The role of high-resolution oil spill response models in emergency scenarios, The ATLANTIC POLEX.PT 2017 example

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Abstract: The Portuguese coast is strongly vulnerable to sea hazards, particularly oil spills, due to intense vessel traffic and sea conditions. In this article, an operational integration of high-resolution oil spill response models is presented, supporting the ATLANTIC POLEX.PT 2017 exercise. Simultaneously two surface drifting buoys were deployed. The MOHID Lagrangian Oil Spill Model was used, forced by two different sets of forcing fields: One based on CMEMS and other based on SOMA. Results prove the adequacy of the method in supporting emergency responses. Standard error parameters obtained from comparison with buoy positions show good results, with errors of the same order of magnitude of those encountered in the literature. Comparison of trajectory distances with available operational forcing models highlighted the inadequacy of current operational met-ocean products. An evolution is proposed towards a set of integrated local high resolution models, covering the coast of Portugal.

Key words: Oil Spill, Operational Modelling, Drifting Buoys, Coast of Algarve, Decision Support

1. INTRODUCTION

Portugal is strongly vulnerable to sea hazards due to intense vessel traffic and sea conditions. Focusing on the southwest region off the Iberian Peninsula (Algarve) it lies in the main route from the Mediterranean and Southern Hemisphere to the Northern Europe. Tankers represent a significant part of the vessel traffic and the occurrence of oil spills cannot be disregarded (Janeiro *et al*., 2012). Since 2007, EU Member States saw their surveillance capability regarding oil spills, strengthened with the creation of the European Maritime Safety Agency CleanSeaNet program. CleanSeaNet aims at identifying possible marine oil spills through satellite remote sensing. From late 2015, the European Space Agency mission SENTINEL-1 is responsible for providing this service. Satellite images are acquired and analysed to provide information regarding the potential for an oil spill. When a spill is detected, a pollution alert report is sent to national authorities with information regarding the detection including the level of confidence (low, medium, high) of it being a potential oil spill (EMSA 2012). For the 2008-2016 period, 500 CleanSeaNet oil spill detections were issued in the Portuguese Economic Exclusive Zone (Fernandes *et al*., 2017).

In Portugal a national contingency plan towards hydrocarbon pollution - “Plano Mar Limpo” (PML) - was approved in April 1993. This plan gives overall responsibility for spill response to the National Maritime Authority and, in particular, to its coordinating body, the Maritime Authority Directorate General (DGAM). In the scope of PML, all relevant authorities responsible should prepare and develop suitable response mechanism towards an efficient response in the event of an oil spill. This has been accomplished in the Algarve region through the oil spill exercise ATLANTIC POLEX.PT since 2016.

The processes that govern both the transport and weathering processes of oil in water are complex and depend not only from oil characteristics, but also from the hydrodynamic and atmospheric conditions at the spill site (Mackay and McAuliffe 1988). To deal with this complexity and transform it in a predictable solution, which is paramount to support planning and response activities, operational modelling systems coupled with models that can simulate the oil weathering processes are required. These operational modelling systems must be able to resolve coastal scale processes, thus providing enough accuracy to be and efficient response tool.

This work recognizes the importance of accurate information systems for decision-making processes in an oil spill situation. Towards that goal, an operational integration of high-resolution oil spill response models is presented, supporting the ATLANTIC POLEX.PT 2017 exercise (POLEX17). Results obtained were validated on site using real-time drifter trajectories, deployed during the initial stages of the exercise.

2. METHODS

Two modified MetOcean iSPHERE Oil Spill and Current Tracking buoys were deployed during the POLEX17 exercise. The GPS and communication components inside the buoys are SPOT devices from Orbital Satcom Corp., communicating by Iridium with a 5 minutes tracking rate. The buoys were used as a proxy of the hypothetical spill position. Additionally, the buoy positions were used as ground truth, to compare with the model results. Moreover, it was possible to demonstrate the adequacy of this kind of equipment in oil spill emergencies.

The oil spill modelling approach used in this work is based in the MOHID modelling system (www.mohid.com). Specifically the “Lagrangian” module was used to simulate the buoy trajectories and the most relevant oil-weathering processes were included using the “oil” module. MOHID considers seven weathering processes: spreading, evaporation, dispersion, emulsification, dissolution, sedimentation and beaching (Janeiro et al., 2008). An Arabian Light crude oil was considered. The forcing fields necessary to run this Lagrangian model are Eulerian (gridded) fields of water currents and wind velocities. To plan response activities these forcing fields must be operational forecasts. Two different approaches for the forcing fields were used and compared during the exercise. One set of runs was conducted using forcing fields coming from the Copernicus Marine Environmental Monitoring Service (CMEMS) IBI Regional Product PHYS_005_001, which provides 5 days hourly forecasts of water current velocities at 1/36° horizontal resolution (approximately 2.3 km). The meteorological forcing used on IBI are produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). Another set of runs was conducted using forcing fields from the pre-operational regional downscale model for the coast of Algarve (SOMA), maintained by the authors at University of Algarve (Janeiro et al., 2017). SOMA downscales the CMEMS Global Product PHY_001_024, which provides 10 days daily forecasts of water current velocities at 1/12° horizontal resolution (approximately 7 km). The resulting SOMA solution have a 2 km horizontal resolution mesh. The meteorological forcing used on SOMA is produced by “meteoTecnico” using 9 km resolution MM5 model results ran at the Instituto Superior Técnico.

