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Reproducing trajectory of oil spilled from Turkmenistan oil fields

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Abstract

In order to numerically simulate transmission of oil spilled in Caspian Sea from Turkmenistan oil fields, wind induced currents in the sea were simulated using an unstructured grid Finite Volume Community Ocean Model (FVCOM) in the summer and spring of 2012. The results of the model in the fall season were then compared to the measured data for surface currents in three stations of Astara, Roudsar, and Amirabad. Comparison of the measured data and the current model output revealed that implementing turbulence closure module produces more accurate results than once when the module was excluded. Later on, in order to determine the destination for the oil spilled from Turkmenistan oil fields, the output of flow model was imported into the GNOME computer application along with 6-hourly wind time series. Turkmenistan's oil wells on the eastern shores of the southern fields of the Caspian Sea in front of the Cheleken Peninsula were considered as the locations of oil pouring. The type of pouring was momentary and the volume of oil pouring in each well was 100 barrels. Simulation of trajectory of spilled oil was conducted based on different pouring time and the location of the oil spill hitting the shore were acquired. Comparing the results from simulation and location of collecting oil spills in August 2012 demonstrates acceptable accuracy; thus, it could be said that, considering the wind system governing the Caspian Sea, it is quite feasible that oil spills from Turkmenistan oil fields could reach the shores of Iran in the summer.

Keywords: Oil spill; Turkmenistan; Oil field; Numerical simulation; FVCOM; GNOME.

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1. Introduction

The Caspian Sea, the largest lake on the planet, is located in the middle of five countries: Iran, Russia, Azerbaijan, Turkmenistan, and Kazakhstan between 46.6º E and 54.8º E. and 36.6º N and 47º N. Since this vast lake is a closed basin with very weak tidal currents, oil spills could accumulate in a single location and expand with storms or turbulent water. Besides, removal of contamination in a lake with no access to open seas is extremely slow (Jafari, 2009).

Pollution is a serious threat for the biodiversity of the Caspian Sea. The main sources for pollution are industrial sources, agriculture, sewage, and accidental discharge of pollutants in the sea. The main stream of pollution comes from the Volga. Volga pollution current is comparable to the industrial pollution and oil spill from Baku oil fields. The main source of pollution from Turkmenistan comes from Turkmenbashi and Cheleken oil fields. Pollutions related to Kazakhstan oil fields is relatively small and mainly enter the Caspian Sea through the Oral River (Aladin and Plotnikov, 2004).

The oil spilt over the surface of water goes through a weathering process the outcome of which is major changes in physical and chemical properties of oil. Apart from the factors releasing oil pollutants, two main mechanisms of advection and diffusion could be blamed for distribution of oil pollutants. These mechanisms utilize waves, winds, and sea currents determine local distribution of pollutants. Oil expands over the surface of water after it is spilled. The movement of this spill is controlled by advection and turbulent diffusion induced by current, wave, and wind effect (Wang *et al.* 2005). The present study does not aim to investigate weathering processes affecting oil spill; yet, its focus is on the advection. In studies on transmission of oil spills in sea environments, the oil spill advection is calculated through two or three dimensional hydrodynamic models. Then, in order to trace oil spills, wind induced current speed acquired by hydrodynamic model is put into a Lagrangian model to calculate oil spill drift and predict its direction. The common inputs in oil spill trajectory models include of the sea level, sea surface temperature, hydrography information, wind speed, type of pollutant, and the speed of oil spill. However, some studies contain different factors like emulsion, evaporation, solubility, distribution, and decomposition as well. Since most oil spills are on the surface and move by the wind and surface currents, two dimensional models integrated in the depth using one average speed for whole column from the surface to the bed do not seem to be applicable; thus, the advection of oil spill on the surface seems to be better calculated by multilayer three dimensional hydrodynamic models. Another point worth mentioning is that transmission of oil spill could occur over a few days period under influence of particular wind fields. Accordingly, investigation of oil spill via wind data over shorter period is caused better trajectory simulations that confidently depend on the accuracy of wind data.

