

AN APPLICATION OF THE ADAM MODEL FOR POLLUTION AND OIL SPILL TRACKING IN BOSPHORUS

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ABSTRACT

Pollution of the marine environment by oil spill is a critical problem with worldwide ecological consequences.

The Bosphorus, between the Black Sea and the Sea of Marmara is a very strongly driven international maritime route, which exhibit an increased pattern of marine pollution. Bosphorus is the only maritime route for the five Black Sea neighboring states 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. As a result, maritime traffic reached a critical threshold, where accidents are unavoidable. The heavy traffic through Bosphorus undoubtedly presents substantial ecological risks to the local environment.

Oil spill trajectory modeling is a useful tool for ecological risk assessment. A model system can be used to estimate potential impacts of various spill scenarios. Many oil spill models use some variant of the Lagrangian particle tracking technique, where a certain number of particles simulate the oil on the water and move due to currents and some kind of spreading or dispersion mechanisms. Results from a hydrodynamic model are used to calculate water velocities.

In this paper, we present a detailed statistical survey of oil pollution in Bosphorus. Then we use a 2-D, non-linear, time stepping, hydrodynamic model, ADAM, to calculate the particle velocities on the water surface in Bosphorus and we present a simulation of the flow field in Bosphorus. In the ADAM model, the non-linear diffusion equation is discretized with linear finite elements by the Galerkin method in space and solved implicitly by iteration in time. The results from the ADAM model can further be used to assess the impacts of oil spill scenarios.

KEYWORDS

Bosphorus; Hydrodynamic Modeling; Oil Spill; Ship-based Pollution

INTRODUCTION

Bosphorus is a narrow strait, approximately 31 km in length. The width of the strait is 3600 m where it meets the Black Sea and is 3220 m where it meets the Sea of Marmara. The Bosphorus is only 700 meters wide at its narrowest bend, Kandilli point. The depth varies between 30 m and 60 m, and it reaches a maximum of 110 m at Kandilli. The strait has sharp curves. Ships have to make at least twelve sharp turns to cross Bosphorus. In addition to the severe weather conditions, strong currents also harden the navigation. The average current velocity is 3 km/h, going up to 7-8 km/h.

Bosphorus is threatened by the heavy ship traffic. The volume of traffic in Bosphorus is five times heavier than the traffic in the Panama Canal. While crossing Bosphorus, large tonnage ships need to watch out fishing boats and ferries, which sail between the European and the Asian shores. Two million daily commuters cross the strait in ferries and private boats making the passage even more dangerous.

In 1936 the Treaty of Montreaux, guaranteeing free passage in peacetime through Turkish Straits was signed. The Treaty guarantees Turkey's sovereignty, but states that in peacetime, vessels of any nation carrying any cargo may pass freely without delay or regulation through the Straits as defined earlier by the Treaty of Lausanne. In 1936, supertankers did not exist, and traffic through the Straits was minimal. The number of ships passing through Bosphorus in a year was only 6.200 ships per year in 1936 when the treaty had been signed (Yonsel and Istikbal, 2001). This number increased significantly, and today the traffic volume exceeds 40.000 ships per year including 5.000 tankers, which corresponds to an average of 15 tankers per day.

Since 1960, over 40 heavy accidents occurred in Bosphorus. In 1979, a Greek freighter collided with *Independenta*, a Romanian tanker. The tanker sank after an enormous explosion and its crude oil load leaked into the sea. The crude oil polluted the sea surrounding the city, and kept burning for about a week causing heavy smoke. Another large-scale accident took place in 1994 at the northern entrance of Bosphorus when an oil tanker and a cargo ship collided. The tanker *Nassia* burned for several days and the traffic on Bosphorus stopped for 6 days. In December 1999, the Russian tanker *Volganef* 248 split in two and sank at the southern entrance of Bosphorus, spilling 235000 gallons (893000 liters) of fuel and blackening some 10 kilometers (six miles) of coastline. Many birds were soaked in the sticky tar.

