_0}\frac{\partial p_s}{\partial x_1} - \frac{g}{\rho_0}\int_z^\eta \frac{\partial \rho'}{\partial x_1}\,dx_3 + \frac{\partial}{\partial x_j}\left(A_j \frac{\partial u_1}{\partial x_j}\right) \tag{4.2}$$

$$\frac{\partial u_2}{\partial t} + \frac{\partial (u_j u_2)}{\partial x_j} = -f u_1 - g\frac{\rho_\eta}{\rho_0}\frac{\partial \eta}{\partial x_2} - \frac{1}{\rho_0}\frac{\partial p_s}{\partial x_2} - \frac{g}{\rho_0}\int_z^\eta \frac{\partial \rho'}{\partial x_1}\,dx_3 + \frac{\partial}{\partial x_j}\left(A_j \frac{\partial u_2}{\partial x_j}\right) \tag{4.3}$$

$$\frac{\partial p}{\partial x_3} = -\rho g \tag{4.4}$$

Where u_i is the component of velocity vectors in Cartesian directions x_i, η the free surface elevation, f Coriolis parameter, A_i the turbulent viscosity, p_s atmospheric pressure, ρ density and ρ' density variation. Density is calculated based on salinity, temperature and pressure using the UNESCO equation [UNESCO, 1981]. The shear stress at the bottom can be calculated with a calculation hypothesis for a logarithmic velocity gradient:

$$\tau = \rho C_d \left|\vec{u}_+\right| \cdot \vec{u}_+ \tag{4.5}$$

$$C_d = \left[\frac{k}{\ln\left(\frac{z_+ + z_0}{z_0}\right)} \right]^2 \qquad (4.6)$$

Where τ is the shear stress at the bottom, u_+ is the velocity field at a distance z_+ above the bottom, C_d the roughness coefficient, k Von Karman constant, z_0 the length of the bottom roughness. The MOHID model configuration was performed on the 3 nested domains based on the downscaling procedures, in MOHID Studio, a GUI software produced by Action Modulers, a spin-off company of Technical University of Lisbon/Maretech Center:

1. The Black Sea, the domain covers the entire Black Sea basin;
2. The Romanian shelf, the domain covers the entire plateau related to the Romanian shore;
3. Constanța area, the domain covers the area near the city of Năvodari/Constanța/ Eforie.

All models are implemented as 3D baroclinic models, having as a driving force the meteorological conditions (wind, solar radiation) and the flows of the main rivers.

Level 1 - The Black Sea Model. The Black Sea model is the basic level from which it starts and covers the entire Black Sea basin. The computing network has a horizontal resolution of approximately 42 vertical layers and a calculation cell size of 5.0 km. The boundary conditions are the wind data (from the GFS / NOAA), the solar radiation fluxes (from the GFS) and the average annual flows of the hydrological regime: the Danube, the Dnieper, the Kerci Strait (Don and Kuban), Bosphorus Strait (surface and bottom). The initial conditions for temperature and salinity are currently obtained from CMEMS / Copernicus.

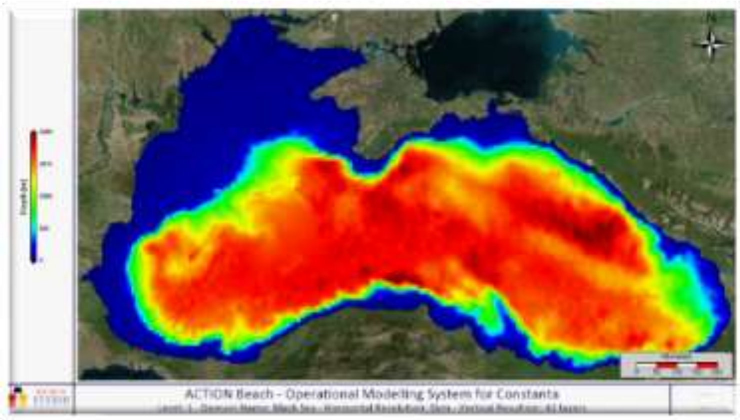

Fig. 4. 1 – Black Sea bathymetry

Level 2 - Romanian Shelf. Level 2 covers the Romanian shelf, on a grid horizontal resolution of 39 layers and a vertical calculation cell size of 1.25 km. The boundary conditions are given by the wind parameters (GFS), solar radiation fluxes (GFS) and the average annual flows. The initial conditions at the open boundary are provided from the Black Sea model (stage 1).

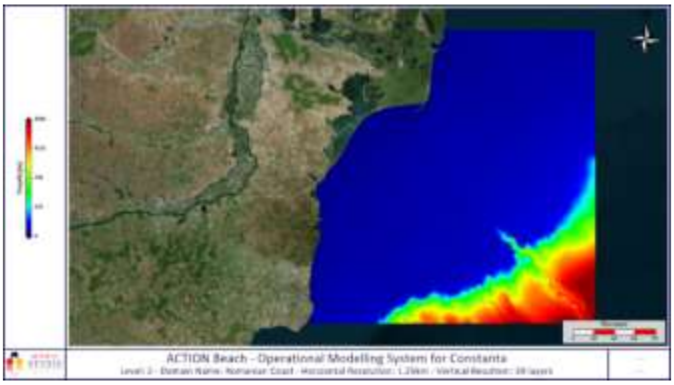

Fig. 4. 2 - Romanian Black Sea shelf bathymetry

Level 3 - Coastal model of Constanța area covers Mamaia Bay, Constanța and Eforie Bay as shown in the following figure. This model has been configured to have a horizontal grid resolution of 0.3 km and approximately 18 vertical layers. The boundary conditions are the wind (GFS) and radiation fluxes (GFS). The open boundary conditions are imposed by the initial conditions of the regional model (level 1 – Black Sea Basin) and the Romanian shelf (level 2).

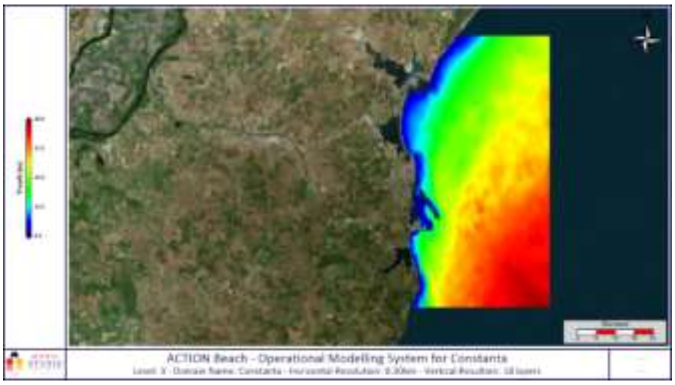

Fig. 4.3. Bathymetry of Constanta metropolitan area

RESULTS. MOHID model provides information on water quality parameters (temperature and salinity distributions), the currents dynamics at the water surface.

