Remote Sensing and Modelling of the Mopang Oil Pollution Near the Bulgarian Black Sea Coast

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Abstract This work investigates the extend of oil pollution released by the sunken cargo ship Mopang, located in the Bourgas bay on the Western Black Sea shelf. We have analysed the available Synthetic Aperture Radar (SAR) data from the Sentinel-1 mission for the years 2017 and 2018 and identified the surface features which could be referred to oil pollution, originating from Mopang for the given timeframe. To detect the oil leaks an adaptive threshold algorithm is used and the detections are visualized cumulatively in order to estimate the continuity and intensity of the leak throughout the period. The radar acquisitions from both the ascending and descending pass of the Sentinel-1A and B satellites with oil detections visible for three dates are plotted together with the surface currents in attempt to study the evolution of the leak and its dependence on the marine conditions. The possibility to simulate the dispersion of oil pollution on the surface with a Lagrangian particle model is tested for one of the dates. Three seeding scenarios are run: (1) release from a shape, such as the one of the morning detection; (2) release from a point source; and (3) continuous release from a point source for the entire simulation period. The numerical simulations are performed with the OpenDrift trajectory model and the results after 12-h run are validated against the satellite images.

Keywords Oil pollution in Black Sea · SAR · Lagrangian particle modelling

1 Introduction

Oil pollution is a serious threat for the marine ecosystems: it might enter the water system through anthropogenic activities or through natural sources such as crude oil sleeks from the sea bottom. The ecosystems in semi-enclosed basins like the Black Sea are especially vulnerable to oil pollution as the water exchange in such seas is limited.

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Fig. 1 Position of the sunken ship in Bourgas bay, marked with a star

Over 80% of the Bulgarian shoreline is protected area by Natura 2000 as it provides a nesting area for various protected bird species, which makes it particularly vulnerable to chemical contamination [1]. However, oil pollution is common in the Bulgarian waters due to accidental spills or routine waste discharges from cargo ships. In this work we study another, rather uncommon source of oil pollution for the region—a sunken ship with significant amount of engine fuel.

In the beginning of August 2018 the sunken ship Mopang began releasing some of its engine fuel, which attracted serious public attention and concerns, as the ship remains are located in direct vicinity of the island St. Ivan, about 10 km away from the busy tourist town Sozopol, Fig. 1. The accident was reported by citizens to the Maritime Safety Agency in Bourgas which then initiated cleaning up the tanks and pumping out the remaining fuel. The activity was compleated in the summer of 2019.

Mopang was an US build cargo steamship of the Liberty ships type, build in 1920 and sunk in June 1921 after hitting a mine. The sea depth in the region where the shipwrecks are located is between 20 and 33 m [2]. The capacity of the engine tanks is to hold about 600 tons of fuel and it was estimated to have ~100 to 150 tons inside [3].

The potential of the Synthetic Aperture Radar (SAR) as an information source for the automatic detection of oil pollution released in the sea has been acknowledged and investigated years ago and nowadays this method is widely used for the operational monitoring [4–6]. On radar images oil appears as dark formation, as it smoothens the natural sea roughness and thus decreases the backscattering properties of the sea surface. Other natural phenomena, such as local surface currents, eddies or algal blooms, have the same appearance on radar data and might cause false detections in case of an automatization of the oil detection process.

Simulation of the dispersion of oil pollution on the sea surface is important practice to support the sea operations to limit the leak, especially in the case of more severe pollution events. The model calculations consider the local meteorological and marine conditions and could define the affected areas, thus optimizing the cleanup activities.

The use of Lagrangian particle tracer models is a reliable method to simulate the movement of pollution particles in fluids. In the current study we use the module for oil simulations of the OpenDrift model [7] for tracing the movement of oil particles released from Mopang.

The satellite data used in this study is from the Sentinel constellation, which is part of the Copernicus program for Earth observation. The program is managed by the European commission, together with the European Space Agency and all data it delivers is distributed free to the scientific and business community [8]. We have analyzed Sentinel-1 radar data and use an adaptive threshold algorithm for detection of surface features which can be related to oil pollution on the sea surface in direct vicinity of the sunken ship Mopang. All available acquisitions for the years 2017 and 2018 were reviewed in order to understand the extend of the pollution and its intensity. Radar data reveals slicks on most of the summer time images with varying intensity and distribution.