Several studies have been conducted on the movement and transmission of oil spill like the most basic ones on developing a model to calculate the area of oil spill using averaged Navier-Stokes in depth (Fay, 1969) and also on the developing a model including physical and chemical processes affecting oil spill (Sebastião and Soares, 1995). There are similar studies in the Persian Gulf by Elhakeem *et al.* (2007), Faghihifard and Badri (2016), and Badri and Faghihifard (2017) which investigated the advection and fate of oil spill using MIKE model. Wijayaratna and Hajisalimi (2013) conducted another study on expansion of oil spills in the Persian Gulf using a hydrodynamic model and considering the simultaneous effect of wind, current, and wave. Among other studies conducted in the Caspian Sea, the study by Korotenko *et al.* (2000 and 2002) tracking down the oil spills originated in the Volga River and oil wells of Azerbaijan through Lagrangian approach. Considering current (extracted from POM model) and the drift affected by wind and the procedures affecting oil spill were also mentioned. Considering different factors and scenarios, Mirzahossein *et al.* (2014) and Mirkhalil and Mazaheri (2015) studied the movement and transmission of oil spills in the Caspian Sea using MIKE model. With a completely different approach, Shirneshan *et al.* (2016) used "chemical fingerprint analysis" to show that the origin of tarballs collected from the southwestern the Caspian Sea shores in August 2012 could possibly be Turkmenistan's oil fields.

2. Materials and methods

In the present study, in order to numerically simulate transmission of oil spill from oil fields of Turkmenistan to the Caspian Sea, wind induced currents were simulated using Finite Volume Community Ocean Model (FVCOM). The wind time series data used in this simulation were extracted from European Centre for Medium Range Weather Forecasts (ECMWF) with 0.75º resolution in horizontal direction. After simulating the current induced by wind in FVCOM, the General NOAA Oil Modeling Environment (GNOME) was utilized to determine the direction of movement of particles under the influence of the simulated current.

This FVCOM model solves integral form of governing equations in Cartesian, terrain-following, and spherical coordinates of the earth using finite volume method on an irregular, triangular, horizontal grid. Governing equation of the model in the absence of snow and ice include two or three dimensional equations of momentum, continuity, temperature, salinity and density. Some of the prompts whose effects (in case of availability) considered in this model are wind tension, heat flux, evaporation, rainfall, and river entrances. This model could be executed for fixed or changeable place and time prompts. Not only could this model be used with fixed horizontal and vertical emission coefficients, but also, it could use the turbulent closure module. The module includes Smagorinsky method and MY-2.5 (Mellor and Yamada) model. Spatial discretization in FVCOM is conducted through finite volume method. Horizontal computing grid in this model consists of irregular triangular non-overlapping cells (Chen *et al.* 2013). The irregular horizontal computing grid was produced by EMC open source application. This computing grid included 14557 nodes and 27816 triangular elements, the biggest and smallest sides of which were 27133 and 1450 meters, respectively. The basin was considered 20 layers in the vertical, so that in regions with depth of less than 50 meters, layering was steady and in the regions deeper than 50 meters, 10 meters from the surface was divided into three layers of 2, 4, and 4 meters, the next 30 meters near the bed was divided into three layers of 10-meter. The layering between surface and bed layers was conducted uniformly. The reason for this type of layering was the high importance of surface flow in transmitting oil pollution. Based on the characteristics of the grid and executing the model with various time steps, the external time step mode, and the ratio of external time step mode to the internal mode considering which the model did not become unstable was 2.5 and 2 seconds, respectively. The bathymetric data were obtained with 30 second resolution from General Bathymetric Chart of the Ocean data bank (GEBCO). Then, altitude data for dry regions were removed from them. Considering the fact that the sea level in the Caspian Sea is 27 meters lower than open seas on average (Kosarev, 2005), data for inside the boundary were added with +27. Finally, bathymetric data for node points were interpolated based on the corrected bathymetric data. Wind data were another necessary data for the present study which were obtained for the period from first of July 2012 to the end of December 2012 in a 6-hourly time step, and with a 0.75-degree resolution from the ECMWF data bank as a product of European Reanalysis-Interim project. Location of Turkmenistan's oil fields on the eastern side of the southern basin of the Caspian Sea, in front of the Cheleken peninsula was extracted through Google Maps (Figure 1). The number of these locations according to the image was 33 points which were taken as the oil spill places in the present study.

