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OIL SPILL RISK ASSESSMENT FOR AN OIL TERMINAL AT THE PORT OF TARANTO (SOUTHERN ITALY)

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Abstract

Stochastic simulations of hypothetical oil spills are performed to assess risk of oil pollution originated from a single-point buoy mooring and subsea pipeline operated at the Port of Taranto. The MEDSLIK-II oil spill model is coupled to a high-resolution hydrodynamic model implemented in the framework of the unstructured-mesh finite element method at a high resolution and run in operational forecasting mode. The hypothetical oil spill scenario is based on a historical pipeline rupture at the Port of Genoa, 2016. Around 15,000 spills are simulated randomly sampling over the meteo-oceanographic conditions 2018 – 2020. Under the combined transport by highly variable currents, wind, and turbulent mixing, the released oil drifts mainly southwesterly towards the outlet to the open sea. Due to multiply strandings and washing-offs from the concrete constructions in the port, oil is dispersed almost isotropically over the Mar Grande, indicating a rather moderate level of concentrations. The most probable first beaching times vary 7 – 17 hours determining the timescale of the required response. The results obtained can be applied to develop strategic response and mitigation plans, environmental protection and cleanups.

Keywords: accidental pollution, single-point buoy mooring, subsea pipeline, Lagrangian oil spill modeling, high-resolution unstructured-grid hydrodynamic modeling

1. Introduction

Despite the increased focus on maritime safety in ports and harbors, possible oil leaks during loading or discharging operations remains a cause of concern at European ports. The consequences may be aggravated in the semi-enclosed basins. The Port of Taranto is located in the semi-enclosed area of the limited water exchange with the open sea.

During the past decade, stochastic or probabilistic oil spill modeling has been widely developed as a tool for various management tasks, including response and mitigation plans, environmental protection and cleanup activity. The methodology is based on a statistical analysis of model outputs composed of a variety of individual oil spill trajectories. These trajectories represent the hypothetical spill scenarios from the different start locations and time sampled randomly over a relatively long-time window. Start locations and/or start time of each spill are regarded as random variables. Each spill is exposed to different environmental conditions, leading to various spatio-temporal distributions of oil concentration.

Several studies have focused on the statistical analysis of large ensembles of oil spill simulations at different scales, ranging from the overall basin ones (e.g., French McCay *et al.*, 2017, Ji and Johnson, 2017, Sepp Neves *et al.*, 2020) to ultra-fine scales of harbors and ports (e.g., Azevedo *et al.*, 2017, Morell Villalonga *et al.*, 2020).

In the present work, some preliminary results of stochastic oil spill modeling are reported to predict statistically spatio-temporal behavior of possible oil spills at the Port of Taranto.

To this end, we (1) couple the MEDSLIK-II oil spill model (De Dominicis *et al.*, 2013) to a high resolution hydrodynamic model SANIFS (Southern Adriatic Northern Ionian coastal Forecasting System) run on unstructured grid in operational forecasting mode (Federico *et al.*, 2017); (2) compute around 15,000 hypothetical oil spills randomly sampling them from a single-point buoy mooring and along a subsea pipeline over a two-year set of the meteo-oceanographic conditions 2018–2020; (3) describe the results statistically, focusing on spatial distributions and timing the possible spill.

2. Method

2.1 Study area

The Port of Taranto is an essential strategic hub of the European logistic chain located in the southern part of Italy, on the north-eastern coast of the Taranto Gulf in the Ionian Sea. The study area consists of two connected basins called the Mar Grande and the Mar Piccolo (Figure 1). The latter is composed of the two embayments. The Mar Grande represents a shallow semi-enclosed basin with an average depth of 12 m confined by the islands and breakwaters almost on all the sides. Two outlets provide the water exchange with the open sea, and other two ones connect the Mar Grande with the Mar Piccolo. The circulation is mainly controlled by estuarine dynamics (De Pascalis *et al.*, 2016), though some reverses between the two opposite vertical circulation cells can occur during the year (Federico *et al.*, 2017).

In the vicinity of the Port, a densely populated urban area coexists with a large industrial cluster, naval shipyards, unique ecosystems, mussel farms, and recreation zones.

