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Modelling The Impact of The Oil Spill Pollution in Ildır Bay, Turkey

Türkiye'nin Ildır Körfezi'nde Petrol Sızıntısının "Etkisinin" Modellenmesi

Türk Denizcilik ve Deniz Bilimleri Dergisi

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ABSTRACT

On the 18 of December 2016 a Panama-flagged ship, M/V Lady Tuna, was grounded off the coast of Ildır Bay, Turkey. According to the authorities 75.38 m^3 (approximately 73 tons) heavy fuel-oil was released to the sea. It is the worst environmental disaster in the region mainly affecting the coastal areas of the Ildır Bay. To better understand the effects of the oil spill, a series of models were set-up in the region. The fate of the oil spill was predicted by MEDSLIK-II oil spill model forced by currents and temperature from an Aegean Sea circulation model based on NEMO (Nucleus for European Models of the Ocean) and winds from an atmospheric Re-Analysis model (ECMWF, ERA-Interim). A couple of sensitivity experiments were conducted by changing the discharge duration and amount, the sensitivity results were compared with observations. The model results are in good agreement with the available observations. The model successfully predicts the path of the oil spill in the sea surface and its final destinations along the coast. The oil makes first land contact after 36 hours of accident. Due to the dominated and consisted southward currents and weak wind speed at the time of the accident, the effects of the oil were luckily limited without any high dispersion at the coast.

Keywords: Oil spill, Hydrodynamic Modelling, Aegean Sea.

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ÖZET

18 Aralık 2016'da Panama bayraklı bir gemi olan M/V Lady Tuna, Türkiye'nin Ildır Körfezi açıklarında karaya oturdu. Yetkililere göre 75,38 m^3 (yaklaşık 73 ton) akaryakıtın denize sızmış olduğu belirlenmiş ve bu kaza Ildır Körfezi'nin kıyı bölgelerini etkileyen bölgedeki en kötü çevre felaketlerinden biri olarak kayıtlara geçmiştir. Bu sızıntının etkilerini daha iyi anlayabilmek adına bölge için bir dizi sayısal model uygulaması kurgulanmıştır. Petrol sızıntısının akıbeti, NEMO (Nucleus for European Models of the Ocean) Ege Denizi sirkülasyon modelinden elde edilen akıntı ve sıcaklık değerleri ve atmosferik yeniden-analiz modeli (ECMWF, ERA-Interim) tarafından sağlanan rüzgar verileri ile zorlanan MEDSLIK-II petrol sızıntısı modeli ile simule edilmiştir. Sızıntının deşarj süresi ve miktarı değiştirilerek hassasiyet deneyleri gerçekleştirilmiş ve bu sonuçlar gözlemlerle karşılaştırılmıştır. Model sonuçları mevcut gözlemlerle iyi bir uyum içindedir. Model, deniz yüzeyindeki petrol sızıntısının yolunu ve kıyı boyunca nihai varış noktalarını başarılı bir şekilde tahmin edebilmiştir. Kazadan 36 saat sonra sızıntının ilk kara teması gerçekleşmiş, kaza zamanındaki mevcut yüzey akıntıları ve bölgedeki zayıf rüzgar hızına bağlı olarak, petrol kıyıda büyük bir dağılım göstermemiş ve nispeten sınırlı bir alanı etkilemiştir.

Anahtar sözcükler: Petrol sızıntısı, Hidrodinamik Modelleme, Ege Denizi

1. INTRODUCTION

The Aegean Sea is an elongated large bay of the Mediterranean Sea located between Europe and the Turkish coasts. It covers an area of 215.000 km^2 and has a highly complex topography with a maximum depth of ~3.5 km. The coastline is extremely irregular with hundreds of small and large islands spread all over the Aegean Basin (Figure 1 and 2). The hydrodynamics of the Aegean Sea is mainly determined by the exchanges between the Levantine Sea at the south and the Black Sea at the North through the two-layer regime of the Turkish Straits System (Ünlüata et al. 1990) connected to the Aegean Sea by Dardanelles Strait, Poulos et al, (1997). Heavy maritime traffic load through the Turkish Straits System (Turkish Chamber of Shipping, 2021) and the positive growth trend of Turkish maritime transportation (Balık et al. 2015) suggest an increased risk of accidents in the Turkish coasts Aegean Sea. The risk of maritime accidents in Aegean Sea with potential environmental hazards is statistically shown to be contributed by the increased maritime traffic in the region, (Ventikos et al. 2017) which also states an increase in Suez–Dardanelles passages making the Turkish coasts more vulnerable.

