Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 51-30 (2018) 366–371

New approaches and mathematical models for environmental risk management in seaports

A. Kortcheva*, V. Galabov*, J. Marinski*, V. Andrea** and C. Stylios**

*National Institute of Meteorology and Hydrology,Bulgarian Academy of Sciences, Bulgaria (e-mail: anna.kortcheva@meteo.bg, vasko.galabov@meteo.bg, jordan.marinski@meteo.bg)

** Department of Computer Engineering, Technological Educational Institute of Epirus, Arta, Greece (e-mail: stylios@kic.teiep.gr , vandrea@kic.teiep.gr

Abstract: Seaports and surroundings areas environmental conditions are depending on meteorological and oceanographic conditions that affect their infrastructure and also their operations. The increase of marine traffic in the Black Sea Basin has raised issues concerning the environmental quality of coast areas and the sea water. Therefore, accurate and timely predictions of extreme weather and sea state are important for efficient port management in terms of safety, while they are also significant for the sustainable development and environmental quality of seaports and their adjacent coastal areas. The aim of this paper is to present an innovative, fully automated marine monitoring system for the Black Sea Basin, which is able to provide real time monitoring and analysing historical data of wind, wave, storm-surge and oil spill drift. The system is based on advanced numerical models and ICT tools for simulation and visualization of essential information, including early warnings for marine extreme phenomena and hazards. Within ECOPORTIL project new ICT tools will be developed to provide online training and capacity building of stakeholders and decision makers in order to improve their knowledge on legislation issues and adopt good environmental practices.

Keywords: Environmental sustainability, seaports, Black Sea, numerical modeling, wind-waves, oil-spill.

1. INTRODUCTION

The Black Sea is a semi-enclosed basin, situated between latitudes 40°55N - 46°37N and longitudes 27°27E - 43°47E. (Fig.1). It covers an area of 423 km² and has a mean depth of 1,197 m and the greatest depth is 2,258 m. At the Bulgarian coastline there are two main seaports namely, Burgas and Varna and many protected coastal and sea areas along the Bulgarian coastal zone.

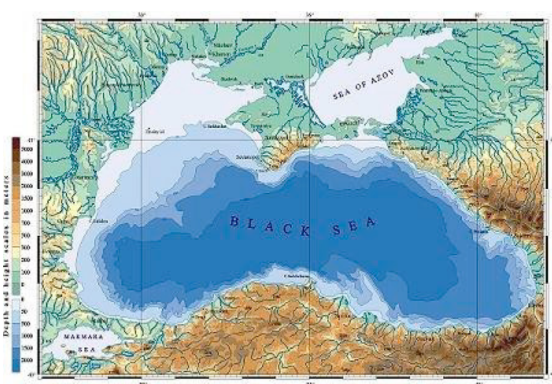

Fig. 1. Bathymetry and location map of the Black Sea.

Specific features of the Black Sea make it very vulnerable to disturbances regarding the natural environment and the ecosystems of the broader area. In recent years economic activities in the Black Sea have been steadily increased, resulting in increased ship traffic (Rata et. al, 2017), and port activities. Consequently, critical issues are raised related to the environmental quality of coasts and sea water. Figure 2 depicts a very high shipping traffic density (red colour code) in the western part of the Black Sea.

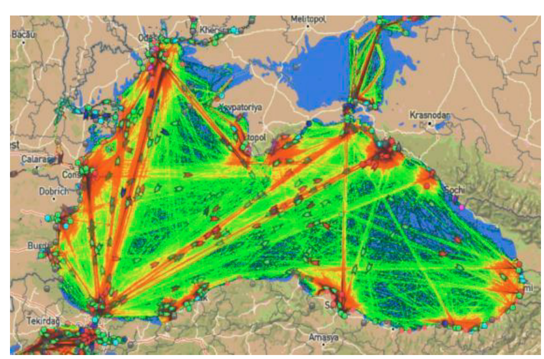

Fig. 2. Black Sea maritime traffic density for the period 2015-2016 from the satellite navigation tracking service *marinetraffic.com*.