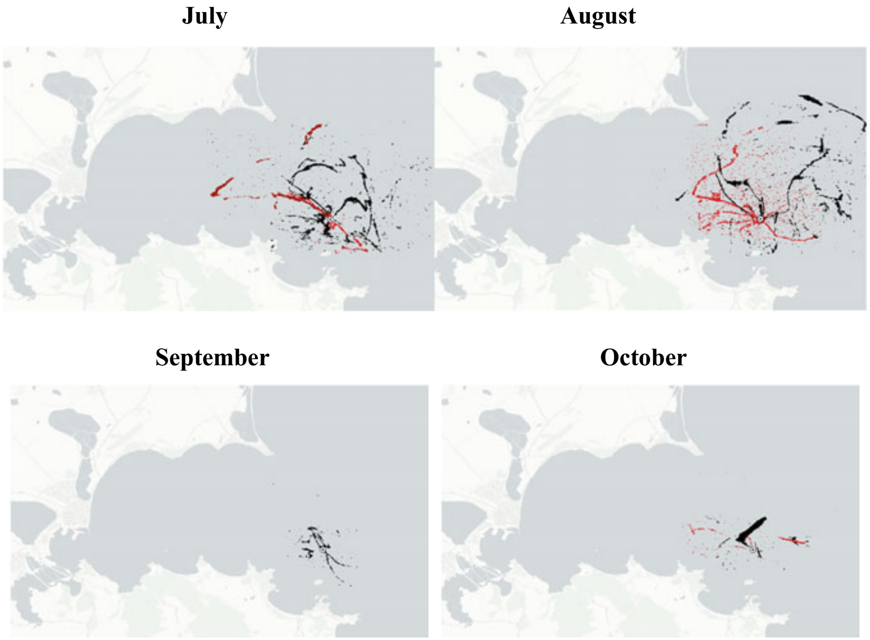
Additionally, the images from the ascending and descending passes of Sentinel-1A and B respectively at 4 am and pm on the same day give possibility to visualize the oil dispersion and relate it with the surface currents at acquisition time in order to study the evolution of the pollution dispersion. A simulation test with the Lagrangian particle model OpenDrift is performed for one of these dates.

We have considered three seeding scenarios as an initial condition of the oil particles position. The satellite image after 12 h gives possibility to validate the model simulation drift in order to evaluate which seeding scenario is probable and to verify the credibility of model calculations.

2 Methods

The satellite data used in this study comes from the Sentinel-1 mission and is processed and visualized with the software SNAP (Sentinel Application Platform). The automatic detection of oil leaks from radar imagery is done using an adaptive threshold algorithm [9] and the detected areas are cumulatively plotted according to the month of acquisition (Fig. 2). For images, acquired on the same day from ascending and descending pass, the detected oil areas are plotted separately on Fig. 3 together with the surface currents of the acquisition time in order to track the development of the slick. The ocean currents data is acquired from the Copernicus Marine Environment Monitoring Service—CMEMS Black Sea physics reanalysis product [10].

The adaptive threshold algorithm calculates the mean backscatter value for pixels in a large window and applies a user defined detection threshold value for estimating each pixel of the area [5]. If the backscatter value of the pixel is below the threshold, it is detected as dark spot. If it is above the threshold, it is estimated as background pixel. Moving the window of averaging and estimating the backscatter for each pixel gives information if a given spot has lower reflectance, which can be caused by oil spreading on the ocean surface, damping the capillary waves. Clustering of the dark



July

August

September

October

Fig. 2 Cumulative plot of all detections for 2017 and 2018 for the summer months from July until October. All oil leak detections from 2017 are plotted with red and those from 2018 in black. The coordinates of the ship wrecks are denoted with a dot

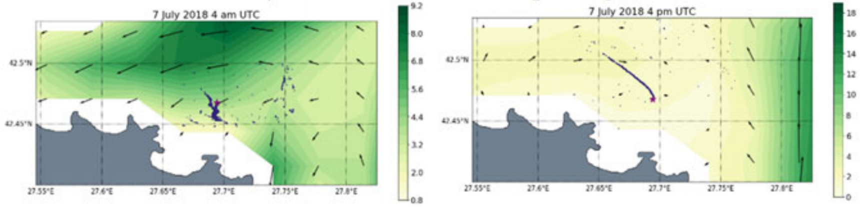
spots and defining a minimum cluster size, provides the user with a mask, showing all detected dark spots having larger dimension compared to the defined minimum [5].

The main drawback of the adaptive threshold is the notable amount of false detection of look-alike objects, caused by other phenomena. These could be minimized by further investigation of the detected areas. A classification according to shape, size and orientation can significantly reduce the amount of false alarms, especially for the areas in direct vicinity of the shoreline [5, 11].

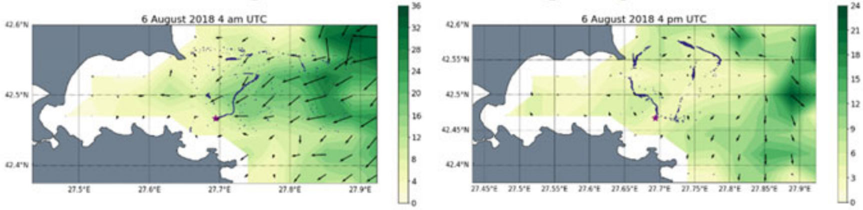
The capability of the SNAP ocean tool for oil spill detection for the Black Sea region has been demonstrated in previous studies and is estimated as good [12]. Some of its major drawbacks is detection in areas close to the shoreline, which underlines the importance of additional analysis and classification of the results in this study. Due to this the initial parameters for detection were fine-tuned and additional inspection of the surface reflectance and texture of the image in the area where the ship is positioned was done for each acquisition. This procedure gave confidence to clearly distinguish between oil trace and look-alike objects detected by the algorithm.