The Ildır Bay as shown in Figure 1 are located at the western coast of Turkey. It is one of the many bays along the Turkish coast of the Aegean Sea. The bay has some of the most beautiful and untouched areas along the Aegean coast with golden beaches (over 20 beaches), It is also internationally famous with turquoise blue seas, and rich underwater fauna. Additionally, it is one of the most important windsurfing sites in Europe with favorable wind conditions with very shallow waters suitable for windsurfing. Actually, the Bay do not have any heavy ship traffics, however, there are offshore fish farms, and this specific accident has happened after the ship took her cargo from a tuna farm in the Bay. The location of the ship when the accident happened was shown in the figure (latitude: 38° 23,26' N, longitude: 26° 25,42' E) which is quite shallow with less than 5 meters of depth. She grounded at 13:40 local time on 18/12/2016 on the way to anchorage area for custom clearance formalities while the ship still under way at a speed of 11.7 knots based on accident investigation report. The pollution is due to the fuel oil leakage of the ship through the cracks on its body after the accident. A company begins the cleaning after the incident. Fortunately, most of the polluted areas were cleaned with this effort. The details of the daily recovery actions are beyond the scope of this paper.

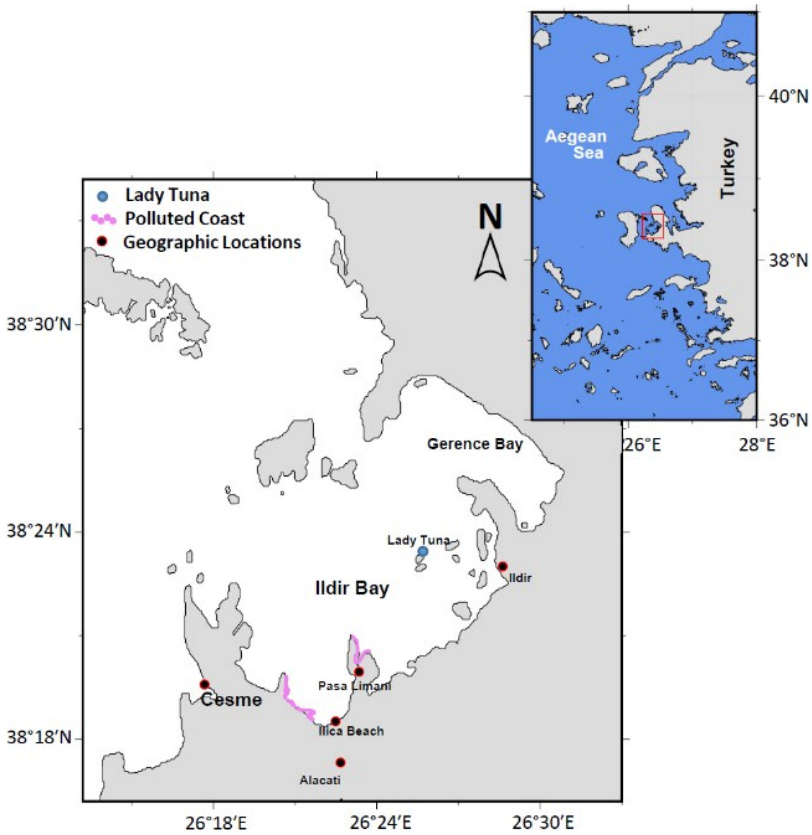

Figure 1. The study area and names of the main geographic features. The violet polygons show the polluted coastline due to oil spill. The top right figure shows the Turkish coast and the red rectangle show the boundaries of zoomed figure.