On the other side, seaports are subject to severe meteorological and oceanographic conditions that affect their infrastructure and operations. Thus, accurate and timely forecasts of extreme weather and sea conditions are important for safe, efficient and environmentally responsible port management (Kolios and Stylios, 2015). Moreover, acquiring these kind of data is of outmost importance also as regards

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2018.11.333

sustainable development of seaports and their adjacent coastal areas (Kolios *et al*., 2017). In particular, as winds and waves constitute the major factors that affect ship performance, the provision of a reliable wind-wave forecast is a key tool when planning the optimum ship weather route. On these grounds, it would be feasible to minimize environmental impact such as fuel consumption and CO_2 emissions from ships, to reduce potential pollution causes and also to reduce the harmful environmental impacts.

Weather forecasting and marine predictions have become the basis of multi-hazard warning systems (Baklanov *et. al*., 2018). In fact, these kind of predictions enable the detection of possible hazardous events while at the same time they tend to provide sufficient lead time in order to organize effective emergency plans and operations (Mehiriz and Gosselin 2016). Preparedness to natural and man-made disasters by the use of multi-hazard warning systems is a key element in disaster risk reduction, while it is acknowledged that multilateral, international and governmental cooperation is vital to meet the high operational standards required in case of emergencies (Haigh *et al*., 2018).

The present paper describes the existing marine forecasting system of the Black Sea, operated by the Bulgarian National Institute of Meteorology and Hydrology (NIMH). In particular, through the use of the marine forecasting system, the NIMH is able to provide real time forecast of wind, waves, storm surge and pollutant drifts within the broader area of the Black Sea. According to Kolios *et. al* (2015), accurate forecasting of sea conditions and adequate forewarning, both constitute a significant tool that can be used for disaster risk reduction namely in terms of vulnerability and risk management of hazards to people, ports equipment and infrastructure and of course as regards the natural environment. Not mention, that the multi-hazard warning system, via the provision of climatological data developed by numerical models, is also used for the efficient management of the coastal zone activities. Added to forecasts, numerical models can be used in hindcast approach to generate climate data archives to develop historical marine environmental data on hydro-meteorological extremes; while they were proven to be reliable, cost effective and time saving tools in dealing with coastal problems (Thomas and Dwarakish, 2015).

The paper highlights the important role of early warning systems as regards the hydro-meteorological hazards and numerical modeling in disaster risk reduction. It is also underlined the supportive role that early warning systems hold towards sustainable management of ports and their broader coastal areas on the grounds of 2030 Agenda for Sustainable Development of the United Nations. Finally, the possibilities of implementing the ICT tools are further discussed, as they are widely used in marine forecast and also within educational and training activities under ECOPORTIL project. Indeed, web-based GIS, numerical simulation technologies and state of the art visualization schemes of environmental parameters (e.g. oil spill simulations) are going to be utilized in the frame of ECOPORTIL for the training and capacity building of stakeholders and decision makers in order to improve their knowledge on legislation issues and adopt good environmental practices. The aforementioned endeavour is designed by a special consortium consisting of marine, ICT and environmental specialists and aspires to improve the skills and qualifications of port managers and the relative interest groups for an integrated and sustainable port - coastal management.

2. A MARINE CONDITIONS MONITORING SYSTEM

The marine monitoring and short-range forecasting system is a result of the scientific collaboration between NIMH and Meteo-France. The system has been in operation since 1996 and has been continuously upgraded with new versions of atmospheric and marine numerical models and cutting edge satellite technologies. The automatic system (Fig. 3) consists of several interconnected operational modules of numerical models. The system includes the limited area numerical weather prediction model ALADIN, wave model SWAN, storm-surge model of Meteo-France and the oil spill drift numerical model MOTHY. The system produces the basic forecasting variables such as winds at 10m level, atmospheric pressure, waves and storm-surges. In practical application the system includes oil spills drift prediction model. The main features of the system are based on the fact that it is based on well calibrated numerical models and on an existing real time control software technology. Indeed, it combines the atmospheric input data preparation (pre-processing), numerical hydrodynamic simulations (processing), output data preparation and visualisation (post-processing), and dissemination of the results to the end-users (Dimitrova *et al.,* 2013). The fully automated system is able to provide 72 hour forecasts of wind, waves, storm-surges and oil spill drift. Furthermore, the system uses advanced numerical models and information and communication technologies (ICT) tools for simulations, visualization and dissemination of user-oriented information, including early warning for marine extremes and hazards.