In Figure-1, a four-year average of monthly traffic volume through Bosphorus between 1996-1999 is shown. Only in 2000, 48000 ships, including 6000 tankers, passed through Bosphorus. Bosphorus and coastal regions of Istanbul are potentially endangered by ship disasters and contamination caused by ships. Particularly, the transport of Russian and Caucasian oil through Bosphorus threatens the lives of 10 million habitants of Istanbul and the local ecology.

Oil spill trajectory modeling has become an important and necessary tool for tracking oil spill and pollution in Bosphorus. The spreading of oil released on water is the most dominant process in the first stage of a spill. Most oils spilled on the surface of water will spread in the form of a thin layer. In this study the authors applied a hydrodynamic model, ADAM, to calculate the particle velocities on the water surface in Bosphorus. The model and model results are described in detail in the following sections.

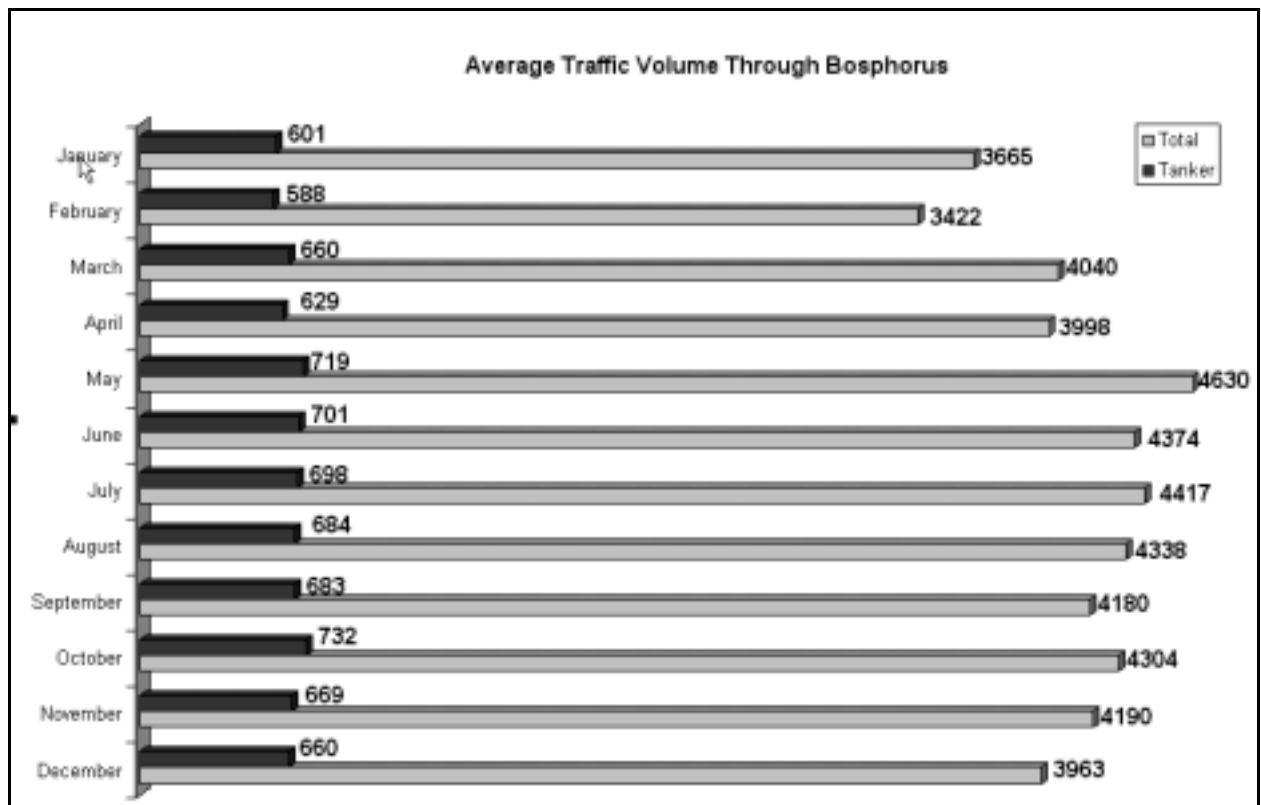


Figure 1. Four-year average of monthly traffic volume through Bosphorus between 1996-1999.