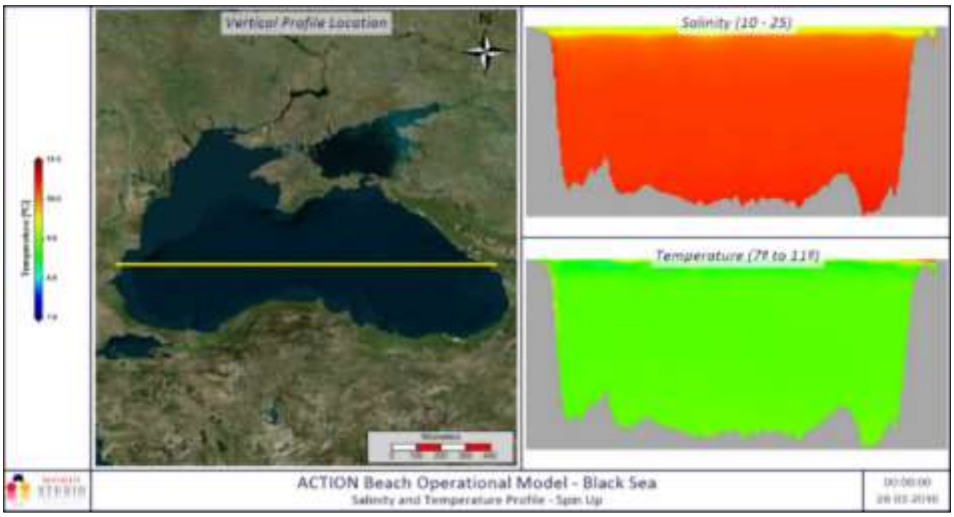

Fig. 4. 4. – Water quality parameters **-** transverse profile

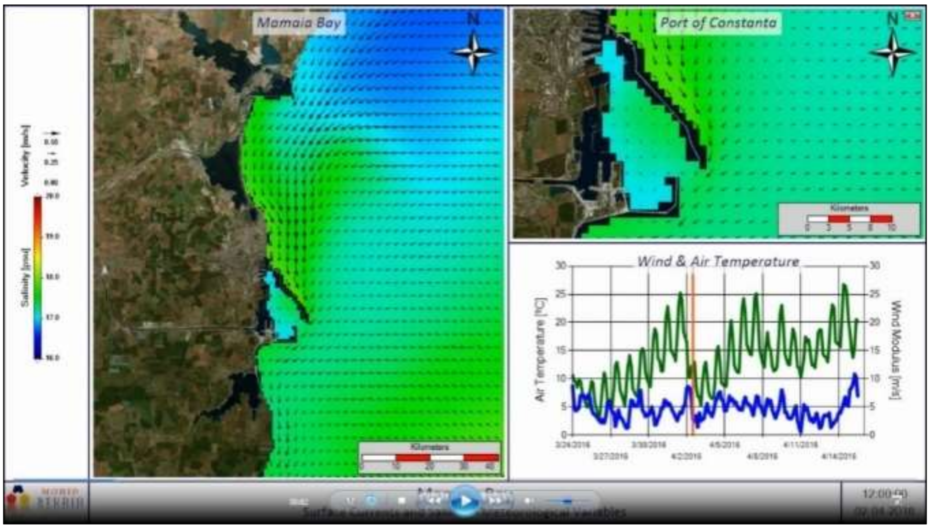

Fig. 4. 6. – Current distribution for Constanța Port area 02.24.2016 (12:00)

The model reproduces very well the surface currents related to the spread of fresh water in the mouths of the Danube and in the natural promontories area / marine obstacles, as well as the extension of the turbulence / suspended sediment fronts in the northern Romanian area (fig.4.7).

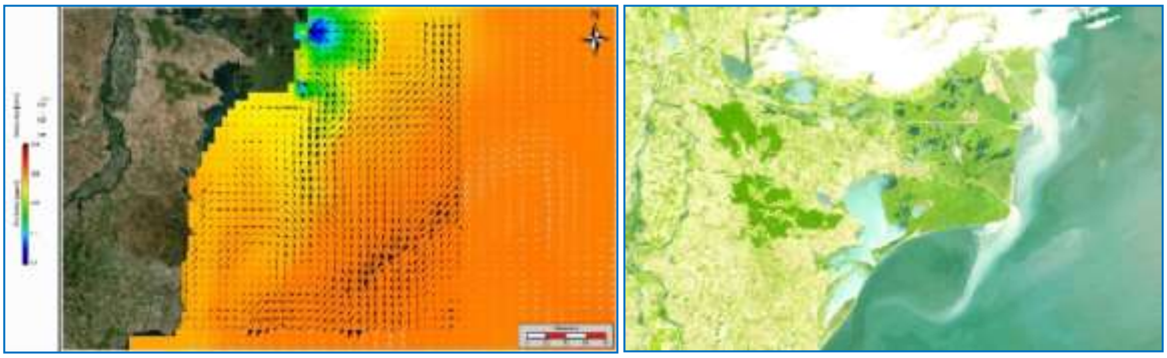

Fig. 4. 7. – The circulation model result vs. the CMEMS satellite data over the Danube Delta area

Simulation of wave propagation in Constanta Port using the 2-D spectral model. SWAN model (Simulating WAves Nearshore), is included in the MOHID Studio software package. The equation system describes the physical processes for shallow waters.

The model is run at a high resolution to take into account the coastal bathymetric variations. Wave propagation is implicit (parameterized), rather than explicit (simulated). It is frequently run in a "stationary" mode. SWAN requires bathymetry data and the forces generated by the wind or waves, as initial running conditions. The boundary conditions provided from wave stations are usually applied on the sea edge of the geometric domain.

Numerical experiment. The Constanta Port area of interest was included in a grid about 21x42 km, ensuring the border conditions for the wave transformation area specific to the Romanian southern shore, as delimited in the figure 4.8.

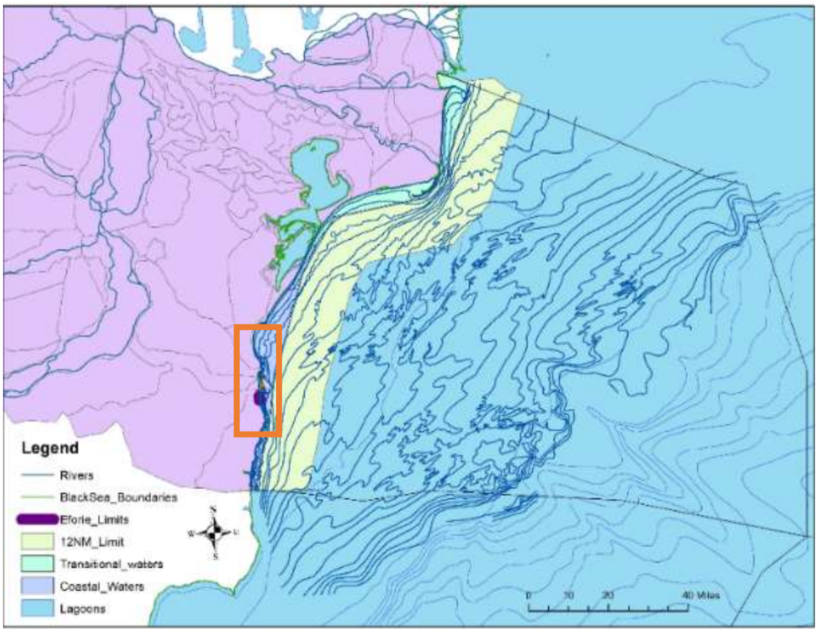

Fig. 4. 8. –The geometric domain for SWAN model implementing

The simulation on the wave fields was performed for extreme events, for different wave regime settings on certain directions of the wind action, especially during the cold season, respectively for the maximum action directions given by the port input configuration, but also by the direction of the port, maximum storm surge calculated for a 100-year return period. The SWAN simulations were run in non-stationary two-dimensional mode, with a one-hour time step of a 21x42 km computing network, covering the chosen geometric model, originating at UTM35N coordinate point (X0 = 629000 / Y0 = 4867000), with a resolution of 75 m on both directions, north and east. The initialization data of the model were bathymetry, the coastline, the wind data. The calculations were made based on semi-empirical relationships derived from the JONSWAP spectrum. The extreme incident waves propagation was simulated for three cases of wide waves at extreme wave conditions near the shore, determined for Constanta Port. The included data in the model were: wind speed at 10 m height [m / s] and direction [°], significant wave height [m], maximum wave period [s], mean wave period [s], the mean wave direction [°], for the three spectral directions - 0°, 45-60° and 135-180°.

RESULTS. It is to be emphasized that the largest waves are generated from the NE direction, and the most dangerous and impacting waves are the waves with perpendicular incidence on the port entrance, respectively, the waves from S and SE, the most vulnerable direction of waves' propagation relative with Constanta Port opening, which according with the project results, generates inside the port area, waves of about 1.5 - 2 m. (Fig. 4.9.). Fact confirmed by the seilling line's acces navigations bouys damages and them running up on the port jetty slope after the wind storms from SE directions.