Figure 1 also show the polluted coast of the Bay. The worst pollution has happened in Paşa Limanı which is a northward directed peninsula with a small bay inside. Due to the direction and position of this bay (like an "open mouth"), most of the oil was landed in this small bay. The rest of the oil pass through this peninsula and reached the Ilıca Beach in which many touristic hotels are located.

Unfortunately, there is no clear satellite images showing the path of the oil spill. For this reason, modelling the fate of the oil spill is important for a better understanding of the consequences of this accident. There are various oil spill models used to investigate the fate of the spilled oil such as GNOME (General NOAA Operational Modeling Environment), the SPILLCALC by Tetra Tech. These models are used in regional and global studies (Beegle-Krause, 2001) and was also successfully implemented for possible oil spill scenarios at Bosphorus-Marmara Sea (Başar, 2010), in Black Sea (Başar et al. 2018) and in İstanbul Strait (Yıldız et al. 2021). MEDSLIK-II model (De Dominicis et al. 2013a, De Dominicis et al. 2013b) was used in this study due to its high flexibility. The model has been used extensively in regional oil spill mode studies (Lopez et al. 2021; Liubartseva et al. 2021; Zodiatis et al. 2021). In the MEDSLIK-II model, it is possible to provide the model spill amount, duration and the observed path of the spill from satellite derived images during the model integration.

2. MATERIAL AND METHOD

As the oil is spilled on sea, winds and currents are the main forcings controlling the spread and movement of the oil slick. In this section the setup and configuration oil spill model is described and the details of the ocean and the atmospheric models providing the ocean surface currents and the winds will be given.

2.1. NEMO Hydrodynamic Forcing

The currents and the and sea surface temperature (SST) necessary for the oil spill model are obtained from a regional ocean circulation model of the Aegean Sea. The model code is based on NEMO (Nucleus for European Models of the Ocean) at version 3.6 stable (Madec et al. 2017). The Aegean Sea is a challenging basin to set-up a numerical ocean model due to its complex coastline and islands (Mamoutos et al. 2021; Korres et al. 2010). Figure 2A shows the circulation model domain. Although the accident happened at one of the small Bay of the Turkish coasts, to better represent the circulation which is very important parameter for oil spill transport, the whole Aegean Sea was modelled. With this approach the effect of the open boundaries is minimized in the oil spill model. The model was forced by Copernicus Marine Environment Monitoring Service (CMEMS) temperature, salinity and currents at the boundaries. The model horizontal resolution is around 1.2 km, and there are 36 vertical levels. The model was forced by ECMWF (European Centre for Medium-Range Weather Forecasts) ERA-Interim atmospheric re-analysis model. The hydrodynamic model simulation ends about a week after the accident but started approximately 6 months before the oil spill with the aim of reaching an equilibrium state during the period of spill prediction.

For the same hydrodynamic model setup, the model results were actually validated with the available in-situ and satellite observations which will be covered extensively by a separate modelling study in preparation focusing on the period between August 2008 to August 2009 due to the available in-situ data for the region. The model derived currents and scalar fields for this period were found to be in good agreement with the observations as seen from the SST comparisons between the model, station based and the satellite supported CMEMS model results for the Athos (Figure 2B) and Lesvos (Figure 2C) stations shown in Figure 2A (taken from the study in preparation).