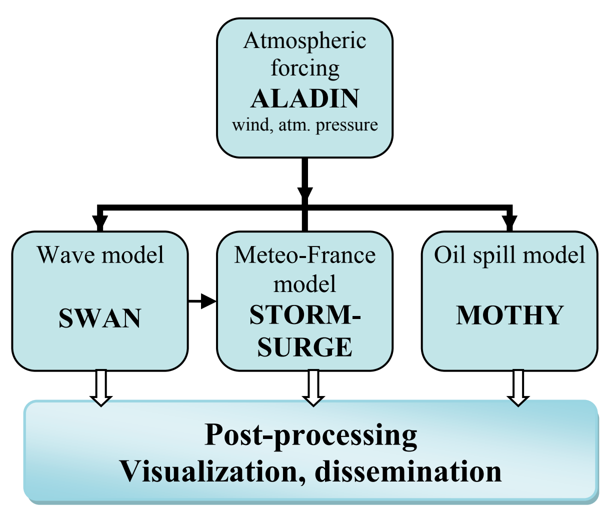

Fig. 3. Flowchart of the marine monitoring and short-range forecasting system

The system is part of the national multi-hazard early warning system for the coastal natural and man-made hazards or upcoming severe weather and hydro-meteorological hazards (strong winds, high waves and sea level rise due to storm surge) along the Bulgarian coastal zone of the Black Sea (Kortcheva *et al*., 2017).

Moreover, the hydro-meteorological hazards related to storms in the Black Sea are strong winds, high waves and storm-surges. More specifically, as regards storm surge and waves, these are strongly dependent on the wind intensity. NIMH research has mainly contributed to numerical sea state forecasts for the Black sea using the spectral wave model SWAN (Booij *et al*., 1999). SWAN is a third-generation stand-alone (phase-averaged) wave model that can be used to predict wave conditions. It solves the spectral action balance equation that describes the evolution of spectrum of random short-crested wind generated waves in time and space. SWAN includes the physical processes that accounts the wind input, whitecapping, bottom friction, depth-induced wave breaking and nonlinear wave-wave interactions in coastal and inland waters. The wave model SWAN is used to produce an operational 72 hour wave forecast for the Black Sea in terms of significant wave height (SWH) and mean direction of wave propagation. Figure 4 depicts the visualization of SWAN model 24h wave forecast for the Black Sea valid for 30 May 2018 00.00 UTC. The static maps (Fig.5) can be presented in correlation with time and be attributed with an animation effect (www.meteo.bg). Moreover, SWH is defined as the average of the highest one-third of all waves. In addition, wave heights are described in meters and are measured from trough to crest.

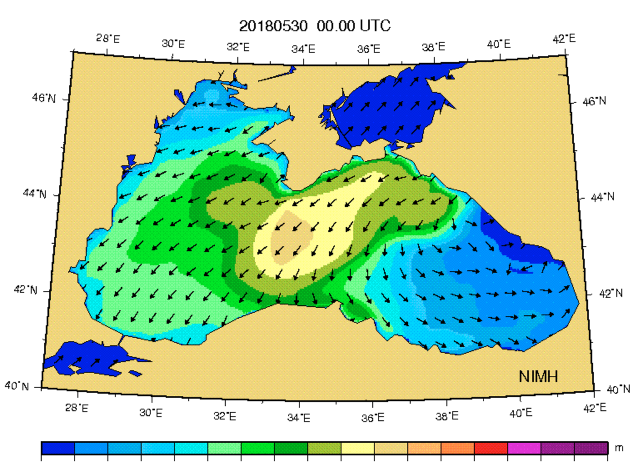

Fig. 4. SWAN modeled SWH and mean direction (24 h forecast for the Black Sea).

Calibration and verification of the model was performed for selected storm events, based on the available historical observations and satellite derived altimeter data. It can be concluded that the results of the system for the Black Sea provide interesting data that can be used for future applications (Galabov *et al*., 2015). NIMH provides to ports of Varna and Burgas with regularly updated high-resolution 72 hours forecasts that include important information for marine and weather conditions; These forecasts assist port managers to plan daily and future activities and operations, while the acquired information also allows the monitoring of weather conditions, something that is really important in order to secure the entry of the ships into the port.