The FVCOM model was conducted as the first stagnation for the six months, beginning from July, 2012 to the end of December, 2012. In the first experience, horizontal and vertical

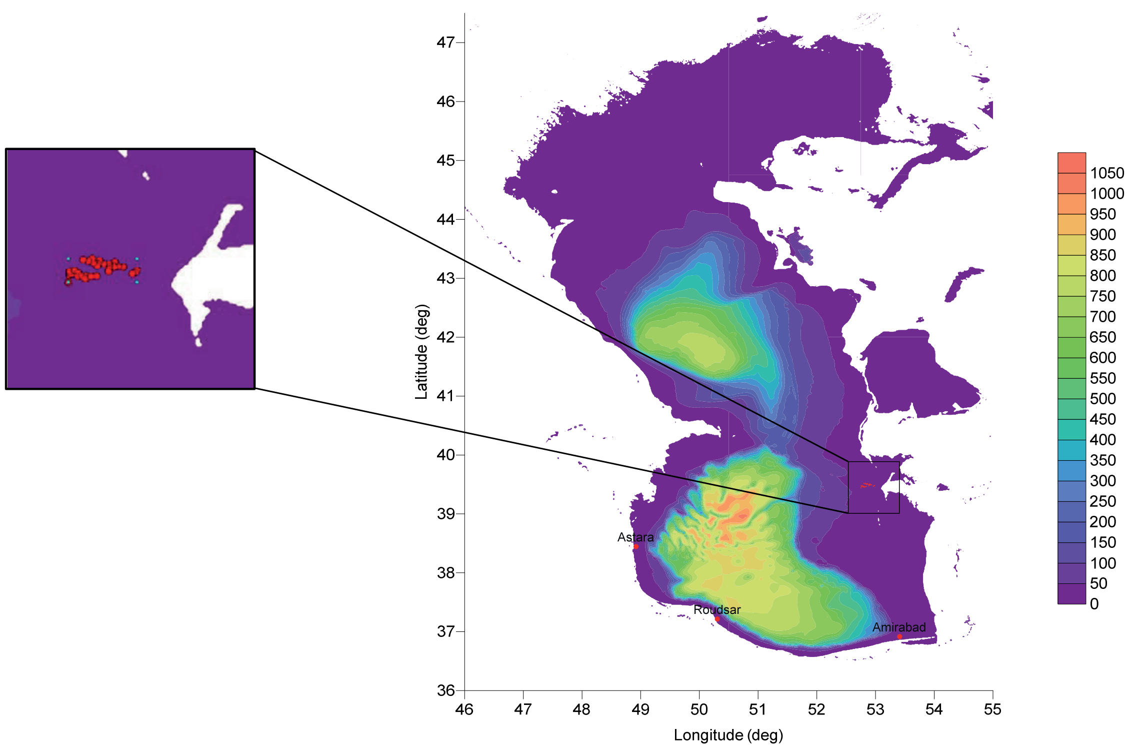

Figure 1. Bathymetric map of the Caspian Sea along with geographical location of Turkmenistan's oil wells and the position of Astara, Roudsar and Amirabad Stations

