# Chapter 8
# Application of Hydrodynamic, Pollution Drift and Wave Models as Tools for Better Environmental Management of Ports

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**Abstract** Numerical modelling provides additional information useful for implementation of the sustainable model for environmental-friendly development of the port networks. This chapter presents an improved modelling approach using better interconnections between the components of the system. The input data has been produced by the usage of an operational hydrodynamic model for the areas in the vicinity of ports, which makes the system applicable in case of extreme situations. This provides the decision makers with examples of worst-case scenarios of pollution drifts during extreme cases like combinations of strong winds, high waves and storm surges.

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## 8.1 Introduction

Providing information about the vulnerability in case of storm weather and oceanographic conditions is essential for the proper environmental management of ports. One of the major problems along the coast is the insufficient data sets of measurements. Numerical modelling provides additional information useful for implementation of the sustainable model for environment-friendly development of the port networks. Ports are vulnerable to severe meteorological and oceanographic conditions that may affect their operability and may increase the environmental risks due to increasing probability for disasters in ports and in the coastal areas. The capabilities to monitor such conditions are limited and therefore the numerical modelling is the primary tool to assess and predict such extreme situations. The study of these extreme situations is important for efficient environmental management of port areas. The output of such 2D and 3D hydrodynamic, pollution drift and wave models in case of severe weather may be used by the port authorities to improve the preparedness and awareness in case of extreme hydro-meteorological events (extreme winds, waves and storm surge sea level rise) by means of proper forecasts. In our previous study (Galabov et al. 2012a, 2013), we evaluated the risk of oil pollution for the Port of Bourgas in case of ship accident under normal meteorological conditions using climatic data for the sea currents. This chapter presents an improved modelling approach using better interconnections between the components of the system and hydrodynamic model data as an input to the system. The input data has been produced by the usage of an operational atmospheric and hydrodynamic models for the areas in the vicinity of ports, which makes the system applicable in case of extreme situations, because it provides the decision makers with examples of worst case scenarios of pollution drifts during extreme cases of combinations of strong winds, extreme waves and storm surge.

## 8.2 The Modelling System

The meteorological and oceanographic conditions in case of extremes may increase significantly the probability for the occurrence of accidents not only in open waters, but also in harbours, ports and in the coastal area outside the ports. Some notable examples of accidents with oil pollution, caused by extreme weather and sea hazards that are further worsened by the weather conditions include the Prestige accident in 2002, the Erika Accident in 1999 and more recently the Kerch Strait disaster (Matishov et al. 2013). The studies (Daniel et al. 2004) of such accidents confirmed that proper numerical simulation of the winds, sea waves and currents are crucial not only prior to the accident, but also during the liquidation of consequences.

Based on the knowledge gathered during such cases and the practices in other countries, we implemented the modelling system consisting of the following four components:

- *A hydrodynamic 3D model* for the Bay of Bourgas and the Bay of Varna with high spatial resolution nested within a lower resolution hydrodynamic model for the entire Black Sea. The coarser resolution model for the entire Black Sea is the NEMO model (Nucleus for European Modelling of the Ocean; Madec 2006). The model to represent adequately the Black Sea hydrodynamics has to permit eddy resolving resolution. It also has to provide a good representation of the vertical processes in order to represent adequately the stratification, the permanent picnocline and the existence of a layer of cold intermediate water persisting during the summer. It also has to represent the fresh water inflow in the northern part of the western Black Sea shelf and the Bosporus plume of Mediterranean saline water. The NEMO model is such a model—a primitive equation model—adapted not only to global, but also to regional scales. The setup of the model for the entire Black Sea is with a spatial resolution of 1/27 by 1/36° in zonal and meridional directions (about 3 km horizontal resolution) and 31 vertical levels. It is initialized by the monthly mean temperature and salinity 3D fields. The atmospheric forcing comes from the operational model of the European Centre for Medium Range Forecasts (ECMWF): the output is every 6 h with 0.25° resolution, including information about the air pressure, temperature, humidity and wind on the sea surface, as well as cloud cover. In order to ensure the fresh water fluxes budget vs. evaporation, the ECMWF precipitation is used and also the river runoff of 40 rivers along the Black Sea coast. The runoff is balanced by the Bosporus Straits transport, which is treated in the same way as rivers. The areas of the bays of Varna and Bourgas are resolved with a horizontal resolution of 20” (approximately 500 m) using a nested GETM model (General Estuary Transport Model; Bruchard and Bolding 2011) due to the fact that it is more adapted for such shallow water areas and includes the flooding and drying mechanism. The NEMO model was integrated for 2012 and the results represent adequately the seasonal variation in the Black Sea circulation. The dominating Rim current is evident, enhancing the speed in winter. Around Cape Kaliakra the current accelerates throughout the year (Fig. 8.1).