Next step in this study is to investigate the propagation of the oil pollution, released from the sunken ship Mopang by simulating the movement of oil droplets with a Lagrangian particle model. It enables a simple tracking of tracers by which we can determine the position of oil particles at selected time.

7 July 2018, 4 am (left) and 4 pm (right)



6 August 2018, 4 am (left) and 4 pm (right)



29 September 2018, 4 am (left) and 4 pm (right)

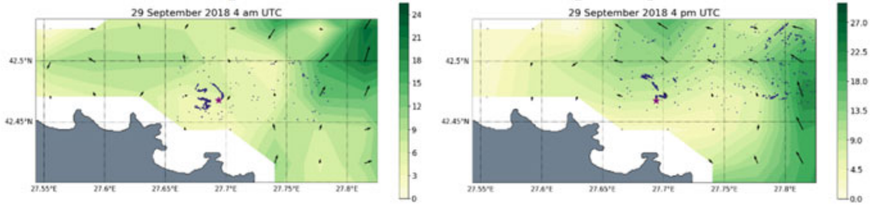


Fig. 3 Oil detections, plotted in navy blue for three different days—7 July, 6 August and 29 September 2019. Acquisition, taken at 4 am is on the left and from 4 pm is on the right. The speed of the surface currents is color-coded, units—[cm/s] and the arrows indicate the direction. The position of the ship is marked with a star

The simulations are conducted with the open source model OpenDrift which is developed at the Norwegian Meteorological Institute and is Python-based [13]. OpenDrift is a generic framework for tracing objects, drifting in the ocean and more specific functionalities, depending on the purposes are implemented in the available trajectory modules [7]. For our purposes we use the module OpenOil which is developed specifically for simulating the fate of oil in marine environment and includes a number of features aiming description of the processes with maximum accuracy.

OpenOil requires input for the meteorological and marine conditions which are necessary as forcing data for the correct calculation of advection and transformation of oil particles. For the simulations done in this study we use hourly values for the ocean surface current velocity from the Copernicus Marine Services [10] and surface wind speed at 10 m height from the European Center for Medium-Range Weather Forecast (ECMWF) atmospheric reanalysis—ERA5 [14].

In OpenOil the horizontal drift of oil droplets is parametrized with the assumptions that particles drift with the ocean current and are subject of Stokes drift, depending on their depth. Oil elements on the sea surface get an additional moving factor from the wind stress and Stokes drift. The horizontal movement is scaled by taking into consideration the vertical transport, which is implemented in the calculations by different factors. One of the major agents for the vertical mixing is the presence of strong wind and waves, which leads to intensive mixing of oil and water and entrainment and sinking of oil droplets in the water column [15]. The oil properties, such as its density, viscosity and the size of the oil droplets together with the ocean stratification profile, determine the buoyance of oil particles.

The model has implemented a broad library of different oil types, which includes specific information about their densities and viscosities, which is then considered for the weathering and emulsification of oil in marine environment. For the particular example of oil seeps, originating from ship wrecks, which is the subject of our study, after experimenting with different oil types we have selected a generic heavy fuel oil for the simulations, as it has similar properties to the mazut fuel, which was widely used as ship fuel at that time and which we assume was in the ship tanks.

3 Results and Discussion

3.1 Mopang Oil Detections from 2017 to 2018

In order to estimate the outreach of the oil pollution originating from the ship wrecks of Mopang all available acquisitions from Sentinel-1 for the years 2017 and 2018, which include the region of interest were processed. Both time periods reveal similar results and conclusions.

Figure 2 is a cumulative plot, showing the detections for both years only for the summer months July, August, September and October. The purpose is to check if the leaks differ in number and intensity during the suggested period of Mopang oil release. The detections done in 2017 are pictured in red and from 2018 in black. In September 2017 there were no significant detections related to Mopang.

Acquisitions from the rest of the year were processed as well. Occasional surface features, which could be referred to Mopang were visible in few days spread throughout the year without significant accumulation related to particular month or season.

The small colored areas which are not clustered with the main detection slick (see the position of the ship with dot) are caused by false detections due to the small scale of the event and inaccuracy of the detection algorithm.

The majority of the detections for both 2017 and 2018 are during the summer months. This observation can be explained with the calmer sea conditions being favourable for the oil to remain on the sea surface and not mix with the ambient water after emerging from the ship tanks. During 2018 there are more oil detections compared to 2017, as visible in Fig. 2. July and August 2018 show similarly intensive oil releases, which could be related to the Mopang leaks. In the Bulgarian media it was stated, that part of the ship collapsed due to its age and poor state in the beginning of August 2018, leading to the oil leakages, but our investigation disproves it as the leak was evident during most part of the summer during the previous year as well [16].

Due to the small scale of the event there are number of false detections deteriorating the clear assignment of the oil detections on the cumulative plots. They remain visible despite the fine-tuning of the variables which can be changed in the detection algorithm. This illustrates the challenges in front of the complete automatization of the process in the case of small scale events close to the shoreline.