eddy coefficients were considered constant and equal to the default rates as $0.2m^2s^{-1}$ and $0.0001m^2s^1$. In the second one, in order to determine eddy coefficients, turbulent closure module was utilized and 6-hourly time series of the wind was implemented as a prompt to the environment. The temperature and salinity was homogenized at 15 ˚C and 12 psu. After the model execution, the results from both experiments were compared to the surface current data measured in three stations of Astara, Roudsar, and Amirabad. These measurements were done by ADCP current profiler in the mentioned stations at the depth of 5m from the surface that is obtained in the integrated coastal zone management (ICZM) project. The comparison was made and the surface current data obtained from the model and wind data during July, August, and September, 2012 were imported to GNOME and the final destination of the oil pollutions spilt from oil platforms of Turkmenistan were scrutinized. The reason for selecting those three months was the collection of tar balls mentioned in the study by Shirneshan *et al.* (2016). GNOME application which is developed by National Oceanic and Atmospheric Administration (NOAA) solves equations via Euler–Lagrange equation. In other words, oil spills move as Lagrangian particles in marine environment as a continuous function of Euler and the effect of each parameter on its movement could be investigated. Type of oil, volume of oil spill, geographical coordinates of the oil spill region, the time of its entrance and wind and current data are considered as the inputs of this application.

3. Results and Discussion

The results from FVCOM model execution in two aforementioned experiences were investigated along with surface current data measured in three stations of Astara, Roudsar, and Amirabad (Figure 1). Considering diagrams in Figures 2 to 4 and comparing the measured surface flow and the model output in three abovementioned stations, represents that when the turbulent closure module is used, the results are closer to the field measurements. The mean absolute error was calculated as 0.027 m and 0.035 m in the case of exclusion of turbulent closure and in the case when existence of turbulent closure, respectively. In other words, when the turbulent closure was applied, better agreement was noted between the model results and the observations. Different time periods stated in comparisons is because of difference in measuring times of current speed available in the mentioned stations. Lack of full comparability of the measured data and the model output could be attributed to the low resolution of wind data and lower resolution of bathymetric data. Furthermore, the wind data used as input in numerical simulations of wind induced currents seems to be under estimated in the Caspian Sea and affects the numerically simulated current values. Low resolutions of bathymetric data especially in low depth areas could also significantly affect the computation of current in sea shore and shallow regions. Moreover, when the eddy coefficients are considered constant, in most regions, computed currents are stronger than in which turbulent closure module is used for utilizing turbulence. In other words, using constant eddy coefficients leads to less turbulence and the current speed could increase considerably.

Figure 4. The speed of measured surface flow (the blue line), the flow acquired from executing flow model in case where eddy coefficients

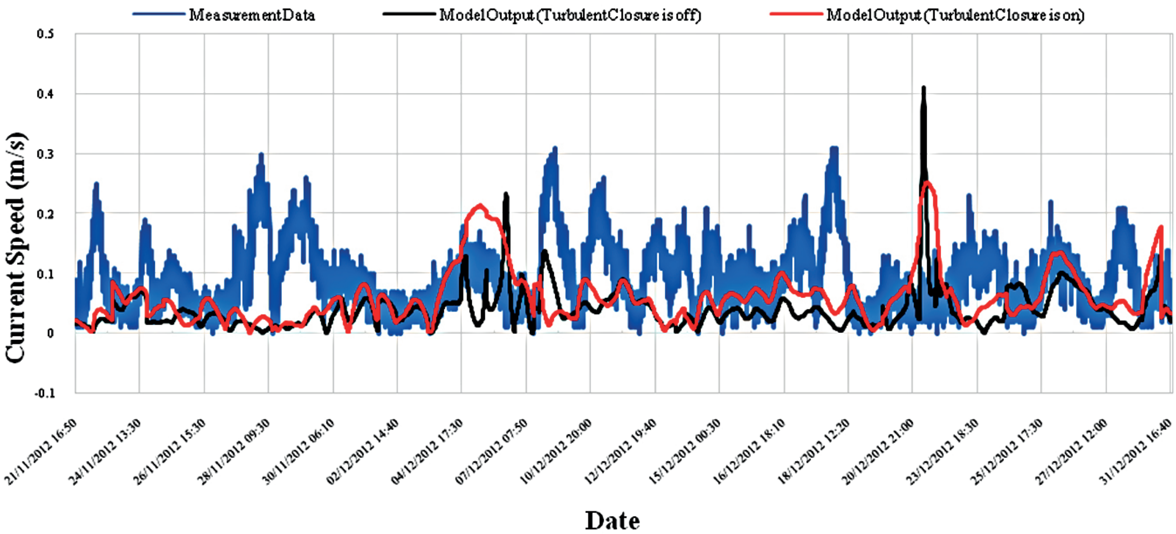

Figure 2. The speed of measured surface flow (the blue line), the flow acquired from executing flow model in case where the eddy coefficients are considered constant (the black line) and the case where turbulent closure module is implemented (the red line) in Amirabad Station between November 21 and December 31, 2012

