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Modeling oil spill trajectory in Bosphorus for contingency planning

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A B S T R A C T

Bosphorus, is a strongly driven international maritime route between the Black Sea and the Sea of Marmara and is a high risk area for oil spill due to the heavy tanker traffic. In this study an oil spill trajectory model was developed for investigating the potential risks of accidental oil spills in Bosphorus. The proposed oil spill trajectory model combines the surface current velocity data obtained from a calibrated hydrodynamic model with the advection, spreading, and evaporation processes that are effective only on the sea surface and dominant for a couple of hours after the oil spill. Model simulations revealed that spilled oil reaches the shoreline on both sides of Bosphorus in < 4 h following the spill. We proposed locations for emergency intervention stations in Bosphorus which can be used to devise a suitable oil spill contingency plan to keep the adverse impacts of oil spills at minimum.

1. Introduction

Bosphorus, is a very strongly driven international maritime route between the Black Sea and the Sea of Marmara (Fig. 1), which exhibit an increased pattern of marine pollution. Bosphorus is the only maritime route for the six Black Sea neighboring states (Bulgaria, Georgia, Romania, Russia, Turkey, and Ukraine) and the Central Asian Turkish Republics. After the foundation of the independent states, following the collapse of the Soviet Union, the volume of traffic in Bosphorus increased substantially. The opening of the Main-Danube channel and the rising use of other channels in the region contributed to the increase in maritime traffic.

Since 1960, over 40 heavy accidents occurred in Bosphorus. In 1979, a Greek freighter collided with Independenta, a Romanian tanker at Haydarpaşa. The tanker sank after an enormous explosion and 70,000 tons of oil spilled into the sea, polluting the sea surrounding the city and 50,000 tons of this oil kept burning for about a week causing heavy smoke (Oral and Öztürk, 2006.)

Another large-scale accident took place in 1994 at the northern entrance of Bosphorus when an oil tanker and a cargo ship collided. 20,000 tons of crude oil spilled into the sea. The tanker Nassia burned for several days and the traffic on Bosphorus stopped for 6 days (Oral and Öztürk, 2006).

In December 1999, the Russian tanker Volganeft 248 grounded and split in two and sank at the southern entrance of the Bosphorus, spilling 4000 tons of fuel and blackening some 10 km of coastline. Many birds were soaked in the sticky tar. At least 3000 gulls, ducks and cormorants were found dead (Oral and Öztürk, 2006).

At the end of the grounding of Georgian-flagged cargo ship M/V Svyatoy Panteleymon, close to Anadolu Feneri in 2003, 220 tons of diesel and 260 tons of fuel oil spilled into the sea.

The maritime traffic in Bosphorus reached a critical threshold, where accidents and spills are unavoidable. Although the tanker traffic in the Bosphorus has eased due to both a slowdown in the global economy and the Baku-Tbilisi-Ceyhan pipeline, which was constructed in 2006, today, the traffic volume exceeds 50,000 vessels per year, including 5500 oil tankers, which corresponds to an average of 15 tankers per day (Saundry, 2013). The heavy traffic through the Bosphorus undoubtedly presents substantial ecological risks to the local environment.

Turkey has raised concerns over the navigational safety and environmental threats to Bosphorus. In order to improve the navigational safety measures using traffic management, the current Turkish Straits System (TSS) regime in the Bosphorus is supported by the Turkish Straits Vessel Traffic Service (TSVTS), which became fully operational on 1 July 2003. The system is based on 7 radar stations which fully covers the area and enables monitoring the whole Bosphorus. The system can provide the essential information for ships to avoid unwanted encounters and collision risks in critical regions in the Strait such as Kandilli, Yeniköy and Umuryeri where two ships should not proceed in opposite directions at the same time (Akten, 2004).

Commercial ships have the right of free passage through the Turkish Straits System in peacetime. However, Turkey claims the right to impose regulations for safety and environmental issues. Pilotage is one of

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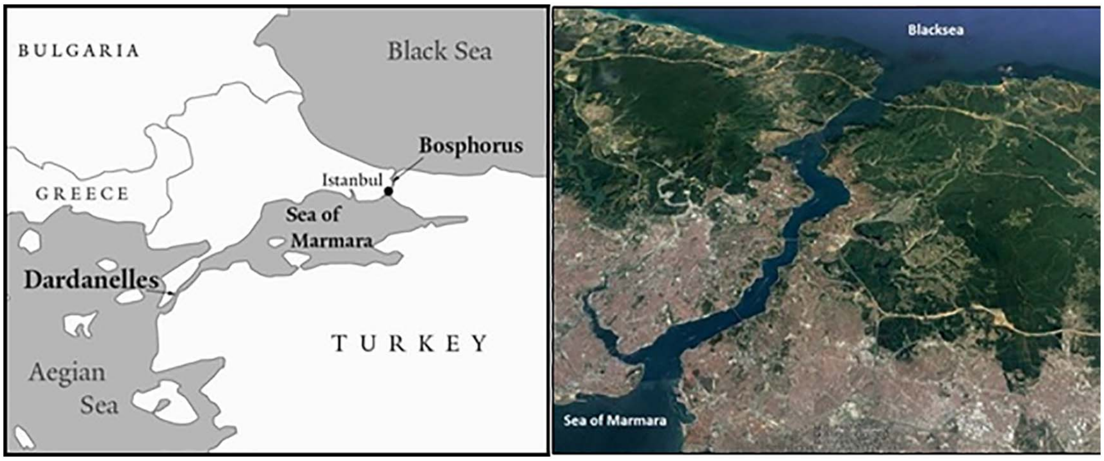

Fig. 1. Bosphorus is a narrow strait located in Turkey that connects the Black Sea and the Sea of Marmara.

the proper means of minimizing shipping accidents in confined waters. Article – 4 (2) of the Montreux Convention states that pilotage and towage remains optional; accordingly, compulsory pilotage has not been a binding instrument for ships passing through the Bosphorus. However, the IMO Rules and Recommendations adopted in association with the TSS zone strongly recommend that all ships should use the pilotage services in order to comply with the requirements of safe navigation (Akten, 2004).