3.2 Propagation of Oil with Surface Currents

Every six days the Sentinel-1A and B pass over the area of interest, acquiring images at 4 am in descending and 4 pm in ascending orbit. In favorable meteorological conditions, such as low sea waves and moderate winds, the oil slick originating from the sunken ship is visible on both acquisitions, which provides a unique opportunity to study the evolution of the surface dispersion over time depending on the surface currents, wind speed and direction.

Three selected cases are presented in Fig. 3: the position of the oil slick is plotted on the map together with the surface current speed at the moment of acquisition. The vectors indicate the direction of the current and their length—the speed. The grid resolution of the reanalysis data for the surface currents is ca. 3 km (1/36° in meridional and 1/27° in zonal direction), thus the current speed closer to the shoreline cannot be determined.

Comparing the left and right column images, one can conclude that the current direction affects the shape of the oil slick after 12 h: on 6th of August 2018 the slick is moved to the west due to the north-eastern current; similarly on 27 of September 2018 the slick is displaced from the southeastern current. An interesting case is the 7th of July—morning-to-afternoon the current changed to the opposite direction (from east to west), and the slick on second position is most likely new released Mopang oil.

The plots in Fig. 3 reveal that the position of the oil slick is in the low current speed area and it disperses mainly along when the speed is higher than 10 cm/s or across the stream lines in the case of weak current.

It is noticeable that the oil leaks are of similar size and form throughout the same day, however they are usually visible as discontinuous patches. This, together with the moderate speed of the surface currents, which varies between 5 and 25 cm/s for the areas of oil propagation, suggests that the oil detections in the afternoon are not of the same oil which was visible in the morning. This statement is also in tact with the presence of more intensive breeze circulation in the afternoon hours with typical wind speeds between 2 and 4 m/s, which would lead to entrainment of oil particles in the water column.

The assumption that during the summer months a continuous release of oil from the ship tanks was visible is also intact with the results of the simulation, ran for 7 July 2018 with the trajectory model OpenOil presented in Sect. 3.3.

3.3 Simulation of the Propagation of Oil Leaks with OpenOil

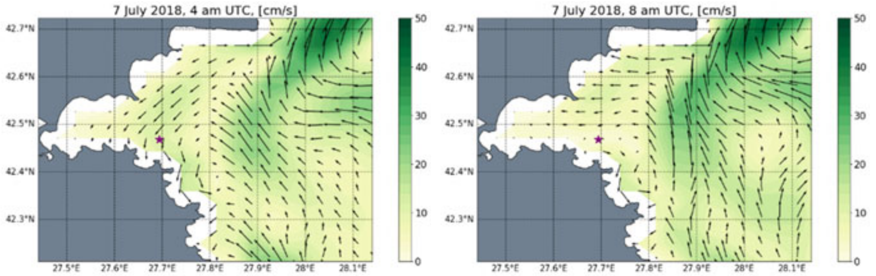
As test case to simulate the propagation of oil leaks with the model OpenOil the date 7 July 2018 at 4 am to 4 pm UTC was chosen (Fig. 3). The reason is that both detections are of particular and different form and can clearly be referred as originating from the ship wrecks.

The aim is to simulate the distribution of oil droplets with starting time 4 am, when the first Sentinel-1 acquisition is taken and compare the results with the real detection from the second acquisition at 4 pm. The good overlapping of the form and position of tracers from model calculations with the actual detection from the satellite image would prove the credibility of the Lagrangian particle trajectory method for predicting the spread of oil in marine environment for the particular case we observe.

The speed and direction of propagation of the surface currents at 4 am (morning acquisition time), 8 am, 12 pm and 4 pm (afternoon acquisition time) are shown in Fig. 4. These are the time steps in which we track the position of the oil elements after starting the simulation. The plotted area covers the entire Bourgas bay.

Figure 5 displays the wind barbs in 2 h steps again for the timeframe of the simulation—12 h at the coordinates where the ship wrecks are located (the source of

4 am **8 am**



12 pm **4 pm**

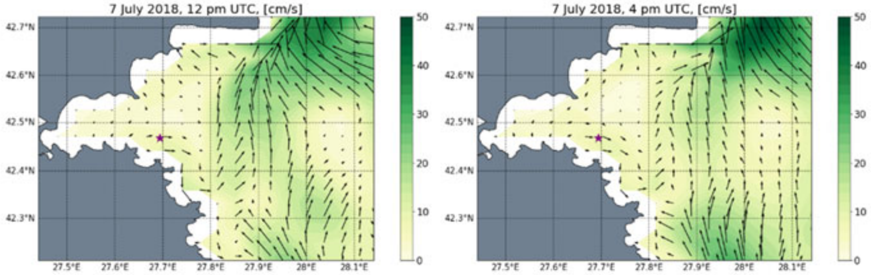


Fig. 4 Surface current speed (in [cm/s]) and direction for the day, when model calculations are done—7 July 2018 from 4 am until 4 pm in 4 h' time steps. The data is from the CMEMS—Black Sea physics reanalysis product. The position of Mopang is located with a purple star