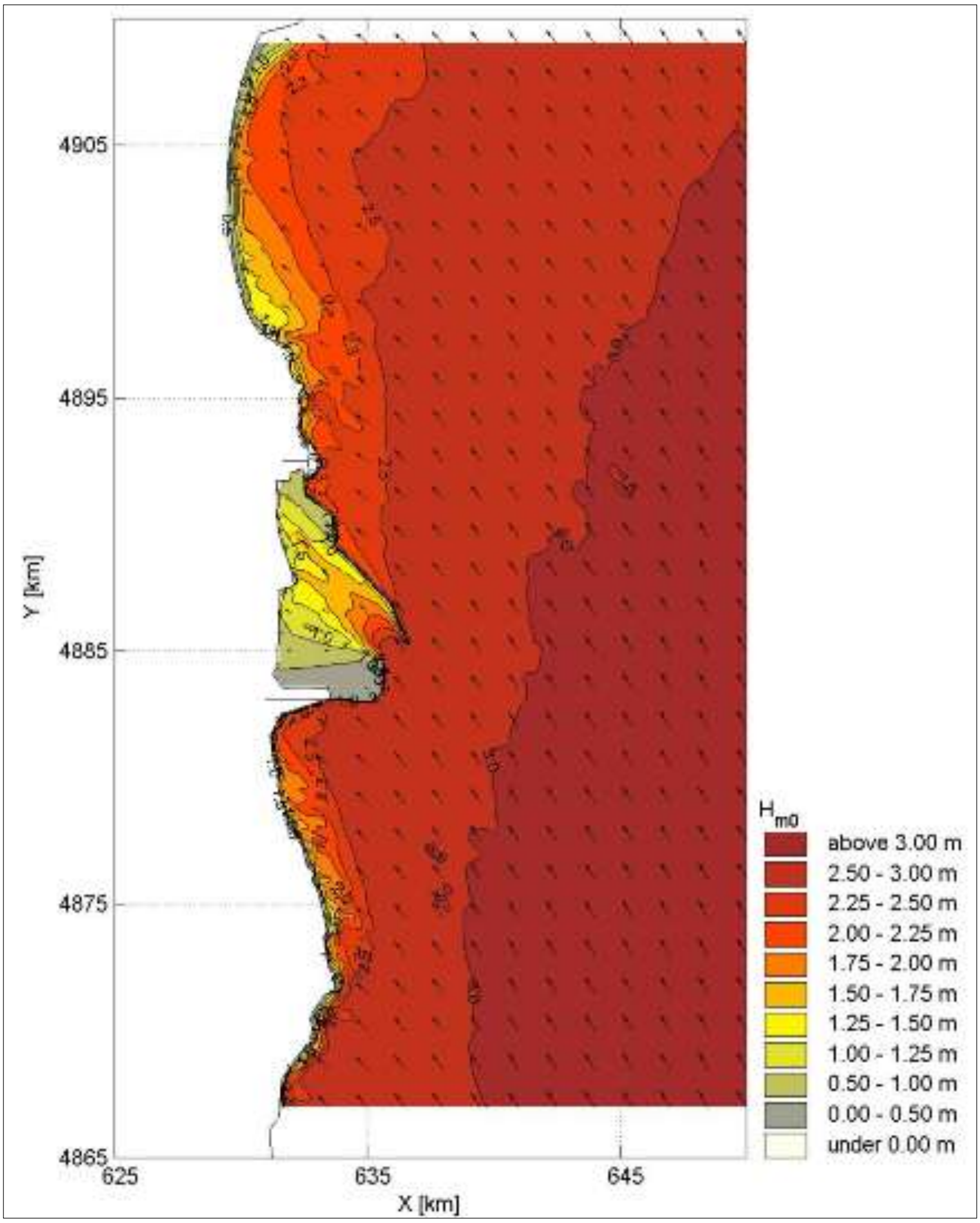

Fig. 4. 9. – Incident waves spatial distribution from the SE direction, 135° (H_{m0} = 2.75m, T_p = 9sec), at a wind speed of more than 10m / s.

Wave transformation processes Modeling in Constanta Port using the BOUSS 2D hydrodynamic model. The model is based on a time solution for Boussinesq equations, solving the wave transformation processes. The model is part of the SMS (Surface Water Modeling System) software package, useful for storm surge regime applications, surf waves phenomena and tide waves in ports areas. BOUSS-2D can be successfully used to study the specific phenomena at the ports entrance and navigable channels.

Wave transformation simulations in Constanta Harbor. In developing the application of the Bouss 2D model for the study of wave propagation in the Romanian seaports, all the necessary steps for were completed. The geometric model was built by coupling all the data sets in the UTM35N projection (fig.4.10.).

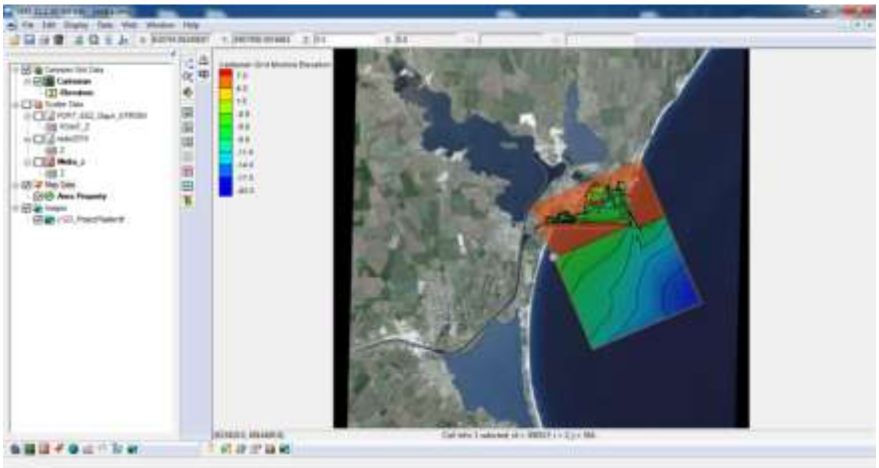

Fig. 4.10. Cartesian computing grid for Midia Port

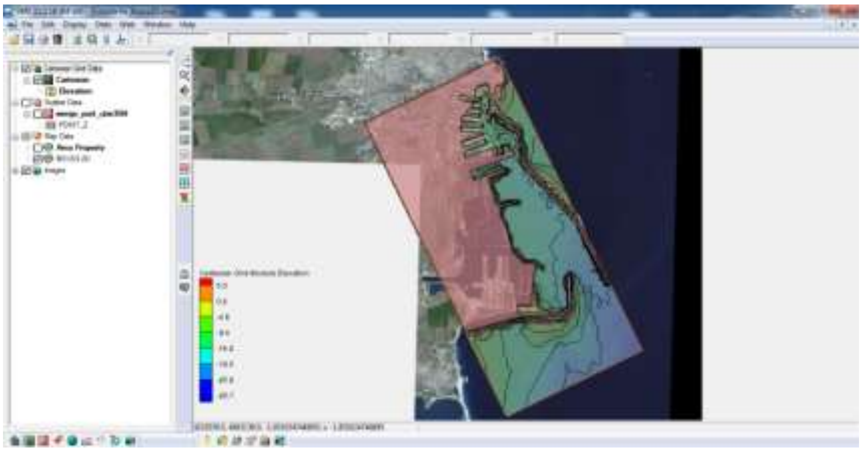

Fig. 4.11 Cartesian computing grid for Constanta Port

The results obtained were visualized with a routine related to the SMS11.2 software package (fig. 4.12 and 4.13).