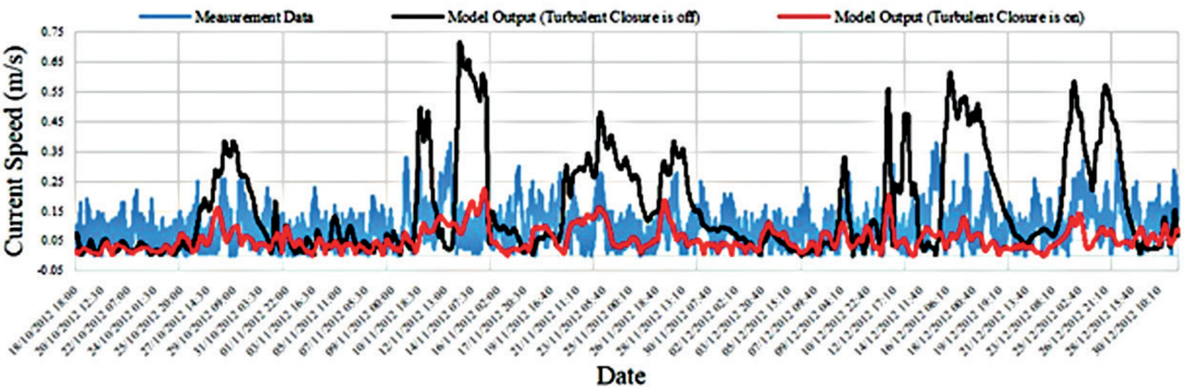

Figure 3. The speed of measured surface flow (the blue line), the flow acquired from executing flow model in case where eddy coefficients are considered constant (the black line) and the case where turbulent closure module is implemented (the red line) in Roudsar Station between October 18 and December 30, 2012

are considered constant (the black line), and the case where turbulent closure module is implemented (the red line) in Astara Station between November 28 and December 30, 2012 Figure 5 demonstrates the most prominent wind fields and the current affected by the wind in the second half of July and August 2012 when turbulent closure module was utilized. The wind fields and the currents demonstrated in Figure 5 played the biggest role in accelerating the movement of oil spill. Since the oil tarballs were collected in August 2012 and the wind