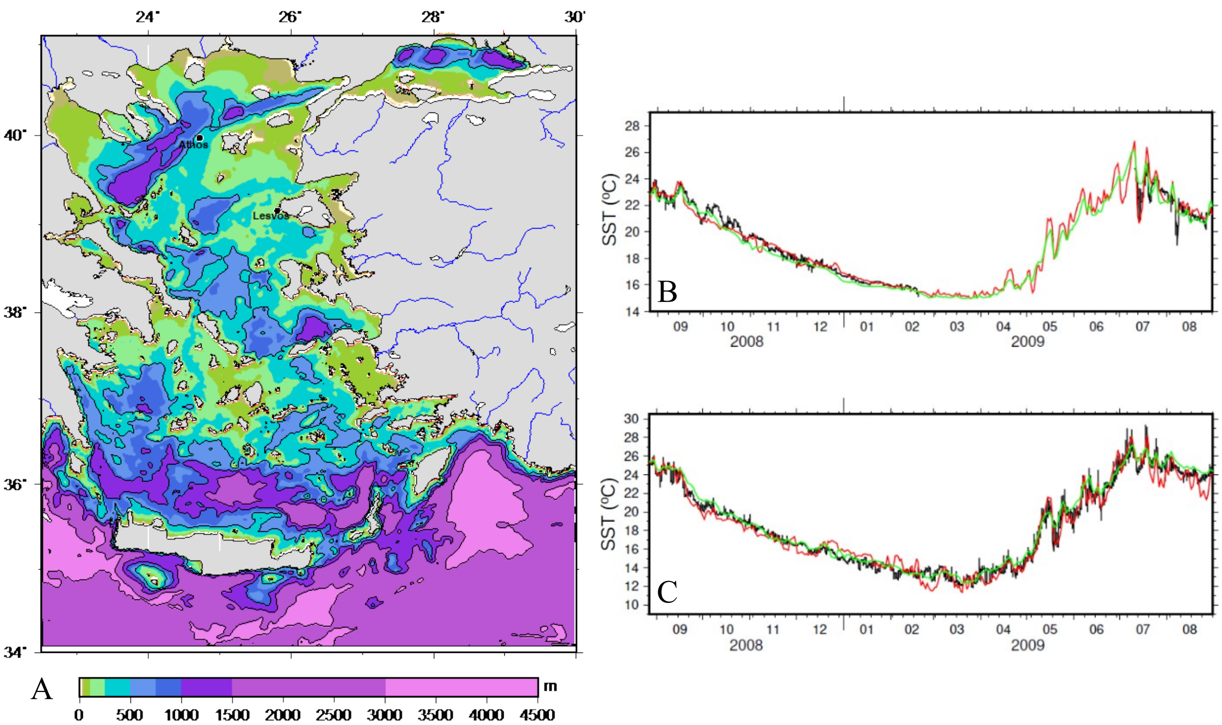

Figure 2. A) The domain and the bathymetry of the hydrodynamic model and time series comparisons of the model generated (red), station based (black), CMEMS (green) SST at B) Athos and C) Lesvos stations.

2.2. Atmospheric Model

The oil spill model input of atmospheric wind at the surface of the ocean were obtained from ECMWF. The ERA5 re-analysis product of ECMWF was chosen. ERA5 is the latest and better resolution product of the ECMWF with 4 km horizontal resolution. The atmospheric forcing was received in an hourly time interval. The wind conditions are shown in Figure 3. During the time of accident, the weather is moderate with wind speeds less than 2 m/s. The wind blows mainly from the north in the area of interest. However, a strong wind starts approximately two days after the accident and reaches up to 7 m/s on 21 December and continue several days at a similar strength. Due to the weak wind speed on following 2-3 days after the accident, it is clear that the current at the sea surface is critical parameter for the fate of the oil spill in this special case.

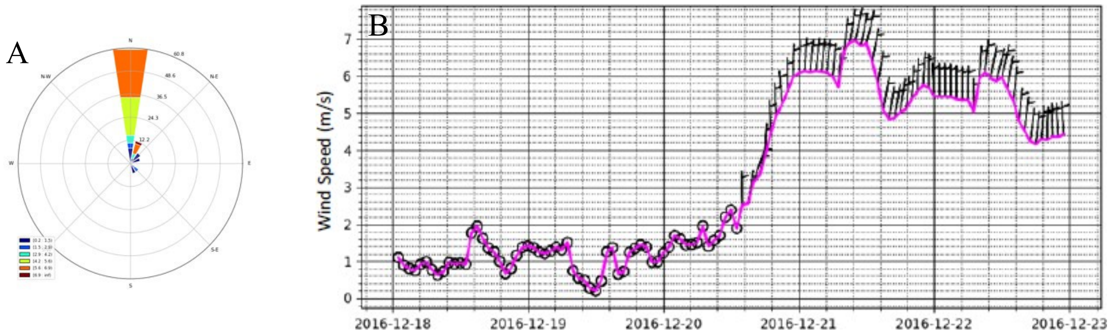

Figure 3. A) Wind rose for the period of 18.12.2016 to 23.12.2016 and B) Time series of the wind speed and wind direction from ECMWF re-analysis data set.