The implementation of NEMO and GETM for the port areas provides a state of art information for the sea currents, temperature, salinity and other hydro physical fields in terms of climatic seasonal means and actual values during extreme sea storms. The model output serves as an input to the wave model and the pollution drift model. Example of the output of the model is presented in Fig. 8.1 for the currents during the extreme storm of February 2012 and the variation of the current speed for a selected point (location of a ship accident that is mentioned later in the chapter). The atmospheric forcing that is used in the frame of the present study is the operational model of the European Centre for Medium Range Forecasts (ECMWF) for the entire system when we are evaluating potential pollution scenarios or the operational regional model of NIMH-BAS which is an implementation of the ALADIN Model—for more details see Bogatchev (2008), for operational forecasts.

- *A sea wave model* implemented for the western part of the Black Sea is SWAN (simulating waves nearshore; Booij et al. 1999). The SWAN model provides

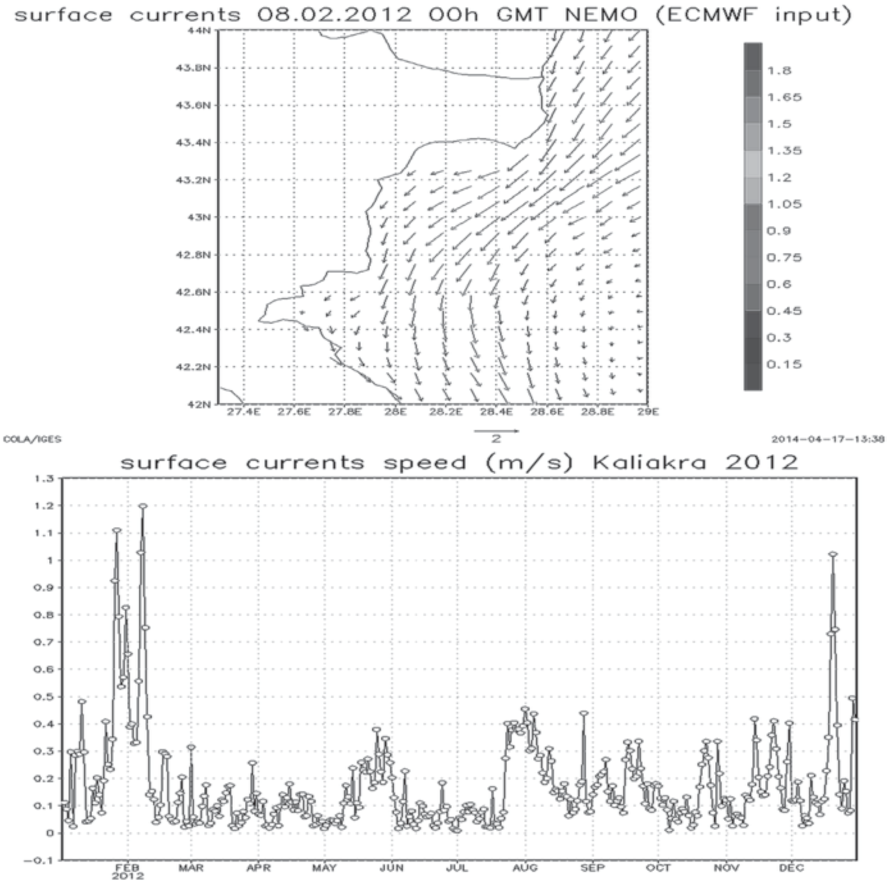


**Fig. 8.1** The NEMO hydrodynamic model: *the upper graphic*—the surface currents during the storm of 06–08 February 2012 around the Bulgarian coast; *down*—the current speed variation during 2012 for a point close to Kaliakra Cape—notice the significant difference of the current speed from the mean seasonal value

forecast of significant wave height and direction for the whole area and time series for the wave heights at the entrance of three ports: Bourgas, Varna and Constanta (Fig. 8.2—the upper three graphics).The model has been validated and calibrated for the open sea, using satellite data and coastal locations, using the observations in the coastal stations of NIMH-BAS (Galabov et al. 2012b). SWAN is also used for similar systems providing sea state information for the needs of ports like the systems presented in Rusu and Guedes Soares (2011, 2012). The operational SWAN implementation is based on SWAN version 40.91. The horizontal resolution is 1/30°. Also for the Bays of Bourgas and Varna a nested implementations are available with a horizontal resolution of 1/180° (approximately 3 km).