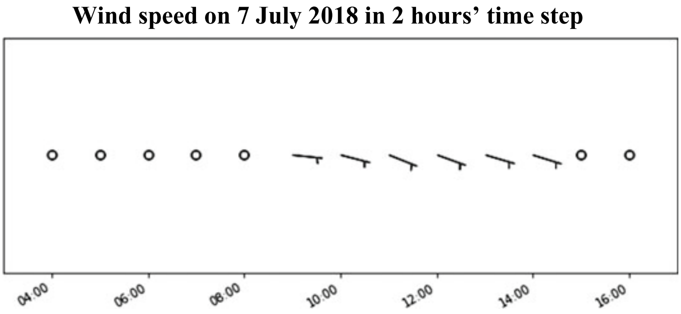


Fig. 5 Wind barbs indicating wind speed in [m/s] and direction for the coordinates, where the ship wrecks are located at the day of model calculations—7 July 2018. Start time is 4 am, end time 4 pm in 2 h' time steps. The data is from ECMWF climate reanalysis ERA5

the data is ERA5). In the beginning of the period a calm weather is observed followed by weak eastern wind.

The model performance depends on the initial conditions for the oil slick tracers position. We did three simulations with different initial conditions, reflecting the oil release treatment. Each simulation ran for 12 h with 12 time-steps and 300 tracers. The number 300 tracers is chosen as optimal for the size of the oil slick and the horizontal resolution of the marine data. Their distribution during the oil dispersion is indicative for accumulation of oil droplets in certain areas and their general movement pattern. All simulation results are being illustrated in 4-h time steps from the time of the morning overpass of Sentinel-1, until the afternoon overpass together with the oil detection in the afternoon in order to verify the reliability of the calculations.

The forcing data for meteorological conditions is the same for all experiments. The major drawback for the process is that the resolution of the surface current speed data doesn't reach the shoreline, but ends approx. 3 km in water, as it is visible on the surface current plot on Fig. 4. OpenOil extrapolates the values of the current direction and speed, which however doesn't take into account the local circulation specifications and unpredictable changes in the direction of the current flow. This limitation should be considered at the final evaluation of the environmental impact of the oil leak on the coastal ecosystem.

During the simulation experiments different values for all variables, needed for the description of the behavior of oil in marine environment, were tested. The oil entrainment rate is implemented in the model as calculated by Li et al. [17].

The diffusion rate of oil in the marine environment can be regulated with the two drift parameters for current and wind uncertainties. Different values for both of them were tested, resulting in broad dispersion of the tracers at their maximum and drifting solely with the speed of the forcing data at their minimum. A middle range value for the parameters was chosen, which according to our observations most realistically describes the behavior of the tracers considering the meteorological conditions at the time of simulation.

The processes of evaporation, dispersion and emulsification are taken into consideration and their impact on the final results depend mostly on the type of oil, which is chosen. Tests with different oil types have shown little change in the evaporation and entrainment rate, since the simulation is run for 12 h, which is rather short period of time. The here presented simulations are done with a generic type of heavy fuel oil. Main limitation for the exact description of oil type for the simulations is that the ship wrecks were under water for almost 100 years, which has caused significant impact on the chemical composition of the oil product.

Nevertheless after finishing the simulations we are positive that the chosen variables and oil type accurately describe the drifting behavior of oil and reveal the tendency of the dispersion mechanisms.

Three runs of the model are performed with different initial shape of the oil slick: (1) the tracers follow the shape of the oil-slick from the satellite image; (2) the oil is released at once as a point source; (3) the oil is continuously released by a point source at the ship location. The results from the three runs are summarized in Figs. 6, 7 and 8.

For the first simulation all 300 tracers are distributed within the boundaries of the form of the detected oil leak at 4 am UTC on 7 July 2018 and are released for drifting with forcing data for the same time. The results of the simulation after 4, 8 and 12 h from the beginning are shown on Fig. 6 together with the detected oil leak at 4 pm on the same day.