2.2 Stochastic MEDSLIK-II simulations

The oil spill model MEDSLIK-II (De Dominicis *et al.*, 2013) is a freely available community model (http://medslik-ii.org) successfully used for nearly 10 years to simulate the transport and fate of oil spills in deterministic and stochastic mode. Each Lagrangian parcel moves due to currents, wind, and waves, data on which are provided by external atmospheric and oceanographic models. The oil weathering processes include the viscous-gravity spreading, evaporation, natural dispersion, and the formation of water-in-oil emulsion. Randomized turbulent mixing is applied to account for the sub-grid processes.

MEDSLIK-II is forced by the 6-hour wind datasets provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) at a horizontal resolution of 1/8° (~12.5 km), and hourly fields of currents and sea surface temperature produced by SANIFS (http://sanifs.cmcc.it).

SANIFS (Southern Adriatic Northern Ionian coastal Forecasting System (Federico *et al.*, 2017)) is based on SHYFEM (System of Hydrodynamic Finite Element Modules (Umgiesser *et al.*, 2004, Ferrarin *et al.*, 2020, Trotta *et al.*, 2021)), which is a three-dimensional fully-baroclinic finite-element hydrodynamic model solving the primitive equations under the hydrostatic and Boussinesq approximations. The model follows the unstructured-grid approach with variable horizontal resolution, particularly suitable for coastal applications with complex geometry and bathymetry, while not neglecting also large-scale processes.

In this work, SANIFS has been specifically improved in terms of spatial resolution to better represent the study area. Concretely, the horizontal resolution ranges from 3 km in the open sea, through 100 m in the coastal waters, to 20 m at the Port of Taranto. With this high resolution, an accurate representation of irregular coastal boundaries is achieved, now resolving tiny straits, small islands, as well as the Port constructions and facilities: wharfs, marinas, narrow breakwaters, and revetments.

The bathymetry data at a resolution of 1/8 arc minutes (~230 m) obtained from the EMODNET Portal for the open sea and coastal waters has been combined with the high-resolution bathymetry at the Taranto Port provided by the Italian Navy Hydrographic Institute. The model levels are uniformly distributed along the vertical axis from the sea surface to 90 m with a step of 2 m and then, they increase down to the seabed up to a maximum layer thickness of 200 m. Atmospheric fields with a horizontal resolution of ~12.5 km and 3-hour frequency delivered by ECMWF are used for atmospheric forcing.

The latest release of Mediterranean Forecasting System (Clementi *et al.*, 2019) with a horizontal resolution of 1/24° (~4 km) is used for a parent model initialization and imposing the lateral open boundary conditions. A total of 8 tidal components are imposed at the open boundaries of the parent model. Tidal data are taken from the OTPS tidal model (Egbert and Erofeeva, 2002).

To run the stochastic MEDSLIK-II simulations a hypothetical oil spill scenario is defined as follows:

- Randomly sampled start locations: 50% from the single-point buoy mooring and 50% along the subsea pipeline;
- Uniformly distributed start times with an interval of 2 hours from 1 July 2018 to 30 June 2020;
- Crude oil type with a density of 856 kg m^3 at 16°C (API = 33.8);
- Continuous release of 600 tons of oil with a spill duration of 2 hours;
- Each spill is represented by the 100,000 Lagrangian parcels;
- Simulation length of 48 hours;
- Bin size of 50 m;
- Integration time step of 5 min.

The oil spill scenario is based on a real oil spill accident caused by a catastrophic pipeline failure at the Port of Genoa on April 17th 2016 (Vairo *et al.*, 2017).

In the coupled MEDSLIK-II and SANIFS model, some modifications are made (Liubartseva *et al.*, 2020) in comparison with the default Mediterranean applications (De Dominicis *et al.*, 2013) to adapt to the small-scale features in the study area. Firstly, the coastline types are updated to comply with the Mediterranean Integrated Geographical Information System on Marine Pollution Risk Assessment and Response (MEDGIS-MAR) developed by REMPEC. In the Port Taranto area, concrete wharfs and seawalls dominate followed by sandy beaches and then, by the rocky shore type. Secondly, the horizontal diffusivity coefficient is set 0.2 m^2 s^1. To integrate the model displacement equations, the forward Euler scheme with a 5-minute time step was used. To reduce the computation time, a 1% windage coefficient was applied instead of the JONESWAP parametrization of the Stokes drift (Liubartseva *et al.*, 2015), which is a rather first-order approximation.