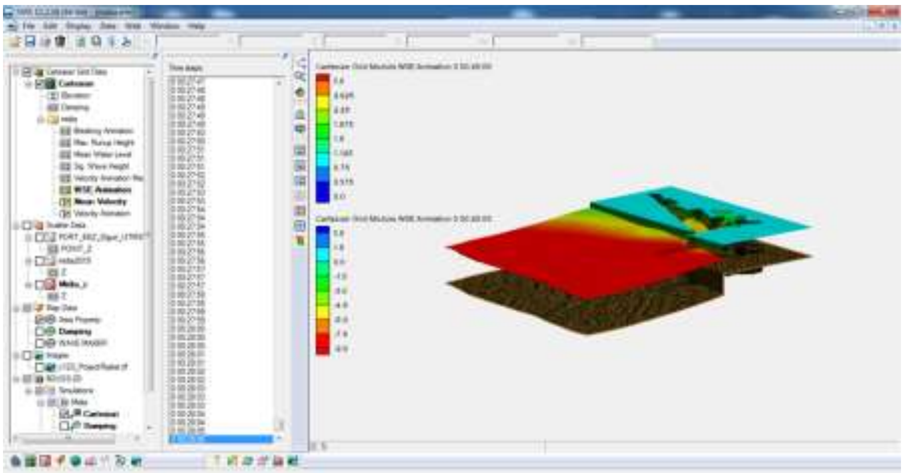

Fig 4.12 The sea/ water surface elevation (WSE) above the bathymetry of the Midia Port

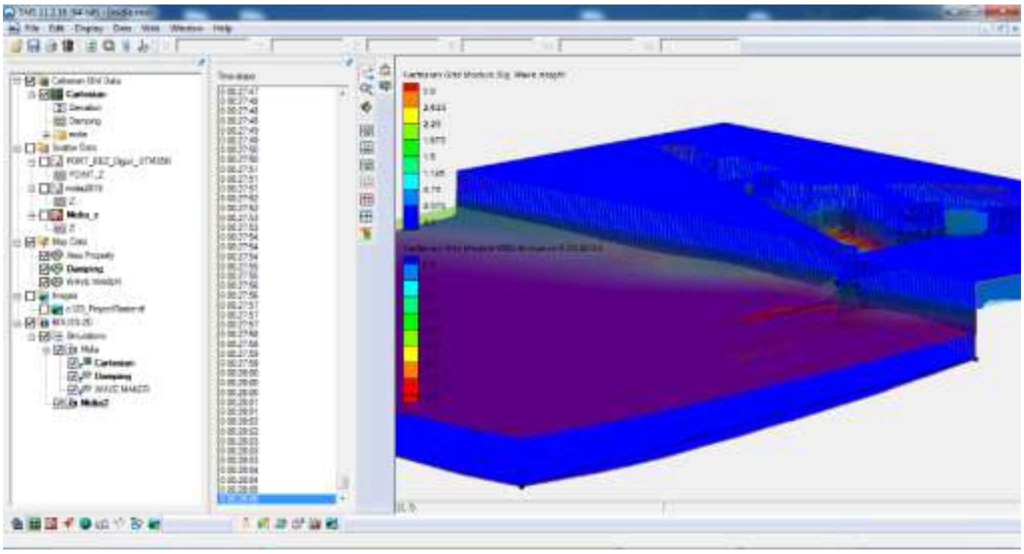

Fig. 4.13. - The sea surface height above the bathymetry of the Midia Port and adjacent area (covered by the computing network of the BOUSS2D model)

The change of the wave field in the area of the port access channel can be observed, as well as the intensification of the waves near the vertical structure of the enclosure. The port of Midia, due to a large area of shallow depth (due to the sediment deposition), has the advantage of the decreasing of captured waves. This fact is less encountered in the Constanța port, especially in the inlet area, where the waves/ the sea surface (Water Surface Elevation) has high values in the case of wave's incidence coming from SE-S sector (fig. 4.14.)

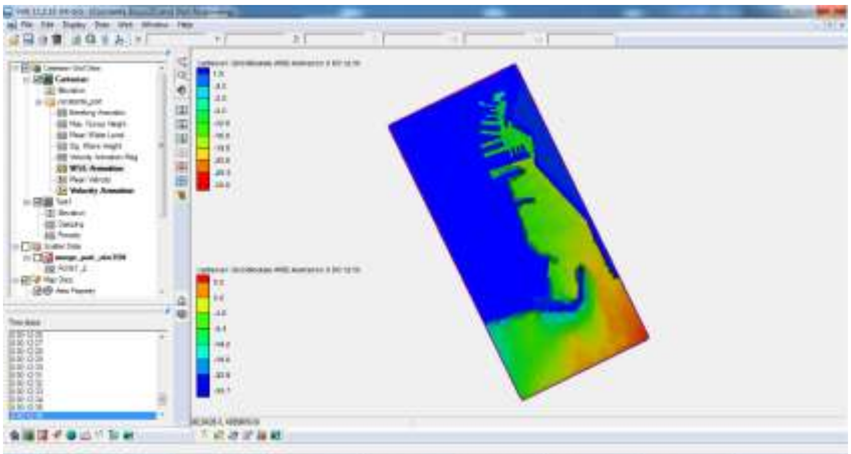

Fig. 4.14. The sea surface height in the Constanța port area

The reflected captive waves from the land side are observed in a test point, previously set in the calculation network (fig. 4.15. and fig.4.16.)

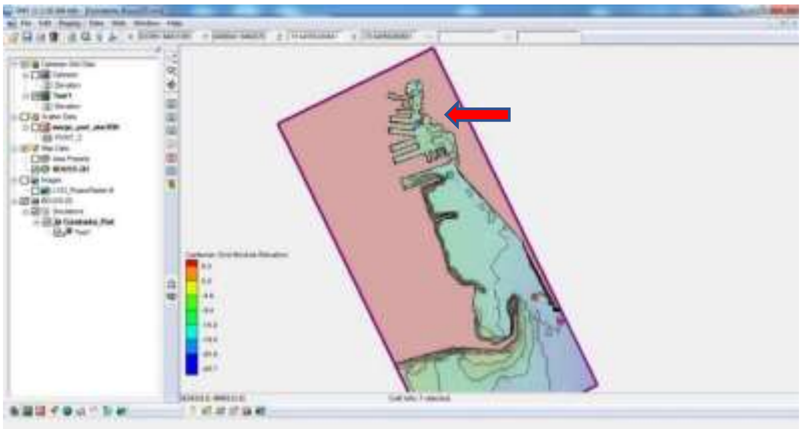

Fig. 4.15. Test point position near the Constanța seal level recording station

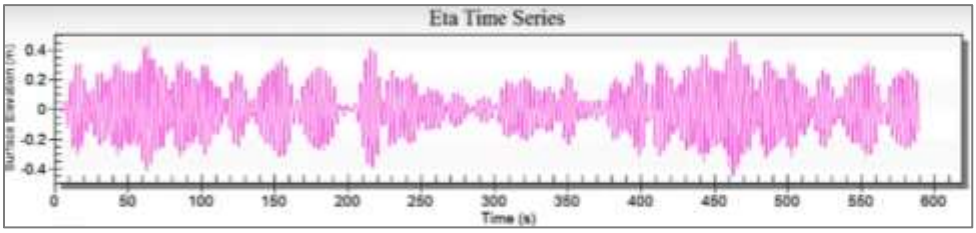

Fig. 4.16. Oscillations related to the test point associated to with Constanța seal level recording station

The simulated oscillation into the terminal basin highlights the possibility of long wave's occurrence in this port sector, due to the presence of the quayside. Such an oscillation was recorded during the storm periods, even though the dominance of the incident waves was from other directions. Thus, for the storm of February 26, 2018, the sea level station indicates an oscillation of approx. 20 minutes (fig. 4.17).

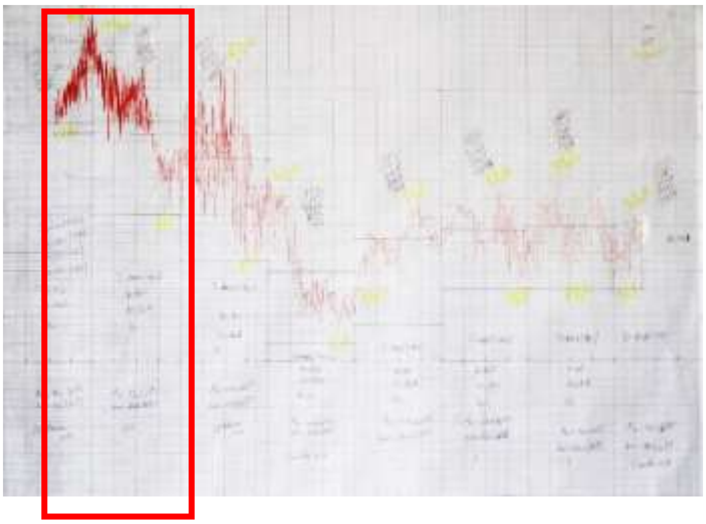

Fig. 4. 17. – Sea level record at Constanta mechanical station - 26-27.03.2018

Conclusions. The wave transformation is well provided by the model, even the effects of refraction are evident from the rotation of the waves to the perpendicular directions along the coastline (approximately 90 °), and the wave heights propagated in the port basin underline the need to extend the north dam to the south to ensure the increasing conditions for shelter and safe port operation.