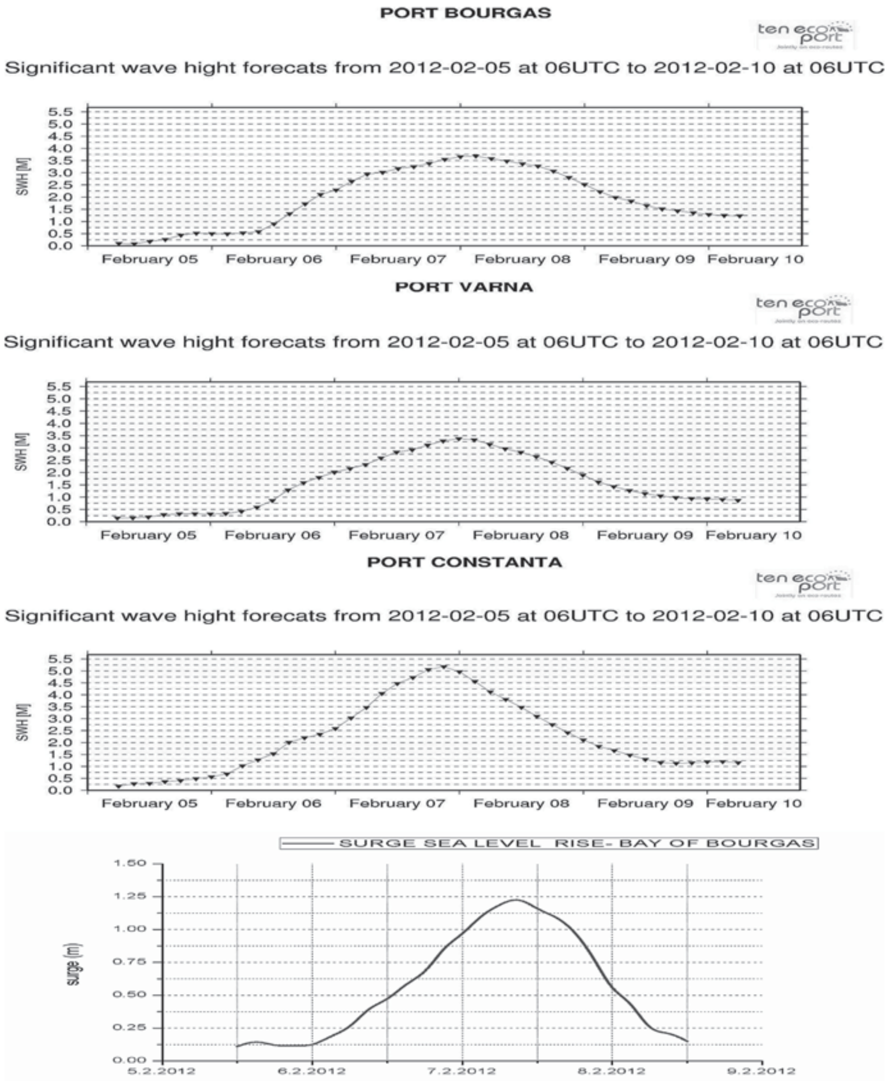


**Fig. 8.2** The storm of 06–08 February 2012: the first three graphs represent the forecast of the significant wave height at the entrance of the ports of Constanta, Varna and Bourgas. The last graph represents the storm surge forecast for the area of the port of Bourgas and the town of Bourgas

- *A storm surge model* implemented for the Black Sea by Mungov and Daniel (2000). The modification to the model consists in the interconnection (one way coupling) between the storm surge and the wave model. In order to account properly the air–sea interaction we use the sea state parameters and wave radiation stress in the storm surge model. An example of the model time series output for the area port of Bourgas is shown in Fig. 8.2 (the last graph). Together with the previous two graphs, these are examples of an extreme weather and sea situation, causing significant damages around the Bulgarian coast.