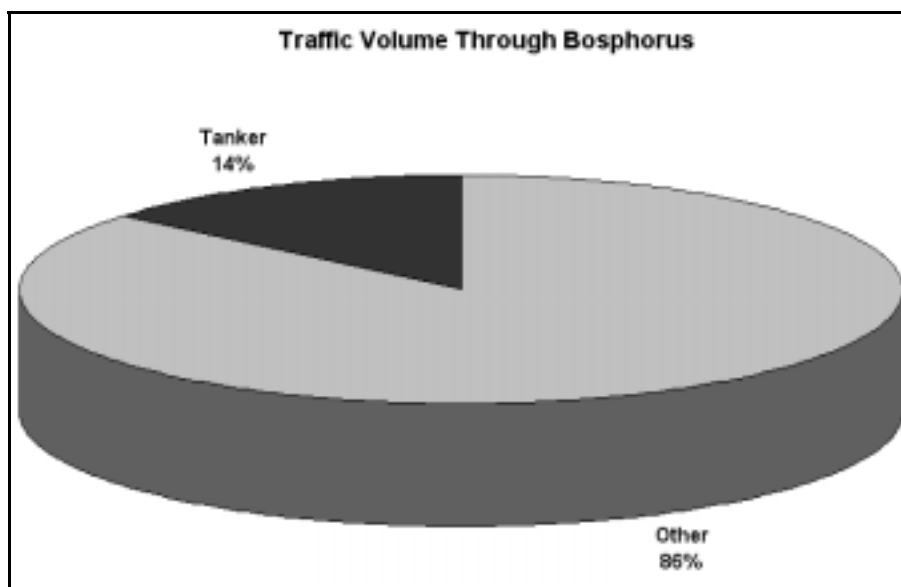


Figure 2. Four-year average of traffic volume through Bosphorus between 1996-1999.

METHOD OF APPROACH

We adopted a fixed-domain finite-element model, ADAM, developed by Ip *et al.* (Ip *et al.*, 1998) to simulate the semi-diurnal tides in Bosphorus. ADAM is a two-dimensional, non-linear, time stepping model. A detailed description of the model is given by Ertürk *et al.* (Ertürk *et al.*, 2002). Assuming that oil spill is basically a surface phenomenon in its initial phases, two-dimensional flow field generated by the modified shallow water equations should be considered sufficiently accurate. According to Alpar and Yuce (1998) the tides are diurnal in the Black Sea and in Bosphorus, mixed but mainly diurnal at the south of Bosphorus and in the Sea of Marmara. However, we focus on semi-diurnal sea level forcing at the open boundaries as more data for semi-diurnal forcing and response is available for comparison (Gunnerson and Özturgut, 1974).

Model performance has been evaluated through comparison with tidal predictions based on a suite of current and surface elevation observations made between July 1966 and December 1967 (Gunnerson and Özturgut, 1974).

The computational mesh (mesh4) that is constructed from available bathymetry for the Bosphorus is given in Figure 3-a. The finite element domain boundary corresponding to the mean water level (datum) was digitized from the SHODB (Turkish Navy, Department of Navigation, Hydrography and Oceanography) topographic maps and the domain was discretized using linear triangular elements. The tributary rivers, such as Göksu, Küçükusu, Kanlıkavak and Kurbağalı rivers and Haliç were not included in the computational grid because of their minimal effect on the overall circulation. These were edited out at locations where they intersect with Bosphorus and are treated as shoreline boundaries. The resultant mesh has 1170 nodes and 2038 elements. All elements have areas less than 22 m² with inside angles larger than 20 degrees. The grid resolution δ (estimated by $\delta \approx \sqrt{2A_e}$, with element area A_e) is in the range, 1.18 m < δ < 6.69 m with an average of $\delta = 2.75$ m.