CHAPTER 5 RESULTS VALIDATION OF HYDRODYNAMIC MODELS

Validation of coastal circulation models by carrying out measurements in Constanța port. The measurement session was held on 26.10.2019. The equipment used was an equipped motorboat with GPS and a WHS600 - Workhorse Sentinel, 600 KHz ADCP (Acoustic Doppler Current Profiler) with Bottom Track mode, for dynamic measurement of current profiles on the water column. The area where the current measurements were made includes the entire channel of Constanța port from the port entrance, up to the first dock berth, located in the most sheltered sub-basin, starting from the Tomis marina area (Fig. 5.1)

Fig. 5. 1. – The route of currents measurements

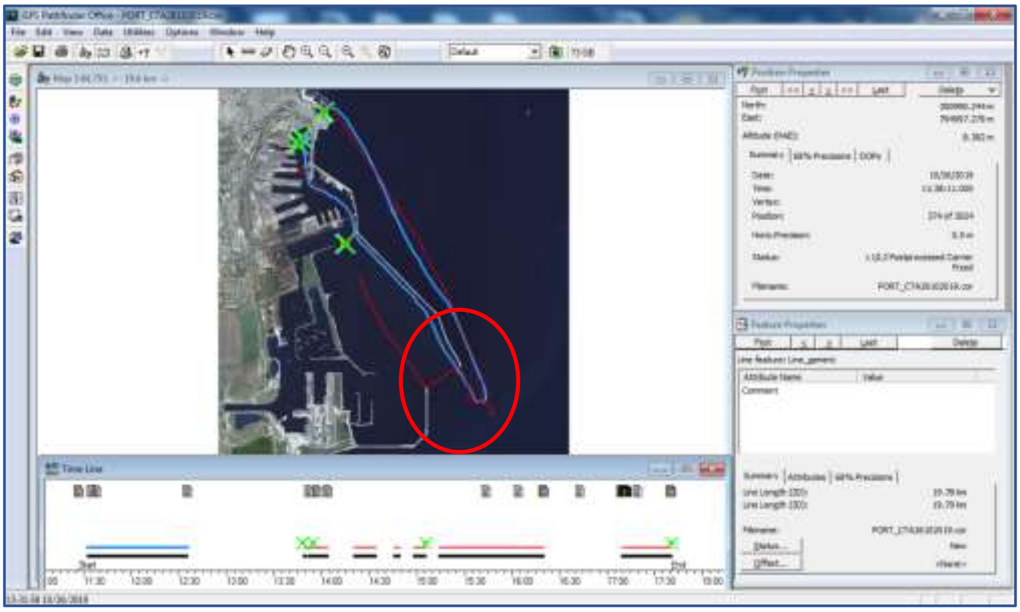

Fig. 5. 2. – GPS data Post-processing with Trimble Pathfinder Office software

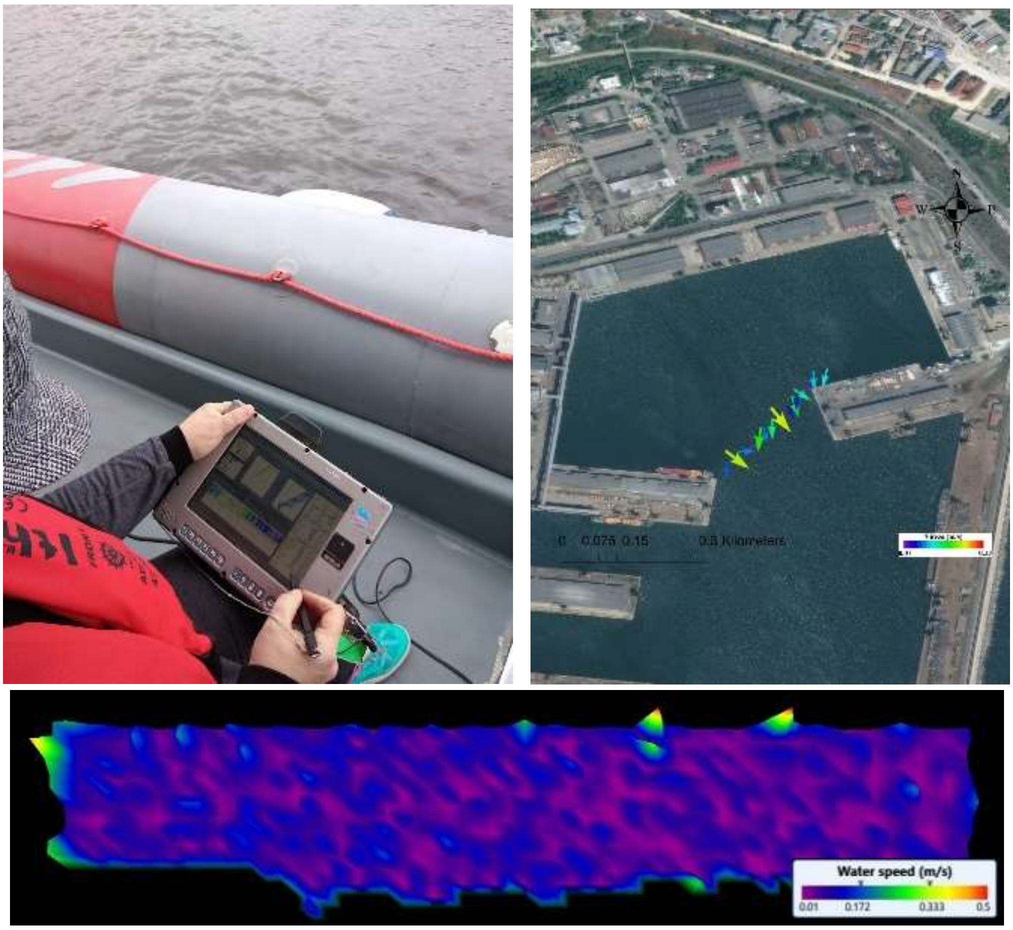

Fig. 5. 3. – a , b, and c. Surface currents from the SE direction recorded in the closure section of the Maritime Station basin

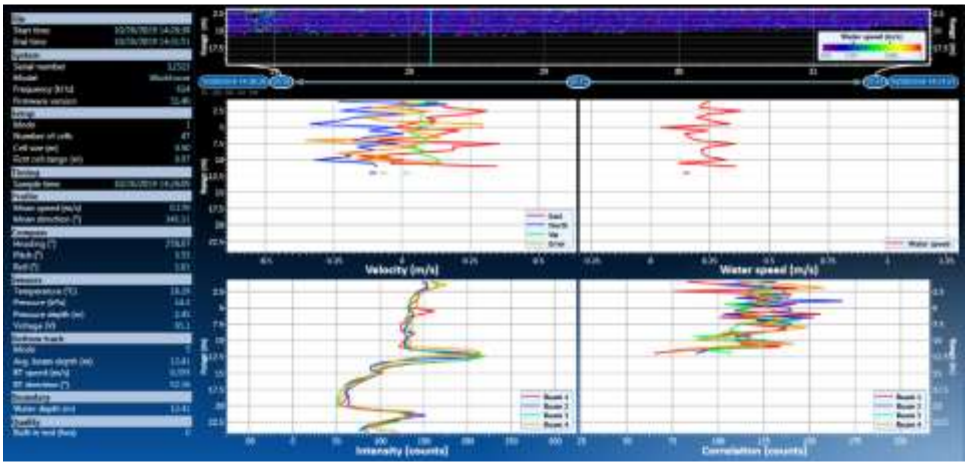

Fig 5.4. The sheltered area in the "Queen's Nest" / Digital Sea Level Station area (screenshot Velocity-software)