2.3. MEDSLIK-II oil spill model description

Oil spill model used in this study id MEDSLIK-II (De Dominicis et al. 2013a, De Dominicis et al. 2013b), based on its precursor oil spill model MEDSLIK (Lardner and Zodiatis 1998; Lardner et al. 2006; Zodiatis et al. 2008). MEDSLIK-II is a well-established 3D model used for predicting the fate of an oil spill. The details of the governing equations of the model can be found at (De Dominicis et al. 2013a). There are various regional applications of the model. The model source code is a freely available community model and can be downloaded from http://medslik-ii.org/ website. The detailed description of the model equations can be found in De Dominicis et al. 2013b.

The oil spill parameter values chosen for this specific case are given in Table 1. For the rest of the parameters the nominal values from published literature were chosen (Liubartseva et al. 2020 and Liubartseva et al. 2021). The spilled oil is assumed as heavy fuel-oil with a density 900 kg/m^3 and API gravity degree of 15. The spill was modelled as a continuous release of oil over a period of 2h starting from 18 December 2016 at 13:30 with a total volume of 75 m^3 of oil.

Table 1. MEDSLIK-II oil spill model parameters used in this study and their nominal values from published literature.

Model parameters	Used values in this study
the tracer grid cell size, (δxT, δyT)	50 km
the thickness of the thin slick	0.0015 m
and the horizontal diffusivity coefficient, K_h	0.01 m^2/s
Amount of oil spill	70 tons
Type of oil spill	Heavy fuel oil

3. RESULTS AND DISCUSSION

The surface concertation of oil (kg/m^2) derived from the oil spill model results is shown in Figure 4. During the whole model integration, the current direction is mostly south-westward with a speed of around 0.1 m/s. This feature is persistent during the integration period with small departures.

The oil transport to that direction under the influence of current, the oil first landed on Paşa Limanı around 40 hours of accident (Figure 4c). Most of the oil was landed on this bay causing environmental disaster along the beaches. The rest of the oil travel to the south-west direction and landed on the Ilıca beach which is another important tourist place famous with its clear water. The final destination of the oil after 68 hours of integration was shown in Figure 5. The location of the polluted coast is in good agreement with the observation (as shown in Figure 1 with violet color). The surface oil concentration reaches up to 20 kg/m^2 along the coast.