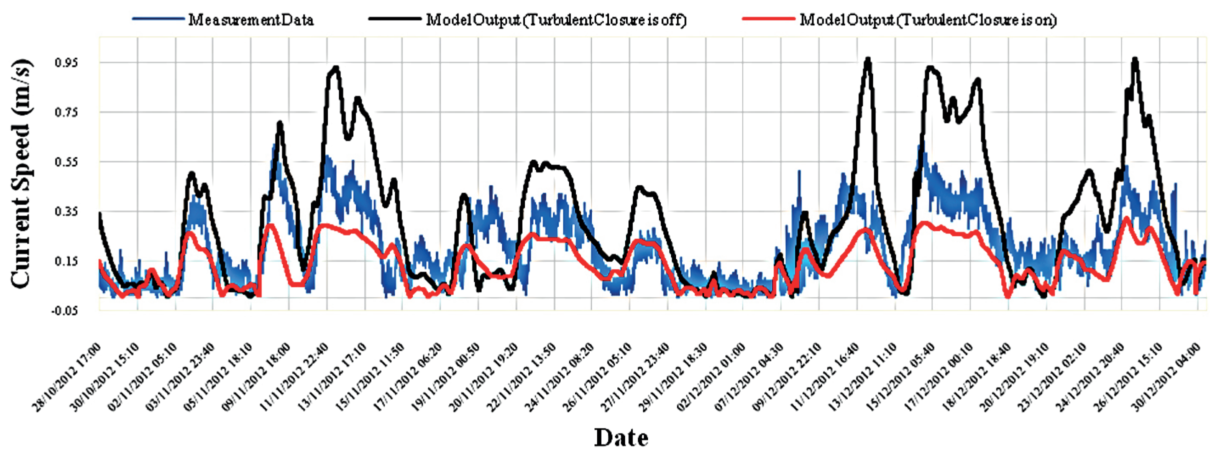

Figure 4. The speed of measured surface flow (the blue line), the flow acquired from executing flow model in case where eddy coefficients are considered constant (the black line), and the case where turbulent closure module is implemented (the red line) in Astara Station between November 28 and December 30, 2012

system in the late July and August is mainly in southern and southwestern directions, and also the oil tarballs collected from southwestern shores of the Caspian Sea possibility enter to the environment in the period between 20th to the 31st of July 2012, that is why the second half of July were selected as the time for the oil spills in simulations. In order to hind-cast the destination of the oil spilled from Turkmenistan oil fields, wind induced current' speed from the FVCOM model (every 6 hours) together with the wind data were imported to the GNOME application.

Simulations were conducted based on a fixed scenario yet with different spill times. In fact, spills were considered momentarily with a volume of 100 barrels at each point at the location of Turkmenistan's oil wells (Figure 1). Results from various simulations in GNOME application are demonstrated in Figures 6-8. As it could be seen in these figures, as the time of spill changes, oil spills hit the shore at different locations. In other words, when the spill occurs on July 20, they hit eastern shores while as the time moves toward the end of July they hit further western shores rather than the eastern ones. In a study by Shirneshan *et al.* (2016), the location of removing oil tar balls

Table 1. Location of collecting oil tarballs in August 2012 (Shirneshan *et al.* 2016)

Station	Location	Latitude (N)	Longitude (E)
TB1	Kiashahr City	37°28′35.74″	49°56′20.40″
TB2	Asgarabad City	37°24′43.58″	50°3′58.38″
TB3	Chaf City	37°21′30.05″	50°13′42.49″
TB4	Chamkhaleh City	37°15′54.06″	50°15′9.03″
TB5	Hasansara City	37°8′32.69″	50°19′9.70″
TB6	Kalachy City	37°4′21.56″	50°26′5.46″