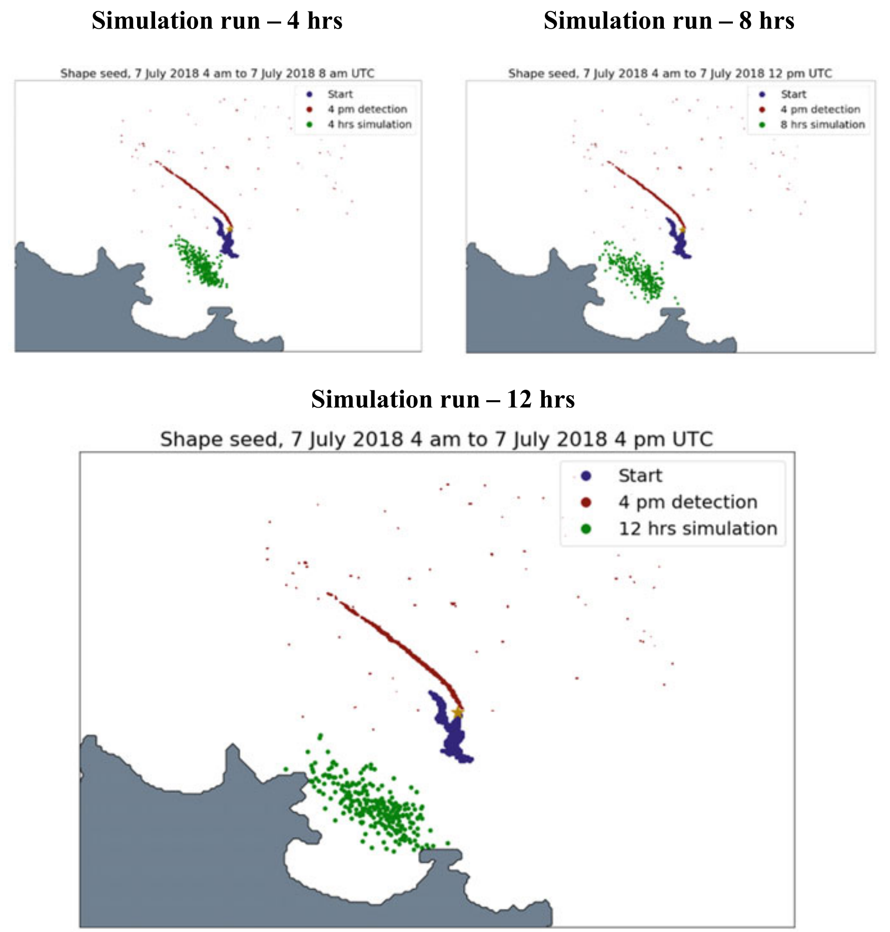
The time steps reveal that the exact shape of the oil leak is lost shortly after release due to diffusion and entrainment, however the tracers keep the elongated form, similar to the initial. In the end of the simulation the tracers are located in the small bay between Sozopol and Chernomoretz, identifying that a longer drift would spread them along the entire coastline of the region and indeed there are reports from tourists for notable oil amount on the near beaches. After 12 h running time 54 elements of the initial 300 are stranded and the active tracers are more widely dispersed.

The second simulation is done with a point source with small diameter, which released all 300 tracers at once at 4 am UTC on 7 July 2018. The results are displayed on Fig. 7 in the same manner at three time steps, 4, 8 and 12 h after beginning of the integrations together with the satellite acquisition at 4 pm, so that we are able to estimate the credibility of the simulations.

The plots are similar to the ones in Fig. 6, but the cloud of tracers has more circular form. After 12 h simulation time none of the tracers was stranded and they haven't reached the coast in Chernomoretz village area and the Sozopol beaches. This type of source shows significantly less dispersion of the tracers.

The third simulation is done as well with a point source with small diameter, which this time starts releasing the tracers at the same time as the previous simulations at 4 am, and continuously releases the entire amount of 300 tracers throughout the time of the simulation, which is 12 h. Figure 8 illustrates the propagation of the tracers during the time of integration.

The cloud of tracers moves in the form of a plume originating from the Mopang location. It moves at slower rate than in the other two cases and does not reach the



Simulation run – 4 hrs

Simulation run – 8 hrs

Simulation run – 12 hrs

Fig. 6 Results of the simulation of oil dispersion, seeded from a source with the shape of the oil leak detection at 4 am on 7 July 2018 are plotted in green. The initial detection is plotted in navy blue. Simulation results are presented after 4, 8 and 12 h propagation after start. The oil detected from the acquisition at 4 pm is plotted with dark red. The exact coordinates of the ship are denoted with a yellow star

coast within 12 h integration. However, the probable coast landing is Chernomoretz area.

As expected, the longer the tracers were in the sea water, the further they are from the source and the more dispersed they are between each other. The tracers close to the coordinates of the sunken ship keep a propagation in a more straight line as those released earlier. The propagation of the release is further to the West, compared to the previous which kept more South to South-West direction. For the running time of this simulation no tracers were stranded.