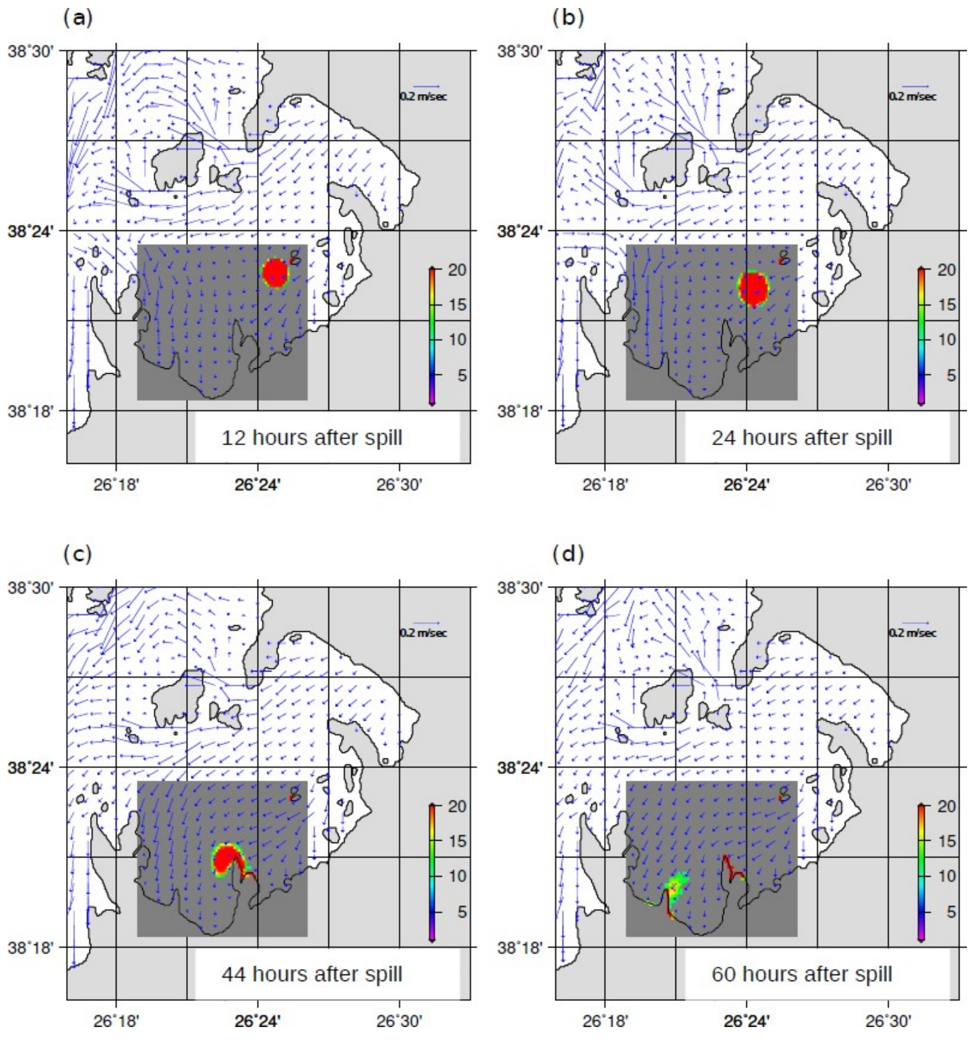

Figure 4. Oil spill model derived surface concentration of the oil overlaid on ocean current velocities. The panel shows the concentration after (a) 12, (b) 24 (c) 44 (d) 60 hours after the spill start by *18/12/2016 13:30*.

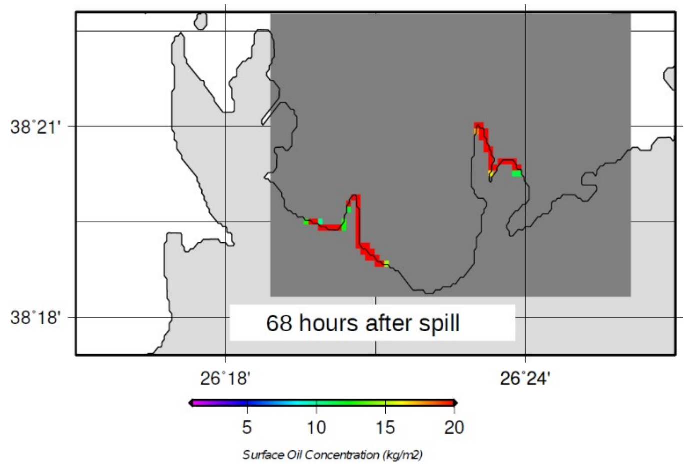

Figure 5. The surface oil concentration (kg/m^2) and the final landed position of the oil after 68 hours of integration.

Figure 6 shows the oil-fate parameters simulated by the MEDSLIK-II model. The evaporated oil (green line) is rather limited due to the cold sea water temperature at the time of incident. In average % 10 of the oil is evaporated for each model time level. The oil on the coast (blue line) is almost constant until 34 hours of integration, however after first landing of the oil on the coast there is fast flushing of the oil on the coast. At the end of the simulation there is very small amount of oil still exist at the surface of the sea (red line). Trotta et al. (2021) have shown the importance of the downscaling of the basin-wide ocean models for the early warning systems. While larger-scale operational models gives the coarse overview of the sea conditions, it is necessary to develop a regional ocean model nested in this larger-scale operational model to better forecast the oil-spill behaviour. In this study, it is shown that developed regional ocean model successfully predict the behavior of the oil spill located in a relatively small Bay.