- *The MOTHY model* (Daniel 1996). The model simulates the evolution of oil spills and other floating pollutant spills. In our previous research (Galabov et al. 2012a, 2013) we evaluated the vulnerability of the Bourgas port to oil pollution under different typical weather conditions by using MOTHY and the model was used as a standalone model, while in the present study we are using the information from the wave model and the hydrodynamic model (in the previous work we used climatic currents while here we use a nonstationary time evolving currents from the hydrodynamic model). The variation of the surface currents speeds in Fig. 8.1 shows that a significant difference between the mean seasonal current speeds especially under stormy conditions may lead to significant changes in the numerical simulations of the drift pollution under such conditions. The standalone version of the MOTHY system for the Bulgarian coast takes into account the differences in the wind driven currents by the usage of two dimensional depth integrated circulation model (the OCEAN2D component of the system) but it does not take into account that difference of the thermohaline circulation under such conditions are also expected. Another advantage of the approach with the usage of three dimensional hydrodynamic model is that it explicitly resolves the stratification and the mixed layer depth, while the two dimensional model requires a preliminary setup of the mixed layer depth of the Black Sea as a single parameter or as two dimensional matrix. By the usage of three dimensional hydrodynamic model a new mean seasonal currents are also produced which may also be used in the future studies (like risk analysis and real accidents).

Two examples of pollution drift are presented in Fig. 8.3. The source location is the actual location of a sunken ship that may cause pollution if the heavy bunker fuel that is still in the ship leaks in the water. NIMH-BAS providing the Bulgarian authorities (the Maritime Administration) with numerous simulations of the behaviour of a possible spill under different meteorological (different wind speeds from different directions) and oceanographic conditions (presence or absence of an anticyclonic eddy). The left part of Fig. 8.3 shows the behaviour of the spill in calm weather using the mean seasonal currents. The right part of Fig. 8.3 also presents a simulation for calm weather but for a situation when the Kaliakra anticyclonic eddy is not present but the circulation is cyclonic. As it may be seen, the simulation with the mean seasonal currents suggests that there is a significant risk for a pollution of the area of Constanta (including the Constanta port) while the simulation without the presence of the anticyclonic eddy leads to a significantly lower risk for a pollution of Constanta (and the Romanian coast in general).

The pollution drift model in the present version of the model system uses not only information from the atmospheric and the hydrodynamic model, but also from the wave model. Two different approaches were tested to calculate the wind drag coefficient Cd. First approach is by the usage of the friction velocity from the model (computed explicitly when the Janssen's parameterization (Janssen 1991) of the wind input is used) and the second using the wave steepness, following the results of Guan and Xie (2004). Explicit calculation of the drag coefficient is expected to

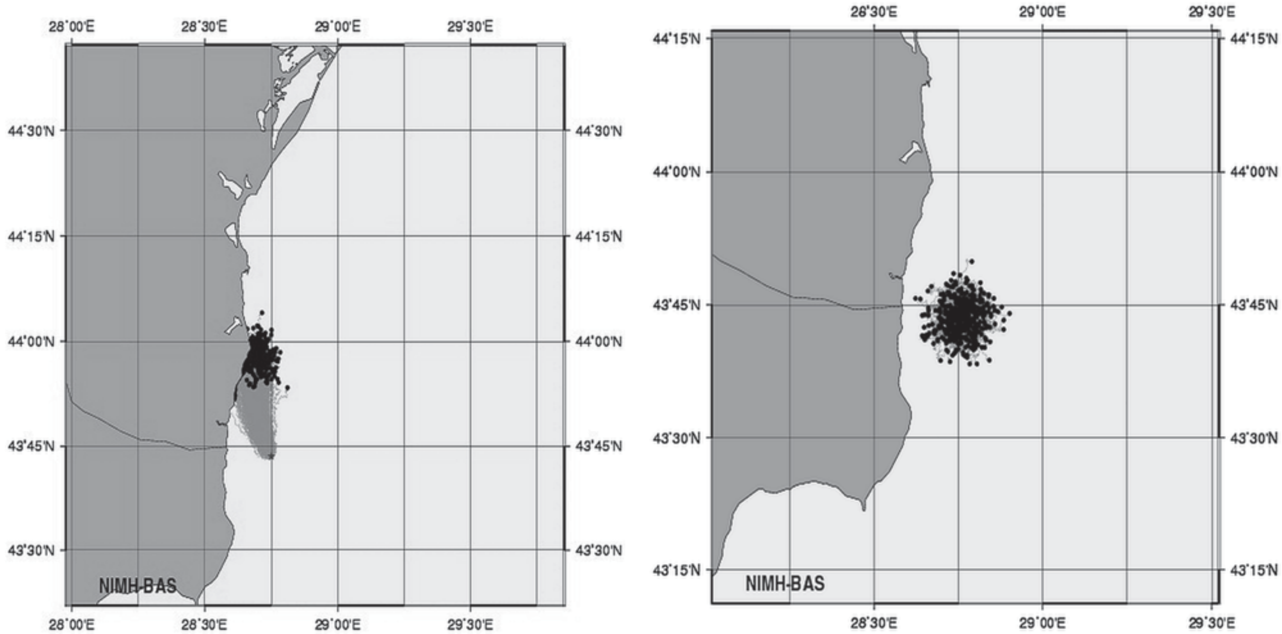


**Fig. 8.3** MOTHY model simulations in calm weather conditions for the location of a ship that sunk during February 2014 (a potential source of oil pollution). *Left*—the movement of the spill when the Kaliakra anticyclonic eddy is present. *Right*—the same simulation when the eddy is not present (the thermohaline circulation is cyclonic)