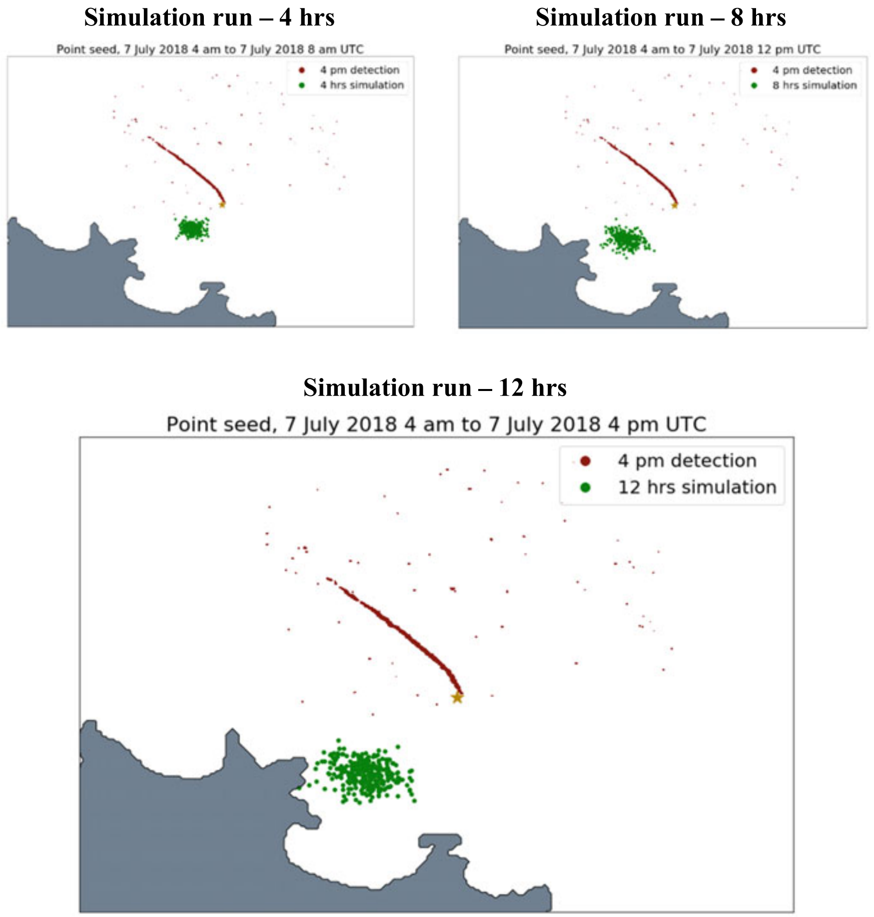


Fig. 7 Results of the simulation of oil dispersion, seeded from a point source which released all 300 tracers simultaneously at 4 am on 7 July 2018 are plotted with green. Simulation results are presented after 4, 8 and 12 h propagation after start. The oil detected from the acquisition at 4 pm is plotted in dark red. The exact coordinates of the ship are denoted with a yellow star

Finally, a comparison of the position of the tracers in the end of the 12 h simulation time with the actual oil detection from the afternoon Sentinel-1 overpass should serve as orientation for the credibility of the model calculations.

The simulation done with tracers seeded in the same shape as in the morning acquisition (Fig. 6) reveals stronger diffusivity among ensemble members and a generally similar prolonged form, which however is shifted away from the coordinates of the source and has drifted towards the coastline. This behaviour is expected as the simulation assumes that the oil leak is separated from the source right after release and no more oil is further leaking. Thus the seeded elements disperse in the environment.

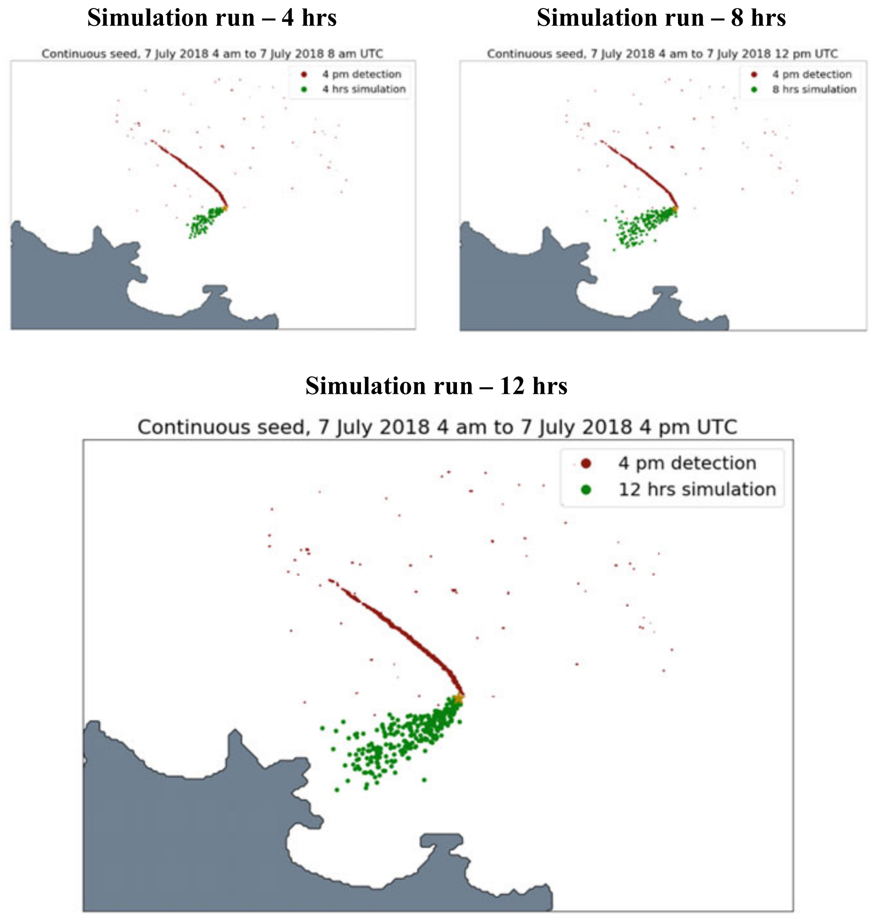


Fig. 8 Results of the simulation of oil dispersion, seeded from a point source which releases its tracers continuously from 4 am on 7 July 2018 until 4 pm on the same day are plotted in green. Simulation results are presented after 4, 8 and 12 h propagation after start. The oil detected from the acquisition at 4 pm is plotted with dark red. The exact coordinates of the ship are denoted with a yellow star

The dispersion of tracers, released simultaneously from point source (Fig. 7) shows least similarities with the acquisition at 4 pm. Such dispersion scenario appears more plausible in the case of sudden ship incident, which releases its fuel. In this case the ensemble of released tracers keep a circular shape, moving towards the coastline. This behaviour doesn't comply with the satellite observations.