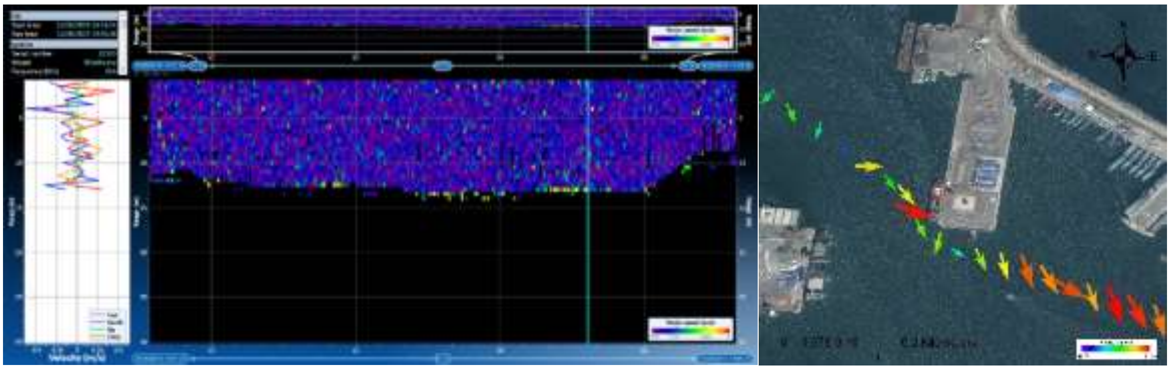

Fig 5.5. Passing measurements in the passenger terminal area (Velocity-software screenshot, and rendering respectively)

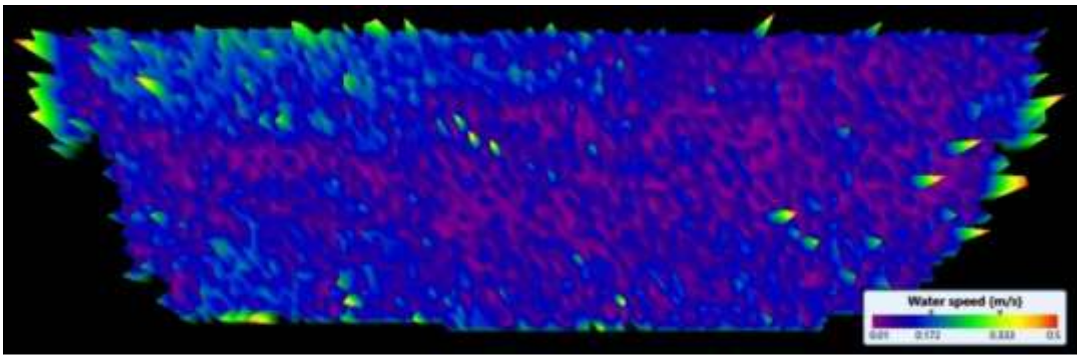

Fig 5.6. - Currents distribution in the end of the north dam section - The access to Constanța Port

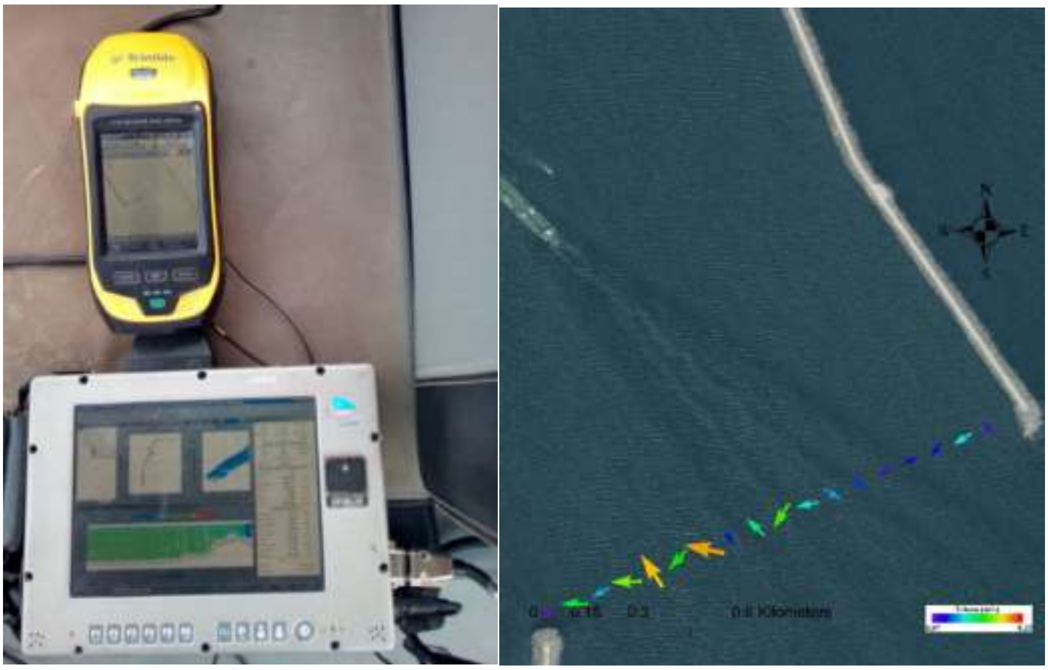

Fig. 5.7.- ADCP profile recorded on the tablet (a) and highlighting the currents at the port entrance (b), as well as an anti-cyclonic current near the north dam of the port enclosure.

Measured data analysis. Current speeds were recorded in the range of 0.002 m / s - 1.058 m / s, which is a normal speed current regime for the area of interest of Constanta port. There are some exceptions, near the corner of terminals and / or at the end of the channel and to the passage channels where the average value of the currents exceeds 0,5m / s, approaching the value of 1m / s. For the critical areas, measurements were made in a fixed station, providing details on the speed distribution on the water column (fig. 5.16).

Fig 5.8.- Velocity distribution in the surface layer in the semi-closed port basin

Validation of numerical wave transformation models by remote observation methods - satellite remote sensing.

Wave climate models were evaluated in the Mangalia Port area together with changes that might be expected in the marine / coastal area (Fig. 5.17). The remote sensing data provided by Copernicus (Sentinel 2) covering the regional and local level, being able to provide information on the surface wave's generation, but also of internal waves / deep waves in the vicinity of seaports.

Thus, they can highlight the diffracted and reflected wave fields in the coastal area, which is a very useful feature to process and compare the obtained results on the numerical model.

Fig. 5. 9. – Wave field near Mangalia Port / GeoEcoMar buoy position

The measured data for the date of June 15, when the satellite image data was collected, the wave regime was rapidly changed, and the comparison results show a good correlation with model simulations, which can be developed and associated with the various operating system (Fig. 5.18.).

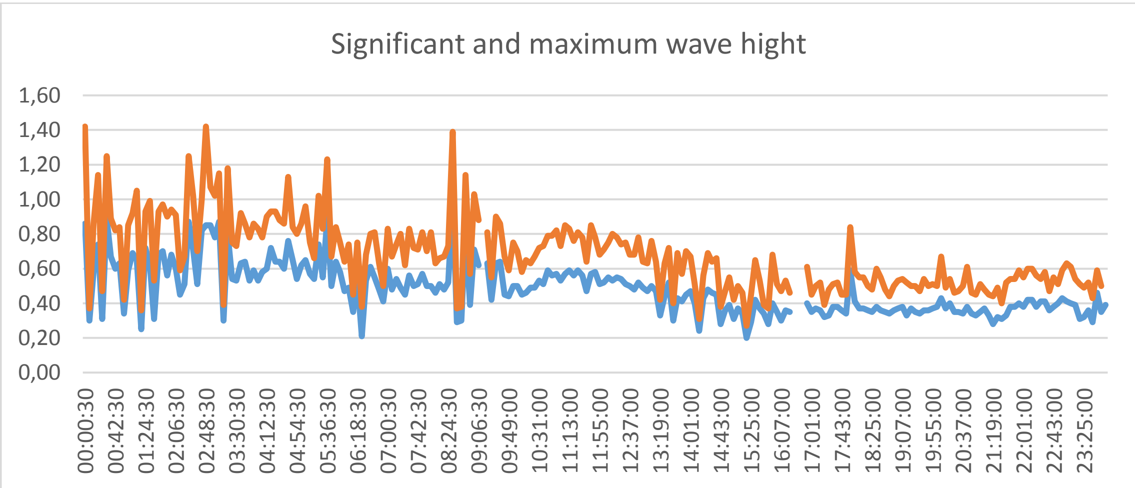

Fig. 5. 10. – Wave's significan hight and wave's maximum hight (Hs and Hmax) recorded in 15.06.2018 at Mangalia's station administrated by GeoEcoMar
(Data obtained with the cordiality of GeoEcoMar)