The establishment of a high resolution weather and marine monitoring and analyzing service along with the operation of early warning systems should be taken into account when planning the optimal vessel routing and also in order to enhance safety measures; moreover, an integrated plan for sustainable port management can also lead to fuel efficiency, minimizing pollution and harmful environmental impacts (van Dongeren *et al*., 2018). An increasing tendency concerning the use of oceanographic parameters including wind and wave information has been observed in order to upgrade safety standards in ports. This is due to the fact that this kind of information provides the managers with effective tools for effective planning and maintaining coastal structures and operations.

According to the Sustainable Development Goals of the UN Agenda 2030, information on extreme wave climate is of vital importance for coastal and marine activities. The monitoring of environmental parameters is an essential part of integrated port management; however oceanographic observations, as well as observations of surface wave parameters, are insufficient for the western part of the Black Sea.

Apart from forecasts, numerical modeling has many other applications and uses. Not mention that far from forecasts, numerical models can be also used for hindcast. The hindcast approach requires the running of ocean models for long past periods of time (typically several decades long), serving as an atmospheric forcing the available reanalysis data, to generate archives of climate data for extreme value analysis (Neykov *et al*., 2017). The storm surge is the component of the sea water level caused by synoptic variations of atmospheric pressure and wind. Combination of high winds and low atmospheric pressure leads to increased water levels at the coasts. Wind waves and elevated water levels together can cause flooding events in low coastal areas. The operational forecasting storm surge model of Meteo-France was adopted for the Black Sea (Mungov *et al*., 2000) in order to predict storm surges along the coastal zone of Bulgaria. The modification of the model (Galabov *et al*., 2017) consists in one way coupling between the storm surge and the wave model. The calibration and validation of the storm-surge model was performed using available in situ sea level observations from the tide-gauge stations along the Bulgarian coast, during the storm events (Bresson *et al*., 2018).

Currently the storm-surge forecast is used for the issuing of flood risk warnings in low-lying coastal areas in the western part of the Black Sea. It is planned to use the storm-surge and wave modelling for the coastal flood risk mapping, according to EU Floods Directive (EC, 2007) for the assessment and management of flood risks.

Furthermore oil spill monitoring and numerical modelling plays an important role in developing of an oil spill response mechanism and also in establishing a contingency plan to deal with potential catastrophic accidents. After a possible spillage of oil, authorized bodies require prompt and adequate information on oil spill behaviour in the next hours or days; this information will serve in order to efficiently plan and implement major actions for the minimization of the negative environmental impacts. Mathematical modelling and computer simulation of oil distribution are the crucial factors to solve the problem. NIMH is responsible for marine oil pollution issues on a national basis.

NIMH provides oil spill drift forecasts to assist relative authorities that are also responsible to manage accidental marine pollution. The system is activated when an actual oil spill is detected. The oil drift forecast is carried out by means of a numerical model, named MOTHY, describing the ocean dynamics and the behaviour of the oil spill over time. The numerical model MOTHY has been developed by Meteo-France (Daniel, P., 1999) and implemented for the Black Sea. The model was used (Daniel et al, 2005) in a few well documented pollution incidents such as Erika (December 1999) and Prestige (November 2002). The MOTHY model system consists of a model for the two-dimensional wind currents and a model for oil spill drift prediction. The 2D model is forced with atmospheric forecast field variables (wind at 10m and atmospheric pressure) from the limited area numerical weather prediction model ALADIN. The wind currents model is depth-integrated and solves the shallow water equations on a regular spherical grid. The shear current is calculated for each droplet by a bilinear eddy viscosity model. The oil slick is modelled as a distribution of independent droplets that move in response to currents, turbulence and buoyancy (Daniel et al, 2005). The larger (more buoyant) droplets tend to remain in the surface layer whereas the smaller droplets are mixed downwards. In general, about 65 to 70% of the droplets remain on the sea surface. If a droplet is moved on to land, then that droplet is considered beached and takes no further part in the simulation. Galabov *et al.* (2013) summarizes the key features of the MOTHY model and presents some examples of model applications. Modelled simulations are visualized through the GMT tools (Fig. 5) and use Google Earth information (Fig. 6).