In 2017 The Scientific and Technological Research Council of Turkey (TÜBİTAK) installed Acoustic Doppler current profilers (ADCP) at six points across the Bosphorus Strait in order to prevent tanker ship collisions that take place due to difficulties in navigation caused by strong currents. The new system will evaluate each ship's capacity and the strength of currents based on immediate data and will either allow or deny passage to each ship. The system is designed to prevent dangerous maritime collisions on the Bosphorus, which can cause both physical and environmental damage (SeaNews, 2017).

As the risks of oil spill incidents increase, the development of a real-time oil transport and fate prediction model for Bosphorus has become a necessity, which is an important tool for preparing oil spill emergency response plans. Oil spill modeling is an essential tool for emergency response during and just after an oil spill. An appropriate oil spill model can help to make predictions about how far an oil slick will travel a few hours after the spill. This will help the authorities in decision making during an emergency response.

Oil spill trajectory and fate models have been developed since the early 1960s to simulate oil movement on the water surface in order to develop pollution response and contingency plans. Oil spill movement on water surface has been a significant research focus, resulting in two-dimensional oil spill models of advection and spreading. Taylor et al. (2003) applied an Eulerian approach and computed the oil slick thickness using the layer-averaged Navier–Stokes equations, and employed advection–diffusion equation for transport of the oil phases in the water column.

Papadimitrakis et al. (2006) simulated the time-dependent behaviour of an oil spill near coastal zones incorporating weathering mechanisms that determine the fate of the spill, such as: spreading, dissolution, hydrodynamic dispersion and turbulent diffusion. In their study, Chen et al. (2007) simulated the movement of oil slick under the effect of tides, wind and waves using the Monte Carlo Method.

Spatial discretization is a vital step in numerical computation. The reliability of simulations, the quality of model outputs and uncertainty in subsequent decision-making are all affected by the spatial discretization. While Li (2007) has demonstrated that spatial discretization is also critical for coastal oil spill modeling, Sebastião and Guedes Soares (2007) introduced a method to account for the uncertainties of a classic oil spill model in the predictions of oil spill trajectories.

Díaz et al. (2008) used a probabilistic particle tracking model to simulate the oil dispersion. They evaluated the validity of the particle model in a hindcast way. Wang et al. (2008) extended a previous two-dimensional simulation model (Wang et al., 2005) to three dimensions for investigating the vertical dispersion/motion of the spilled oil slick and developed a three-dimensional (3-D) model. Their model simulates the most significant processes, such as advection, surface spreading, evaporation, dissolution, emulsification, turbulent diffusion, the interaction of the oil particles with the shoreline, sedimentation and the temporal variations of oil viscosity, density and surface tension. In addition, the processes of hydrolysis, photo-oxidation and biodegradation are also considered in this model.

Wang and Shen (2010) developed an unstructured finite-volume wave-ocean model, which provides great flexibility for modeling the flow in arbitrary and complex geometries. They used the flow module to provide the hydrodynamic parameters to the transport-fate module.

Liao and Li (2010), developed a numerical model for predicting the oil spill trajectory and fate and simulated the "Hyundai Advance" oil spill incident that happened in the Pearl River estuary. They coupled the model with a hydrodynamic model. In this model, the Lagrangian oil particle tracking algorithm is used to predict the trajectory of spilled oil, and the oil spill fate processes including advection and diffusion, surface spreading, evaporation, dissolution, entrainment, emulsification and shoreline interaction are taken into account.

In their study Aghajanloo and Pirooz (2011), introduced an oil weathering model to predict the oil slick behaviour on the sea and to compute the mass transfer rates due to evaporation, vertical dispersion, dissolution and emulsification. The model calculates the change of oil properties during these processes.

Mariano et al. (2011) developed both a 2-D and a 3-D oil particle trajectory forecasting system. Both systems use ocean current fields from a high-resolution numerical ocean circulation model (HYCOM) simulations. The models use Lagrangian technique to advect oil particles, and Monte-Carlo based schemes for representing uncertain biochemical and physical processes.

Cucco et al. (2012), used operational finite element numerical models with high spatial resolution nested within a coarse open ocean operational model based on the finite differences method to reproduce the hydrodynamics and the transport processes occurring in coastal areas characterized by a complicated geometry.

Hou and Hodges (2013), developed a hydrodynamic and oil spill model Python (HyosPy) wrapper to run the hydrodynamic model, link with the oil spill, and visualize oil spill transport results on Google Earth. The HyosPy wrapper can provide an ensemble of model predictions based on wind and tide forcing for creating an estimate of the