All models share the same vertical resolution with 50 z-level layers with a variable vertical resolution decreasing gradually down to 1 m near the surface. If the vertical grid resolution in sufficiently high, the wind stress imposed in the top layer of the hydrodynamic model should be sufficient to drive the Lagrangian model particles. For an oil spill, this would request a vertical resolution at the surface of the same order of the oil slick, which is impractical. The solution is to include explicitly a wind drag on the Lagrangian particles movement. Additionally, in this experiment we are comparing model results with drifting buoys, not with a real oil slick. The drifting buoy always possess a percentage of its body emerged, increasing the wind drag effect. The wind drag effect included in the Lagrangian model must thus account for those processes (Reed *et al*., 1994). The wind forcing used to impose the wind drag in the particles is the same “meteoTecnico” product used in SOMA. Table I summarizes the origins of forcing data used.

2.1 Model Setup

The POLEX17 exercise was conducted at October 19th. 2017. The simulation runs started at October 16th. 2017 with available forecasts for the 19th. and were updated in successive days as new forecast become available. The simulation period was the same for all simulations, starting at 19/10/2017-08:00 and ending 20/10/2017-00:00.

Table I. Origin and characteristics of forcing data used in the simulations.

	“IBI” Runs	**“SOMA” Runs**
Hydrodynamic Model	CMEMS-IBI	SOMA
Horizontal Resolution	1/36° (2.3 km)	1 km
Vertical Resolution	50 z-layers (up to 1m @ surface)	
Wind Forcing	ECMWF	“meteoTecnico”
Wind Resolution	9 km	
Wind drag on particles	“meteoTecnico”	

The emission point for the model particles was selected at the centre of the “exercise box” as the exact buoy deployment positions were not available prior-hand. The simulation performed during the day of the exercise however, used the exact buoy deployment position for the emission point. Table II summarizes the simulations executed.

Table II. Lagrangian simulations executed.

Run #	Hydro. Forcing	Wind Drag	Execution Date	Line Colour in Fig. ***1***
1	IBI	Yes	16/10/2017 18:45	Yellow
2	SOMA	Yes	17/10/2017 14:00	Grey
3	SOMA	No	17/10/2017 14:00	Green
4	SOMA	Yes	18/10/2017 00:00	Orange
5	SOMA	No	18/10/2017 00:00	Dark Green
6	IBI	Yes	19/10/2017 07:00	Magenta

In every simulation, 1000 particles with a volume of 1 m^3 each were released at the surface, evenly distributed over a 250x250 m square box. The runs considering direct wind stress over the particles use a drag coefficient of 0.03. This value and other model parameters use calibrated values for the Portuguese Coast obtained from previous studies (Janeiro, 2015).

3. RESULTS

Fig. ***1*** show the buoy trajectories and the model results for the simulated runs. The model lines represent the centre of mass of the particle cloud.

As referred, only run #6 emitted particles at the position of the buoy deployment, because the exact position was not known in advance. In Fig. ***2*** a zoom of buoy and model positions is shown, including time stamps.

Fig. 1. Buoy and model trajectories. Buoys: black lines; Model runs: line colours as in Table II.

The buoys were recovered at 19/10/2017 13:00 preventing further comparisons. The separation distances between the buoys and the model centre of mass were computed and are presented in Table III.

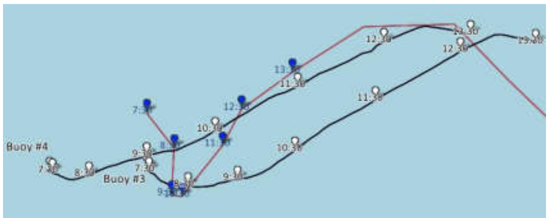

Fig. 2. Zoom of buoys and run #6 trajectories with time stamped positions.

The errors between buoy and simulated trajectories were also estimated using the trajectory-based non-dimensional index proposed by Liu and Weisberg (2011):

$$S = \sum_{i=1}^{N} d_i \Big/ \sum_{i=1}^{N} l_i$$

Were d_i is the separation distance between model and buoy positions at time step i and l_i is the respective length of the buoy trajectory.

Table III. Distances and errors between model and buoys.