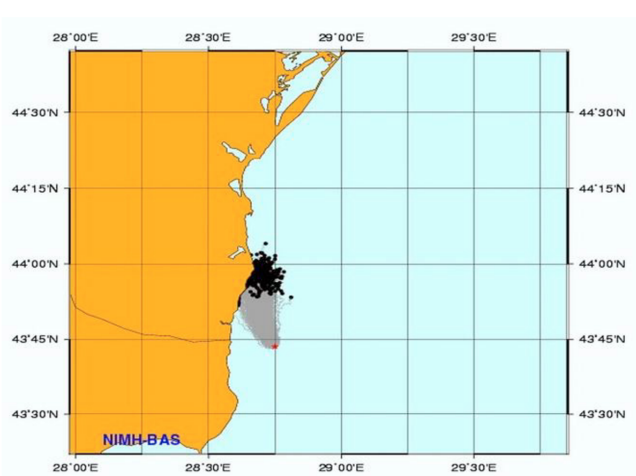

Fig.5. Simulation of an oil spill. The red star is the starting point, black spots figure the final position of the slick.

Visualization of an oil pollution simulation based on the model MOTHY for the Burgas bay is presented in Fig.6. The yellow dot gives the initial position of the spill. The trajectories of the droplets are in red and their final positions are in blue. The simulations indicate the places recorded as of high risk for oil pollution. Accurate and timely prediction of oil pollution is crucial for successful decision-making and planning of operations to reduce pollution of the coastal areas and enhance environmental protection on the whole. The advanced mathematical models are extremely useful for the planning, organization and implementation of appropriate measures for the management of accidental spills of oil and other pollutants in the seas.

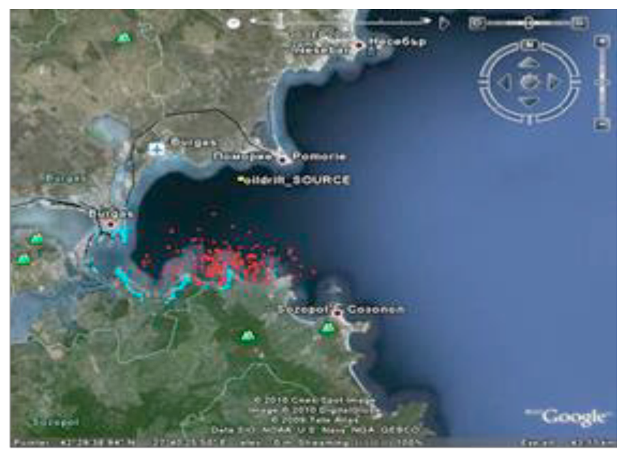

Fig. 6. Hypothetical oil pollution accident simulation for the Burgas bay based on MOTHY model.

3. ECOPORTIL PROJECT

Environmental Protection of Areas Surrounding Ports using Innovative Learning Tools for Legislation (ECOPORTIL) project aims to enhance sustainable and integrated management of ports and coastal areas. An important focus of the project is to incorporate efficient environmental risk management policies and particular strategies in a holistic approach towards effective port and coastal management. Therefore the project aims to improve the environmental quality of ports and their surrounding coastal environment by supporting their sustainability, through the implementation of modern methodologies and good practices according to European Union (EU) and national legislation of the participating countries, as well as through innovative tools and methods for the training and capacity building of stakeholders in the ports and nearby coastal zones; the project is expected to serve as a prevention measure of environmental pollution and preservation of natural maritime resources. ICT tools such as web-based GIS, numerical simulation technologies and visualization of the environmental parameters, widely used in marine monitoring systems within ECOPORTIL project activities.

Fig. 7. Burgas port area with eco-mapping points of interest.

Indeed, the project includes the development and integration of the existing transnational systems, procedures and early warning systems regarding environmental hazards and risk assessment, planning methodologies, management plans, sustainability and adaptation assessments. Through this integration procedure the design and implementation of a Geographical Information System for the optimal visualization of environmental parameters will follow in order to monitor the environmental conditions in the port broader areas; the scope of this interpretation is to highlight vulnerable areas and activities which highly affect the environmental profile in the regions of interest. The environmental needs and requirements for eco-mapping will be geo-referred and described, including and visualizing real-time and archive data.