A different oil spill dispersion model (PISCES II) was applied to model the same accident by Aydin and Solmaz (2019). The major improvement of the current study from that study is to use the real-time currents and winds generated by ocean and atmospheric model. However, Aydin and Solmaz (2019) have used the dominant wind direction and current in their studies. The winds and currents can be change with a short time frequency especially very close to the coast due to the bathymetry and coastline. The current study considers this high frequency variability which is believed quite important for oil spill dispersion.

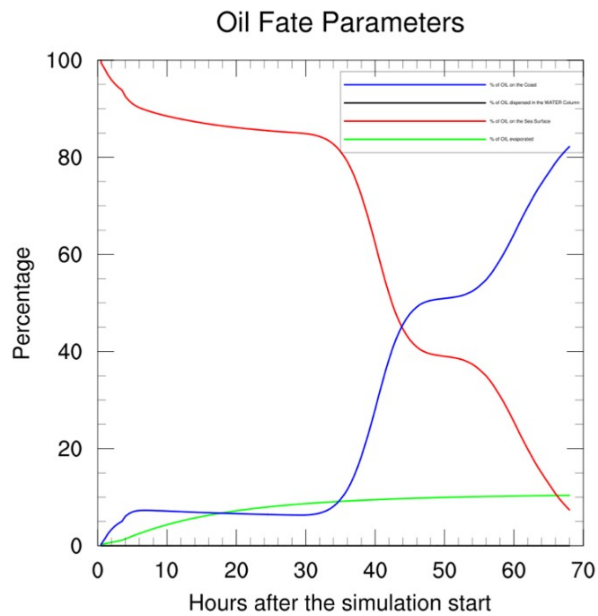

Figure 6. Oil-fate parameters simulated by MEDSLIK-II model from 18 December 2016 13:30 to 21 December 09:30. Green line is evaporated oil; blue line is the oil reaching to the coast and the red line is oil at the surface of the sea.

4. CONCLUSION

The oil spill model used in this study which is driven by the output of a regional circulation model together with the atmospheric forces was able to predict the resultant location of the oil spill quite successfully. Relatively weak wind speeds at the time of the accident and following 2-3 days emphasizes the importance of the ocean surface currents in determining the oil spill fate. Different from the atmospheric inputs used in the oil spill prediction models, ocean parameters driving the oil spill is generally not available and especially difficult to obtain in high resolution which could be very important as in the case analyzed here where the accident happened in a relatively small bay located on a very irregular shoreline.
Oil spill are one of the major threats to the marine environment and has a very short window of opportunity to fight for reducing the contamination. The biodiversity of the Mediterranean, Aegean and the Black Seas and the total fisheries production from these basins have a great importance for not only surrounding countries but also for Europe as an importer-consumer in the seafood market. Considering the adverse effects oil spills to the coastal marine environments which are vital for the marine ecosystems, the ability of prediction of the transport and behavior of the oil spills by numerical approaches is an absolute necessity and introduces a great advantage in reducing potential impacts of these hazards. However as in the case of this incident ocean surface circulation may play a significant role in determining the fate of the oil spill and the availability of high-resolution operational ocean circulation models become a crucial necessity.

AUTHORSHIP CONTRIBUTION STATEMENT

Murat GÜNDÜZ: Conceptualization, Methodology, Modelling, Analysis, Writing, Visualization.
Adil SÖZER: Conceptualization, Methodology, Analysis, Writing, Visualization, Editing.

CONFLICT OF INTERESTS

The authors declare that for this article they have no actual, potential or perceived conflict of interests.

ETHICS COMMITTEE PERMISSION

Authors declare that no ethics committee permissions is required for this study.

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