The nodal bathymetries were interpolated from a data set digitized from the SHODB navigational charts. The domain bathymetry consists of a deep center channel, running along Bosphorus from the southern boundary to the northern boundary with elongated potholes reaching a maximum of 110 m at Kandilli. The domain bathymetry is shown in Figure 3-b.

Semi-diurnal tidal forcing is specified as a Dirichlet elevation boundary condition across the northern and southern boundaries. The elevation time series used to force the model at the boundaries was obtained from surface elevation observations made between July 1966 and December 1967 (Gunnerson and Özturgut, 1974).

A constant Manning's roughness coefficient, n , of 0.025 was used throughout Bosphorus.

The simulation was started with the fluid at rest at high tide at 09:00 AM July 3, 1967. The simulation was terminated at 09:00 AM July 6, 1967 after six tidal cycles. The period of the semi diurnal tidal cycle is $T = 12.00$ hr and each cycle is divided into 300 time steps, which corresponds to a time increment of $\Delta t = 144$ sec. Time series of velocities and surface elevations were generated and analyzed at the completion of the simulation. All the simulation parameters are summarized in Table-1.

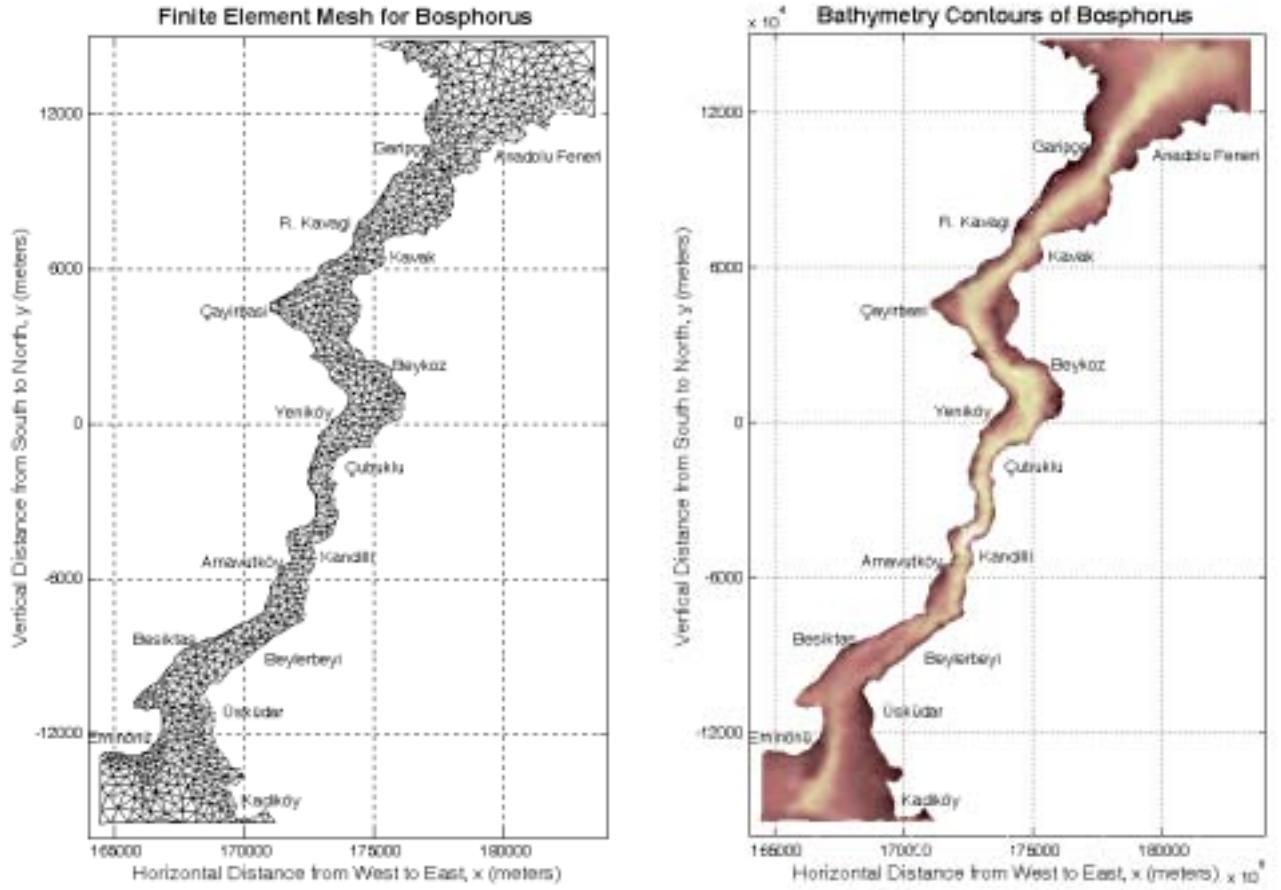


Figure 3. a) The finite element mesh for Bosphorus (mesh4) has 1170 nodes and 3028 triangular elements. b) The bathymetry contours in Bosphorus reaching 110 m at Kandilli.

Table 1. Simulation parameters for the tidal flow simulation on mesh4.

Description	Parameter
Grid resolution	$1.18 \text{ m} < \delta < 6.69 \text{ m}$
Average grid resolution	$\delta = 2.75 \text{ m}$
Bathymetry range	$0.1 \text{ m} < h < 110 \text{ m}$
Time increment	$\Delta t = 144 \text{ sec}$
Time steps per tidal cycle	300
Tidal periodicity	$T = 12.00 \text{ h}$
Length of simulation	$6T$

MODEL RESULTS

Velocity results

The highest velocities are observed in Kandilli, where the cross-sectional area of the strait is the minimum and the depth is maximum. The highest velocity value at Kandilli is 2.8 m/s and is observed at time step 1630. The lowest velocity value at Kandilli is 1.5 m/s and is observed at time step 1780.