It is thus of outmost importance that ECOPORTIL is expected to contribute towards a sustainable maritime sector able to balance between the needs of shipping transportation, the commercial port activities and the environmental protection measures and EU/national legislations. The sustainable Blue Growth, the main objective of Europe 2020 strategy. The introduction of the environmental management systems (EMS) in the maritime sector and port related activities with the contribution of ICT tools and integrated training education and lifelong learning methods/ practices for these sectors is considered of great importance towards Blue Growth and the resilience to climate change.

4. CONCLUSIONS

Coastal areas and sea waters have always been areas of high social, financial and environmental interest. Extensive concerns about sustainable utilization of natural resources and preservation of environmental quality constitute issues than stand at the top of agendas for decision makers. Resilience increasing strategies for coasts are part of effective integrated environmental management of ports and coastal areas; while effective planning requires realistic information about the state of marine environment, its changes and extremes. Therefore, marine forecasting systems and numerical modelling are appropriate tools able to meet high standards and requirements for environmental protection and sustainable development as well.

It is important for modern green ports to establish not only weather station networks for monitoring, but also to promptly use the products arising from numerical models of weather and marine monitoring systems (Anastasopoulos *et al.,* 2011). This will contribute to decreasing or preventing impacts from extreme weather phenomena and accidents that can lead to serious environmental disasters.

Safety, efficiency and environmental management of port activities can be improved through a better knowledge and understanding of environmental conditions, including early warning for marine extremes and natural and man-made hazards.

In addition to this, it is of outmost importance to provide the end-users with simple and clear information on hazards, vulnerabilities, risks, to inform them as well for methods and action that should be taken in order to reduce disaster impacts. Information technologies capable of disseminating user-oriented information that is based upon the wave monitoring and analyses while oil-spill drift simulations will be applied within the project ECOPORTIL to increase the risk knowledge and raise awareness on natural disasters.

The implementation of the relative legislation, measures, directives and strategies designed to prevent pollution and environmental protection is associated with difficulties due to voluminous and complex national and international environmental legislation (Long, R. 2011).

ACKNOWLEDGEMENTS

This work was conducted within the framework of the project ECOPORTIL with code BMP1/2.3/2622/2017 (Environmental Protection of Areas Surrounding Ports using Innovative Learning Tools for Legislation), which was funded by Transnational European Programme INTERREG Balkan-Mediterranean 2014-2020.

REFERENCES

Anastasopoulos, D., Kolios, S., Stylios, C., (2011). How will Greek ports become green ports. *Geo-Eco-Marina* 17, 73-80.

Bogathev, A. (2008). Changes in operational suite of ALADIN-BG. *ALADIN Newslettet,* 34, 20-24.

Baklanov, A., Grimmond, C.S.B., Carlson, D., Terblanche, D., Tang, X., Bouchet, V., Lee, B., Langendijk, G., Kolli, R.K., and Hovsepyan, A. (2018). From urban meteorology, climate and environment research to integrated city services. *Urban Climate*, 23, 330-341.

Booij, N., Ris, R.C., and Holthuijsen, L. H.(1999). A third generation wave model for coastal regions. Part 1: model description and validation. *J. Geophys. Res*.104, 7649-7649.

Bresson, E., Arbogast, P., Aouf, L., Paradis, D., Kortcheva Dimitrova, M., Kortcheva, A., and Galabov, V. (2013). Validation of the operational wave model against altimetry data from Jason2 satellite. *Bulgarian Journal of Meteorology and Hydrology*, 18/1-2, 4-10.

Daniel, P. (1999). Operational forecasting of oil spill drift at Meteo-France. *Spill Sci Technol.* B3(1/2), 53-64.

Daniel, P., Josse, P., and Dandin, P. (2005). Further improvement of drift forecast at sea based on operational oceanography systems. *Coastal Engineering* VII, *Modelling, Measurements, Engineering and Management of Seas and Coastal Regions*, 13–22.

European Commision (2000), Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000, establishing a framework for Community action in the field of water policy (Water Framework Directive). *Official Journal of the European Union,* L327, 1-72.

European Commision (2007), Directive 2007/60/EC of the European Parliament and the Council of 23 October 2007, on the assessment and management of flood risks (EU Floods Directive). *Official Journal of the European Union,* L288, 27-34.

European Commision (2008), Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008, establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official Journal of the European Union,* L164, 19-40.