The MEDSLIK-II simulation results are represented by an ensemble composed of ~15,000 hypothetical oil spills.

3. Results and discussion

Maps of the ensemble mean oil concentrations[1] provide an overview of potential impacts at the sea surface and on the coastlines of the study area (Figure 1). Within the first hours after the start of the release, the highest sea surface concentration values (up to 12 ton km^2) are expectedly found in the vicinity of the sources: the buoy site and along the pipeline. After that, the area of elevated values gradually drifts in the southwestern direction to the open sea. More specifically, almost the whole Mar Grande is found to be contaminated in 12 hours after the possible accident (Figure 1). The highest sea surface concentrations of around 5 ton km^2 can be seen near the widest outlet to the open sea. Oil in notable concentrations starts also to be transported to the West Port area, and the Mar Piccolo. The local bands of elevated concentrations surround almost the entire internal perimeter of the Mar Grande, including the Port wharfs and the breakwaters.

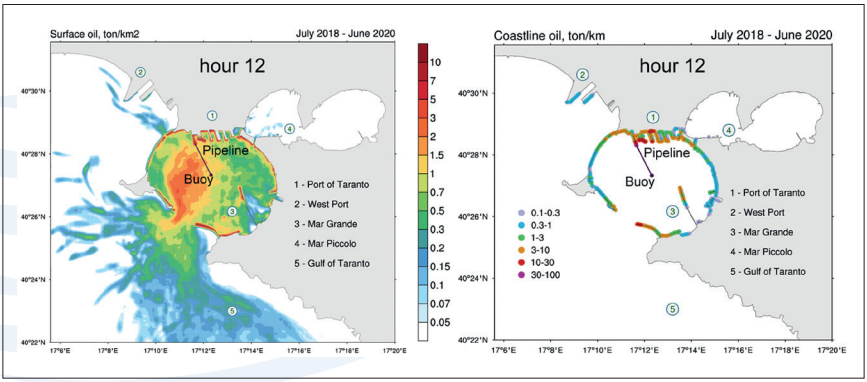

Fig. 1. Ensemble mean oil concentration maps at the sea surface (on the left) and on the coastlines (on the right) in 12 hours after the start of the release.

These peculiarities can be explained by the low absorbing ability of the concrete wharfs and sea walls that dominate the study domain. The majority of hypothetical oil spills move southeastward, which is consistent with the averaged 2018–2020 surface flow direction. The islands and breakwaters prevent the West Port from penetration of oil. Looking at the concentration maps on the coastline, we note that oil pollution growths over time gradually capturing the shores. In 12 hours (Figure 1), not only all the coastlines of the Mar Grande are found to be contaminated, but also some parts of the West Port. The concentrations peak at the Port berths and on the tips of the breakwaters. Nevertheless, the shores of the Mar Piccolo are hardly affected.

[1] http://plastics.cmcc.it/files/Taranto_oil_LiubartsevaEtAl_2021.mp4

The analysis of the first 48-hour oil drift simulations shows that oil is advected by highly variable currents and waves, and is thus exposed to multiple reflections strandings and washing-offs from the concrete constructions in the study domain. Consequently, the oil tends to be dispersed almost isotropically over the Mar Grande, indicating a rather moderate level of concentrations. The breakwaters, that were originally constructed to protect the Port and city from wind-generated waves, influence the circulation patterns, which affects the pollutant transport. Interestingly, the breakwaters can reduce to some extent the number of oil landings in the Port and urban areas.