Conclusions. The data sampled by EO in the vicinity of the Mangalia Port provide the assessment of the water masses, thus emphasizing in the surface layer, certain critical zones in case of the marine hydrological regime intensification, especially in the winter season, under the dominance of the strongest storm winds from NE direction. In the case of the measurement session were observed several special situations, which gives a clear image on the special regime phenomena. The recorded data permits the validation of the MOHID model, applied for the three nested domains, afferent to the BS Basin, Romanian Shelf and Constanta coastal area, for the normal regime, chosen for the measurements interval of normal series of coastal currents and currents inside the port basin, respectively for the time interval of translation to winter season. It can be observed small intensifications of circulation, due to a wind rotation during the interval of validation measurements' experiment, but also due to complex configuration of Constanta Port's sub-basins, in connection with Agigea port and barges' port of the Black Sea – Danube channel.

CHAPTER 6 MARITIME RISK ANALYSIS

Emergency management methods require the combination between different types of information (measurements / data, forecasts, images, maps, etc.), run on complete hardware / software systems / components, all under direct coordination and determination of the human component. They can have the methodological support specific to the following fields:

- ✓ **Geographical Information Systems (GIS)** are part of the widest information systems class. GIS systems necessarily involve the unitary involvement in a unique and non-redundant database of graphical, cartographic, topological and tabular components.
- ✓ **Hydraulic modeling of marine processes**. A hydraulic model, as those presented above, is a system that will transform a series of input data into a set of results to be used in fundamental studies for ports structure design and execution, having a very good applicability in the integrated management of the port / maritime navigation activity.
- ✓ **The map of major storms hazard** is the document that represents the areas potentially affected by waves and currents, being characterized by the following probabilities of overcoming: 0.1% (low probability), 1% (medium probability) and 10% (high probability).
- ✓ **The map of storm risk** is the documentation that indicates, for the vulnerable areas at various probabilities of exceeding the maximum calculation wave, the potential material and human damages at the economic unit’s level in ports, coastal administrative units, etc.

CHAPTER 7 - CONCLUSIONS

The present work has tackled the detailed investigation of marine and coastal hydrology and hydrodynamics, as well as certain hydrodynamic processes associated with maritime ports, processes which can be understood through their complex integration methodologies.

The eventual aim of the study is the presentation of certain ways of optimizing coastal navigation as well as several innovative methodologies, which are also management methodologies for portuary operations. By way of consequence, we have taken into account certain sea-land types of interaction, which a crucial for the spatial maritime process and risk managementin exceptional storm circumstances.

The hydrodynamics of marine portuary areas is a topical problem. It is a problem difficult to solve, because of a lack of systematic measurements carried for the processes that generate the emergence and progress of all sorts of processes related to the waves resonance, but also the currents induced in basins with a complex configuration.

The study of the types of interaction between various chracteristics of wave and current regimen in coastal areas can entail the understanding of the phenomena in their entirety. On the other hand, the obtained results can thus contribute to an enhanced control and optimization of the ways to design the structural and functional extension of the ports. By the same token, the results may contribute to the safety of maritime navigation in ports and the adjacent areas.

Methods of data collection and analysis of information in the marine and coastal environment, as well as the automated calculation methods included in the new ways of integrative approach of the involved processses may generate the understanding of the ways to appropriately manage the characteristics of the ports' shelter areas. Concurrently, various types of numerical modelling, adapted to the portuary basins located in coastal areas may somewhat solve the issue of navigation safety.

Accordingly, the methods presented in the dissertation are derived from the classical approach on marine hydrology, on one hand. On the other hand, though, the methods include the careful implementation of certain interconnected numerical models, which at present are the tools required for the study of the coastal hydrodynamic processes.

By way of conclusion, certain natural or constructive causes can be understood and managed correctly, apart from the great variability of the marine hydrological and/or technological risk phenomena, related to maritime navigation. In the present work, we have systematically shown that such a conclusion was made possible thanks to the analysis of the results obtained through numerical similations of marine and coastal currents changed by the existence of small-depth areas and certain marine/natural and/or navigation obstacles that may occur in the Romanian sector of the Black Sea. Concurrently, the above-mentioned conclusionswas also made possible thanks to the field measurements made with modern, high-resulution equipment.

Personal contribution to the field of research

The present work is only the early stage of a line of research which seeks to be very efficient. Notwithstanding, some of the contributions made for the study of hydrodynamics of coastal areas ought to be mentioned, albeit briefly.

- ✓ The designing of an adequate research strategy tailored for the study of the Romanian maritime ports, including the selection of a work hypothesis and of a series of appropriate methodologies, to go with a fully-fledged study undertaking (carried on a numerical model, and validated through the comparison of the in-situ collected data).
- ✓ Systematizing and processing data and information regarding the characteristics of marine and coastal hydrology,the Romanian Black Sea coast, using international, but also local and regional sources.
- ✓ A synthetic approach of the theories related to the study of marine and coastal processes associated with maritime ports through classical methods, as well as using high-resolution numerical simulations.
- ✓ The field collection and the processing of data, as well as the checking of and the management of the data registered by various oceanographic monitoring devices.
- ✓ The use of a series of methods of statistical calculation of the hydrometeorological time series, registered in marine and coastal stations.

The adequate use of IT methods and instruments for the automated evaluation and calculation of the transformation processes in the case of waves and currents fields in the nearshorebathing area.

- ✓ The processing of entrance data for the initialization of hydrodynamic models – the use of the GIS and remote sensing programmes for the greoreferentiation and topological harmonisation of the spatial data required for the consreuction of geometrical models related to the numerical applications.
- ✓ The construction of several detail sets including updated shoreline and bathymetry data, the consideration of various data and marine meteo-hydrological informations, as well as their updating, with a view to constructing a series of corresponding border factors, the construction of realistic models, resoectively.
- ✓ Identification of data sources provided by various European and international oceanographic/meteorological centers and the purchase, in an adequate format, of the data required for the initialization of the models;
- ✓ Conducting a case study based on 2D and 3D numerical applications, but also carrying field measurements in the Constanta port, using the MOHID program, in three development configurations and levels of calculation, respectively;
- ✓ The sequential implementation of the models, on PC platforms, in order to eliminate distortions, the rolling of numerical routines (the elimination of bugs), testing the models for various configurations and the presentation of data on various spatial scales;
- ✓ The implementation of a waves model for the coastal areas, on a sectorial scale (SWAN), as well as the implementation of a wave automated calculation model in

portuary waters (BOUSS2D) for the study of waves propagation processes at the scale of Constanta Port premises;

- ✓ The evaluation of the influence currents and waves can have on Romanian maritime ports;
- ✓ The validation of circulation and waves models with satellite data sets, data provided by similar models, by various European/international oceanographic services, but also in situ, data obtained as the result of an experiment carried in the field, in the area of Constanta port, with the official approval of APC and ANR;
- ✓ The identification of the limitations imposed by the data and information used, as well as the limitations of the models used in the present research;
- ✓ The identification of an optimization methodology for the methods used in the construction/adaptation of numerical models and the optimization of their applicability for the support of the coastal naviagtion and of various portuary management activities under storm conditins;
- ✓ The outlining of several short, medium and long-term research directions for the study of coastal processes associated with maritime activities.

Future research directions

The present study has met the constraints of the scheduled doctoral research timeframe, but also because of the exceptionally wide scope of the research focus. Accordingly, only a part has been selected, of the discipline components that have been tackled, with the clear purpose of meeting the eventual aim of the present research. Nevertheless, a continuous documentation and investigation will be necessary in order to highlight several other directions the present study may further take.