Galabov, V., Kortcheva, A., Kortchev,G., and Marinski, J. (2013). Contamination of Bourgas Port Waters with Oil, *Proc. Global Congress on ICM: EMCES10, Medcoast 2013 joint conference*, Marmaris, Turkey, 1077-1079.

Galabov,V.**,** Kortcheva**,** A**.**, Peneva, E., Kortchev, G., Dimitrova, M., and Marinski, J. (2015). Application of Hydrodynamic, Pollution Drift and Wave Models as tools for Better Environmental Management of Ports. *Sustainable Development of Sea-Corridors and Coastal Waters, Book chapter: 8, Springer International Publishing*, doi:10.1007/97833191138528, 69-76*.*

Galabov, V.**,** Kortcheva, A.**,** Bogachev, A.**,** and Tsenova, B. (2017). Investigation of the hydro-meteorological hazards along the Bulgarian coast of the Black Sea by reconstructions of historical storms. *Journal of Environmental Protection and Ecology*, 16, 3, 1005-1015.

Haigh, R., Amaratunga, V., and Hemachandra, K. (2018). A capacity analysis framework for multi-hazard early warning in coastal communities. *Procedia Engineering,* 212, 1139-1146.

Kolios, S. and Stylios, C. (2015). *Coastal Marine Environment Monitoring Using Satellite Data Derived from MODIS Instrument*, Chapter 14, In: C.D. Stylios, T. Floqi, J. Marinski, L. Damiani (Eds), Sustainable Development of Sea-Corridors and Coastal Waters: The TEN ECOPORT project in South East Europe, pp. 125-131 Springer, London, ISBN 978-3-319-11384-5.

Kolios, S., Stylios, C., and Petunin, A. (2015). *A WebGIS platform to monitor environmental conditions in ports and their surroundings in South Eastern Europe*. Environmental Monitoring and Assessment, 187:574, DOI 10.1007/s10661-015-4786-x

Kolios, S. Vorobev, A. Vorobeva G. and Stylios, C. (2017). *GIS and Environmental Monitoring: Application in the Marine, Atmospheric and Geomagnetic Fields,* Springer, ISBN 978-3-319-53084-0.

Kortcheva, A., and Galabov, V. (2017). GIS-based visualization of Numerical wave forecast for the Black Sea. *Bulgarian Journal of Meteorology and Hydrology*, 22, 18-26.

Law on the Maritime Spaces, Inland Waterways and Ports of the Rebublic of Bulgaria (2000). *State Gazette,* No 12, 11th February 2000.

Long, R. (2011). The Marine Strategy Framework Directive: A new European approach to the regulation of the marine environment, marine natural resources and marine ecological services. *Journal of energy and natural resources law,* 29(1), 1-44.

Mehiriz K., and Gosselin, P. (2016). *Municipalities' Preparedness for Weather Hazards and Response to Weather Warnings.* PLoS ONE, 11(9): e0163390. https://doi.org/10.1371/journal.pone.0163390

Mungov, G., and Daniel, P. (2000). Storm surges in the western Black Sea. Operational forecasting. *Mediterranean Marine Science*, 1(1), 45-50.

Neykov, N.M.**,** Galabov, V.**,** Korcheva, A.**,** and Neychev,P. (2017*)*. Return value estimates of significant wave height along Bulgarian Black Sea coast. *Bulgarian Journal of Meteorology and Hydrology*, 22, 1-2, 2-17.

Rata, V., Gasparotti, C., and Rusu, L. (2017). The importance of the reduction of the air pollution in the Black Sea basin. *Mechanical Testing and Diagnosis*, 2.

Thomas, T.J., and Dwarakish, G.S, (2015*). Numerical Wave Modelling – A Review,* Aquatic Procedia, 4, 443-448.

Wessel, P., Smith, W., Scapirpo, Lous, R., J., and Wobbe, F. (2013). Generic Mapping Tools Improved version. *EOS Trans. AGU,* 94(45), 409-410.

van Dongeren, A., Ciavola, P., Martinez, G., Viavattene, C., Bogaard, T., Ferreira, O., Higgins, R., and McCall, R., (2018). *Introduction to RISC-KIT: Resilience-increasing strategies for coasts*, Coastal Engineering, 134, 2-.4.