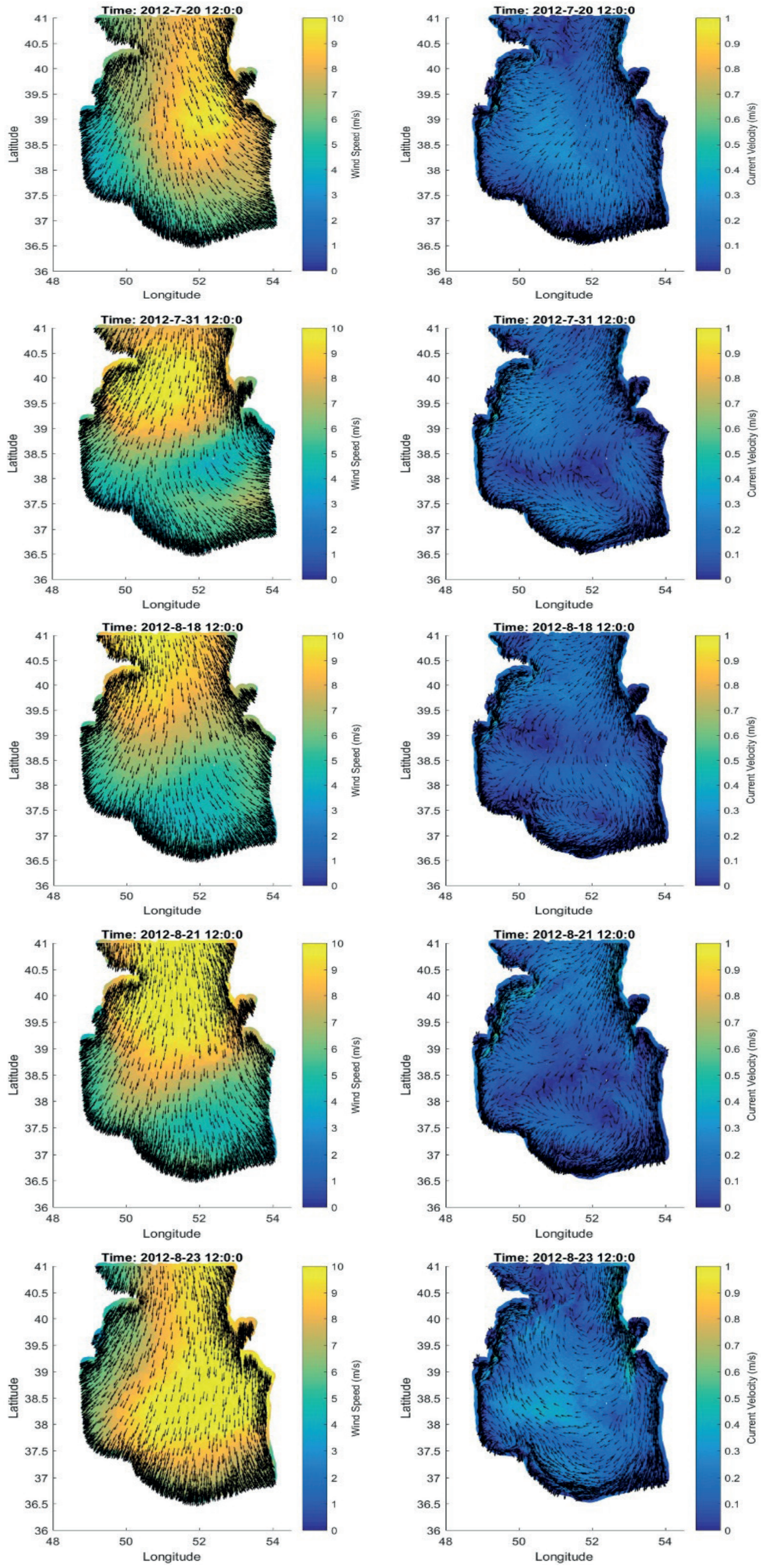

Figure 5. Prominent wind field and the affected flow referring from the second half of July to the end of August 2012

Figure 6. The location at which oil spill hits the shore; Right) spill time was 00:00 of 20.07.2012 and the hit time in the eastern shores was 01.08.2012, Left) spill time was 18:00 of 24.07.2012 and the hit time in the southern shores was 24.08.2012

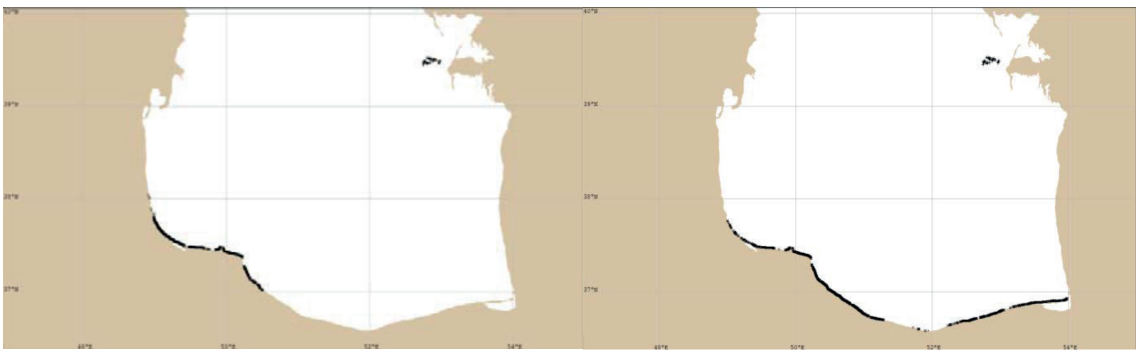

Figure 7. The location at which oil spill hits the shore; Right) when the time of spill is considered 00:00 of 25.07.2012, the hit occurred in southern shores on 24.08.2012, Left) when the time of oil spill is considered 18:00 of 25.07.2012, the hit occurred in southwestern shores on 23.08.2012