Time	d #3 (m)	S #3	d #4 (m)	S #4
07:30	560	-	1085	-
08:30	390	0.88	856	2.38
09:30	647	0.76	439	1.00
10:30	1160	0.76	727	0.69
11:30	1509	0.70	907	0.54
12:30	2139	0.68	1482	0.50
13:30	2316	0.64	1743	0.47

4. DISCUSSION

Buoy trajectories in Fig. ***1*** are quite similar for the two buoys, both in shape and in travelled distance, despite the deployment distance of 900 m between them. This behaviour correlates well with the met-ocean conditions of that day, with light to gentle breeze (Beaufort scale 2 to 3). Buoys #3 and #4 have travelled 4029 and 4246 m respectively, representing an average velocity of 0.2 m/s. With this conditions sub-grid turbulent processes are preponderant, influencing the comparison with model results. The horizontal resolution of the hydrodynamic models used to force the particles are 1 km for the SOMA simulations (Runs #2 to #5) and 2.3 km for the IBI simulations (Runs #1 and #6). In this last case, although, the forcing fields are interpolated to the same 1 km grid of the SOMA case. With these resolutions, the total length of the buoy trajectories during the 6 hours of the experiment covers only 2 cells in the case of the IBI forcing and 4 cells in the case of the SOMA forcing. The wind resolution is even smaller, with a 9 km grid, meaning the entire displacement of the buoys during the exercise lay inside a single wind cell. This context must be taken into consideration when comparing the model results with the buoy observations. Despite that, the model results of run #6 are able to reproduce reasonably well the buoy behaviour, as can be seen in Fig. ***2***. The direction and shape of the trajectory is similar, although the length is shorter in about 1500 m (37%).

The model discharge was located close -but not exactly over- the buoys deployment positions, because the exact deployment position was still not known at the beginning of the run. Due to this, the distances between the model and the buoys are not zero at the beginning of the exercise. Table III show that the initial distances between the model and the buoys are 0.6 km for buoy #3 and 1.1 km for buoy #4. During the exercise, these distances start decreasing as the model particles approach the buoy trajectories and then increase steadily towards a maximum distance of 2.3 km from buoy #3 and 1.7 km from buoy #4. Average distances between the centre of mass of the model particles and the buoys are 1.2 km for buoy #3 and 1.0 km for buoy #4. These distances are within the order of magnitude of the hydrodynamic model resolutions, which is remarkable, taking into consideration the mild met-ocean conditions of that day and the short period of the exercise. The errors were also evaluated using the non-dimensional S index as explained in the results section. Since S is a cumulative index, integrating the distances between model and buoy and normalizing it by the trajectory length, it is a more robust indicator of the error evolution along time. Results from Table III show that S start with relatively high values but maintain a sustained decrease in time toward values smaller than 0.5. The high initial value is due to the initial distance between buoy deployments and model release. This initial error is then progressively attenuated by the good performance of the results. The order of magnitude of S is similar to the values Liu and Weisberg (2011) considered as good results.

Fig. 1 show the results for all model simulations. All simulations refer to the period between 19/10/2017-08:00 and 20/10/2017-00:00 but were executed in different days before the exercise using the available met-ocean forcing fields at the time, as summarized in Table II. Simulation #1, executed at 16/10/2017 and simulations #2 and #3, executed at 17/10/2017 show very similar evolutions. This seems to indicate that, at these scales, both SOMA and IBI are performing in a very similar way. The similitude between simulation #2, including wind drag on particle movement and simulation #3, without wind drag, seem to indicate wind drag is not an important factor for these met-ocean conditions. This is due to the mild conditions occurring in the simulation day, which were well forecasted by the two models. Simulations #4 and #5, executed at 18/10/2017 show a very distinct pattern, with the particles describing a tight anti-clockwise loop. The water current fields for the exercise day, predicted in day 18 show a very unstable structure composed by high frequency eddies. The simulations were forced by the SOMA model but the IBI fields show a similar structure. Results of simulation #6, executed at 19/10/2017 soon before the beginning of the exercise, show again a smoother trajectory, similar to the one obtained in simulations #1, #2 and #3. These results are relevant to show the degree of variability that can be encountered in forecasts while supporting response activities.

5. CONCLUSIONS AND PROSPECTIVE WORK

A Lagrangian oil spill model was used to demonstrate the potential of such tools in support of response activities during oil spills. The application was employed during the POLEX17 exercise, along with the deployment of two surface drifting buoys. Results prove the adequacy of the method in supporting emergency responses. The comparison of model and buoy results show the high variability of forecasted model results when transitory met-ocean conditions are present. The last forecast executed, concurrently with the start of the exercise and the deployment of the buoys, show good comparison with the buoy positions. Error parameters were computed for that run, showing results similar to those encountered in the literature. Comparison of trajectory distances during the exercise with available operational forcing models highlighted the inadequacy of current operational met-ocean product. In fact, the total trajectory length during the exercise was of the size of only 4 cells of the best resolution hydrodynamic model and smaller than one cell of the wind model. This clearly shows the need for much higher resolution met-ocean forcing fields. The authors believe the way to be paved is one including a set of integrated local high resolution operational models, covering the entire national coast, assimilating the CMEMS operational products and complementing the forcing by assimilating also High Frequency Radar Fields.

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