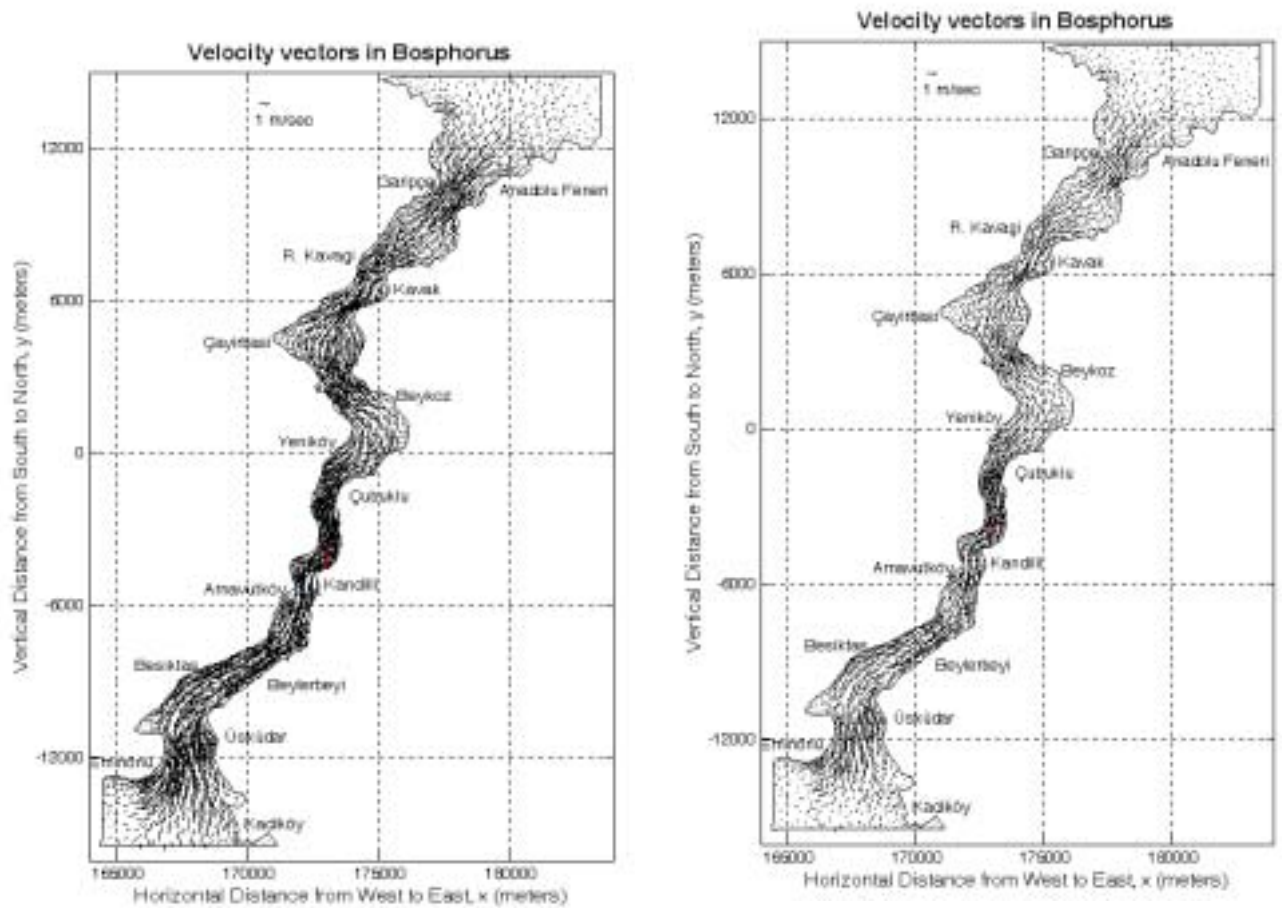


Figure 4. a) Model predicted maximum velocities in Bosphorus for semi-diurnal tidal forcing. The highest velocity occurs at Kandilli. b) Model predicted minimum velocities in Bosphorus for semi-diurnal tidal forcing. The highest velocity occurs at Kandilli.

Surface elevation results

The southerly flow of surface water from the Black Sea is caused by the difference in surface elevations between the north and south ends of Bosphorus. Çeçen et al. (1981) reported a difference in elevation of about 33 cm, while Gunnerson and Özturgut (1974) reported a difference of 35 cm. Surface elevation time series for stations at Kavak, Çubuklu and Beylerbeyi is given in Figure 5-b. Model predicts a surface elevation difference of about 33 m between stations at Kavak and Beylerbeyi. Stations at Kavak and Çubuklu are in phase and both lead Beylerbeyi by 5 hours or lag by 7 hours. Identical phase relations are found in Gunnerson and Özturgut (1974).