Figure 8. The location at which oil spill hits the shore; Right) when the time of spill is considered 00:00 of 26.07.2012, the hit occurred in southern shores on 23.08.2012, Left) when the time of oil spill is considered 18:00 of 30.07.2012, the hit occurred in southwestern shores on 27.09.2012

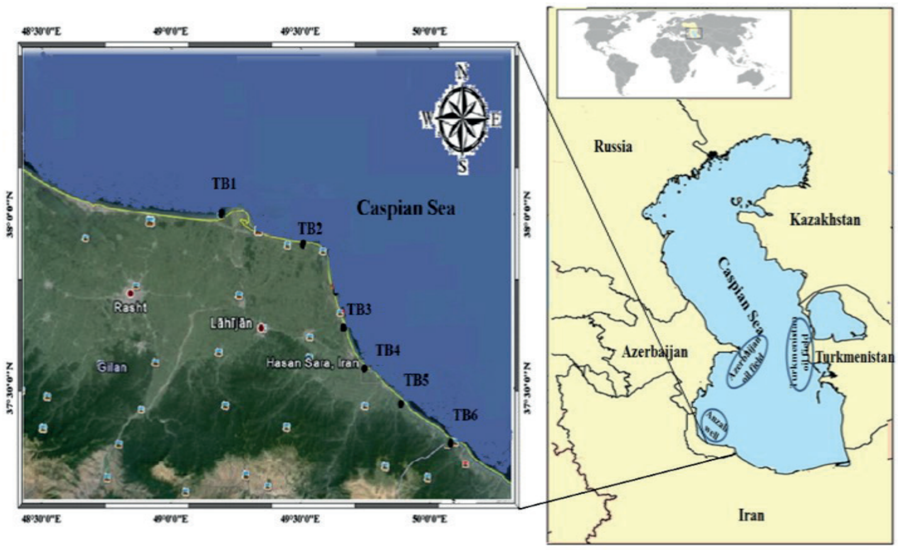

Figure 9. Location of gathered oil tarballs in august 2012 (Shirneshan *et al.*, 2016)

in August 2012 was reported (Table 1). Figure 9 also demonstrates the location of gathering these oil tar balls. Comparing the places of oil spills hit in simulations, and the location of collecting the oil tar balls, discussed in the study by Shirneshan *et al.* (2016). It could safely be concluded that the oil spills from Turkmenistan's oil fields occurred in the July 25, 2012.

Conclusion

In the present research, wind induced currents were simulated using FVCOM model in order to track the oil spilled from Turkmenistan's oil field. Results from the model were then compared to the measurement data of surface flows collected from three Astara, Roudsar and Amirabad stations. The comparison demonstrated that in case of utilizing turbulent closure module in flow model, results become more realistic. The wind data input in the model were obtained in the form of 6-hourly time steps from ECMWF data bank. Later on, in order to determine the destination of oil spills, model output was imported to the GNOME application along with the 6-hourly wind data. The location of oil spill was considered to be oil wells of Turkmenistan in the eastern shores of the southern basin of the Caspian Sea and across from Cheleken peninsula. Type of spill was momentarily and the amount of spill at each oil well was supposed to be 100 barrels. Simulations were conducted for different spill occurrence times; regarding the sections on which the oil spills reach to the shore. Comparing the results obtained from simulations and the location of removing oil tar balls in August 2012 demonstrated the accuracy of simulation results; thus, it could be supposed that considering the wind system governing the Caspian Sea, the oil spills from Turkmenistan could reach to Iran shores in the summer.

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