Information about timing the drift of oil and its arrival at the coastline leads to strengthened spill preparedness and to define response priorities. To this end, the probability distribution of the first beaching time is studied primarily. As shown in Figure 2, the maximum probability of 3.9%–4.3% is found in the time interval of 7–17 hours after the start of the release, which determines the timescales of the required response. Around 0.9% of spills demonstrate the fastest beaching that takes less than 0.4 hours. Remarkably, around 5% of simulated spills do not show any beaching of oil during the 48-hour drift. The majority of them leaves the Mar Grande through the widest outlet. Analyzing the Cumulative Distribution Function (CDF) we conclude that 50% of spills will reach the coastline within the first 14 hours after the start of the release, 75% will strand in 21 hours, and 90% – within 32 hours.

According to an oil mass balance diagram, approximately 48% of oil evaporate within the first 10 hours, which is typical of the crude oil. After that, evaporation almost stops. Natural dispersion remains steady with a mean value that does not exceed 3% at the end of the 48th hour simulation. As a consequence, starting from the 11th hour, the beaching overtakes dispersion, and starts to play a key role in the oil mass balance, demonstrating an almost linear increase of the beached oil mass in both the mean values and standard deviations.

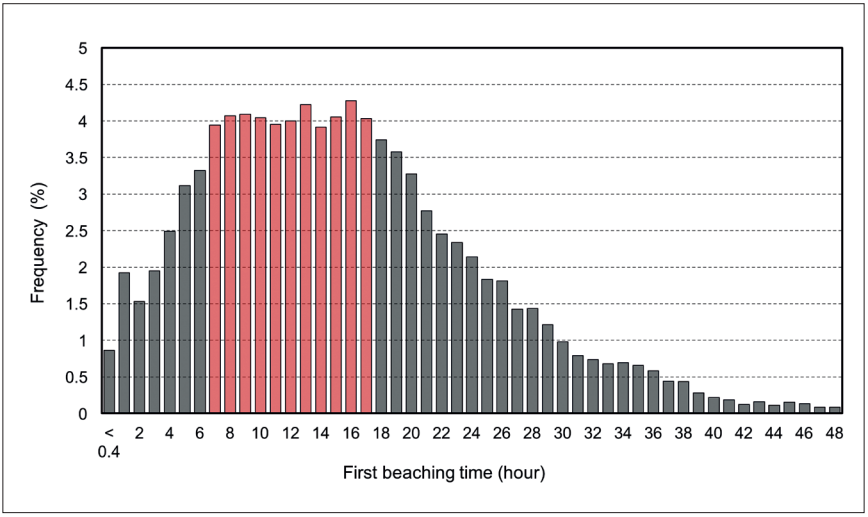

Fig. 2. Histogram showing the probability distribution of the first beaching hour. Time interval of 7 – 17 hours after the start of the release indicates the highest probabilities of 3.9% – 4.3% highlighted in red.

4. Conclusion

Stochastic model simulations have been conducted to predict the statistical footprint of oil contamination associated with the potential spill from the single-point buoy mooring and subsea pipeline at the Port of Taranto. To this end, the MEDSLIK-II oil spill model (De Dominicis *et al.*, 2013) has been coupled to the Southern Adriatic Northern Ionian coastal Forecasting System (Federico *et al.*, 2017) run on the unstructured grid, which provides high resolution. The hypothetical spill scenario is based on the real case occurred at the Port of Genoa in April 2016 (Vairo *et al.*, 2018). Around 15,000 hypothetical spill simulations are carried out randomly sampling over the environmental conditions 2018 – 2020.

The main oil drift is found to be directed southwesterly towards the outlet to the open sea. Under the combined transport by highly variable currents, waves, and turbulent mixing, the oil released from the buoy and pipeline is exposed to multiply strandings and washing-offs from sea walls and concrete wharfs that dominate at the Port. Consequently, the pollution tends to be dispersed almost isotropically in the Mar Grande, indicating the moderate level of the oil concentrations. The first oil beaching is predicted to occur within 7 – 17 hours after the start of the release. Simulated oil spill mass balance shows that after the rapid evaporation of ~48%, oil tends to be re-distributed between the sea surface and coastline with gradually growing the latter component.

The methodology is applicable to any domain and potential oil spill sources providing decision-makers with an overview of potential impacts and timing as well as a guidance for the strategic spill response, which is of particular interest at European ports and harbors.

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