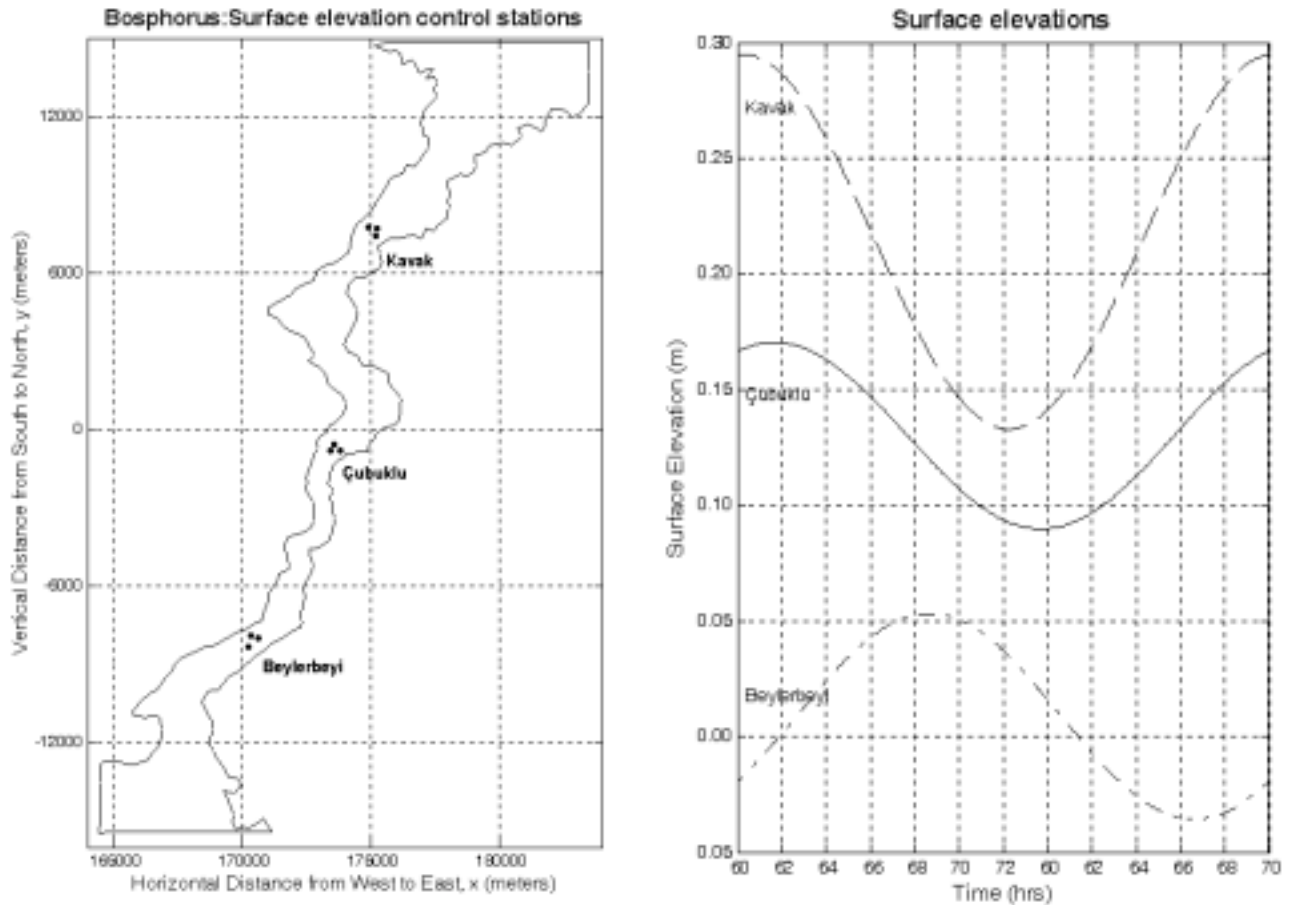


Figure 5. a) Bosphorus surface elevation-sampling stations at Kavak, Çubuklu and Beylerbeyi. **b)** Model predicted surface elevation time series for stations at Kavak, Çubuklu and Beylerbeyi.

CONCLUSION

Accidental oil spills, by their very nature, are unpredictable. The number of vessels passing through Bosphorus in relation to the physical characteristics of Bosphorus, show that the probability of a serious environmental catastrophe occurring in or around Istanbul is very high. This high probability puts the lives of 12 million residents at risk. Forecasting a possible oil spill scenario through numerical modeling becomes an important issue in order to see how the oil slick spreads out on the water surface and in the water column, to evaluate its effect in the sea and to assess its damage to the habitat and the environment. However, it is a difficult task to introduce all the unique oceanographic features of Bosphorus to the model.

Our application of the ADAM model demonstrated numerical robustness and gave qualitatively correct simulations of semi-diurnal tidal response in Bosphorus. The model is able to capture the surface flow regime in Bosphorus. The surface elevation amplitude and phase predictions and the velocity predictions show good agreement with the observations. Based on these hydrodynamic results, future applications will include oil spill release and particle tracking, taking into account the spreading, evaporation, emulsification, viscosity and density increase of the oil.

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