The final experiment scenario of continuous oil release (Fig. 8) has as a form, vaguely similar of the detected oil patch at 4 pm, even though the direction of propagation is different. Here the low resolution of the forcing data close to the shoreline should be taken into consideration and the possibility that the exact current circulation might differ from the extrapolated values used in OpenOil.

The three figures Figs. 6, 7 and 8 suggest that the simulations fail to reproduce exactly the detected by satellite shape of the oil slick on 7th of July at 4 pm. In order to understand the reason we have performed sensitivity experiments for the wind speed and horizontal diffusivity coefficient. Our results (not shown here) indicate that the wind speed is very important and a good correlation is obtained when moderate south wind is taken as input in the model. Our conclusion is that more sensitivity experiments should be performed in order to fine tune the model and the input global atmospheric model data should be compared with the local meteorological conditions.

4 Conclusions

In this study we demonstrate the capacity for reliable detection of small scale oil slicks near the shoreline from radar satellite data, using images from Sentinel-1 processed with an adaptive threshold algorithm. As a test case is used the particular case of the oil leakage from the sunken ship Mopang, which has been under water since 1921, located in direct vicinity of the Bulgarian coastline.

For the purposes of our research we process the available Sentinel-1 data-sets from 2017 and 2018 and we demonstrate that oil spills, which could be identified as released from the ship tanks are visible as early as February 2017 and throughout the summer seasons of 2017 and 2018. The oil pollution visible during the summer period of 2017 is of the same order as that in 2018, which leads to the conclusion that the leak started before 2017. Both in July and August 2018 and August 2017 similarly intensive leaks are identified. The spatial extend of the detected oil patches varies between 0.17 and 2.4 km^2.

The findings of our study suggest that oil leaks from the tanks of sunken ships might be a common problem and regular monitoring of such areas using radar data and knowing the exact position on the ship wrecks might be beneficial for preventing significant oil releases and thus additional pollution load on the marine ecosystem.

The availability of SAR satellite images with detected oil slick in the morning and afternoon for three dates (7th July, 6th August and 29th September 2018) gives an unique opportunity to investigate the evolution of the spill in terms of shape and extension and to evaluate the surface current impact on dispersion. It is visible that in general the shape and extension don’t change significantly over the day, however they change their direction and orientation relative to the surface current. The slicks propagate along or across the surface current stream, away of the areas with large current velocity.

In the final part of the study we simulate the dispersion of oil particles with the open source trajectory model OpenOil for one of the days when Sentine-1A and B overpassed our area of interest within the same day—7th of July 2018. The elements are seeded according to three different scenarios—embedded in a shape such as the oil detection at 4 am, seeded at once from a point source with small diameter and continuously seeded from a point source throughout the entire time of the simulation. All simulation experiments were done for 12 h running time as this is the time difference between the Sentinel overpass. The main limitation of the approach is the resolution of the forcing meteorological data, as the observed leak is very close to the shoreline and the surface current data ends approx. 3 km away from the coast. In this case OpenOil extrapolates the values, which process however cannot take into consideration local circulation phenomena.

According to the findings of the simulation tests we conclude that the model fails to describe precisely the propagation of oil droplets as none of the simulation scenarios predicts correctly the exact form and propagation direction of the oil leak detected at 4 pm on 7th of July 2018.

The third seeding experiment with a continuous oil leak results in a shape slightly similar to the expected detection, however it has different spatial orientation, as it follows the extrapolated surface currents in southwestern direction and the detected oil slick is elongated towards northwest from the Mopang location. This finding suggests that forcing the model with more precise meteorological data especially about the wind direction from local measuring stations could deliver more accurate predictions.

Considering these model simulations and taking into account the forms and orientations of oil detections within the same day, it can be speculated that in the Mopang case we observe continuous engine fuel leak throughout the day and the oil patches observed on the afternoon acquisitions are not of the same oil, which was visible in the morning. This would suggest that the oil originating from Mopang which was released in the marine ecosystem is of a significant amount and is more intensive than visible on the occasional radar observations. Nevertheless the exact impact of the oil pollution on the coastal area cannot be estimated as the detection algorithm is not applicable at the shoreline and 2–3 km away from it. However radar detections from 19th July and 12th August 2017 and 1st July and 6th August 2018 spread through a large area in the Bourgas bay and propagate very close to the coast, increasing the probability of oil reaching recreation tourist areas and directly impacting the marine habitat in the coastal shelf zone.

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