By way of consequence, research and documentation in the fields we have expored in the present work will have to include components and aspects of a complex approach/in-depth study, as follows:

- ✓ Addressing the aspects related to the monitoring of the vulnerability of portuary basins and their critical zones, induced by marine hydro-morphological processes;
- ✓ Identifying the potential factors with an impact on basins' hydrodynamics and the sediment dynamics, in the area of the navigable waterway and the anchorage areas, as part of the Constanta Port;
- ✓ The anlaysis of the multiannual variation of the Blacl Sea level, reported for the Port of Constanta and corroborated with the CMEMS/altimeter data as well as a fractal analysis of the sea level variations inducd by the undertow waves;
- ✓ A deeper examination of the waves' transformation processes in portuary basins/vertical waves and basins' resonance – correlated with the reported tide-gauge level in Constanta Port's Berth zero and the Agigea Lock;
- ✓ The development and inclusion of a series of assimilation routines of the data reported for the coastal area into prognosis models adapted to coastal processes;
- ✓ The comparative study and the 3D extension of waves models, analysed in their interaction with the coastal currents;
- ✓ The transformation of the intervention methodology based on Artificial Neural Network-type structure algorithms;

- ✓ Testing and adapting the evaluation methodology of the cumulative impact as well as viewing the impact in the ellaboration of anticipatory scenarios based on warning systems in the case of storm/dangerous phenomena;
- ✓ Developing and optimizing the components of the maritime spatial planning system regarding the sea-land interactionprocesses pertsining to the western basin of the Black Sea.

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ANNEX 1 - LIST OF PAPERS

I. PUBLICATIONS IN ISI JOURNALS

1. **E. Vlasceanu**, N. Buzbuchi. (2019). *Application of numerical hydrodynamic models in the study of the marine currents in Romanian black sea area*. **In press** in JEPE journal.

2. Razvan Mateescu, **Elena Vlasceanu**, Liliana Rusu. *Analysis-based results on the delineation of prearrangement areas for marine renewable energy installations in the Western Black Sea Basin*. ICACER 2018, Barcelona, Spain, 6 – 8 April 2018. Editors: W. Cui. E. Rusu. E3S Web of Conferences, Volume 51.

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6. M.-L. Lungu, A. Vasilachi, R. Vlasceanu, R. Mateescu, **E. Vlasceanu,** D. Niculescu, E. Memet. (2015). Hydro-morphological risk phenomena induced by the climatic changes within Romanian Black Sea coastal zone. Journal of Ecology and Environment Protection) Vol 16, (4): 1307-1314, ISBN1311-5065, http://www.jepe-journal.info/vol-16-no-4-2015

7. **E. Vlasceanu**, D. Niculescu, S. Petrisoaia, A. Spinu, R. Mateescu, M.-L. Lungu, A. Vasilache, R. Vlasceanu, E. Memet. (2015). *Romanian shore vulnerability due to storm induced erosion within the last decades. Journal of Ecology and Environment Protection* Vol 16, (4): 1468-1478, ISBN1311-5065, http://www.jepe-journal.info/vol-16-no-4-2015.

II. PUBLICATIONS IN WOS VOLUMES OF CONFERENCES

8. **PhD Student Elena Vlasceanu**, PhD Student Dragos Niculsescu, Dr.Razvan Mateescu, Prof.Dr. Nicolae Buzbuchi (2019). *Complex assessment on the marine hydrologycal variability regime of the western Black Sea coastal zone, its support for the regional Marine Spartial Planning activities.* 19th International Multidisciplinary Scientific Geoconference SGEM 2019, Conference proceedings, Volume 19, Issue 3.1. ISBN 978-619-7408-81-2, ISSN 1314-2704, DOI 10.5593/sgem2019/3.1, pg.97-104.

9. **PhD Student Elena Vlasceanu**, Dr.Razvan Mateescu, Prof. Dr. Nicolae Buzbuchi, *Synergic remote sensing data routines for the validation of the hydrodinamic model's results, applied towards the Romanian maritime ports safe operations*. 19th International Multidisciplinary Scientific Geoconference SGEM 2019, Conference proceedings Volume 19, Issue 2.2. ISBN 978-619-7408-80-5, ISSN 1314-2704, DOI 10.5593/sgem2019/2.2, pg.647-653.

10. *Angela Ivan, **Elena Vlasceanu**. The monitoring of the shoreline evolution adjacent to maritime ports, in the context of marine storms intensification*. The 18th International Multidisciplinary Scientific GeoConference SGEM 02-08 July, 2018, Varna, Bulgaria, research areas: Hydrology and Water Resources, Volume 18, Book 3.1, Pg.745-750, ISBN 978-619-7408-42-3, ISSN 1314-2704, DOI 10.5593 / sgem2018 / 3.1 / S12.097.

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17. **E.Vlasceanu**, D. Niculescu, I. Omer, E. Rusu, A. Ivan. (2015). *Offshore wave regime investigations towards safety port operations in the transitional zone of the Romanian coast.* SGEM Proceedings Volume 2, Issue 3, 2015, pp. 675-682. https://sgemworld.at/sgemlib/spip.php?article6097.

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III. PUBLICATIONS IN BDI JURNALS

19. **Elena Vlasceanu**, Nicolae Buzbuchi, Razvan Mateescu, Alexandra Craciun, Simona Tascu, *Analysis-basedresultsonthewavesmodelapplicationsfor theRomanianshelf.* The 4th International Conference Water Across Time in Engineering Research,21-23 iunie 2018 proceeding, pg. 43, ISBN 978-606-598-663-3, http://revista-constructii.univ-ovidius.ro/conferinte/index.php/publication.

20. Razvan Mateescu, EmanuelaMihailov, **Elena Vlasceanu**. *Earth observation poducts for the validation of the Hydrodynamics model aplications on the Romanian shelf area*. Scientific Conference of Doctoral Schools, SCDS-UDJC-6th Edition, Dunarea de Jos Galati University, 7-8 June 2018, Galati 07/08.06.2018.

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24. RăzvanMateescu, DragoșNiculescu, **Elena Vlăsceanu**, EmanuelaMihailov. (2016). *Specific capabilities to earth observation technologies, created within the COSMOMAR competence center, for the sustainable development of Romanian marine and coastal areas.* Buletin AGIR nr. 3, ISSN – L 1224-7928. http://www.buletinulagir.agir.ro/articol.php?id=2801

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27. **Elena Vlasceanu**, DragosNiculescu, Nicolae Buzbuchi. (2014). *Numerical modeling of hydromorphological processes, a scientific tool of environmental engineering and its applications in the reconstruction of deltaic coastal areas with intense sedimentation.* Buletinul AGIR nr. 4, pp. 12-16 http://www.agir.ro/buletine/2153.pdf.

28. R. Mateescu, D. Niculescu, **E. Vlasceanu**, Conf. Univ. Dr. Ing. Ichinur Omer. (2014). *Use of automatic flight systems in integrated coastal zone surveillance*. Buletinul AGIR nr. 4, pp. 65-69. http://www.agir.ro/buletine/2163.pdf

ANNEX II - PARTICIPATION IN RESEARCH PROJECTS

1. **iSWIM** - integrated Service for Water Quality Monitoring in Mamaia bay**http://iswim.rmri.ro/**
2. **SkyFISH** - Service for water quality monitoring for sustainable fishing in Romanian Coastal Area Project, http://skyfish.terrasigna.com/
3. **Ro-CEO** – Romanian Cluster for Earth Observation; https://www.ro-ceo.ro/
4. **ECOAST** – New methodologies for an ecosystem approach to spatial and temporal management of fisheries and aquaculture in coastal area;
5. **ECORYS** – Assistance Mechamism for the Implementation of Maritime Spatial Planning;
6. **COSMOMAR** – Constanta Space Technology Competence Centre Dedicated to the Romanian Marine and Coastal Regions Sustainable Development;
7. **MARSPLAN-BS** -Cross-Border MARitime Spatial PLANning in the Black Sea;
8. **ECOMAGIS** 69/2012," Implementation of a complex geographic informatic system for ecosystem-based management, through integrated monitoring and assessment of the biocoenosis status and its evolution trends in a fast-changing environment at the Romanian coastal zone of the Black Sea" http://ecomagis.rmri.ro/