improve the calculation of the surface currents for strong wind conditions for which the drag coefficient deviates from the linear approximations. SWAN wave model also provides to MOTHY the components of the wave radiation stress. MOTHY takes into account the Stokes drift. While usually the most widely used pollution drift models do not take into account the Stokes drift, to use it is justified because thereby the prediction of the spills behaviour in shallow water depend also on the Stokes drift.

## 8.3 Conclusions

In order to provide fast predictions of potential impacts for different environmental scenarios information about the vulnerability in case of typical and extreme weather and oceanographic conditions to the South East European ports of western Black Sea area a modelling system has been implemented. The system consists of interconnected modules based on input information from the state-of-art ocean model and possible usage of various atmospheric models. The applications of modelling system produce the following results:

1. The sea wave model implemented for the western part of the Black Sea (SWAN) provides forecast of significant wave height and direction at the entrance of three ports: Bourgas, Varna and Constanta which are included in TEN ECOPORT project. The model has been validated and calibrated using satellite data and the observations in the coastal stations of NIMH-BAS.
2. The MOTHY model was implemented for numerous simulations of the behaviour of oil spills caused by sunken ship if the heavy bunker fuel leaks in the water under different meteorological (different wind speeds from different directions) and oceanographic conditions (presence or absence of an anticyclone eddy). The simulation with the mean seasonal currents suggests that there is a significant risk for a pollution of the coast area of Constanta (including the Constanta port) and the Romanian Black Sea coast in general.

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## References

Bogatchev A (2008) Changes in operational suite of ALADIN–BG, ALADIN Newsletter No 34
Booij N, Ris R, Holthuijsen L (1999) A third-generation wave model for coastal regions 1. Model description and validation. J Geophys Res 104:7649–7666
Bruchard H, Bolding K (2011) GETM a general estuarine transport model. Scientific documentation, Technical report, European Commision, ISPRA

Daniel P (1996) Operational forecasting of oil spill drift at Météo-France. Spill Sci Technol B 3(1/2):53–64

Daniel P, Josse P, Dandin P, Lefevre JM, Lery G, Cabioch F, Gouriou V (2004) Forecasting the prestige oil spills. In: Proceedings of the Interspill 2004 conference, Trondheim, Norway

Galabov V, Kortcheva A, Marinski J (2012a) Simulation of oil pollution accidents in the bay of Burgas, using hydrodynamic model. In: Proceedings of the 12th conference SGEM doi:10.5593/SGEM2012/S14.V3009

Galabov V, Kortcheva A, Dimitrova M (2012b) Towards a system for sea state forecasts in the Bulgarian Black Sea coastal zone: the case of the storm of 07–08 February 2012. In: Proceedings of the 12th conference SGEM, doi:10.5593/SGEM2012/S14.V3012

Galabov V, Kortcheva A, Kortchev G, Marinski J (2013) Contamination of Bourgas port waters with oil. In: Ozhan E (ed) Proceeding of global congress on ICM, 30 Oct–03 Nov 2013, pp 1077–1086

Guan C, Xie L (2004) On the linear parameterization of drag coefficient over sea surface. J Phys Oceanogr 34:2847–2851

Janssen PAEM (1991) Quasi-linear theory of wind-wave generation applied to wave forecasting. J Phys Oceanogr 21:1631–1642. doi:10.1175/15200485

Madec G (2006) NEMO ocean engine. Note du Pole de modélisation, Institut Pierre-Simon Laplace (IPSL), France

Matishov GG, Inzhebeikin YI, Savitskii RM (2013) The environmental and biotic impact of the oil spill in Kerch Strait in Nov 2007. Water Resour 40(3):271–284

Mungov G, Daniel P (2000) Storm surges in the Western Black Sea. Operational forecasting. Mediterr Mar Sci 1(1):45–50

Rusu E, Guedes Soares C (2011) Wave modelling at the entrance of ports. Ocean Eng 38:2089–2109

Rusu L, Guedes Soares C (2012) Evaluation of a high-resolution wave forecasting system for the approaches to ports. Ocean Eng 58:224–238